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# Research on experiment teaching of anthropometry and virtual clothing design based on Gagné information processing theory

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**ABSTRACT – REZUMAT**

**Research on experiment teaching of anthropometry and virtual clothing design based on Gagné information processing theory**

*With the promotion of education informatization in colleges and universities, virtual simulation technology is increasingly used in experimental teaching. In the teaching of fashion-related majors, virtual simulation technology can help students quickly and efficiently understand design theories, which are difficult for them to understand. However, due to the complexity of the virtual simulation experiment, it is difficult for students to master all the techniques required for the operation of the experimental system in a short time. In traditional teaching, students passively accept knowledge taught by the teacher and follow the teacher's operation, thereby affecting the learning effect. Such teaching and learning process cannot fully functionalize students' sensory system coding, and therefore cannot form long-term memory. To optimize the application of virtual simulation technology in the teaching of fashion-related majors, this paper proposes a clothing virtual simulation experimental teaching method based on Gagné information processing theory. To verify its effectiveness, anthropometry and virtual clothing design experiment was adopted as the research object. Two groups of students were involved in the experiments. One group was taught traditionally while another group was taught by the Gagné information processing mode. Through a set of learning and teaching process evaluation, experiment results demonstrated that Gagné information processing mode can effectively help students to fine-process the knowledge they have learned, so that important information can be extracted and encoded to form long-term memory. This paper provides support for future Gagné information processing theory in the teaching of virtual simulation courses and exercises.*

***Keywords:*** *information processing mode of Gagné, virtual simulation, virtual clothing design, exercise teaching, control experiment*

**Cercetare privind predarea experimentală a antropometriei și a designului virtual de îmbrăcăminte bazată pe teoria procesării informațiilor Gagné**

*Odată cu promovarea informatizării educației în colegii și universități, tehnologia de simulare virtuală este din ce în ce mai utilizată în predarea experimentală. În predarea specializărilor legate de modă, tehnologia de simulare virtuală poate ajuta studenții să înțeleagă rapid și eficient teoriile de design, care sunt greu de înțeles pentru ei. Cu toate acestea, din cauza complexității experimentului de simulare virtuală, studenților le este dificil să stăpânească toate tehnicile necesare pentru funcționarea sistemului experimental, într-un timp scurt. În predarea tradițională, studenții acceptă pasiv cunoștințele predate de profesor și urmează instrucțiunile profesorului, influențând astfel procesul de învățare. Un astfel de proces de predare și învățare nu poate funcționa pe deplin în codificarea sistemului senzorial al studenților și, prin urmare, nu poate forma memoria pe termen lung. Pentru a optimiza aplicarea tehnologiei de simulare virtuală în predarea specializărilor legate de modă, această lucrare propune o metodă de predare experimentală de simulare virtuală a îmbrăcămintei bazată pe teoria procesării informațiilor Gagné. Pentru a-i verifica eficacitatea, antropometria și experimentul de design vestimentar virtual a fost adoptat ca obiect de cercetare. Două grupuri de studenți au fost implicate în experimente. Predarea pentru un grup a fost efectuată în mod tradițional, în timp ce predarea pentru un alt grup a fost efectuată prin modul de procesare a informațiilor Gagné. Printr-un set de evaluare a procesului de învățare și predare, rezultatele experimentului au demonstrat că modul de procesare a informațiilor Gagné poate ajuta în mod eficient studenții să proceseze cunoștințele pe care le-au învățat, astfel încât informațiile importante să poată fi extrase și codificate pentru a forma memoria pe termen lung. Această lucrare oferă suport pentru viitoarea teorie Gagné de procesare a informațiilor în predarea cursurilor și exercițiilor de simulare virtuală.*

***Cuvinte-cheie****: modul de procesare a informațiilor Gagné, simulare virtuală, design virtual de îmbrăcăminte, predarea exercițiilor, experiment de control*

## INTRODUCTION

Learning through virtual simulation is proving to be an enormously beneficial resource for both students and professionals [1]. For professionals, virtual simulation can help them to see the result of the design at any time during the design process to verify the feasibility of the design, without making a physical object [2]. For students, it could be used in the learning process and allows the learner to operate instantly after watching a step-by-step simulation procedure [3]. It is therefore a new emerging supportive technology for digital teaching. In the traditional teaching method, students are passively receiving knowledge and only their human aural and the visual system will be involved. But in the learning process via virtual simulation, students will participate actively, engage their brains and learn by doing [4]. It means that other parts of the human cognitive system will be also involved to support the learning process. Learning through virtual simulation is proven to be a safe, efficient, and low-cost method, especially for operational skill learning [5].

Although virtual simulation can simulate the real world and carry out the operations in the virtual environment, to a certain extent, it is still different from real operations in the real world [6]. Therefore, students' awareness of using virtual simulation needs to be improved. According to related theories of pedagogy, in the process of operational skill learning, the key factors that will affect the operational skill learning effect are "short-term memory" and "long-term memory" in the processing of skill-related operational information [7]. If the input skill-related information is encoded by the learner's sensory register and enters the short-term memory, it will be simply processed and quickly enters the reaction generator [8]. It is therefore difficult to be stored. If the skill-related information enters the long-term memory, it can be finely processed and coded. Relevant information will be transferred to the long-term memory, and then can be stored well [9]. In this context, when designing operational experiments, it is necessary to fully consider how to enable students to fine-process information, so that important information can be focused on or selected by students as the central object of attention so that important information can be transferred to long-term memory.

Information processing theory was proposed by American educational psychologist Robert Gagné in 1974, which combines cognitivism and behaviourism, regards people as the mechanism of information processing, regards cognition as the processing of information and believes that learning is constituted by the acquisition and use of information [10]. Information processing theory emphasizes the validity of the acquisition, which is a potential individual state of mind or mental quality, under certain conditions or situations that can be demonstrated by the explicit act or condition of an individual, focusing on the application of knowledge in a real environment [11]. Information processing theory divides the teaching process into nine stages: attract attention, inform learning goals, arouse memories, present stimulating materials, provide learning guidance, elicit behavioural performance, provide feedback, measure behavioural performance, and promote knowledge retention and transfer [12]. This teaching mode is conducive to the effective communication of information between teachers and students and promotes students to form long-term memory of knowledge in practice [13]. Gagné information processing theory is considered to be the most appropriate method to solve the problems in virtual simulation experiment teaching. It is therefore we propose in this study a Gagné information processing theory-based virtual simulation experiment teaching method.

Fashion is a discipline combining theoretical knowledge (design theory, fashion history, fashion marketing theory, etc.) and skill-oriented knowledge (pattern making, sewing, prototyping) [14]. With the support of virtual simulation, skill-oriented experimental projects, such as fabric development, garment design, clothing manufacturing, clothing trade and fashion marketing could be realized in an open and independent experiment environment [15]. Therefore, more and more fashion institutes are involving virtual simulation tools in different fashion-related subject teaching. Currently, due to technical reasons, compared with other fashion subjects, virtual simulation technology is more widely used in anthropometry and virtual clothing design experiment.

Based on the analysis of the shortcomings in the experimental teaching using virtual simulation, this study takes anthropometry and virtual clothing design experiment as an example and explores the influence of the Gagné information processing theory on the experimental teaching effect of anthropometry and virtual clothing design experiment. Two comparative experiments are designed to teach anthropometry and virtual clothing design experiments. One group of experimental samples is carried out using the teaching mode guided by Gagné information processing theory, while the other is carried out using the traditional method. The effect of the involved two different teaching methods is evaluated through a set of learning and teaching evaluation, including process evaluation, cognitive evaluation and self-evaluation.

The rest of this paper is organized as follows: in the research framework section, the tools and evaluation methods of the whole paper are introduced. The third section comprises two experiments. Experiment I aims to study the learning effect of students in anthropometry and virtual clothing design experiment in the traditional way. The influence of Gagné information processing theory on teaching effect is investigated in Experiment II. At the end of the third section, the results of the two experiments are evaluated. Finally, the fourth section is the conclusion and prospect.

## METHODOLOGY

### Research framework

In this study, the method of the comparative experiment is applied to anthropometry and virtual clothing design experiment to explore the influence of Gagné information processing theory on the effect of experiment teaching. The research framework of this study is shown in figure 1. A total of 60 students majoring in Fashion Design and Engineering from the College of Textile and Apparel Engineering, Soochow University in 2018 (60 students) were divided into two experimental groups of 30 each in order of Student ID Number was selected as the experimental samples. The first 30 students were in the control group and the rest 30 students were in the experimental group. The two sets of experiments were carried out simultaneously from September 14, 2020, to September 21, 2020.

In *Experiment I*, the teacher used the traditional teaching model to teach the control group. These students were aged (21.2 ± 2.2 years), including 4 males and 26 females. In *Experiment II*, the teacher used Gagné information processing theory to teach the experimental group. These students were aged (21.3 ± 2.1 years), including 5 males and 25 females. The instructors, teaching content and teaching materials of the students in the two groups were the same, and there was no statistically significant difference between the scores in the college entrance examination of the two groups ($P > 0.05$).

This research takes the teaching mode as the independent variable, and the student's final grade as the dependent variable, which can intuitively reflect the difference in teaching effect between the two different teaching modes. The entire experimental design is based on the single factor principle to ensure the validity of the experimental results. The evaluation of experimental results mainly includes three aspects: process evaluation, cognitive evaluation and self-evaluation of experimental group students. Process evaluation refers to the performance evaluation obtained by the two groups of students in teaching, which is the students' short-term memory of knowledge. Cognitive evaluation is the evaluation of students' inner learning motivation under the same incentive, which is carried out one month after the end of the experiment. The evaluation standard is the students' long-term memory of knowledge. Self-evaluation is the evaluation of the teaching effect of Gagné information processing theory by the students in the experimental group.

### Learning materials

Anthropometry and virtual clothing design experiment is an important subject of clothing virtual simulation experiment [16]. Its purpose is to enable students to understand the relationship between anthropometry and fashion design, mastering the relevant professional skills. The experiment requires students to master basic anthropometric methods and knowledge of clothing structure, which is of great significance for students to understand the relationship between ergonomics and fashion design.

*Experiment I* and *Experiment II* are mainly realized through the automatic anthropometric system and the automatic pattern generation system. The specific procedures are shown in figures 2 and 3. Firstly, the non-contact anthropometric system is an anthropometric method using image processing technology, which directly extracts the body data information of the tested person through the front and side photos. It is used to obtain the height, chest circumference, shoulder width and other data information of the subject. Then the three-dimensional human body model of the subject is automatically generated in the human body three-dimensional simulation model generation system. Based on the basic data of the human body in ergonomics, including human body structure, human body scale and human action domain, rationalize the details of the human body model generated by the system, and extract the human body data needed to make the prototype.

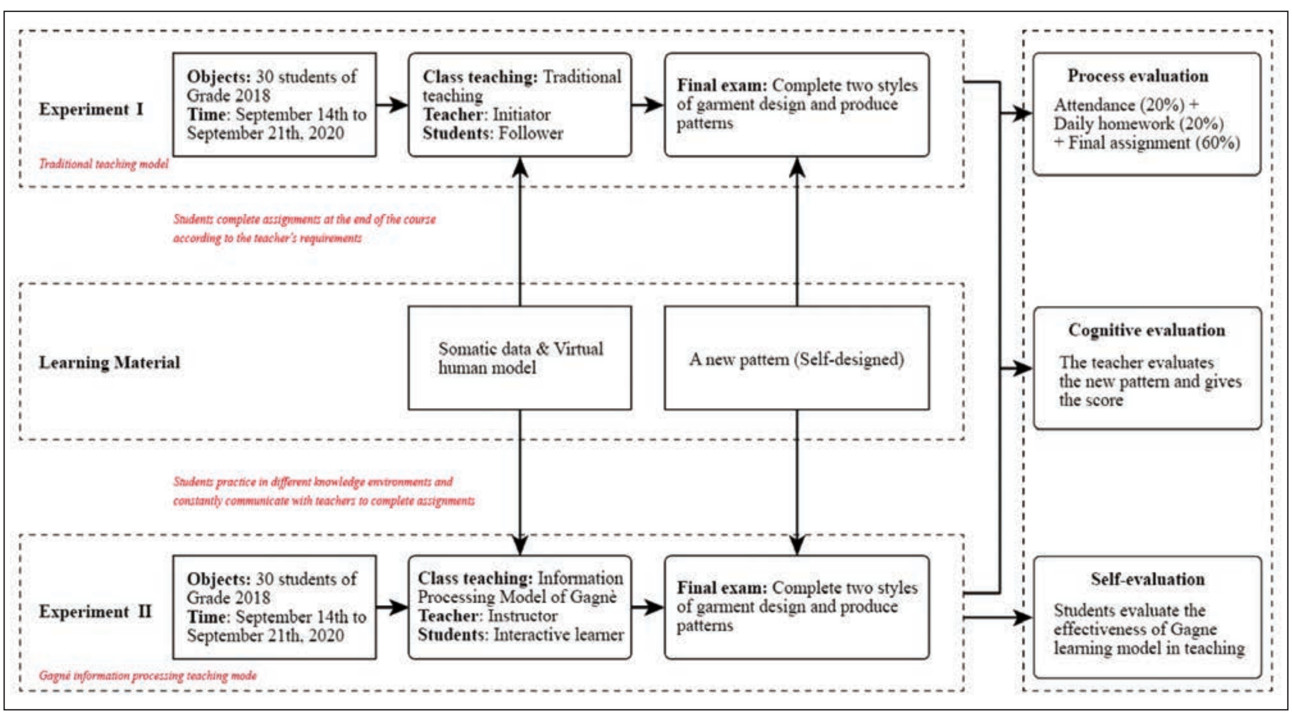



Fig. 1. Framework of this research

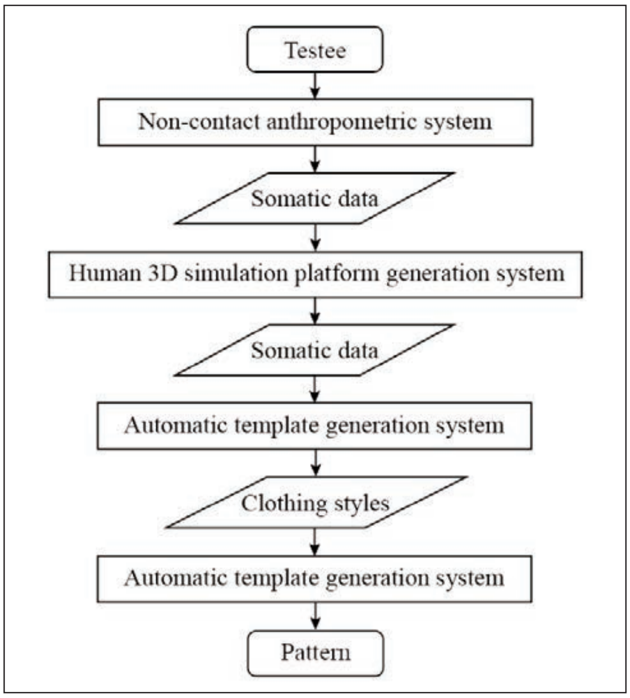



Fig. 2. Experiment flow of anthropometry and virtual clothing design

Finally, input the data into the automatic pattern generation system and select the style that meets the design requirements in the database [17]. The system automatically will generate the corresponding clothing pattern.

## Evaluation methods

*Process evaluation*

The scores obtained by students in experiments (*Experiment I* and *Experiment II*) will be used as evaluation indicators for process evaluation. Due to the change of teaching mode, the teaching interaction between teachers and students has increased, and each student will communicate with teachers. As a result, students' attendance rate and grades will also change. Teachers give the scores based on students' attendance and evaluate the periodic assignments submitted by students during the teaching process. After all, students have completed the virtual costume design, the teacher will make a comprehensive evaluation of their final works (2 sets in total). The composition of the process evaluation score is attendance (20%) + Daily homework (20%) + final work (60%). The evaluation criteria are as follows (tables 1, 2 and 3).

Table 1

ATTENDANCE TIMES AND CORRESPONDING SCORES

| **Day** | 7 | 6 | 5 | 4 | <4 |
|---|---|---|---|---|---|
| **Score** | 20 | 18 | 15 | 12 | 0 |

Table 2

DAILY HOMEWORK AND CORRESPONDING SCORES

| **Daily homework** | **Anthropometric data** | **Virtual human generation** | **Style** | **Pattern** |
|---|---|---|---|---|
| Score | 5 | 5 | 5 | 5 |

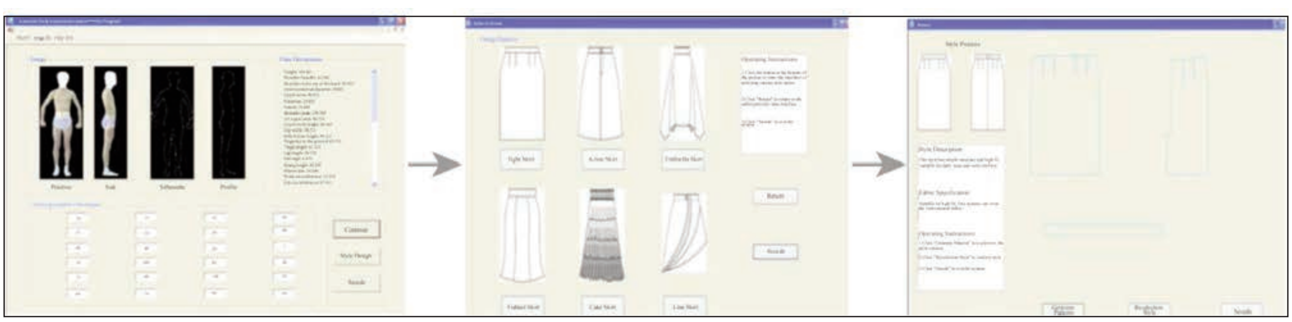
Table 3

FINAL WORK EVALUATION AND CORRESPONDING SCORES

| **Work** | **Anthropometric data** | **Virtual human generation** | **Style** | **Pattern** | **Time** |
|---|---|---|---|---|---|
| Score | 10 | 10 | 10 | 10 | 20 |

*Cognitive evaluation*

One month after the end of the above experiment, another set of experiments was carried out. The experiment content is the same as the above experiment. Students are required to complete a set of virtual clothing design which is completely different from the teaching of *Experiment I* and *Experiment II* within the specified time, including new human body data measurement, generation of new virtual human models, and new clothing categories and templates. The final score of the experiment will be assessed by 10 teachers from the Department of Fashion Design and Engineering of the College of Textile and Apparel Engineering, Soochow University, totalling 100 points. The results of the experiment are used in the



*a* *b* *c*

Fig. 3. An example of anthropometry and virtual clothing design: *a* – anthropometric data measurement and results; *b* – clothing style selection; *c* – clothing pattern automatic generation

evaluation of students' long-term memory effects under two different teaching modes.

*Self-evaluation*

This research explores the influence of Gagné information processing theory on the teaching effect of clothing virtual simulation experiment while starting from humanism to focus on students' evaluation of the teaching effect of the new teaching model. Therefore, after the end of the experiment teaching, questionnaires will be issued to the students participating in Experiment II, including the students' evaluation of classroom atmosphere, knowledge cognition, learning attitude and comprehensive ability

### Statistical methods

SPSS software was used for data processing and analysis. The statistic is expressed as ($\overline{X} \pm S$), where $\overline{X}$ is the mean and $S$ is the variance. T test was used for data analysis of independent samples between groups, and the counting data was expressed in (%). T test calculation formula is:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \quad (1)$$

$\overline{X}_1$, $\overline{X}_2$ are the mean of two samples, $S_1^2$, $S_2^2$ – the variance of two samples, and $n_1$, $n_2$ – the capacity of two samples.

## EXPERIMENTS AND RESULTS

### Experiments

*Experiment I: Anthropometry and virtual clothing design experiment in the traditional way*

*Experiment I* adopted the traditional teaching methods. The students had not been exposed to the knowledge of the experimental background and content before the start of the course. In the teaching process, the teacher first explained the background knowledge related to the experiment and demonstrated the operation of the experimental system. Students operated the experimental system according to the teacher's explanations, according to short-term memory to complete the entire experiment, including inputting front and side photos of the human body, extracting anthropometric data, choosing clothing styles and generating corresponding clothing patterns. Throughout the experiment, the teacher had an absolute dominant position. The students passively accepted knowledge and formed short-term memory through mechanical memory. There was no interaction between the student and the teacher. A month after the above experiment, students will complete the anthropometry and virtual clothing design experimental test within the specified time. A month after the above experiment, students should independently design a set of clothing patterns within the specified time, which is different from the previous one, to complete the anthropometry and virtual clothing design experimental test.

*Experiment II: Anthropometry and virtual clothing design experiment in Gagné information processing mode*

*Experiment II* adopted Gagné information processing theory. The teacher had informed the students of the experiment content and objectives before the start of the experimental teaching, and the students had independently previewed the knowledge related to the experiment. During the teaching process, students can discuss experimental knowledge with the teacher. The teacher will demonstrate the operation of the experimental system corresponding to each step of the experiment in turn. When the teacher performed the operation, the students could perform the operation synchronously and communicate with the teacher on the problems that arise. After the teacher finished all the demonstrations, the students extracted information based on the short-term memory formed before and formed effective long-term memory in the operation of the experimental system. According to the specific requirements of the experiment, the information in the long-term memory is extracted to complete the entire experiment, including inputting anthropometric data, generating a virtual human model, choosing clothing styles and generating corresponding clothing patterns. Throughout the experiment, the teacher appeared as the instructor, and the students and the teacher continued to interact with each other and formed a thinking mode to solve similar experimental problems through knowledge transfer. One month after the above experiment, students should independently design a set of new clothing patterns within the specified time to complete the anthropometry and virtual clothing design experimental test.

### Results

There are three different results involved in this study: (1) process evaluation; (2) cognitive evaluation; (3) student self-evaluation. Tables 4, 5 and 6 present these results respectively.

Table 4

PROCESS EVALUATION RESULTS

| Type size | Number | Attendance | Daily homework | Final work evaluation | Total score |
|---|---|---|---|---|---|
| Experiment I | 30 | 18.73213 | 17.50436 | 50.13232 | 86.36310 |
| Experiment II | 30 | 19.67075 | 19.26112 | 54.94233 | 93.87221 |
| T value | - | 9.82 | 8.71 | 3.83 | 3.87 |
| P value | - | 0.030 | 0.039 | 0.000 | 0.000 |

Table 5

| COGNITIVE EVALUATION RESULTS | | |
|---|---|---|
| **Type size** | **Number** | **Total score** |
| Experiment I | 30 | 84.68±4.65 |
| Experiment II | 30 | 90.34±3.35 |
| T value | - | 7.58 |
| P value | - | 0.000 |

A total of 30 questionnaires were distributed and 30 questionnaires were recovered, with a recovery rate of 100%. Descriptive statistical results of students' views on Gagné information processing mode are shown in table 6 ($n$ = 30, %).

## Discussion

It can be seen from table 4 that in the process evaluation, the average scores of the experimental group are higher than those of the control group. This shows that the students who use Gagné information processing theory for course learning are more likely to form long-term memory of knowledge. This makes students a deeper understanding and mastery of knowledge. In addition, the attendance of students in the experimental group is significantly better than that of the control group. This proves Gagné information processing theory can enable students to better learn and apply professional knowledge. The process of interacting with the teacher can stimulate students' enthusiasm and enthusiasm for learning. Except for the similar standard deviations of the final homework scores graded by the teacher, the standard deviations of the scores of other items in the experimental group were significantly smaller than those of the control group. This proves that Gagné information processing theory is more conducive to the improvement of students' overall academic performance and is more suitable for class teaching activities. As $P \leq 0.05$ in the T test, there is a significant difference between the two groups relating to attendance, daily homework, final homework and total score.

The cognitive assessment test is conducted a month after the end of the course. It can be seen from table 5 that in the cognitive evaluation, the P value of the scores of the experimental group and the control group is less than 0.05, which indicates that the scores of the two groups are significantly different. The average score of the experimental group is higher than that of the control group, which shows that the students in the experimental group have significantly higher knowledge transfer ability than the control group in dealing with professional problems with similar knowledge background. This proves that Gagné information processing theory is more conducive to maintaining students' learning effects and forming students' long-term memory of knowledge and skills. The standard deviation of the number of experimental components is smaller than that of the control group, which shows that Gagné information processing theory can eliminate differences between students and is more suitable for class teaching.

As seen from table 6, overall, 76.7% of the students recognized Gagné information processing theory and 80% of the students hope to continue to learn other courses in Gagné information processing theory. In terms of learning atmosphere, 80% of students believe that Gagné information processing theory has enlivened the classroom atmosphere and improved their learning enthusiasm. 66.6% of students believed that Gagné information processing theory has improved their communication skills. In academic terms, 70% of students believe that Gagné information processing theory is conducive to analysing and solving problems. 53.4% of students believe that Gagné information processing theory is conducive to understanding and mastering the knowledge they have learned. 90% of the students think that Gagné information processing theory is

Table 6

| SELF-EVALUATION RESULTS | | | | | |
|---|---|---|---|---|---|
| **Item** | **Totally agree** | **Agree** | **Uncertain** | **Disagree** | **Totally disagree** |
| Recognize the Gagné information processing theory | 40.0 | 36.7 | 16.7 | 3.3 | 3.3 |
| Improve the enthusiasm of learning | 43.3 | 36.7 | 10.0 | 6.7 | 3.3 |
| Classroom atmosphere active | 56.7 | 23.3 | 13.3 | 6.7 | 0 |
| Conducive to analyzing and solving problems | 46.7 | 23.3 | 16.7 | 3.3 | 10.0 |
| Conducive to understanding and mastering knowledge | 36.7 | 16.7 | 33.3 | 10.0 | 3.3 |
| Improve the communication ability | 43.3 | 23.3 | 10.0 | 16.7 | 6.7 |
| Improve professional knowledge | 66.7 | 23.3 | 10.0 | 0 | 0 |
| Improve the ability of knowledge transfer | 40.0 | 23.3 | 16.7 | 16.7 | 3.3 |
| I also want to learn other courses in the mode of the Gagné information processing theory | 43.3 | 36.7 | 10.0 | 6.7 | 3.3 |

helpful to the learning of professional knowledge and 63.3% of the students think it improves their professional skills. It can be seen that students generally have a positive attitude toward Gagné information processing theory, which verifies the advantages of Gagné information processing theory over traditional teaching methods.

It cannot be ignored that there are still some students who do not recognize Gagné information processing theory, which shows that it also has certain drawbacks and cannot be suitable for all students. For example, some introverted students may affect the effect of learning feedback due to their personality problems in the process of communicating with teachers. In addition, due to the long-term acceptance of the traditional teaching mode, some students need some time to adapt to the new teaching mode, which will also affect students' evaluation of the new teaching mode. As the main body of education in Gagné information processing theory, teachers should guide students, help students change their learning thinking, adapt to the new teaching model, and improve learning efficiency.

## CONCLUSION

In this paper, we investigated the application of Gagné information processing theory in anthropometry and virtual clothing design experiment. Our research consists of a set of control experiments (traditional teaching methods and Gagné information processing theory) and three evaluations (process evaluation, cognitive evaluation and student self-evaluation). The results show that Gagné information processing theory is more conducive to improving students' learning enthusiasm, enabling students to form long-term memory of knowledge, behaviour patterns, and new cognitive strategies in practice, to achieve the effect of cultivating students' knowledge and skill transfer ability. At the same time, it can be seen that most students prefer to be taught by Gagné information processing theory and are willing to continue to use this model for course learning through student self-evaluation. It can be verified that Gagné information processing theory is suitable for anthropometry and virtual clothing design experimental teaching. It has more advantages compared with the traditional teaching model, which provides a theoretical basis for the application of Gagné information processing theory in education reform in the future. However, the results of the questionnaire survey showed that a small number of students did not support Gagné information processing theory. Therefore, the future research direction will tend to improve the learning experience of these students in Gagné information processing theory and formulate a teaching plan suitable for all types of students. To maximize the advantages of Gagné information processing theory.

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# Influence of rotor structure and process parameters on polyethylene oxide (PEO) nanofibers produced through centrifugal

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**ABSTRACT – REZUMAT**

**Influence of rotor structure and process parameters on polyethylene oxide (PEO) nanofibers produced through centrifugal**

*The application of new tools and equipment in conventional spinning has increased with the advancements in operations, handling and optimal yarn production. For example, in the centrifugal electrospinning process (CESP), the rotor is assembled for its high-speed production. Therefore, the purpose of this study is to introduce a new rotor design with a triangular groove structure and to investigate its influence on the fast industrial manufacturing of polyethylene oxide (PEO) nanofibers. In addition, electric voltage (45 kV, 55 kV, 65 kV), concentrations of the spinning solution of PEO polymer (6 wt. %, 7 wt. % and 8 wt. %) and the flow rate of the spinning solution were analysed at different levels (45 ml/h, 55 ml/h, 65 ml/h). The subsequent PEO nanofibers were characterized through a scanning electron microscope (FESEM). It was observed that the diameter of PEO nanofibers changed with the variation in voltage, concentration and flow rate. The results revealed the best and uniform fibre diameter dimension at 65 kV, with an 8 wt.% solution concentration and flow rate of 55 ml/h. The outcomes also implied that the proposed triangular groove rotor was an efficient approach for the improvement in the nano fibres with its high uniformity as compared to the conventional structure (rectangular rotor structure).*

***Keywords:*** *centrifugal electrospinning, polyethylene oxide, nano-fibres, rotor, yarn*

**Influența structurii rotorului și a parametrilor de proces asupra nanofibrelor de oxid de polietilenă (PEO) produse prin centrifugare**

*Aplicarea de noi instrumente și echipamente în filarea convențională a crescut odată cu progresele în operarea, manipularea și producția optimă de fire. De exemplu, în procesul de electrofilare prin centrifugare (CESP), rotorul este realizat pentru producția la mare viteză. Prin urmare, scopul acestui studiu este de a introduce un nou design de rotor cu structură triunghiulară și de a investiga influența acestuia asupra producției industriale rapide a nanofibrelor de oxid de polietilenă (PEO). În plus, tensiunea electrică (45 kV, 55 kV, 65 kV), concentrațiile soluției de filare de polimer PEO (6 wt. %, 7 wt. % și 8 wt. %) și debitul soluției de filare au fost analizate la diferite niveluri (45 ml/h, 55 ml/h, 65 ml/h). Nanofibrele PEO rezultate au fost caracterizate cu microscopul electronic cu scanare (FESEM). S-a observat că diametrul nanofibrelor PEO s-a modificat odată cu variația de tensiune, concentrație și debit. Rezultatele au evidențiat cea mai uniformă dimensiune a diametrului fibrei la 65 kV, cu o concentrație de soluție de 8 wt.% și un debit de 55 ml/h. Rezultatele au indicat, de asemenea, că rotorul propus cu canelura triunghiulară este eficient pentru îmbunătățirea nanofibrelor prin uniformitatea sa ridicată în comparație cu structura convențională (structura dreptunghiulară a rotorului).*

***Cuvinte-cheie****: electrofilare centrifugală, oxid de polietilenă, nanofibre, rotor, fir*

## INTRODUCTION

Tailored fibrous strands are currently in high demand because of their potential applications in a wide variety of fields [1]. These fine fibrous strands from natural or synthetic polymers with diameters extending from tenths of nanometres to a couple of microns [2] presently are produced by techniques such as template synthesis [3], phase separation [4], self-assembly [5], melt blowing [6], and electrospinning [7]. Amongst all techniques, electrospinning (ES) has been considered the most extensive and proficient method for fabricating fine fibrous strands at the nanoscale [3, 8]. Moreover, electrospinning is believed to be a state-of-the-art fibre and membrane manufacturing technique. The process can produce endless fibrous strands from a huge range of polymer solutions. Fibres produced by the electrospinning technique are considered building blocks for developing tailored membrane structures for a wide range of applications such as energy, biomaterials, filtration, composites and protective textiles etc. [9]. However, the limited production rate of the process hinders acceptability on a commercial scale [10, 11]. Therefore, it is highly needed to figure out some means to enhance the production rate of the electrospinning process to make it scalable enough to overcome the constraints of fast industrial manufacturing [11].

For this purpose, the needless electrospinning method is believed to be a high potential and feasible option. A thorough literature review suggests that only a very small number of studies have reported the successful fabrication of micro/ nano-fibres using centrifugal electrospinning (CES). Various polymers, such as polyethylene oxide [12–15], polyvinylidene fluoride [16], polymethyl methacrylate [17], and polycaprolactone [18] have been electrospun using CES. Thus, this recently established CES method has gained considerable attention due to its simple working principle and improved rate of production fibres with submicron diameters [19–21]. Additionally, in CES, the rate of fibre production is more (≥ 1 g/min per nozzle) and two nozzles are used [22, 23]. Moreover, the CES has successfully overcome the major obstacles such as (solution conductivity, application of high-voltage electric field, safety and environmental concerns etc.) that the former type of electrospinning (ES) encounters [14, 24–26]. Other studies proposed a model that included solution viscosity, and evaporation rate, and contained a specific charge [27]. Similarly, Gao H. et al. anticipated a touch spinning method for the fabrication of core-sheath nanofibrous piezoelectric yarns with a single filament electroconductive core [28]. Thus, various parameters of the CES process can greatly influence the dimension and diameter of the resultant fibres [29, 30]. These parameters include the concentration of polymer, rotational speed, electric voltage, nozzle size, temperature (for melts), evaporation rate, collector distance, etc. [24–34]. All the parameters are obligatory to configure appropriately before the production of desired dimension fibres [35]. However, amongst these parameters, solution concentration and rotational spinning speed are considered the foremost factors [36]. When the solution concentration is kept lower, the fibres produced have a narrower diameter [37]. Further, there is an elusive relationship between fibre morphology and the rotational speed of the machine [38].

Several studies and research have demonstrated the pros and cons of optimising ultrafine fibres [17, 39–42]. So far, the most associated study describing the influence of rotor structure design in the CES process was reported by Hui Wu et al. for generating highly oriented ceramic nanofibers. It was different from the conventional CEP process as unlike the conventional setup a metallic triangular tip without any solution supply was used as electrospinning sources. The tip was prepared by cutting down a 1-mm-thick aluminium sheet into a 1–5 cm rectangle with a triangular tip; it helped to establish a Tylor cone while electrospinning [43, 44]. Thus, we believe using an electrospinning machine having both centrifugal and electrostatic force with a newly proposed high-speed rotor structure i.e., triangular groove rotor structure, maybe a possible way forward. The polymer spinning solution was fed to the nozzle with a controlled feeding rate. The centrifugal force throws the spinning solution, electrostatic force draws the polymer jet into fine strands with simultaneous evaporation of the solvent, and resultant fibres are then deposited on the collector. Herein, we report a comparative study and analysis of polyethylene oxide nano-fibres prepared by using a rectangular groove structure rotor and triangular grooved structure rotor via electrospinning. Furthermore, the effect of various process parameters on fibre diameter and its uniformity obtained from both rotor structures was also examined. Compared to fibres produced using a triangular groove structure rotor, fibres produced by a rectangular structure rotor presented better morphology and overall characteristics.

## MATERIALS AND METHODS

### Materials and rotor structures

Polyethylene oxide (PEO) Mw = 100000, was received from Shanghai Macklin Biochemical Co Limited. The metering pump was attained from Shanghai Angel Electronics Co Limited and the DC generator was acquired from the Scholl-run factory of Fudan high school. The solutions for the centrifugal electrospinning experiment were prepared using polyethylene oxide (PEO). PEO powder was dissolved into distilled water in a beaker and stirred with the help of a magnetic stirrer at 80°C. It was done in 4 hours for making spinning solution with the different concentrations i.e., 6 wt. %, 7 wt. %, and 8 wt. %. Figure 1 has shown the two types of rotors i.e., rectangular groove structure (conventional method) and triangular groove structure (proposed method). The diameter and uniformity of PEO nanofibers attained from both rotors were compared and analysed. Table 1 shows the fundamental scheme of producing PEO nanofibers, i.e., four process variables with three levels.

Table 1

PRODUCTION SCHEME OF PEO NANOFIBRES

| Level | Solution concentration (%) (A) | Additional voltage (kV) (B) | Rotor speed (R/min) (C) | Spinning fluid flow rate (ml/h) (D) |
|---|---|---|---|---|
| 1 | 6 | 45 | 4600 | 45 |
| 2 | 7 | 50 | 5500 | 55 |
| 3 | 8 | 55 | 6400 | 65 |

### Sample preparation

The dissolved PEO solution was prepared and sucked through the vessel meter. The flow rate (ml/h) of the solution was kept constant with the metering pump. The motor rotated the spinning rotor smoothly. The liquid dropped down under the action of centrifugal force and electric field. The development of the jet was collected on the circular collector and finally, the

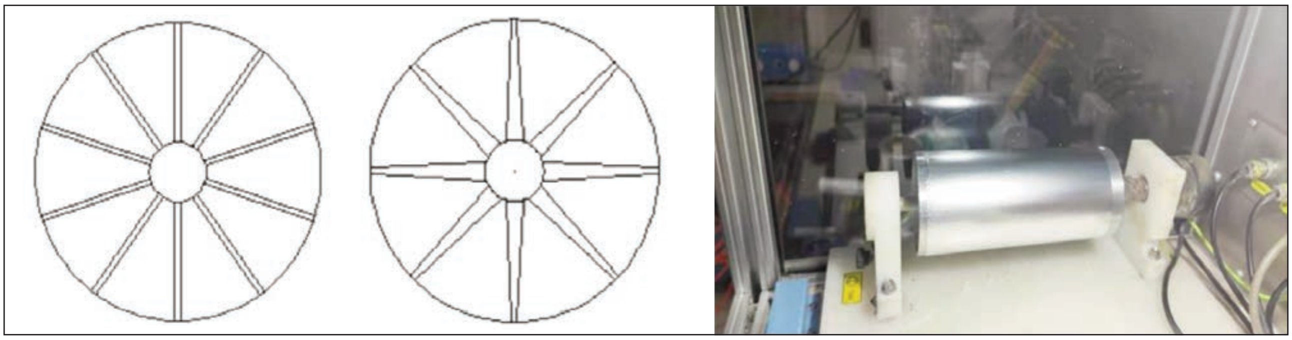

a b c

Fig. 1. Two types of rotor structures:
*a* – rectangular groove rotor; *b* – triangular groove rotor; *c* – rotor adjustment machine

continuous PEO nanofibers were obtained. The receiving distance (between the needle and the circular collector) was fixed at 30 cm. The factors i.e., the spinning solution concentration, rotor speed, liquid flow, and electric voltage, were examined. The fabricated material (samples) was acquired on the aluminium foil. The whole spinning process was completed in 1 hour.

### Working principle

The centrifugal electrospinning system (CES) used was simple and capable of excluding the limitations of the electrospinning (ES) process. All through the CES process, a polymer spinning solution was fed to the nozzle, which was controlled by the metering pump. The polymer solution was dropped down in the centre of the spinning rotor. When the rotational speed of the rotor reached a critical value, the centrifugal force has thrown out the spinning solution from the rotor. The spinning solution received a stretch due to the strong electric field and deposited on the collector forming dried nanofibers (shown in figure 2).

Additionally, the high rotational speed indorsed fast and accessible fibre fabrication, improving the production rate by two to three orders of magnitude. It reduced the production cost in association with the electrospinning process. Otherwise, the centrifugal electrospinning process enables the fabrication of nanofibers from polymer solutions with much higher concentrations than the needle electrospinning process, which also reduces the production cost by using less solvent. PEO is a man-made polyether that is easily accessible in a range of different molecular weights. Water solubility is the premium property of these polymers. Higher molecular weight PEOs (white and waxy solids) have melting points relative to their molecular weights to an upper limit of about 67°C [45]. While low molecular weight PEOs are colourless and viscous liquids. According to the standard of food and drug administration (FDA), PEO is nontoxic and could be used as excipients in various foods, cosmetics and pharmaceutical formulations [46].

### Characterization

The morphology of nanofibers was characterized using FE-SEM (Scanning electron microscope) instrument. All the samples were coated with gold before the observations. 100 different fibre points of nanofibers were randomly selected from the FESEM images. The diameter of the selected nanofibers was

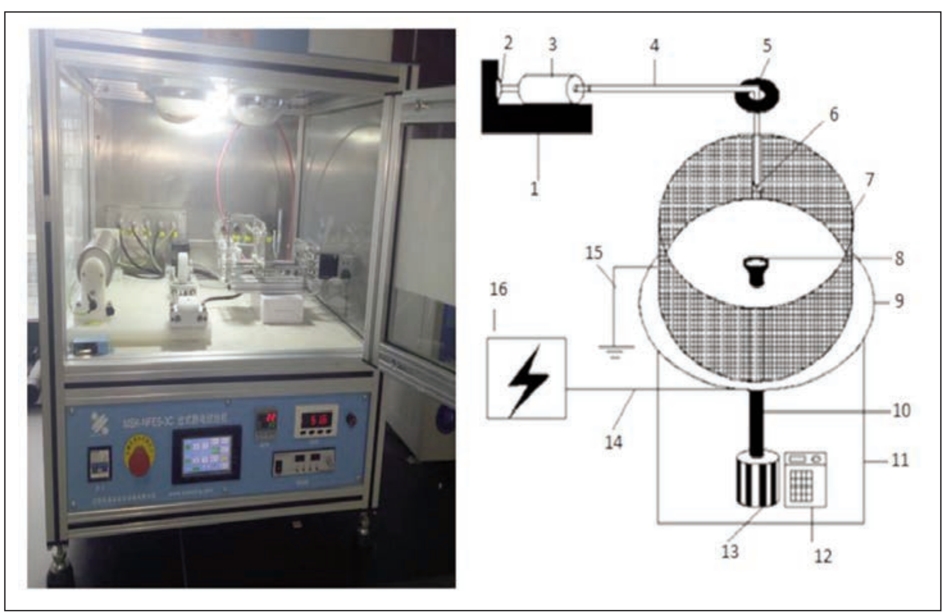


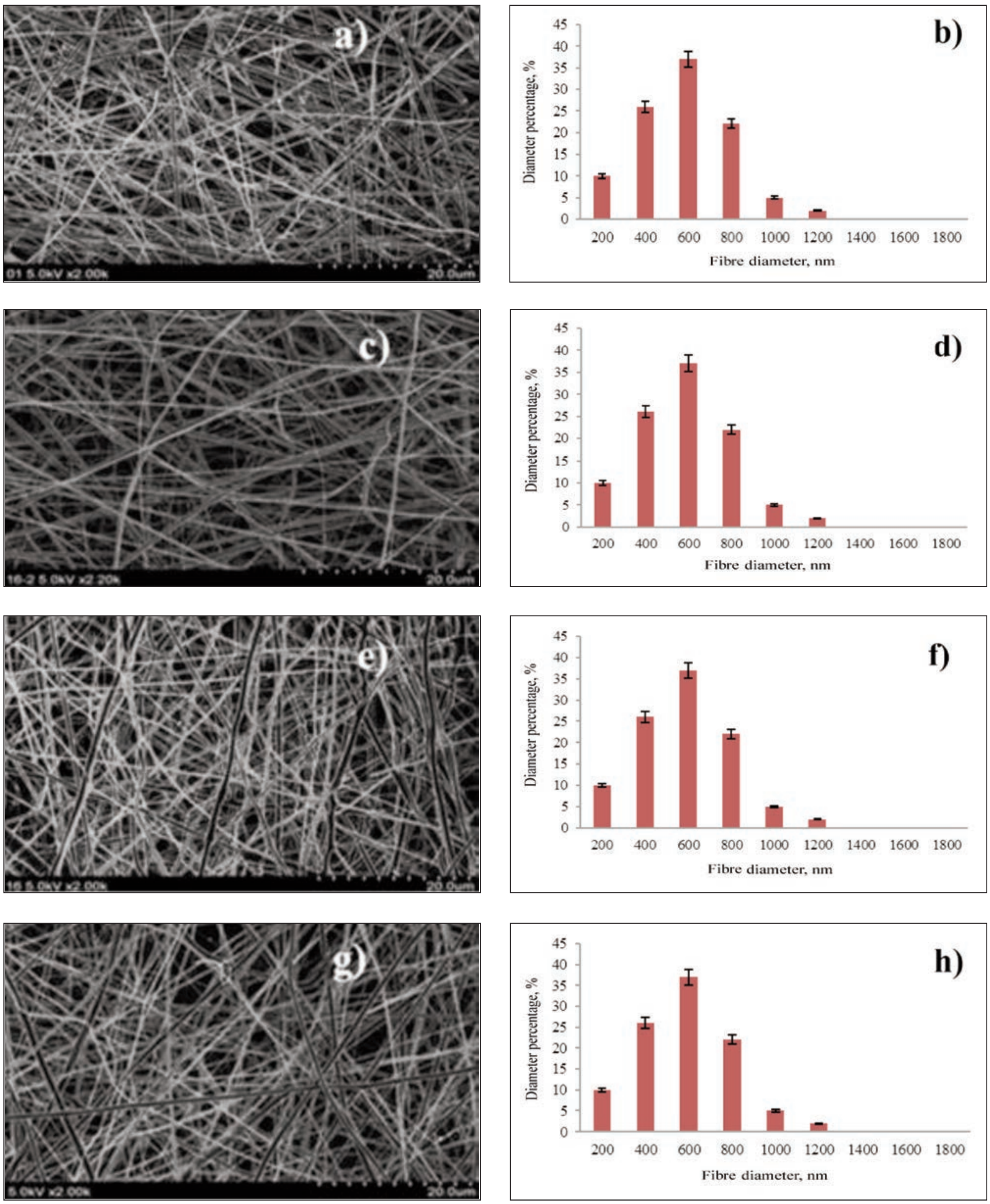

Fig. 2. Structure of centrifugal electrostatic spinning device: *1* – metering pump; *2* – piston; *3* – spinning liquid reservoir; *4* – wire liquid conveying hose; *5* – pipe support plate; *6* – flow plastic tube; *7* – receiving device; *8* – spinning rotor cup placement slot; *9* – insulating support plate; *10* – rotating spindle; *11* – case; *12* – inverter; *13* – drive motor; *14* – positiv\e power cord; *15* – negative power cord; *16* – high voltage electrostatic generator

measured through the nano measure software, used for the collection of SEM images data.

## RESULTS AND DISCUSSIONS

### Influence of spinning solution concentration

At a concentration of 6%, it was found a large number of droplets and a small number of beads in the fibre resulted in non-continuous fibre. With concentration (7%), there was a reduction in the number of droplets and beads which resulted in a long, continuous fibre with an improvement in fibre morphology. With the solution concentration of 8%, the resultant fibres were developed into a more fine and continuous form. It was found that fibre diameter increased with the increase of solution concentration. The reason is that the higher the solution concentration, the higher the viscosity and the surface tension. Thus, the formed fibres were thicker due to insufficient chain stretch. Figure 3 shows SEM images and corresponding fibre distributions of PEO nanofibers with different solution concentrations, i.e., 6 wt. % to 8 wt. %.



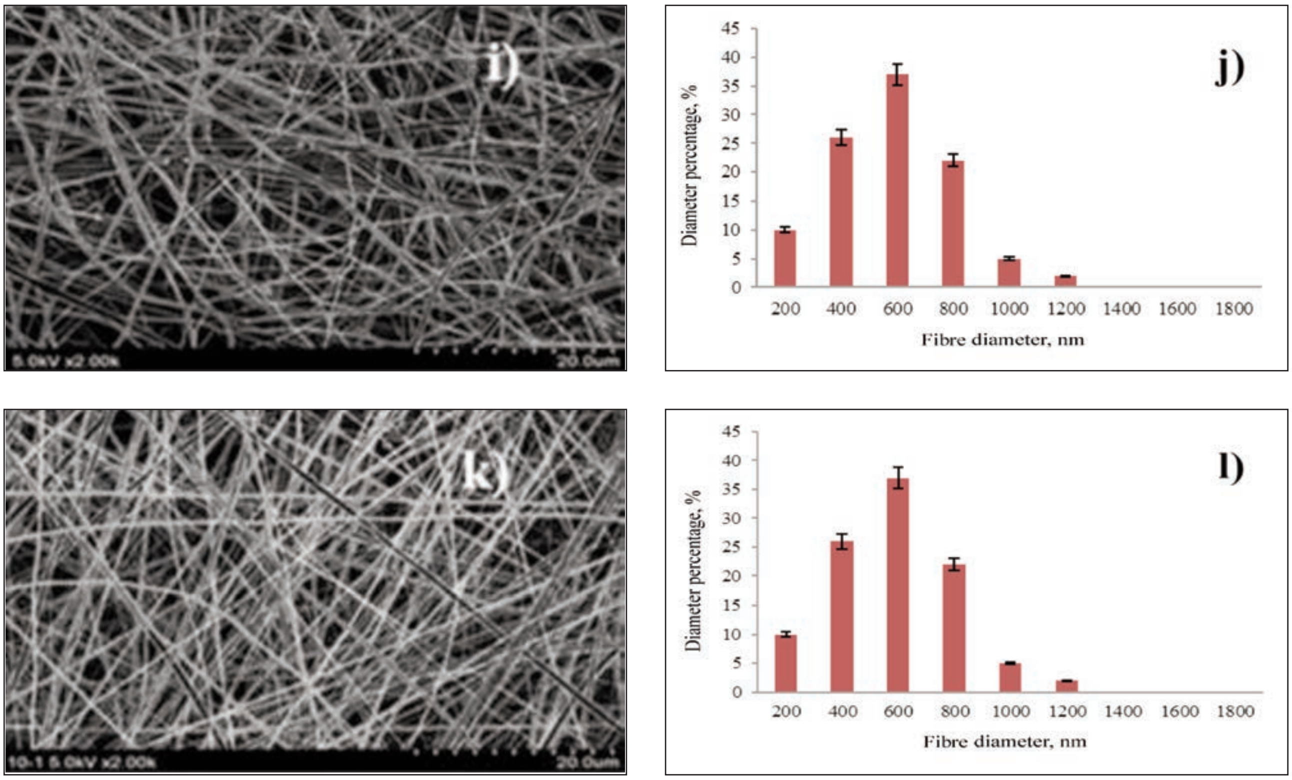



Fig. 3. SEM images and diameter of PEO nanofibers at 4600 rpm centrifugal electro spun with different solution concentrations (6 wt %, 7 wt %, and 8 wt %) using 45 kV electric voltage and 45 ml/h liquid flow rate, through the triangular rotor

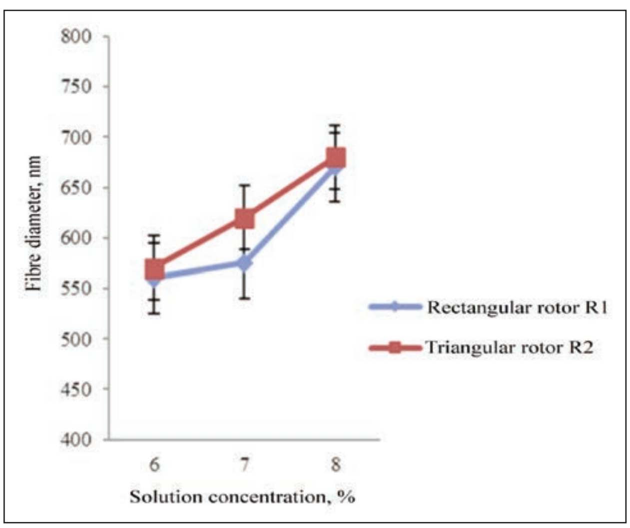



Fig. 4. Influence of solution concentration and fibre diameter

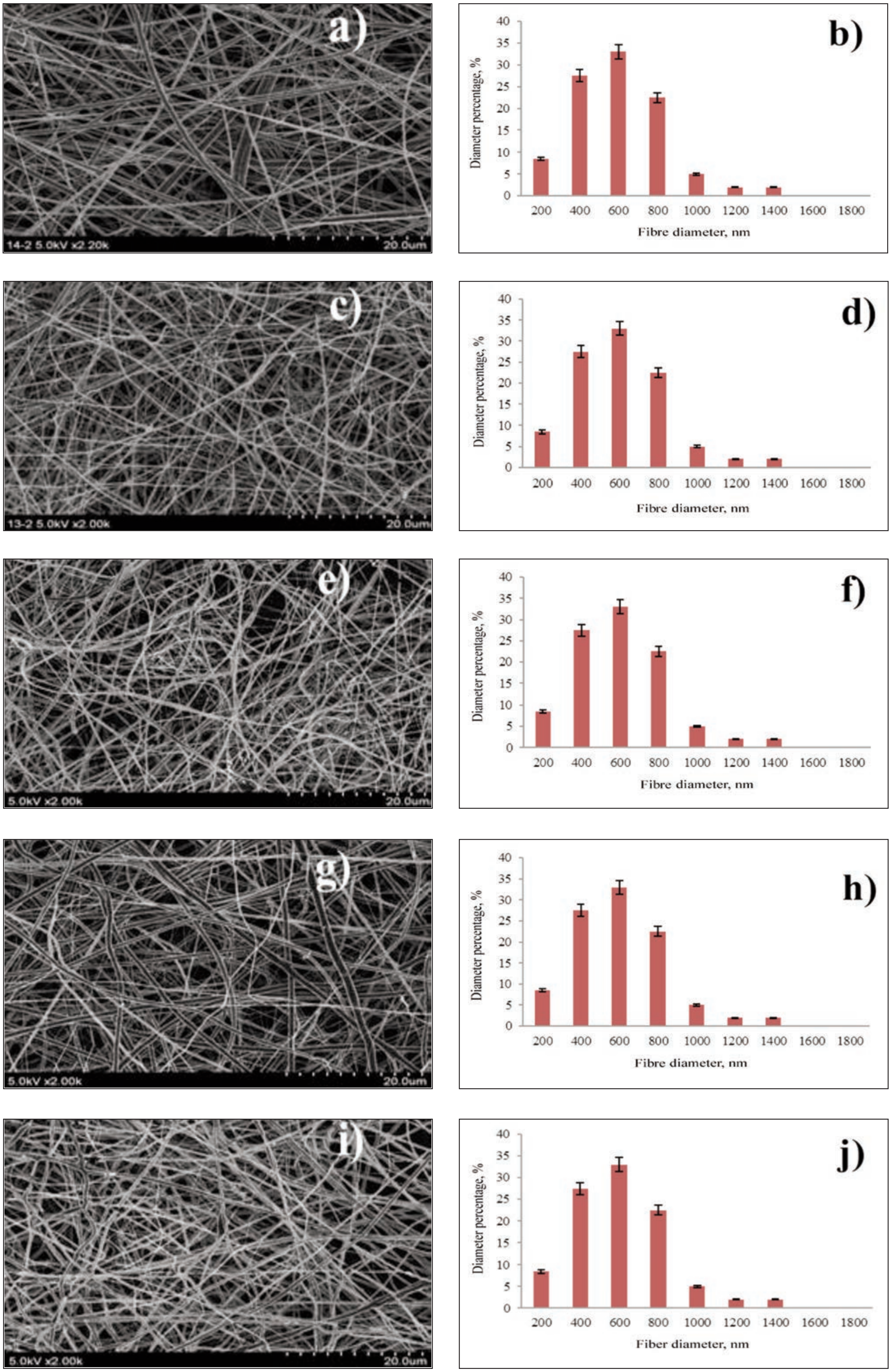
Figure 4 has shown that with the increase in solution concentration the diameter of spun fibres increased. It meant that once the solution concentration reached a high range, for example at 8% or more, the highly-viscous solution produces the fibre with a thicker diameter. It was due to the higher surface tension which resisted the elongation resulting in an insufficient drawing under a certain centrifugal force and electric field strength.

**Influence of electric field**

For the effect of the electrostatic force on fibre morphology, PEO nanofibers of varying voltage were fabricated at constant operational conditions of rotational speed, liquid flow rate, and solution concentration. Figure 5 (R1) and (R2) show the SEM images and corresponding fibre diameter distributions of PEO nanofibers under different electric voltages, i.e., from 45 kV to 55 kV. Moreover, at a very high voltage, the formation of the fibres was fine but uneven (not uniform).

When the applied voltage was lower than 45 kV, the fibre has a relatively larger diameter. There were also many beads or small droplets on the surface of the fibre that could not form continuous fibres. Thus, with less voltage, an electric field produced was not enough to overcome the surface tension of the small droplet and make it difficult to form the fibre jet. The small droplets were normally not drawn and the discharged fibres were not sufficiently stretched. Therefore, they become uneven. The small droplets on the surface of the fibre disappeared. The beading was hardly seen. However, there were some thick segments, the fibre diameter was still coarse. With the increase of the voltage (55 kV), the beads completely disappeared and the droplets turned into the fibre surface liquid. The resultant fibres were thin and uniform; however, there were still obvious thick joints even with the appropriate applied voltage and the electric field.

When the voltage was raised to 65 kV, the fibre-forming effect was relatively good. It completely overcome the surface tension of the droplets and made them fully stretched. The dimensions were thin with non-uniformity in the thickness. There was also a certain


a)
14-2 5.0kV x2.20k
20.0um
b)
Diameter percentage, %
Fibre diameter, nm
0 5 10 15 20 25 30 35 40
200 400 600 800 1000 1200 1400 1600 1800
c)
13-2 5.0kV x2.00k
20.0um
d)
Diameter percentage, %
Fibre diameter, nm
e)
5.0kV x2.00k
20.0um
f)
Diameter percentage, %
Fibre diameter, nm
g)
5.0kV x2.00k
20.0um
h)
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i)
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20.0um
j)
Diameter percentage, %
Fiber diameter, nm

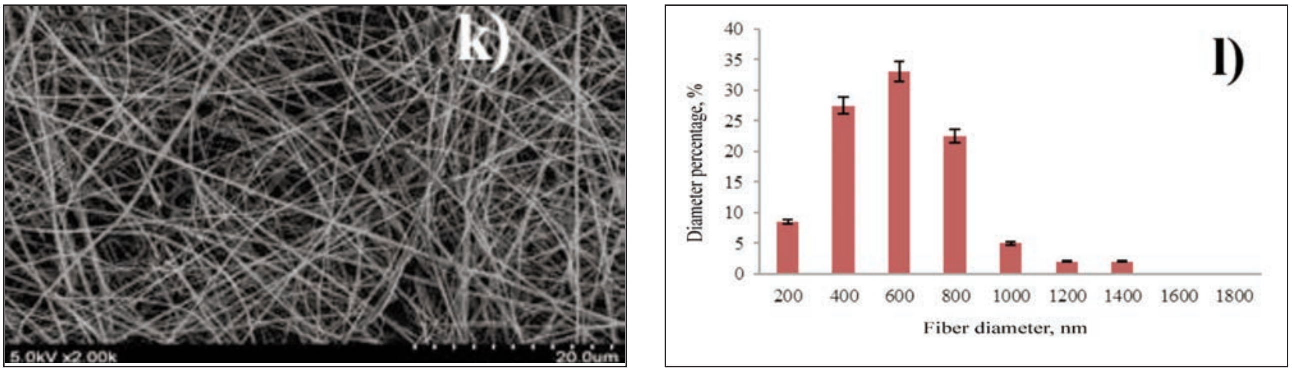



Fig. 5. SEM images and diameter of PEO nanofibers at 4600 rpm centrifugal electro spun with different electric voltage (45 kV, 55 kV, 65 kV) using 6% solution concentration and 45 ml/h liquid flow rate: *a* to *f* – PEO nanofibers through rectangular rotor structure (R1); *g* to *l* – PEO nanofibers through triangular rotor structure (R2)

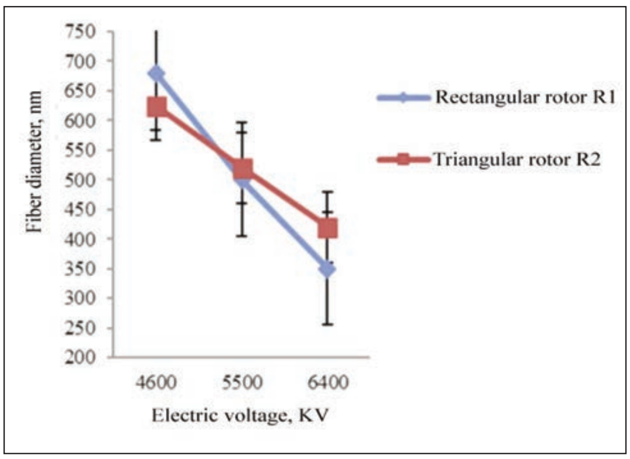
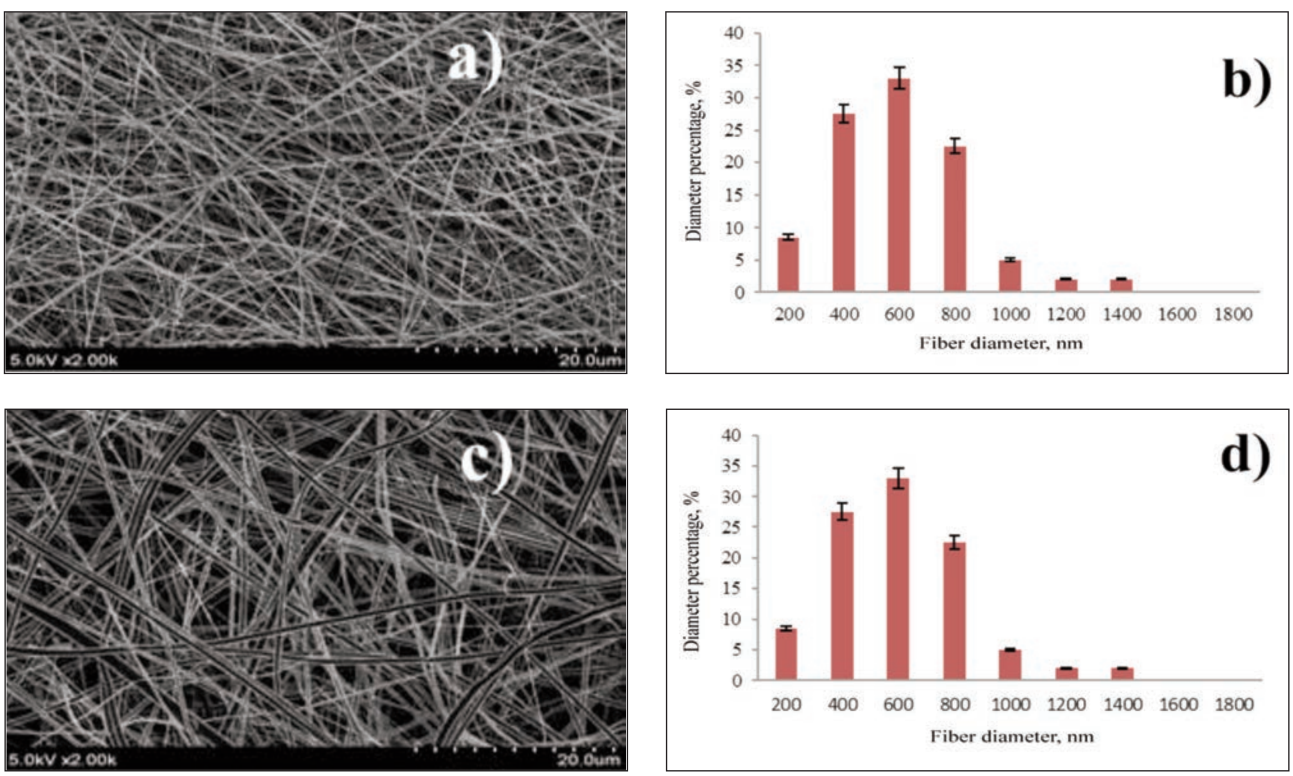



Fig. 6. Influence of electric voltage and fibre diameter

degree of adhesion between the fibres. This was due to the increase of the voltage that caused the acceleration to the surface of the droplet for transformation. Too much-drawing causes irregularity since it seldom provides enough time for the solvent to be volatile and fibre quickly received at the receiving plate. Figure 6 has shown that the diameter decreases with the increase of electric voltage with both rotor structures. It was observed that the increase in electric voltage decreases the diameter. Furthermore, with the increase in electric field strength, the dropped liquid has a greater surface charge density. Thus, it is subjected to a larger electrostatic repulsion. At the same time, the higher electric field strength accelerated the dropped liquid. These two factors have generated a greater drawing force and resulted in a strong drawing under a certain centrifugal force and electric field strength.

**Influence of rotational speed of the rotor**

Figure 7 (R1) and (R2) has shown the SEM images and corresponding fibre diameter distributions of PEO nanofibers with different rotational speeds i.e.,



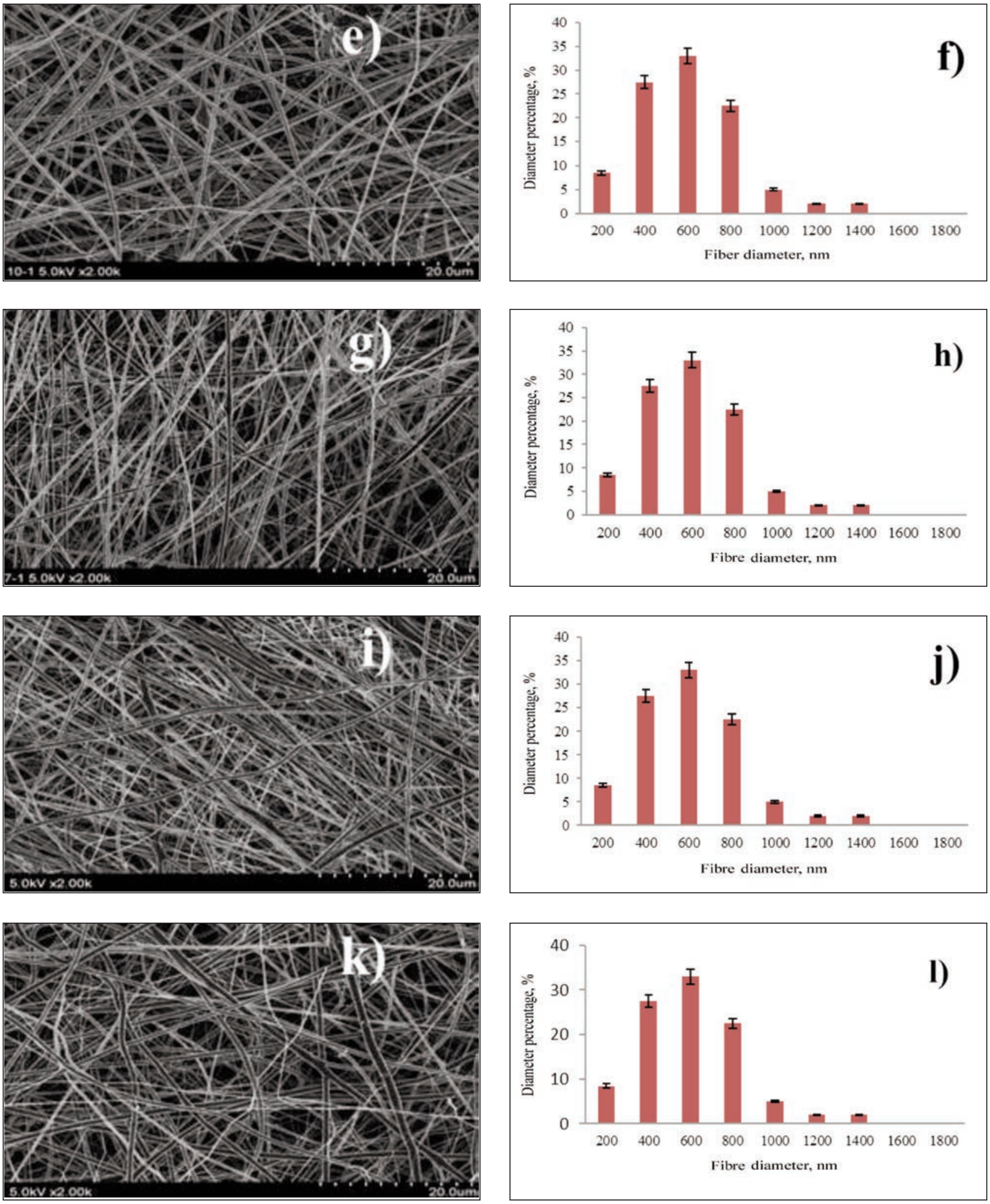



Fig. 7. SEM images and diameter of PEO nanofibers centrifugal electro spun at different rotational speeds (4600 rpm, 5500 rpm and 6400 rpm) with 45 ml/h using 6% solution concentration and 45kV electric voltage: *a* to *f* – PEO nanofibers through rectangular rotor structure (R1); *g* to *l* – PEO nanofibers through triangular rotor structure (R2)

from 4600 rpm to 6400 rpm. However, a very higher rotational speed caused the formation of more beads, non-uniformity and weak fibres. When the rotor speed was lower than 4600 rpm, the fibre fineness was improved to some extent, however, it was not uniform, and several fibres were thicker. With the increase in rotor speed i.e., increased to 5500 rpm, the fibre was thinner and more uniform. Thus, fibre has the best effect. When the rotor speed was increased further, the fibre was finer but uneven. This was because the spinning rotor rotates at a slow speed and the small droplets received a little force while throwing/dropping out in the spinning rotor. The number of droplets dropped was smaller. The droplet area was large, and the electrical energy required generated the jet, increasing fibre diameter. When

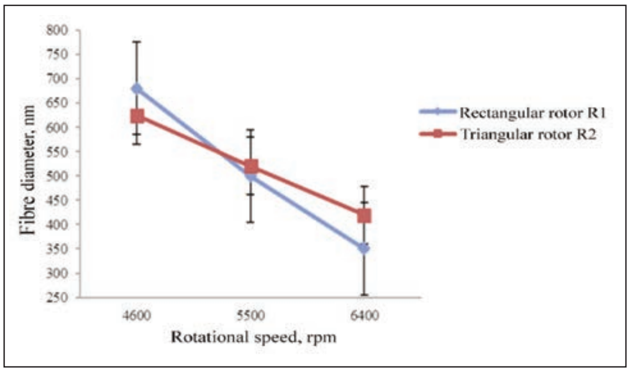



Fig. 8. Influence of rotational speed and fibre diameter

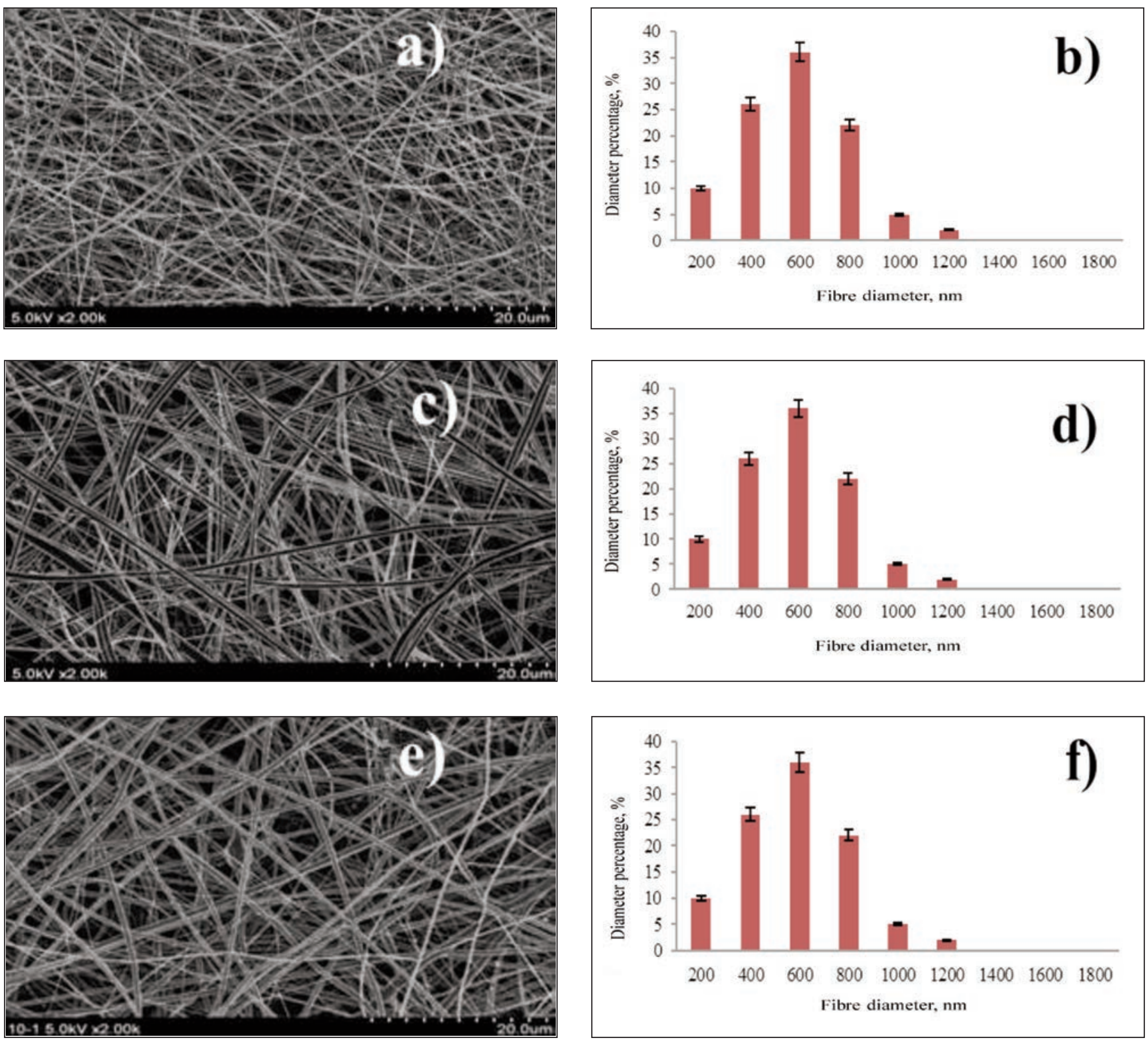
the spinning rotor rotated at a high speed, the centrifugal force of the dropped droplets (small) was greater.

Moreover, the falling of several small droplets on the spinning rotor resulted in a small droplet surface area. The diameter of the fibre decreased with the increase in the rotational speed of the spinning rotor. When the rotational speed was high enough i.e., reached a critical value, the fibre began to crack, and then the jet became bead-like and the diameter of the fibre increased. Rotational speed has a critical role in the determination of the liquid dropped in the drawing process. Figure 8 has shown that the diameter of spun fibres decreases with the increase in rotational speed. Thus, with the increase in rotational speed, the centrifugal force increased and the diameter of spun fibres decreased.

**Influence of liquid flow rate on fibre morphology**

Figure 9 (R1) and (R2) has shown the SEM images and corresponding fibre diameter distributions of PEO nanofibers. It was perceived that very higher flow rates of spinning liquid resulted in the formation of more beads and irregularity in the fibres. It was observed that with the increase in liquid flow rate, the diameter of the fibre increased. This was due to the falling of bigger size drop and faster flow rate of spinning. Moreover, it leads to an insufficient drawing under a certain centrifugal force and electric field strength. It was also noticed that the very slow flow rate of spinning liquid, made the falling of smaller droplets on the spinning rotor.

Additionally, the high-speed spinning rotor has not thrown out small liquid drops continuously. An



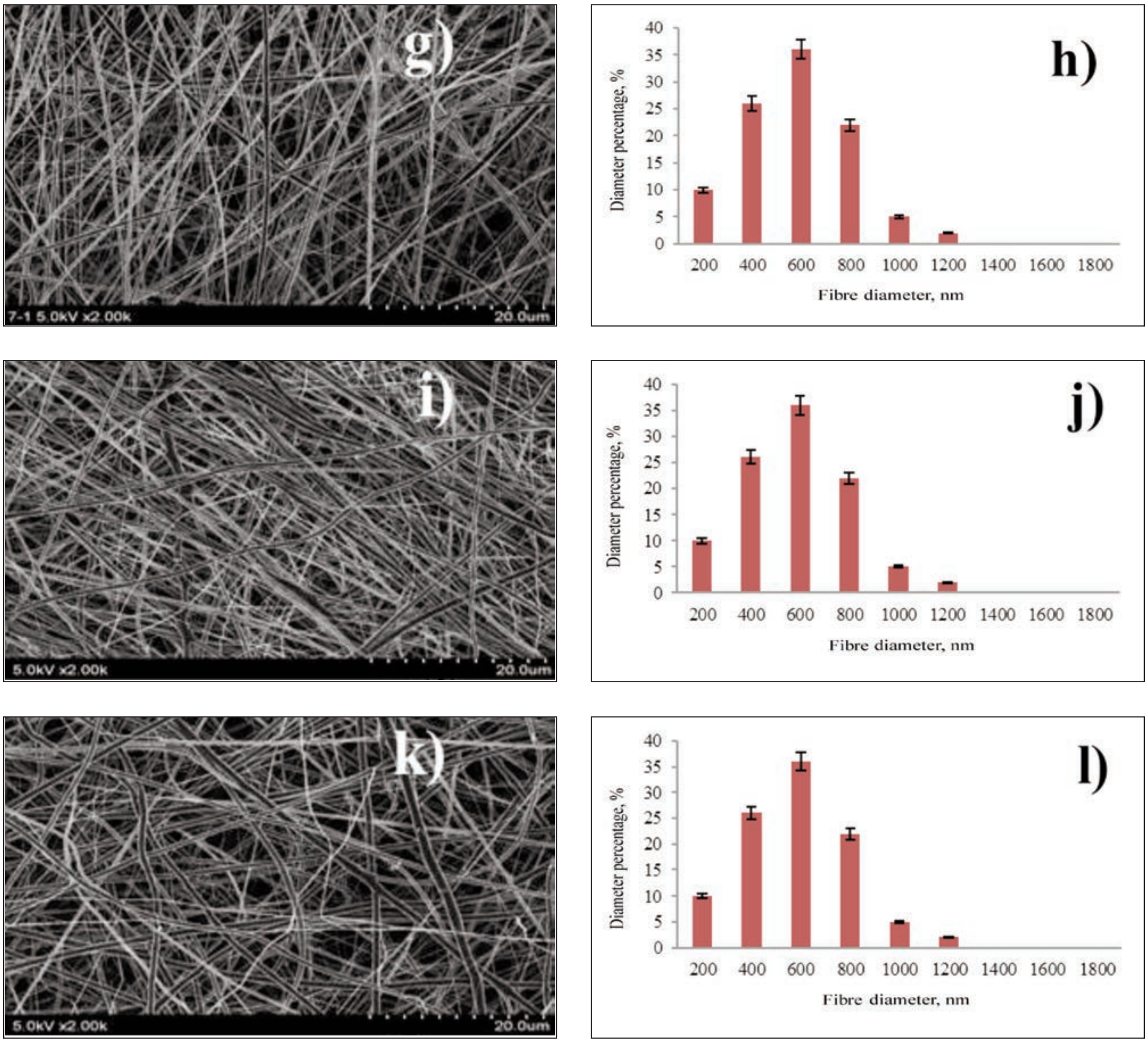



Fig. 9. SEM images and fibre diameter distribution of PEO nano-fibres at 4600 rpm centrifugal electro spun with different liquid flow rates (45 ml/h, 55 ml/h and 65 ml/h) using 6% solution concentration 45 kV electric voltage: *a* to *f* – PEO nanofibers through rectangular rotor structure (R1); *g* to *l* – PEO nanofibers through triangular rotor structure (R2)

increase (appropriate range) in the rate flow of spinning liquid has filled the groove of the spinning rotor and therefore continuous nanofibers were achieved. In figure 10, it was observed that with the increase in liquid flow rate, the diameter of the fibre also increased. This was due to the falling of bigger size drop and its faster flow rate of spinning. Moreover, it led to an insufficient drawing under a certain centrifugal force and electric field strength.

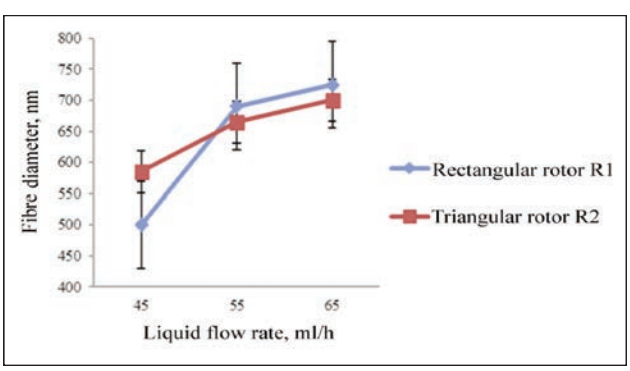



Fig. 10. Influence of liquid flow rate and fibre diameter

**Influence of the spinning rotor structure**

Figure 11 has shown the SEM images and distribution of fibres prepared from both the rotors i.e., conventional rotor (rectangular rotor structure R1) and newly proposed rotor structure (triangular rotor structure R2). These SEM figures demonstrated that the diameters of PEO nano-fibers spun with triangular groove structure rotor (R2) have finer and more uniform results than the conventional i.e., rectangular groove structure rotor (R1) which has some irregular places in the fibres (deficiency in uniformity and fineness). Thus, the overall result indicated that fibres obtained through a triangular grooved rotor were more even and uniform while the fibres gained through a rectangular grooved structure rotor were less effective.

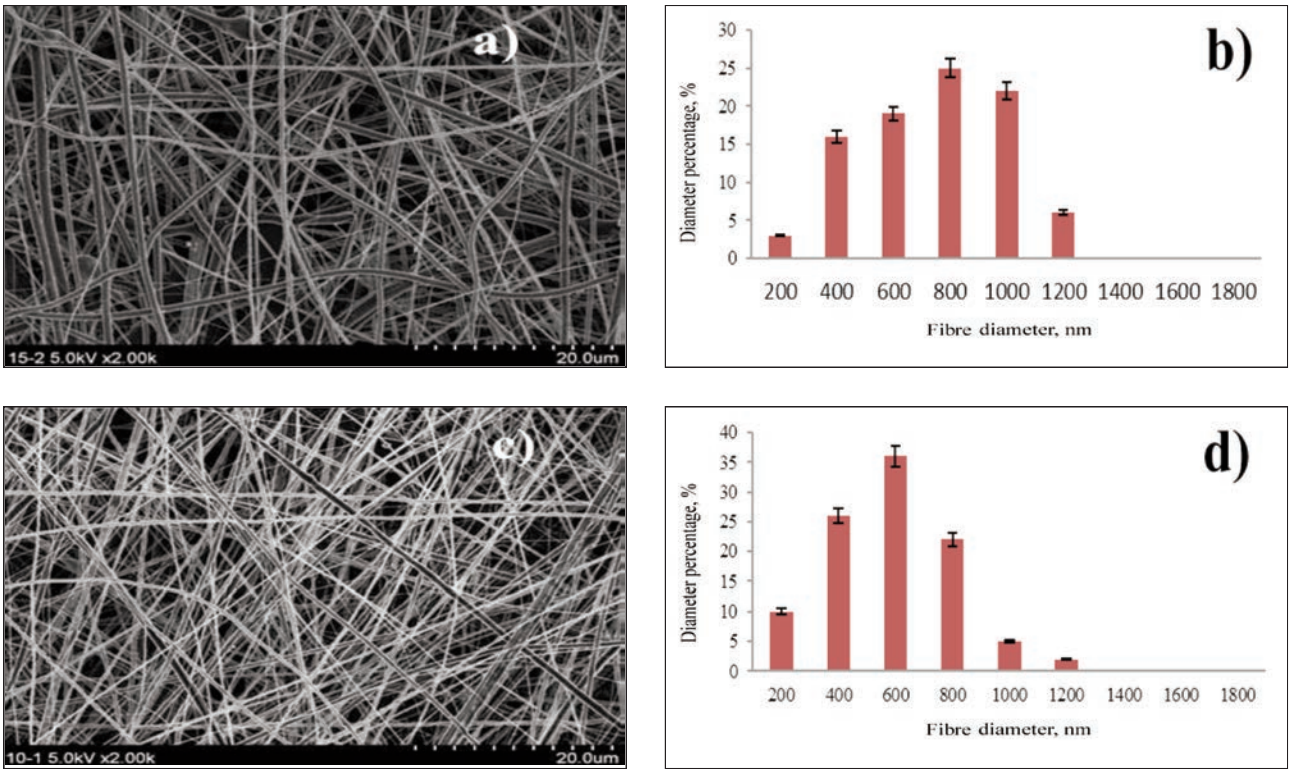



Fig. 11. Comparison of SEM images and effect of two rotor structures: *a* and *b* – effect of rectangular rotor structure (R1); *c* and *d* – effect of triangular rotor structure (R2)

## CONCLUSIONS

In this paper, PEO nanofibers production was investigated and improved through a triangular grooved rotor structure. This is a novel step to develop an adept system for the centrifugal electrospinning (CES) process. The CES technology has low cost and large-scale production of nanofibers. The triangular grooved rotor structure was an effective model in the centrifugal electrospinning process for continuous, fast and high-speed PEO nanofibers. The highest quality of PEO fibres was obtained at 8% solution concentration where the electric voltage of 55 kV, spinning rotor speed of 5500 rpm and the flow rate of 55 ml/h. The diameter of the produced PEO nanofibers with triangular grooved rotor structure was more even and uniform as compared to the rectangular rotor structure. Hence it is a good choice for more technological advancements in the production of low-cost and large-scale production of nanofibers.

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# The impact of OECD's Development Assistance Committee (DAC) Aid Commitments for Education on Human Development in Asian Countries and its implications for textile industry

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**ABSTRACT – REZUMAT**

**The impact of OECD's Development Assistance Committee (DAC) Aid Commitments for Education on Human Development in Asian Countries and its implications for textile industry**

*Education and health are considered a cornerstone for obtaining targeted development in any society. Moreover, both sectors promote prosperity greatly. In this changeable epoch, people are thought out as the real wealth of any nation and this wealth with good human capital serves the economy very efficiently and productively. This research study aims to analyse how Development Assistance Committee (DAC) aid commitment for education along with institutional quality is effective for the human development of selected Asian economies. A panel data set over 2011–2018 is used for this analysis in Asian countries. GMM results show a significant and positive relationship between aid commitment for education and the human development of these economies. A more interesting result is that financial development seems to boost up human deployment in the selected Asian economies. The development of the textile industry is significantly influenced by education, especially considering the effects of OECD's Development Assistance Committee (DAC) Aid Commitments for education on human development in Asian countries. There is a dire need to reconsider more allocation of resources and aid to education and health to utilize these inflows at the maximum level for targeted development.*

***Keywords:*** *Aid Commitment for education, financial development, industrialization, institutional quality, emerging economy, human development, textile industry, sustainable development*

**Impactul angajamentelor de sprijin pentru educație ale Comitetului de asistență pentru dezvoltare (CAD) al OCDE asupra dezvoltării umane în țările asiatice și implicațiile acestora pentru industria textilă**

*Educația și sănătatea sunt considerate piatră de temelie pentru obținerea unei dezvoltări țintite în orice societate. De asemenea, ambele sectoare de activitate promovează foarte mult prosperitatea. În această perioadă în continuă schimbare, oamenii sunt percepuți ca bogăție reală a oricărei națiuni și că această bogăție cu capital uman bun servește economia foarte eficient și productiv. Acest studiu de cercetare își propune să analizeze modul în care angajamentul de ajutor al Comitetului de Asistență pentru Dezvoltare (DAC) pentru educație, împreună cu calitatea instituțională, este eficient pentru dezvoltarea umană a anumitor economii asiatice. Pentru această analiză este utilizat un set de date de tip panel pentru perioada de eșantionare 2011–2018 privind țările selectate din Asia. Rezultatele GMM arată o relație semnificativă și pozitivă de angajament de ajutor pentru educație și dezvoltarea umană a acestor economii. Rezultatul încă și mai interesant este că dezvoltarea financiară pare să stimuleze coordonarea resurselor umane în economiile asiatice selectate. Dezvoltarea industriei textile este influențată semnificativ de nivelul de educație, mai ales având în vedere efectele angajamentelor de ajutor pentru educație ale Comitetului de asistență pentru dezvoltare (CAD) ale OCDE asupra dezvoltării umane în țările asiatice. Există o nevoie urgentă de a reconsidera alocarea mai multor resurse și ajutoare pentru educație și sănătate pentru a utiliza aceste fluxuri financiare la nivel maxim în vederea atingerii nivelului de dezvoltare urmărit.*

***Cuvinte-cheie****: Angajamentul de ajutor pentru educație, dezvoltare financiară, industrializare, calitate instituțională, economie emergentă, dezvoltare umană, industria textilă, dezvoltare sustenabilă*

## INTRODUCTION

In the fast-assimilating world, some countries hardly exclusively support their economies with their financing. These economies have to depend on other economies for financing their economies. Various international donor countries and organizations are supporting emerging economies' governments to attain their developments. So, official development inflows of foreign aid are considered very significant for countries with low finance for achieving their desired progress. Official Development Assistance states those concessional grants are managed for the development of underdeveloped economies.

Heffernan [1] investigated the linkage between textile education performance and industry partnerships and highlighted the importance of effectively driving the textile value chain from both economic and environmental points of view based on academic requirements. Britt [2] has conducted a complex literature survey based on archives and collections related to textile education, industry and practice, while mentioning the importance of digital methods and platforms in this regard. Bullon et al. [3] suggested that the textile industry has a connection with the economic field due to the production of fibres, yarns, fabrics, clothing and textile goods both for household consumption, and technical and industrial objectives. Murzyn-Kupisz and Hołuj [4] investigated the linkage between fashion design education and sustainability and highlighted the importance of multidimensional adjustments to curricula. Moreover, Hall [5] investigated relevant aspects of labour laws, human rights, economic issues, independent union movement and factory management in the case of rapid growth and export-oriented garment industry in Cambodia for the sample period of the 1990s.

Statistics also showed the substantial increased official development assistance inflows to the underdeveloped economies, predominantly for obtaining millennium development objectives to maximum level. These are explicitly given to or allocated to the lower middle-income countries in which, Asia is the second largest region, after getting 37566 million US$ in 2011–2012. Consequently, this massive influx of ODA has become very important for the representatives to check the significance of inflows towards the sectors. Qaiser Gillani et al. [6] suggested that funding assistance represents a very important pillar of health expenditure in less developed countries, which helps increase resource allocation in vital segments of economies. Education and health seem the cornerstone for obtaining targeted development in any society. Different from income, both sectors promote prosperity greatly in an economy. In this changeable epoch, people are thought out as the real wealth of any nation and this wealth with good human capital serves the economy very efficiently and productively.

Countries' human development is evaluated by improved social infrastructure (i.e. education and health facilities). Market developments are interlinked with the improved human capital of an economy. This matter has achieved apprehension predominantly in developing economies. Historically, a complete glance represents that the emergent Asian countries have achieved substantial rates of growth since the 1990s. However, these growth rates hardly affected human development meaningfully. The researchers and academia focused much on health and education. In Asia, rapid growth made it the fastest economically growing region in the world during the last few decades. However, despite this considerable economic growth, this region has observed poverty among people, malnourished children, incompetent health structure, and an insufficient education system and with a large segment of the population having low sanitation amenities. To provide better education and health facilities, capital inflows become mandatory in these developing countries. As these developing economies with inadequate investment desperately require foreign aid to control their capital deficiency.

Hayat et al. [7] argued that for an emerging country like Pakistan, which is a lower-middle-income economy, with a GNI per capita from USD 1036 to USD 4045, price stability is an essential factor of economic growth, while any fluctuations in inflation determine severe repercussions for the growth rate. Naeem et al. [8] suggested that Pakistan is a developing economy without rigorous environmental policies implemented for enhancing economic growth. On the other hand, Qaiser Gillani et al. [6] investigated the linkage between sustainable economic development and government health expenditure in several Asian countries, such as Bangladesh, India, Indonesia, Malaysia, Pakistan, Sri Lanka, The Philippines, Iran and China. The findings suggested that financially healthy people spend more on education, health and nutrition, while immunization, GDP per capita, trade openness, and utilization of basic water service facilities improve under-five and infant mortality in selected Asian economies. Spulbar et al. [9] consider that sustainable development determines a major influence on developing countries, due to the following representative features: environmental degradation, social inequality, demographic dynamics, high degree of poverty, poor quality education, migration, high levels of urbanization, health system deficiencies, rapid technological change and unsustainable economic growth.

Education is a fundamental investment in human capital which recompenses the economy over long periods in way of much earnings, expert worker, a great workforce and eventually affluent people with the improved living standard. Access to initial schooling is the general prerogative of the universal commonalities that government has to make available to all. Regarding underdeveloped countries, the higher part of the budget is not assigned towards education so, these countries have to depend on aid for education because of their limited administrative and financial capabilities of these countries. Consequently, this research aims to analyse the effect of DAC member countries' aid commitment for education with the role of financial development and institutional quality on human development in selected Asian economies because improved education and health, education and access to basic facilities affect human development noticeably. Economic theory explains that education and health are thought to as very important for human development as both enhance the growth of Asian economies. Furthermore, in countries having low capital, it is rather significant to make confirm whether inflows are fulfilling their purpose or not. Its improper allocation towards various unfavourable sectors will not be favourable to its overall influence on growth and development.

Jung and Yoo [10] investigated the achievements of Korea as OECD Development Assistance Committee (DAC) member and revealed that the annual growth rate is approximately 8%, ranking first among the DAC member countries. Rudolph [11] suggested that the global envelope of development cooperation funds is established by governments and highlights what resources they intend to provide to development policy in the overall national strategy in the context of OECD-DAC members. The existing literature provides sufficient evidence regarding foreign aid and human development relationships but a small number of studies have tried to analyse an aspect of the subject to be focused on the Asia region. Thus, dissimilar to numerous further works, this study does not focus on overall aid influence but emphasizes its effectiveness for education commitment with institutional quality in Asia by using the GMM technique. As these developing countries are receiving foreign aid from donor countries to improve their education and health structure of the economy. That's why this research focuses on these countries specifically emphasizing the proper allocation of aid towards higher education for achieving human development.

### Objectives of the study

The research targets to achieve a relationship between aid commitment for education and human development. The study also focuses on other determinants such as industrialization, institutional quality and financial development. Moreover, it analyses the work done in past on the subject overall and for Asia specifically.

### Organization of the study

The paper is organized as follows. After giving an introduction and background, the literature review is shown in section II. Section III comprises a data source and the model specification along with the important variable discussion. The discussion of results and empirical analysis are presented in section IV. The concluding remarks are presented in the last section

### Background

The literature about the effectiveness of foreign aid concludes that aid can get its projected consequences just because of its highly targeted and more deliberately disbursement. Developing countries' education and health sectors are demanding attention to upgrade the positive effects of foreign aid for human development even in the poor world.

The following figure 1 represents Commitment for Post-Secondary Level Education.

Figure 1 shows the DAC aid commitment for the education of selected Asian economies. This aid improves the growth structure and development of these countries. During the past few years, this aid commitment tends to increase in these economies. The highest level with an increasing trend is seen in India while the lowest decreasing trend was observed in Malaysia.

Figure 2 is also very important. A high level of savings and investment increases the economy's productive capacity and sustained economic growth. High investment improves living standards by having a high income which boosts growth. These economies are facing the problem of low capital, so investment through foreign aid can play a significant role in the growth and development of concerned economies.

According to the data trend, industrialization has been increasing in selected Asian economies (except the Philippines which is showing a negative trend) and contributing to improved growth and human development. From figure 2 it can be observed that the highest increasing trend is seen in Bangladesh, while the lowest decreasing trend is observed in Sri Lanka.

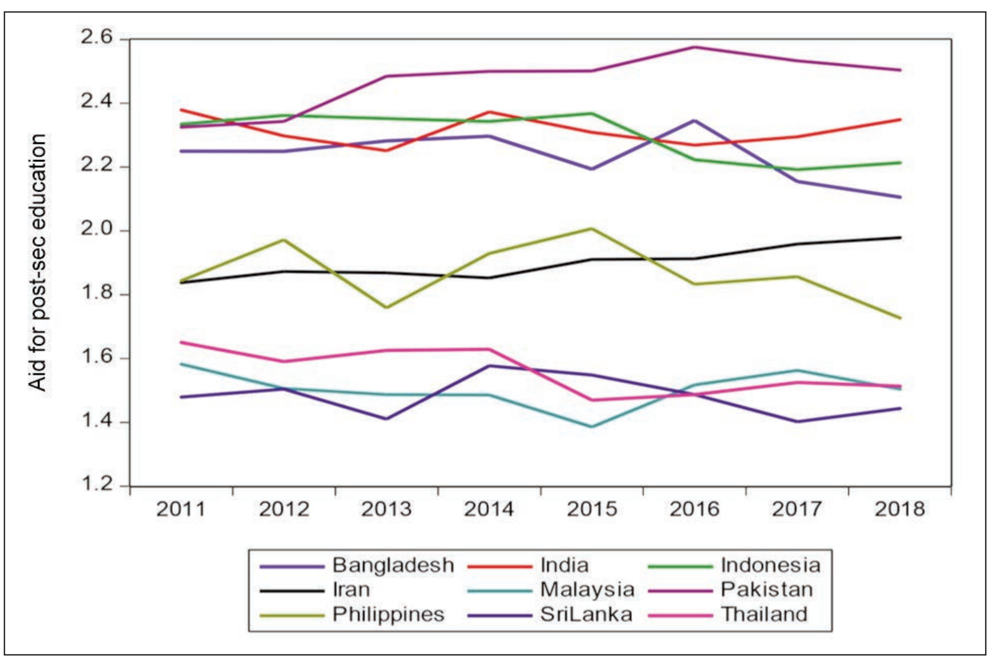


Fig. 1. Commitment for Post-Secondary Level Education

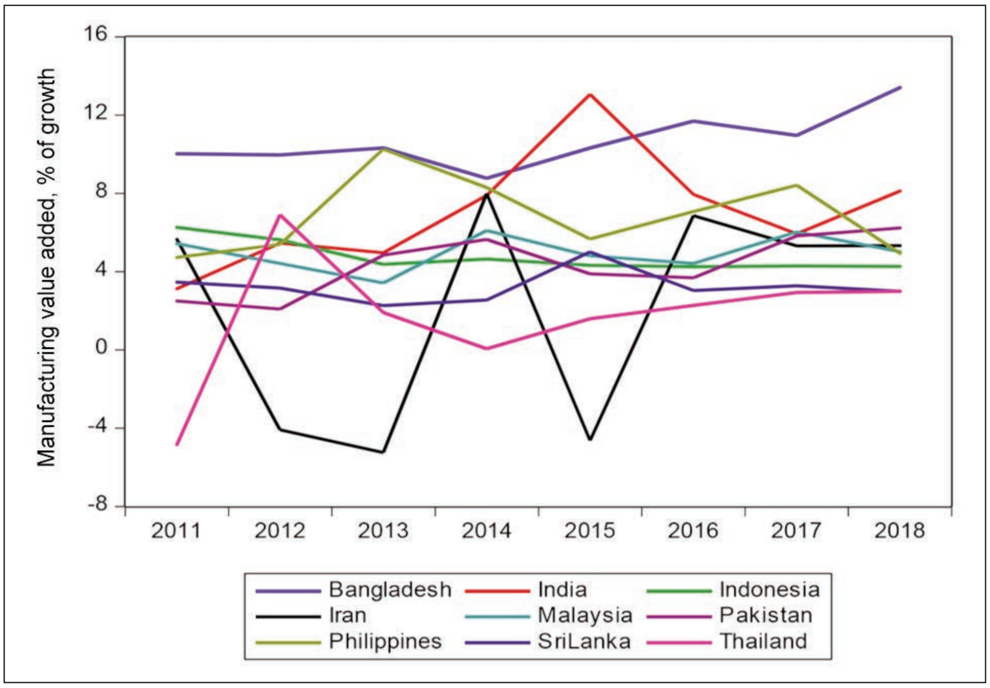


Fig. 2. Industrialization

## LITERATURE REVIEW

By reviewing studies very thoroughly, we have found a positive association between foreign aid inflow and human development in definite ways. We review a succinct assessment of empirical literature to understand the issue very deeply. It can be helpful to analyse conclusions of the studies done earlier and it determines the prospectus of research being done considering literature. For instance, a pioneering approach by Schultz (1961) suggested that modern human capital theory is very important for examining the impact of education on economic growth. Feeny [12] shows that trade and structural adjustment programs affect positively the country's GDP growth rate. Aid in form of projects also enhances the performance of the country. On the other hand, Spulbar and Birau [13] also revealed certain relevant aspects regarding the impact of cybercrimes in ASEAN countries. The majority of the economies have improved their economic situations by making improvements in growth levels however, some countries are still facing socio-economic issues. For this, Lohani [14] uses data from 120 developing countries from the period of 1975–2001. Results show that social aid affects negatively the human development of the country.

Liu et al. [15] conducted an empirical research study for Pakistan and concluded that higher education systems in non-developed countries are surviving under pressure and fluctuating conditions. Moreover, Memon and Liu [16] investigated relevant aspects of higher education in Pakistan and concluded that education can provide a sustainable developmental map for worldwide economic prosperity based on labour market dynamics. Maneejuk [17] investigated the effect of higher education on economic growth in ASEAN-5 member countries, such as Thailand, Indonesia, Malaysia, Singapore, and the Philippines, for the sample period 2000–2018. This research study concluded that higher education magnitude climbs to a level twice as strong when the enrolment rates are higher than a particular kink point.

Minouio and Reedy [18] use the aid data of developing countries from 1960 to 2000. The GMM result finds that developmental aid affects positively the economic growth of the country. Tadesse [19] show that aid has affected positively the growth of the Ethiopian economy in the long run. In addition to capital, the education sector contributes to the development of the economy as well. Asiedu [20] uses GMM and finds that aid in the primary education sector affects positively growth however post-primary education assistance sector reduces growth. Bai Gokarna et al. [21] investigated institutional effectiveness based on an empirical study on higher education universities in India and concluded that academic leadership is neither high such as campus culture nor low such as faculty involvement in decisions. Bileviciute et al. [22] have identified a significant relationship between higher education and the increasing demand for highly qualified and socially responsible labour force and employment strategies.

Abouria [23] examines how foreign aid affects the economic growth of the Philippines by using data from 2009–2012. The result shows that FDI and ODA per capita increase the GDP growth rate. Mishra et al. [24] reveal that health, investment, export, EDRD and R&D have increased the per capita income while import and education adversely affect the per capita. However, Rahman [25] explains that health and education expenditures increase the growth of Bangladesh. Moolio et al. [26] show the impact of aid in selected ASEAN countries from 1997–2014 and find that foreign aid affects positively the growth.

Fasanya and Onakoya [27] revealed that foreign aid plays a significant role in determining the development of the country. Pickbourn and Ndikumana [28] focus on the development outcomes of foreign aid on education, health and gender equity in OECD–DCA. The GMM result shows that those countries showed a noteworthy performance having initial development conditions, with higher literacy rate, low maternal mortality and more equitable gender distribution.

A lot of studies have been made on the effects of external debt on the three main components of the HDI used independently which are health, education and living standards. Dessy and Vencatachellum [29] and Fosu [30] find the influences of external debt on governments' health sector spending and investment. Moreover, Murshed and Saleh [31], Egungwu [32] etc. investigated how external debt affects the education sector spending. However, Lora and Olivera [33], Fosu [34], Sadia and Hafiz [35], check the effect of external debt on social sector spending, predominantly health and education. Checherita-Westphal and Rother [36], Babu et al. [37], Azam et al. [38], Okokondem and Monday [39], Zaghdoudi and Hakimi [40], focused on living standards. Zaghdoudi [41] found the external debt and human development relationship for 95 developing countries during 2002–2015. He finds this relationship as non-linear.

Rahman et al. [25] show the effect of foreign aid on HDI in Bangladesh by using data from 2000–2012. It is confirmed that mortality rate under 5 and inflation decrease the quality of the human development index. Results also reveal that $CO_2$ emission increases HDI in India. Similarly, net ODA affects positively the HDI. However, other authors have checked the impact of the effects of foreign direct investment (FDI), foreign aid, and trade on poverty as a measure of HDI in Sub-Saharan African countries from 1990–2017. The result shows that foreign aid decreases poverty and improves human development in this way. FDI reduces poverty both in the short and long run [42–44]. However, Fowowe and Shuaibu [43] show that institutions with quality and a functioning financial system lead to an increase in the rate at which FDI decreases poverty. However, countries with improved institutions and financial systems will experience the effect of FDI on poverty quicker as compared to those countries that have no good institutions and financial systems. The FDI reduces poverty quickly in poorer countries as compared to rich countries [45].

A comprehensive literature review shows that foreign aid enhances the human development of economies. The significance of aid to different sectors cannot be avoided. To check the potential influence of foreign aid inflows on human development, the other aspects or causes should also be given importance in analysis which is recognized by the studies done earlier.

## DATA AND RESEARCH METHODOLOGY

We have used a panel dataset of nine Asian economies (i.e., Bangladesh, India, Sri Lanka, Indonesia, Pakistan, Philippines, Malaysia, Thailand and Iran) from 2011 to 2018. Data has been taken from the source of the World Development Indicators database. The data for the human development index (an average achievement in three basic dimensions of human development such as long and healthy life, knowledge and a decent standard of living) is taken from HDRO calculations based on data from UNDESA [46], UNESCO institute for statistics [47], United Nations Statistics divisions [48], World bank [49] and IMF [50]. The data of political institutions is taken from worldwide governance indicators. Moreover, the data for DAC commitment for education in the Asian region is taken from OECD Creditor Reporting System. The dependent variable is Human Development Index (HDI). The other independent variables are Industrialization (manufacturing value added annual growth %), institutional quality index (voice and accountability and control of corruption), log of DAC commitment for education US Dollar, Million (LCED)and financial development index (credit to the private sector as a percentage of GDP and commercial bank deposits). For the analysis, we have used the dynamic GMM technique to check the effect of aid commitment for education by DAC member countries on the human development of Asian economies. GMM is used to avoid the endogeneity issue.

## EMPIRICAL ANALYSIS

This analysis investigates the relationship between aid commitments for education and human development in selected Asian countries.

Model Specification

The model is explained as follows:

$$\text{HDI it} = \beta_1\text{INDSit} + \beta_2\text{INQIit} + \beta_3\text{LCEDit} + \beta_4\text{FDINit} + \text{uit} \quad (1)$$

The above variables are the Human development index (HDI), industrialization (INDS, manufacturing value added annual growth %), institutional quality (INQI), DAC member countries' commitment for education in the Asian region (LCED) and financial development index (FDIN). The subscript i indicates each country and the subscript t describes each period in this empirical work. The term uit represents the error term.

## DISCUSSION AND RESULTS

In this section, we empirically analyse the role of DAC commitments for the education of selected Asian countries and the role of institutions on human development by incorporating other explanatory variables such as industrialization and financial development on human development in some selected developing countries.

Table 1

| SUMMARY STATISTICS | | | | | |
|---|---|---|---|---|---|
| **Variables** | **Observation** | **Mean** | **Std .Deviation** | **Min** | **Max** |
| HDI | 71 | 0.6915 | 0.0870 | 0.5280 | 0.8040 |
| INDS | 71 | 5.0767 | 3.6602 | –5.2512 | 13.4022 |
| INQI | 71 | 0.4927 | 0.0795 | 0.3542 | 0.6250 |
| LCED | 71 | 1.9586 | 0.3745 | 1.3845 | 2.5759 |
| FDIN | 71 | 61.4649 | 36.1995 | 22.6515 | 137.9114 |

### Descriptive statistics

Table 1 explains the descriptive statistics of all the variables. Large differences in data are observed regarding some variables. On average, the HDI of selected countries is 0.6915%. The average commitment for education is about 1.96%. Large differences are observed in the institutional quality index having a range from 0.3542% to 0.6250%. Likewise, variations are observed in industrialization (manufacturing value added annual growth %) from 22.6515% to 137.9114%. On average, industrialization (manufacturing value added annual growth) is 5.0767% in selected Asian countries.

### Empirical results and interpretations

In this section, we analyse the impact of DAC countries' commitment for education and institutional quality on the human development of selected Asian countries.

Table 2 reveals the GMM results and the dependent variable is the Human development index. The study results highlight a positive and significant relationship between DAC aid commitment for education and human development in selected Asian countries. The research also reveals that human development seemed to be increased with the financial development of these economies as well. The GMM result reveals that the coefficient of HDI (LAG1)is positive and significant. The development index is 0.7738 and it shows that one year lag in HDI makes better the HDI in selected Asian countries.

Table 2

| GMM RESULTS DEPENDENT VARIABLE: HUMAN DEVELOPMENT INDEX | |
|---|---|
| **Variables** | **GMM Results** |
| HDI(LAG1) | 0.7738* (0.1972) [3.92] |
| HDI(LAG2) | 0.1213 (0.2187) [0.55] |
| INDS | 0.0003* (0.0001) [3.13] |
| INQI | 0.0121 (0.0448) [0.27] |
| LCED | 0.0403* (0.0061) [6.57] |
| FDIN | 0.0002* (0.0001) [1.78] |
| AR(1) | –1.91 (0.056) |
| AR(2) | –0.10 (0.920) |
| Sargan Test | 16.37 (0.797) |

Note: Standard errors are shown in parentheses, whereas t-values are shown in square brackets, * $p < 0.1$.

Industrialization is most important for heavy industrial production, growth and human development. The result is statistically significant. The study result shows that unit increase in industrialization increases HDI by 0.0003 units. The reason can be that industrialization enhances employment, income and living standards. The result reveals a positive coefficient of political institutions. One unit improvement in the institutional quality index increases the HDI by 0.0121 units in selected Asian countries. When institutions play a positive role, it increases employment opportunities and improves investments, per capita income, growth and development. This highlights the positive role of institutions in these countries.

The most important result is that a one percent increase in DAC commitment for education increases the human development index by 0.0403 units. The aid for education is the need of the time in these economies and it has a great effect on human development. The result is in contrast with Lohani [14] and supported by Anetor et al. [51]. The variable financial development index is found to be positive (0.0002) and statistically significant. These results show that financial development tends to improve the HDI in selected Asian countries during this time.

## CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

This research makes a significant contribution while discussing the relationship between aid for the education sector and human development. The prevailing literature focuses on the positive role played by aid for education with institutional quality on human development. Education and health contribute much to economic growth and development of the economy. This study focuses on the role of DAC countries' commitment for education with improved financial development in Asian countries on their human development. Findings of the positive influence of both the variables are found by-product is found by Fowowe and Shuaibu [43], and Anetor et al. [51]. The result shows that commitment for education improves the human development index. It shows that these inflows enhance human development. Increased aid from DAC countries improves the standard of health and educational facilities which ultimately improves their human development index. Whereas, institutional quality is improved and increases the human development in these economies.

Further, the negative influence of industrialization and financial development on human development is also found in these economies. Both increase growth and development over long periods. In these countries, there should be an inclusive set of policies for stability and growth. Moreover, institutional quality leads to improves human development and this is a good indicator for the development of the economy. This institutional quality must be improved further. In addition, industrialization is contributing well toward human development. Moreover, more aid for the higher education of people must be ensured from DAC countries. Government must play a transparent and very effective role in lowering the debt burden by making regulations and reforms in the financial sector. Counties of this region must pursue multi-pronged strategies to boost up their performance and development. Such countries must introduce different initiatives at the national and international level by launching new programmes of capacity building, improving the learning environments and student exposure. For such kind of investment, they have to rely on aid for education to keep on moving at this pace of educational development. Recent studies suggest that aid has contributed well to achieving educational targets over the past decades. The study findings open new panoramas of research in this field. It can be a contentious question for the policy-makers to seek possible and fruitful utilization usage of sector-specific aid in these economies of South Asia.

Although this study has significant contributions to the literature in the form of countries analysed as well as in the objectives of the study. However, there are a few limitations to the study. This includes the unavailability of the data for several countries beyond 2018, which put a constraint to keep the analysis up to that year. A future study may continue on this by improving the number of countries selected as well as extending the dataset to make it more extensive research following the steps of the present research.

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# Environmentally friendly digital printing on cotton using, synthesized pigmented inkjet inks and comparison of their properties

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**ABSTRACT – REZUMAT**

**Environmentally friendly digital printing on cotton using, synthesized pigmented inkjet inks and comparison of their properties**

*The "top-down" approach was adopted to manufacture nano inkjet inks. Pigment Black 7 and Pigment Red 122 both 100% dried powders were used. The premix of these two pigments was subjected to bead milling to reduce the particle size to the nano-scale. The inkjet inks prepared were characterized for their particle size, zeta potential, purity, viscosity, surface tension, foaming properties, and pH using required analysis and spectroscopy techniques. Both inkjet inks were applied digitally on pre-treated cotton. The printing was performed on a Monna Lisa Evo Tre printer (EPSON). The printed samples were evaluated for colour fastness to light, rubbing, washing, and laundering using relevant AATCC and ISO methods. The powders of the same colour index numbers were kneaded and emulsified by a traditional ball milling method. Emulsions prepared were characterized and applied on singed, desized, scoured, bleached, and pre-treated pure cotton through a traditional rotary screen-printing method. The printed samples were evaluated for their application fastness properties for comparative studies. It was concluded that by promoting the use of green chemistry and nanotechnology, the digitally printed fabric samples displayed better print quality, increased application fastness properties and good colour gamut as compared to traditionally printed fabric samples. Moreover, the new digital printing process resulted in reduced chemical, energy and water consumption along with socio-economic, environmentally friendly effectiveness, with almost zero waste production as compared to the traditional printing method.*

***Keywords:*** *bead mill, cotton, digital particle size analyser, inkjet inks, Monna Lisa Evo TRE printer, pigments*

**Imprimare digitală ecologică pe bumbac folosind cerneluri inkjet pigmentate sintetizate și compararea proprietăților acestora**

*Abordarea „de sus în jos" a fost adoptată pentru a produce cerneluri nano inkjet. S-au folosit Pigment Black 7 și Pigment Red 122, ambele pulberi uscate 100%. Preamestecul acestor doi pigmenți a fost supus frezării cu bile pentru a reduce dimensiunea particulelor la scară nanometrică. Cernelurile inkjet preparate au fost caracterizate prin dimensiunea particulelor, potențialul zeta, puritatea, viscozitatea, tensiunea superficială, proprietățile de spumare, pH-ul, utilizând tehnicile necesare de analiză și spectroscopie. Ambele cerneluri inkjet au fost aplicate digital pe bumbac pretratat. Imprimarea a fost efectuată pe imprimanta Monna Lisa Evo Tre (EPSON). Probele imprimate au fost evaluate pentru rezistența culorii la lumină, frecare, spălare, clătire folosind metode relevante AATCC și ISO. Pulberile cu aceleași numere de index de culoare au fost frământate și emulsionate printr-o metodă tradițională de frezare cu bile. Emulsiile preparate au fost caracterizate și aplicate pe bumbac pur pârlit, descleiat, spălat, albit, pretratat printr-o metodă tradițională de serigrafie rotativă. Probele imprimate au fost evaluate pentru proprietățile de rezistență a culorii la aplicare pentru studii comparative. S-a ajuns la concluzia că, prin promovarea utilizării chimiei ecologice și a nanotehnologiei, mostrele de țesături imprimate digital au prezentat o calitate mai bună a imprimării, proprietăți superioare de rezistență a culorii la aplicare și o gamă corespunzătoare de culori în comparație cu mostrele de țesături imprimate în mod tradițional. În plus, noul proces de imprimare digitală a rezultat cu un consum redus de substanțe chimice, energie și apă, împreună cu o eficiență socio-economică, ecologică, cu producție aproape zero deșeuri în comparație cu metoda tradițională de imprimare.*

***Cuvinte-cheie:*** *frezare cu bile, bumbac, analizor digital de dimensiunea particulelor, cerneluri inkjet, imprimanta Monna Lisa Evo TRE, pigmenți*

## INTRODUCTION

Digital textile printing is a green and eco-friendly method of textile printing. This is cost-effective overall and economical for short production runs as compared to the traditional textile printing method. The synthesis of pigment-based nano inkjet inks for digital textile printing is a revolutionary step in the developmental path of the textile printing industry. The use of inkjet inks in digital textile printing resulted in a significant decrease in water, energy, colour, and chemical consumption with reduced waste production to almost zero [1, 2].

The art of textile printing is probably as old as mankind or civilization itself. Over the years, there are significant developments in textile printing. The digital inkjet inks implementation in textile printing is the latest trend, adopted by the industry for its survival. Recent developments in inkjet ink textile printing techniques are not only suitable for short production runs but also for an on-demand rapid market response and the incorporation of unique and diverse designs description to fulfil the requirement for mass customization trend [3].

With the formation of the International Textile Machinery Association (ITMA in 2003), several commercial textile production inkjet ink printers were launched in the marketplace. Digital textile printing has gained popularity as the preferred production technology. Today it is formed a niche part of digital textile printing. The low cost made it competitive for short runs. In addition, the fact that its waste production is almost zero has made this textile printing method socio-economic and environmentally friendly [4, 5].

The digital textile printing technique is interlinked, with the design software, printer, printing environment, fabric pre-treatment, post-treatment methods, and the operator. As digital technology is reaching new horizons, digital textile printing with the use of pigmented nano inkjet inks represents the future development direction in the textile printing industry. The new customer demands are only possible by the use of this new printing technique [5, 6].

This new technology is becoming a popular tool by replacing the traditional textile rotary screen-printing technique. As a result, this sector is encountered significant investments. Because of the combined efforts of inkjet ink manufacturers, printer manufacturers, and designers, inkjet-ink-based digital textile printing has gained popularity worldwide. The output of digitally printed fabric was grown by 300% since 2005 which was approximately 1% of the global market for printed fabrics. Water-based pigmented inkjet inks are especially popular because of their better application and weather fastness properties [7].

The use of pigment-based nano inkjet inks in digital textile printing has gained importance because of the following reasons: high-speed textile processing technology is less complicated, compatibility of pigmented inkjet inks with almost all types of fabric substrates, lowest possible (almost zero) waste production has made it green processing, the possibility of short-run processing, design diversity, with good quality prints, cheap as it is based on computer-aided technology [8].

## MATERIALS

Pigment Black 7 Imported from NINGBO F.T.Z. HONGDA CHEMICALS INDUSTRIAL CO., LTD 535 QINGSHUIQIAO ROAD 11$^{TH}$ FLOOR OFFICE PARK BUILDING NINGBO HI-TECH PARK 315040 CHINA. Pigment Red 122, Imported from HANGZHOU DIMA COLOR IMPORT and EXPORTCO., LTD. ZHEJIANG, CHINA, Co-solvent (deionized water and ethylene glycol), surfactant (Scaural CA, Daico Chemical Industry Egypt), biocide (SPX Thor), buffer (Dytek® HMI, Inveta), chelating agent (EDTA, China), defoamer (no foam SE Sybron-Tenatex.), dispersing agent (styrene-maleic anhydride copolymer) tailored with ammonium dimethyl quinacridone (Am DMQA), emulsifier (N-methyl-N-Oleoyltaurate or OMT, Parchem Fine), dispersing agent (acrylic copolymer, Clariant), anionic surfactant (SDS), and yttrium-stabilized zirconium beads (China).

### Method

The top-down Method of nano-technology was adopted to proceed with the particle size reduction of the pigments. Kneader machine and nano design bead mill were used to reduce the particle size to < 50 nm.

### Synthesis of inkjet ink A (Pigment Black 7)

The pigment-based inkjet ink A concentrate was prepared, using 100 g of the powder of the Pigment Black 7. N-Methyl-N-Oleoyltaurate (OMT) dispersing agent. 50 g and 140 g of diethylene glycol were added in a kneader machine and mixed for 3 h to form a slightly hard semi-dispersed paste with a partially reduced particle size. This paste was then offloaded to a wooden box. It was gradually added to a 1.5 l stainless steel turbo mixer which contains 650 g of deionized water, 10 g of diethylene glycol and 5 g of the dispersing agent. This mixture was agitated slowly using a frequency inverter. The agitation speed was increased slowly to 600 rpm within 15 min. The agitation was performed for another 3.5 h to obtain a smooth liquid (premix). Stirring was performed using the turbo mixer (input) to bead mill that contained 70% yttrium stabilized zirconium beads (1 mm) through a continuous pass system. The bead mill was equipped with a master sizer 2000 laser diffraction particle size analyser to measure the particle size distribution during the milling of the inkjet ink. The inkjet ink premix was stirred in the bead mill at a flow rate of 191 g/h (5 h) for the first pass to complete. The efficiency of size reduction was proportional to the efficiency of energy conversion [9,10]. The temperature was controlled by continuously supplying chilled water (35°C) through the jacket of the bead mill.

An inkjet ink sample was taken out from the sample outlet and its particle size distribution was evaluated offline using a digital particle size analyser to verify the results obtained on the laser diffraction particle size analyser. It was found that only 88% of the particles were in the 0.2–0.3 μm particle size range, the same results were shown by the master sizer 2000 system. At this stage, the remaining 45 g of deionized water was added. The concentration of the inkjet ink was become10 wt.%. High-speed agitation was performed in the bead mill by adjusting the flow rate to 110 g/h. The material was run for a period of 9 h through a pass system which connected the bead mill, 1.5 L turbo mixer and stainless-steel vessel. The temperature of the inkjet ink circulating in the bead mill at 4000 rpm was controlled through its jacket system. After 9 h the agitation was slowed down and the sample was taken out and its particle size distribution was analysed by a digital particle size analyser. At this stage, 96.5% of the particles had attained a particle size < 95 nm while the master sizer 2000 showed that 86% of the particles were in particle size range < 90 nm. Agitation was resumed again by adjusting the flow rate to 90 g/h and the inkjet ink was run for 11.11 h and the third pass was completed.

The speed of the bead mill was again reduced and a sample was taken out and analysed to evaluate the particle size distribution. It was found that 99.6% of the particles were in the size range < 50 nm. This was in keeping with the results obtained using the master sizer 2000 system. The milling and stabilization processes continued until the energy transfer between the grinding beads and the pigment particles reached its limiting value. At this point, the particles were reduced to the size range < 50 nm [11]. Initially, there was a rapid decrease in particle size because of the breakdown of the loosely agglomerated particles. As the milling progressed, the rate of decrease in the particle size was reduced because, at this stage, the milling was breaking the large primary particles. The laser diffraction analyser successfully tracked the milling process over time. Particles of the desired particle size < 50 were obtained after 25.11 h of high-speed milling.

The inkjet ink was filtered through a nano sieve and transferred into a turbo mixer. Agitation was performed at 200 rpm; 100 g of a defoamer and 0.1% of a biocide were added to the inkjet ink during this process stage. The agitation process was stopped once when all the foam was finished. The inkjet ink was collected in a 1.5 L glass bottle with an airtight stopper and was labelled as Inkjet Ink A. Modified structure of carbon black is shown in figure 1.

**Synthesis of inkjet ink B (Pigment Red 122)**

The pigment-based inkjet ink B concentrate was prepared and charged 110 g of the powder of Pigment Red 122 in the kneader machine. Dispersing agent styrene-maleic anhydride copolymer tailored with AmDMQA 90 g and 125 g of diethylene glycol were also added. The kneader machine was operated for 4 h with a temperature of less than 35°C. The kneading process yielded a slightly hard semi-dispersed paste, that was offloaded in a wooden box. This paste was gradually added to a high-speed turbo mixer that contained 600 g of deionized water, 25 g of diethylene glycol and 10 g of a dispersing agent. The agitation process was started slowly, speed was increased to 600 rpm within 15 min and agitation was performed for 4 h to obtain a smooth liquid (premix). Stirring was resumed using the turbo mixer to the bead mill containing 70% yttrium-stabilized zirconium beads (1 mm). For output and receiving 1.5 l, stainless steel tank was connected to the bead mill. The flow rate was adjusted to 160 g/h in the output tank. The inkjet ink B was stirred for 6 h first pass was completed. The particle size distribution of the premix during milling was measured with the master sizer 2000 system. The temperature was controlled by continuously supplying chilled water maintained at 35°C through the jacket of the bead mill. After 6 h of stirring, the speed was slowed down.

The sample was taken out and analysed offline, used the digital particle size analyser to determine the particle size distribution. The results obtained were verified using the master sizer 2000 system. It was found that only 73% of the particles were in the 0.2–0.5 μm size range. The remaining 40 g of the deionized water was added to the pigment and now the concentration

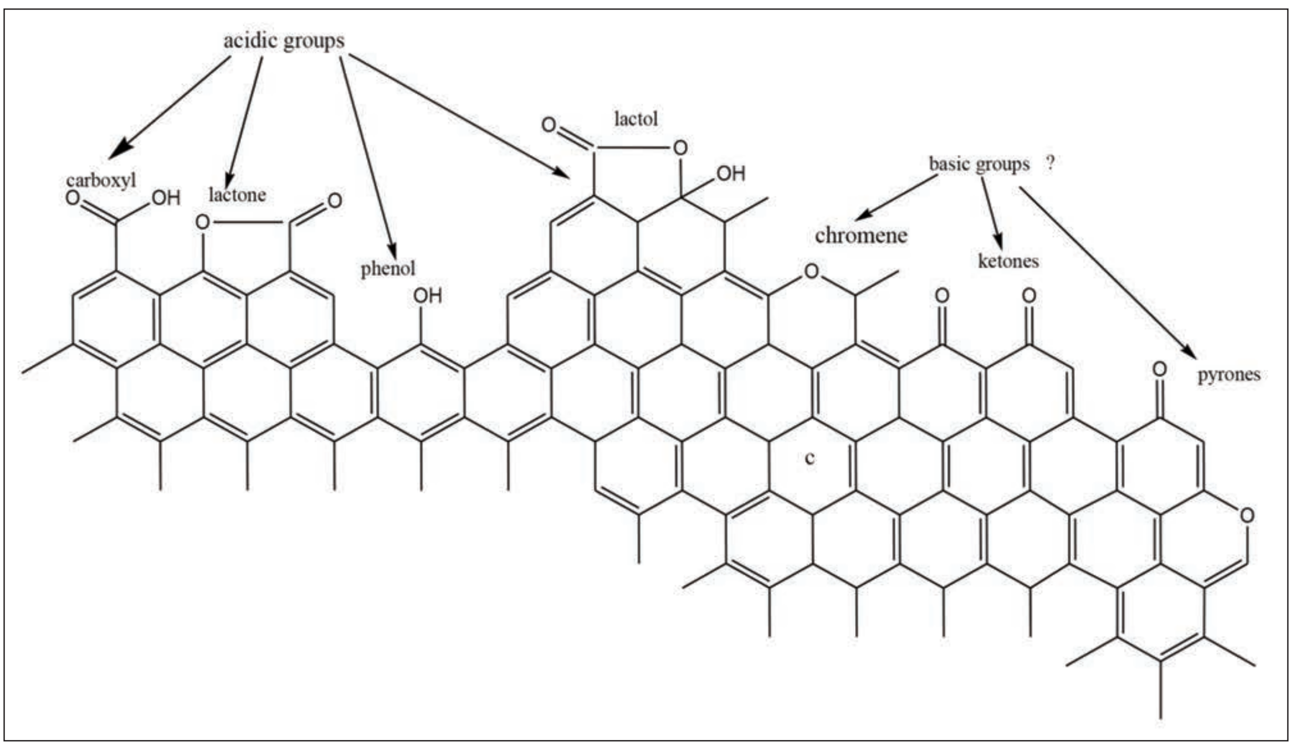


Fig. 1. Structure of carbon black showing different functional groups

in the inkjet ink became 12 wt.%. High-speed agitation was performed in the bead mill via pass system, the flow rate was adjusted at 110 g/h and the inkjet ink was agitated for 9 h; in this way, the second pass was completed. After 9 h, the agitation was slowed down. A sample was taken out and analysed to determine the particle size distribution using the digital particle size analyser. Only 87% of the particles were in the size range < 100 nm. The master sizer 2000 system indicated that 86% of the particles were in particle size range < 95 nm. Agitation was performed again and the flow rate was adjusted to 100 g/h. The inkjet ink was agitated for another 10 h; the third pass was completed.

The speed of the bead mill was reduced and a sample was taken out and its particle size was evaluated. It was found that 97% of particles attained a particle size distribution < 50 nm; the same particle size distribution was noted on master sizer 2000. The agitation was resumed and the flow rate was adjusted at 99 g/h output. The inkjet ink material was run for 10.1 h and the fourth pass was completed. The speed was slowed down. At this point, the particle size was reduced to a range of < 50 nm. The sample was taken out and particle size was evaluated. It was concluded that 99.7% of particles were in a size distribution range < 50 nm. The results demonstrated the ability of laser diffraction to track the milling process as a function of time. A consistent fine particle size distribution was attained after approximately 35.1 h of high-speed bead milling. The inkjet ink was filtered through a nano-tech sieve using a vacuum system and transferred into a turbo mixer. The turbo mixer was operated at a speed of 200 rpms/h. During the stirring, 101 g of defoamer and 0.12% biocide were added; agitation was stopped after the complete foam was finished. The inkjet ink was collected in a 1.5 l glass bottle, which was closed with an airtight stopper and labelled as inkjet ink B. Modified structure of red 122 is shown in figure 2.

Powders of the same colour index numbers were kneaded, premixed and performed their traditional ball milling to emulsify them. The emulsions were characterized and applied on the same cotton for purpose of comparative application studies.

## CHARACTERIZATION

The inkjet inks and emulsions were characterized for their purity, particle size, viscosity, surface tension, pH and shelf life (engineering stability) to meet operational requirements [12, 13].

### Particle size

First, a diluted sample of inkjet ink A was placed in the measurement chamber of the particle size analyser, three successive measurements were performed and the mean of the three measurements was calculated. It was found that 99.9% of the particles were in the size range of < 50 nm. The chamber of (PSA) was calibrated and a sample of inkjet ink B was placed in the measurement chamber and three successive measurements were performed as described above. It was found again that 99.9% of the particles were in the size range of < 50 nm.

A digital particle size analyser was used to measure the particle sizes of emulsion samples A and B. It was found that 99% of the particles were in the particle size range of 0.2–0.5 µm [14].

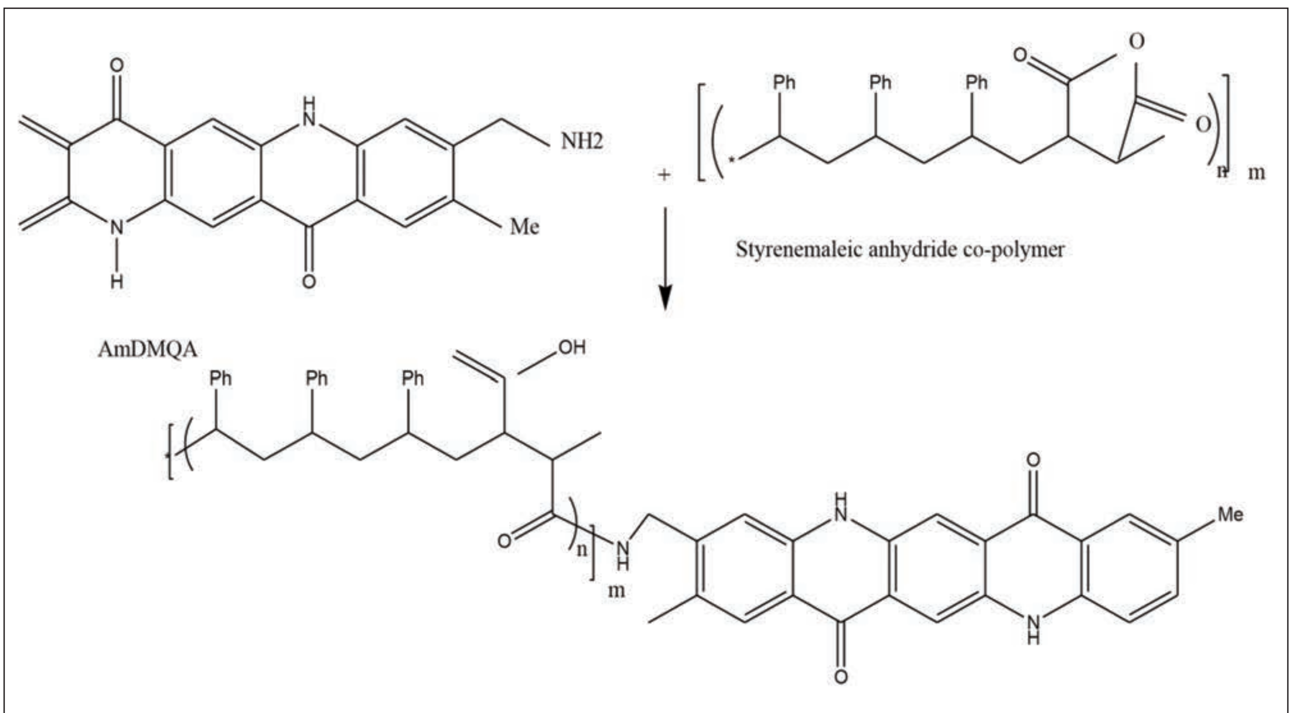


Fig. 2. Modified structure of Red 122

### Purity

The total trace metal contents of inkjet ink samples A&B and both of the emulsion samples were analysed by inductively coupled plasma atomic emission spectroscopy. The samples for the analysis were digested in a mixture of sulfuric acid and nitric acid. The digested material was dried in ash in a muffle furnace. The dried residue was dissolved in hydrochloric acid and nitric acid. The resultant solution was used to measure the trace metal contents present and the results were compared with pure standards for quality assessment. Toxic heavy metals (Hg, As, Cd, Pb, and Cr IV) were present in amounts lower than the permitted limits of the Okeo-Tex® Standard 100 [15, 16].
Results are shown in tables 1 and 2 in section results and discussion.

### Ink viscosity

The polymeric additive was added at a concentration of 0.16% and the viscosities of the inkjet inks A & B were adjusted to 10–12 cps at 25°C. The viscosity was measured under conditions similar to those that were during the application of the inkjet inks at the print head. Modern printers were generally operated at shear rates as high as 105–106 $s^{-1}$. Thus, microfluidic rheometery, a relatively new technique, was used to measure the high-shear viscosity. The viscosity of inkjet ink samples was measured by using an "m-VROCI microfluidic rheometer" at an ultra-high shear rate of 30,000 $S^{-1}$ temperatures 20 to 40°C. The viscosities of both emulsion samples were adjusted to 53 maps. It was evaluated and verified by using "the digital rotary viscometer model SNB-1 (OLD technique). This viscosity ranges of emulsions were 53 maps at 25°C. These were within the applicable limit of the rotary screen-printing method [17].

### Surface tension

The surface tensions of inkjet inks sample A and B were adjusted using a non-ionic surfactant to 25–60 dynes/cm. The surface tensions were measured using a stalagmometer. The choice of solvent used was another important factor for controlling the surface tension within the permitted operational limits [18].

### Foam

A common problem encountered during the use of inkjet ink was the formation of foam on the inkjet ink surface. This problem was solved by using a defoamer (0.01%), which was stable enough during the inkjet ink storage period.

### pH

The pH was also an important factor to maintain, especially in the case of water-based inkjet inks. The zeta potentials of the pigment-based inkjet ink sample A and B were maintained within the required limits to ensure that the inkjet inks were stable. A buffer solution with pH = 7 was used to make the inkjet inks inert or less vulnerable to the effects of changes in the pH.

### Ink storage and stability

All the parameters of pigment-based inkjet nano inks, including the pH, surface tension, particle size and viscosity, remained constant over prolonged periods (i.e., the "shelf life" of the inks). The shelf life for good quality inkjet inks at room temperature is almost two years.

## RESULTS AND DISCUSSION (PROPERTIES OF PRINTED FABRICS)

The volume percentage of the inkjet ink changed into fine particle size distribution < 50 nm concerning cumulative volume (%) changed with time as shown in figures 3 and 4.
Toxic heavy metals (Hg, As, Cd, Pb, and Cr IV) were present in amounts lower than the permitted limits of the Okeo-Tex® Standard 100. Tables 1 and 2 are listed the detected limits, which are lower than the permitted limits as per a previous literature survey [19].

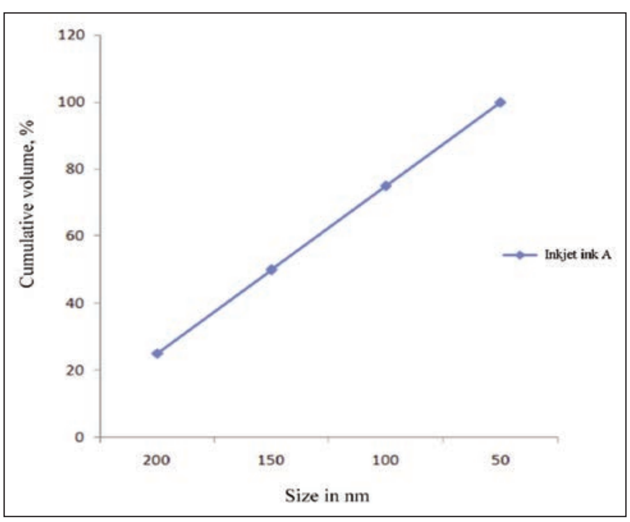


Fig. 3. Change in cumulative volume % age of inkjet ink A as function of particle size reduction

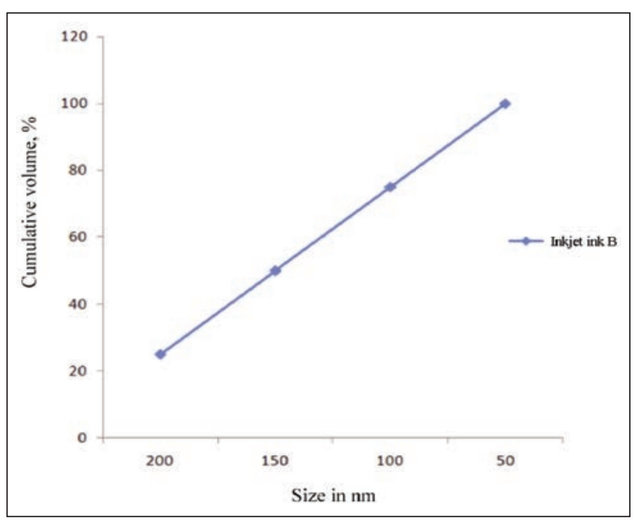


Fig. 4. Change in cumulative volume % age of inkjet ink B as function of particle size reduction

Table 1

| METALS CONTENTS IN INK A | | | | |
|---|---|---|---|---|
| **Heavy metals in sample A** | **Body contact** | **Skin contact** | **Non-skin contact** | **Decomposed metal** |
| Cd | 0.09 (PL 0.1) | 0.089(PL0.1) | 0.098(PL0.1) | 0.99(PL0.1) |
| Cu | 16(PL 25.0) | 14.9(PL50.0) | 17(PL50.0) | 20(PL50.0) |
| Pb | 13(PL90.0) | 11.9(PL90.0) | 14(PL90.0) | 21(PL90.0) |
| ZN | Not detected | Not detected | Not detected | Not detected |
| Fe | Not detected | Not detected | Not detected | Not detected |

Table 2

| METAL CONTENTS DETECTED IN INK B | | | | |
|---|---|---|---|---|
| **Heavy metals in sample B** | **Body contact** | **Skin contact** | **Non-skin contact** | **Decomposed metal** |
| Cd | 0.092(PL 0.1) | 0.091(PL0.1) | 0.099(PL0.1) | 0.1(PL0.1) |
| Cu | 16.3(PL25.0) | 15.1(PL50.0) | 17.2(PL50.0) | 20.4(PL50.0) |
| Pb | 13.1(PL90.0) | 12.1(PL90.0) | 14.3(PL90.0) | 21.2(PL90.0) |
| ZN | Not detected | Not detected | Not detected | Not detected |
| Fe | Not detected | Not detected | Not detected | Not detected |

The results in the graphs are indicating that the viscosities of both inkjet ink samples decreased with an increase in the temperature and shear rate, by results that are reported in a previous literature survey. The effects of the temperature and shear rate on the viscosity are shown in figures 5 to 8, respectively [20].

The most common problem in pigmented inkjet inks is an aggregation of pigment particles due to the inherent stability of the most common dispersion systems. When pigment particles approach each other, Vander walls interaction takes place, causing the particles to aggregate and eventually reached minimum potential energy as shown in figure 9. If the pigment is hydrophobic, it will tend to form a large aggregate in water. To avoid this aggregation, a mechanism to overcome attraction was required. To prevent the phenomenon of aggregation, an anionic surfactant was used. The surfactant SDS was adsorbed onto the surfaces of the pigment particles, where it imparted a negative charge. Thus, when the particles approached each other, they were repulsed electrically, as shown in figure 9 [20]. According to Derjaguin-Landau-Verwey-Overbeek theory (DLVO theory), if the repulsion overcomes the attraction, an energy barrier will exist and prevent the aggregation of particles as shown in figure 9. Thus, the prepared inkjet inks exhibited good storage stability.

### Colour fastness to rubbing

A digital crock meter (KTS) 500×500 was used to perform dry and wet rubbing fastness tests. The AATCC-08 method was used in both cases. For the wet rubbing

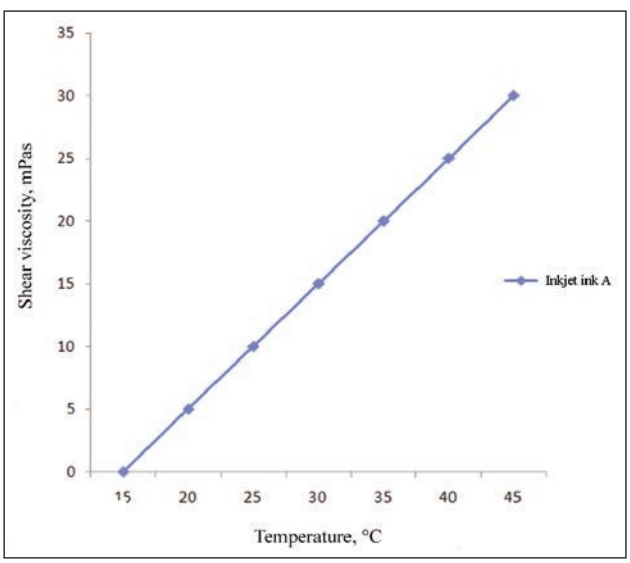


Fig. 5. Effect of temperature on shear viscosity for inkjet ink A

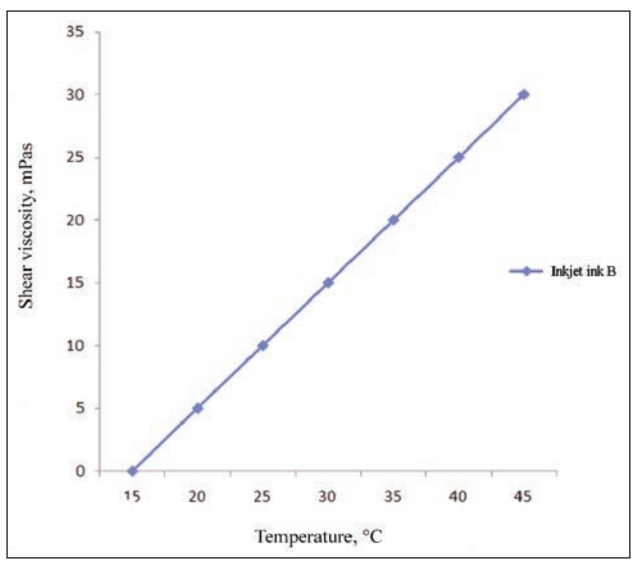


Fig. 6. Effect of temperature on shear viscosity for inkjet ink B

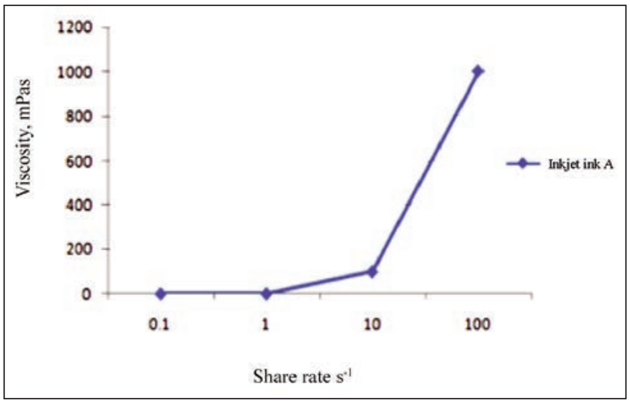


Fig. 7. Effect of shear rate on viscosity for inkjet ink A

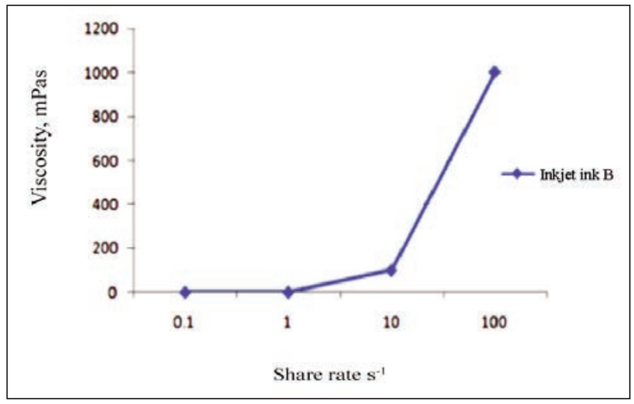


Fig. 8. Effect of shear rate on viscosity for inkjet ink B

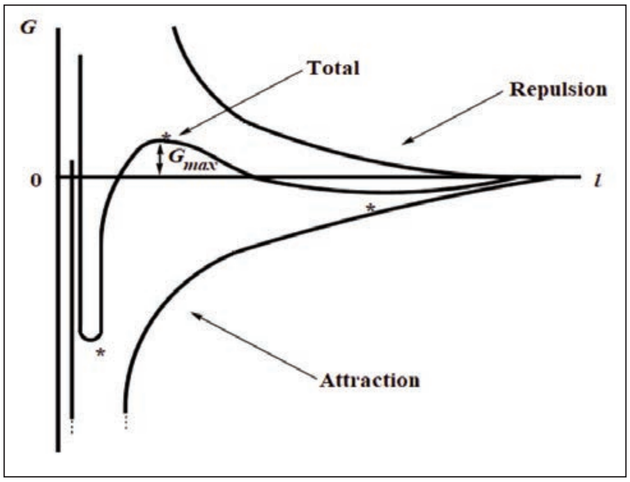


Fig. 9. Mechanism underlying ink stability during storage

test, the rubbing cloth used was 65% wet while for the dry rubbing test, it was 100% dry. The test was performed for dry and wet rubbing turn by turn for digital textile printed fabric samples and traditionally printed fabric samples. It was found that the digitally printed fabric samples exhibited better dry and wet rubbing fastness properties as compared with those of the traditionally printed fabric samples. Images are shown in figures 10 and 11. The quantitative rating of results is listed in table 3.

### Colour fastness to washing

The ISO 105 C06 test method was adopted to evaluate the washing fastness of the traditionally and digitally printed fabric samples. Specimens with dimensions of 4×10 $cm^2$ (ISO) were cut from the traditionally

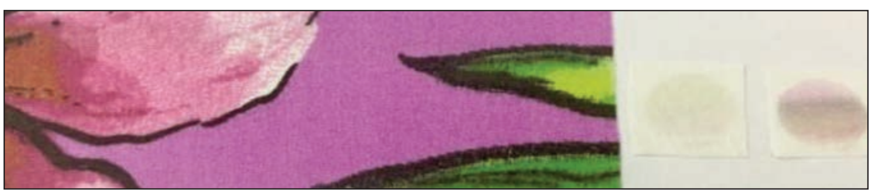

Fig. 10. Rubbing fastness of traditionally printed fabrics

Table 3

| RATING OF DRY AND WET RUBBING OF TRADITIONALLY AND DIGITALLY PRINTED SAMPLES A AND B | | | | |
|---|---|---|---|---|
| **Fastness property** | **Ink A traditionally printed** | **Ink A digitally printed** | **Ink B traditionally printed** | **Ink B digitally printed** |
| Rubbing Dry | 4-5 | 5 | 4-5 | 5 |
| Rubbing wet | 3-4 | 4-5 | 3-4 | 4-5 |

Fig. 11. Rubbing fastness of digitally printed fabric

Fig. 12. Washing fastness of traditionally printed fabric

Fig. 13. Washing fastness of digitally printed fabric

and digitally printed fabric samples. A multi-fibre swatch was attached to each specimen. All the colours of the samples were covered during the cutting process. A wash liquor was prepared using Grade 3 water and the required amount of Sand pan® DTC (Clariant). Steel balls were used in the HT machine, which was run for 30 min at room temperature. The washed specimens were removed, rinsed and dried in still air at a temperature not exceeding 60°C. Once the specimens were dried and conditioned, they were evaluated. It was found that the washing fastness of the digitally printed fabrics was better than that of the traditionally printed fabrics. The rating of results is listed in table 4 and images are shown in figures 12 and 13.

Table 4

| WASHING FASTNESS RATINGS OF TRADITIONALLY AND DIGITALLY PRINTED FABRIC SAMPLES | | | |
|---|---|---|---|
| **Ink A traditionally printed** | **Ink A digitally printed** | **Ink B traditionally printed** | **Ink B digitally printed** |
| 4 | 5 | 4 | 5 |

**Colour fastness to dry cleaning**

The ISO 105–DO1 method was adopted to test the dry-cleaning fastness of the traditionally and digitally printed fabric samples. Specimens with dimensions of $40 \times 40$ mm$^2$ were cut from the samples with care and placed along with white cotton fabric and non-corrodible steel discs (diameter = $30 \pm 2$ mm, thickness $3 \pm 0.5$ mm, smooth and free from rough edges, mass = $20 \pm 2$ g) in a bag with inner dimensions of $100 \times 100$ mm$^2$. The bag was sealed and put in the steel glass of the wash wheel and added perchloroethylene (10 ml/l) and a water-based detergent (0.6 ml/l). All the materials were agitated in the wash wheel for 30 min at 30°C. The specimens were removed from the bag, placed between absorbent paper and squeezed to remove the surplus solvent. They were then dried in air at a temperature not exceeding 60°C and evaluated changes in their shades using the grayscale proposed by the AATCC. It was found that the digitally printed samples exhibited better dry-cleaning fastness as compared to the traditionally printed samples as shown below. The images are shown in figures 14 and 15 and the rating of the results is in table 5.

Fig. 14. Dry cleaning results for digitally printed samples

Fig. 15. Dry cleaning results for the traditionally printed sample

Table 5

| DRY CLEANING FASTNESS RATING OF TRADITIONALLY AND DIGITALLY PRINTED FABRICS | | | |
|---|---|---|---|
| **Ink A traditionally printed** | **Ink A digitally printed** | **Ink B traditionally printed** | **Ink B digitally printed** |
| 4 | 5 | 4 | 5 |

**Colour fastness after light exposure**

The ISO 105/BO2 test method, which is widely accepted in the industry, was used to evaluate the colour fastness after exposure to light. A xenon arc lamp was used as the artificial light source as it was representative of natural daylight.

The specimens were cut carefully and exposed to moderate effective humidity. Light fluorescence (L F) of humidity test control was 5. The maximum black standard temperature was kept at 45 °C. Irradiance was performed at 300–400 nm. The specimens were exposed until a contrast corresponding to grey scale grade 4 and later to greyscale 3 was visible on the test sample, but at most until the blue wool reference was shown a contrast corresponding to grey scale grade 4 AATCC. The specimens were assessed using blue wool as a reference; images are shown in figures 16 and 17 and the rating of results is listed in table 6.

Fig. 16. Results of light fastness tests for traditionally printed fabrics

Fig. 17. Results of light fastness tests of digitally printed fabric

Table 6

| LIGHT FASTNESS RATING OF TRADITIONALLY AND DIGITALLY PRINTED FABRIC | | | | |
|---|---|---|---|---|
| **Fastness property** | **Ink A traditionally printed** | **Ink A digitally printed** | **Ink B traditionally printed** | **Ink B digitally printed** |
| Light Fastness | 5-6 | 7-8 | 5-6 | 7-8 |

## CONCLUSIONS

Inkjet nano inks and emulsions were synthesized, characterized and applied on the same pre-treated cotton fabrics. Their fastness properties, such as rubbing, washing, dry cleaning and light fastness were evaluated using ISO and AATCC methods. It was concluded that all the fastness properties of the digitally printed fabric samples were better as compared to traditionally printed fabric samples. Secondly, the colourants used have the same colour index numbers but the weather fastness properties were better in nanoparticle size as compared to micron particle size. Furthermore, digital inkjet ink printing and traditional rotary screen-printing methods were compared and were concluded that the digital textile printing method was a better printing method for quality printing, socio-economic and environmentally friendly as compared to the traditional rotary screen-printing method.


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# Classification and recognition of young males' waist-abdomen-hip shape based on body photos

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**ABSTRACT – REZUMAT**

**Classification and recognition of young males' waist-abdomen-hip shape based on body photos**

*To improve somatotype and realize rapid customization of clothing, this study proposed a body-shape recognition method based on the front and side body photos. The shape parameters such as angles, heights, lengths, and ratios at the waist-abdomen-hip position were measured or calculated based on the manual and three-dimensional (3D) point cloud data of 180 young men. Through analysis, four morphological parameters were determined to classify the waist-abdomen-hip shape and establish the classification rules of the four body types (fat, normal, forward fat and obese). Finally, according to the front and side photos of the human body, the orthogonal silhouettes were extracted to obtain the four parameters that can be used to distinguish the waist-abdomen-hip body shape of young men, and the photo-based recognition method of the waist-abdomen-hip body shape could be realized automatically. The verification results showed that the recognition accuracy ratio reaches 93.3%, indicating that the waist-abdomen-hip shape identification system using this body-shape recognition method based on body photos is effective and can provide a basis for personalized clothing customization to satisfy the individual needs of the consumers.*

***Keywords:*** *waist-abdomen-hip shape, somatotype method, discriminant rules, size extraction, body photos*

**Clasificarea și recunoașterea formei taliei-abdomenului-șoldului la bărbații tineri pe baza fotografierii corpului**

*Pentru a identifica somatotipul și a realiza personalizarea rapidă a îmbrăcămintei, acest studiu a propus o metodă de recunoaștere a formei corpului bazată pe fotografiile frontale și laterale ale corpului uman. Parametrii formei, cum ar fi unghiurile, înălțimile, lungimile și raporturile la poziția taliei-abdomenului-șoldului au fost măsurați sau calculați pe baza datelor manuale și a celor tridimensionale (3D) ale norilor de puncte pentru 180 de bărbați tineri. Prin analiză, au fost determinați patru parametri morfologici pentru clasificarea formei taliei-abdomenului-șoldului și stabilirea regulilor de clasificare a celor patru tipuri de corp (gras, normal, gras în partea frontală și obez). În cele din urmă, conform fotografiilor frontale și laterale ale corpului uman, siluetele ortogonale au fost extrase pentru a obține cei patru parametri, care pot fi utilizați pentru a distinge forma corpului pentru talia-abdomenul-șoldul bărbaților tineri, iar metoda de recunoaștere pe bază de fotografie a formei corpului ar putea fi realizată automat. Rezultatele verificării au arătat că raportul de acuratețe a recunoașterii ajunge la 93,3%, ceea ce indică faptul că sistemul de identificare a formei taliei-abdomenului-șoldului care utilizează această metodă de recunoaștere a formei corpului pe baza fotografiilor corpului este eficient și poate oferi o bază pentru personalizarea îmbrăcămintei pentru a satisface nevoile individuale ale consumatorilor.*

***Cuvinte-cheie****: forma taliei-abdomenului-șoldului, metoda somatotipului, reguli discriminante, extragerea mărimii, fotografii ale corpului*

## INTRODUCTION

With the improvement of living standards, consumers need higher requirements for the individualization of clothing. The accurate classification of human body shape is an important factor to improve clothing fit since the body shape varies greatly due to the influence of various factors such as gender, age, generation and lifestyle [1]. Therefore, the somatotype method has become a heated topic in the field of clothing research.

To meet the needs of different body types for clothing fit, many scholars and global organizations focus on the classification researches of the whole human body shape based on the body parameters of the samples with different age groups or from different regions, mainly including the front and side body silhouettes, the curve characteristics of the body transverse and longitudinal section, the angles of the body surface, BMI value, etc. [2, 3].

For the ready-to-wear industry, women's body shape was first classified according to their age (such as Women, Misses and Junior) and body measurements (such as bust girth) [4]. According to the standard ISO/TR 10652-1991, the body shape was classified based on girth differences such as chest-waist girth difference [5]. However, the size differences cannot properly identify the specific morphology, since the shape of the waist curve may be different even if the waist girth is the same.

Therefore, scholars began to use quantitative indicators that can represent the characteristics of the human body for classification [6]. Petrova [7] took the hip-to-waist circumference ratio as a classification index and divided 24 women aged between 35 and 55 years old into straight, medium and curvy body types. Moreover, some scholars focused on using angle measurements to classify body shapes. Yoon et al. [8] measured six space angles of the body side surface to classify 317 Korean men into four types, including straight type, swayback type, bend-forward type and back-forward type. In the above research, the upper and lower body were considered as a whole part to classify body types according to height, girths, angles etc., however, the shape differences of the local positions such as neck, bust and hip were ignored.

The shape of the local positions has been analysed later. Hu et al. [9] focused on the different characteristics of the shoulder cross-section curves closely related to the shape to subdivide the shoulder shapes into four types. Pei et al. [10] proposed a new way of systematically extracting breast measurements and an asymmetry index to quantify the degree of asymmetry between left and right breasts to analyse breast shape. However, there are few researches on male body classification, especially on the waist-abdomen-hip position, therefore, it is difficult to meet the demands on men's trousers fit. Finding an appropriate classification method of waist-abdomen-hip shape, which is a research emphasis in the clothing industry, cannot only help consumers identify their body types easily but also help garment manufacturers produce well-fitting pants.

The above researches on body type classification generally used 3D scanning to obtain human body characteristic parameters and then conducted some mathematical statistical analysis to conclude [11]. Though the efficiency of 3D body scanning, from which an infinite number of measurements, body shape analyses, angles, and relational data can be extracted, is well known, high price and poor mobility issues have slowed their widespread applications in routine apparel production, particularly in small-business settings [12, 13]. Therefore, some scholars have explored more simpler and economical approaches for body measurement that have the potential to be used for small business applications and even for home use.

To obtain human body data quickly and realize body-shape recognition more conveniently, this research proposed a waist–abdomen–hip shape recognition method based on the front and side body photos, which has the potential to be used for clothing customization. The 3D body scanner was used to obtain the point cloud data of 180 young men, and the characteristic parameters, such as the angles, thicknesses, heights, and widths at each featuring part were measured to classify the waist–abdomen–hip shape and establish the body type classification rules. According to the human body contour extracted from the human body photos, the corresponding parameters were obtained to identify the body-type category automatically. The research results will provide the basis for virtual fitting, intelligent pattern design and 3D modelling, etc. [14–16].

## METHODS

### Body measuring experiments

The subjects were 180 male college students aged 20–25 years old, with heights between 162.0 and 180.0 cm, and weights between 51.00 and 80.00 kg. The temperature of the environment was (25±2)°C and the relative humidity was (65±5)%, which meets the environmental standard for naked measurement [17]. [TC] $^2$ 3D body scanner from the USA was used to obtain the human body data, and the subjects needed to stand in a designated position with a normal breathing state, wear white light-colour and tight-fit clothes and a hat to completely cover their hair without accessories.

### Body measurements

By considering the influence of young men's waist-abdomen-hip shape on the pant structure design, 13 shape parameters such as the angles, heights, widths, and thicknesses of the waist-abdomen-hip position were selected for the shape analysis, and the definitions and measuring method of these specific shape parameters are shown in table 1 and figure 1. Since there were missing point-could data at the foot and head position by 3D scanning, the height data were manually measured, and the 3D method was used for the rest. The waist position is the thinnest position of the upper body from the front view, and the abdomen and hip positions are both convex from the side view. The edge points which intersect with the contour of the human body at these three sections ($S_W$, $S_A$ and $S_H$) are the waist point ($P_W$), abdomen point ($P_A$) and hip point ($P_H$). $A_W$ is used to reflect the curvature of the waist and the other two angles including $A_A$ and $A_H$ are necessary to characterize the prominence of the abdomen and hip. $R_n$ ($n = W, A, H$) means the ratio between the width and depth at the waist, abdomen and hip position, which can represent the flat or round degree of the curve shape.

Before measuring, the 3D human body point cloud data were denoised to avoid the appearance of noise and holes, which will cause the body contour curve to be uneven [18], and then the parameters of all the subjects were measured by the software IMAGEWARE.

### Silhouette extraction from body photos

The photos of the subjects were obtained by the 2D body measured method, which simply uses digital photos taken from off-the-shelf cameras to obtain body photos [19], as shown in figure 2 and needed to be pre-processed, such as adjusting the contrast and sharpness to make the body easier to recognize. The pixels of the photos were divided into several areas

Table 1

DEFINITIONS OF THE PARAMETERS RELATED TO THE WAIST-ABDOMEN-HIP SHAPE

| Methods | Number | Name | Definition |
|---|---|---|---|
| Manual method | 1 | $H$ | The distance from the top of the head to the ground |
| | 2 | $H_W$ | The distance from the $S_W$ to the ground |
| | 3 | $H_A$ | The distance from the $S_A$ to the ground |
| | 4 | $H_H$ | The distance from the $S_H$ to the ground |
| 3D method | 5 | $W_W$ | The horizontal distance at the waist from the front view |
| | 6 | $W_A$ | The horizontal distance at the abdomen from the front view |
| | 7 | $W_H$ | The horizontal distance at the hip from the front view |
| | 8 | $T_W$ | Maximum horizontal depth of the waist at the level of $P_W$ |
| | 9 | $T_A$ | Maximum horizontal depth of the abdomen at the level of $P_A$ |
| | 10 | $T_H$ | Maximum horizontal depth of the buttock at the level of $P_H$ |
| | 11 | $A_H$ | The angle of the hip convex with the apex of $P_H$ |
| | 12 | $A_A$ | The angle of the abdomen convex with $P_A$ as the apex |
| | 13 | $A_W$ | The angle of the waist with $P_W$ as the apex |

| Methods | Number | Name | Definition | Number | Name | Definition | Number | Name | Definition |
|---|---|---|---|---|---|---|---|---|---|
| Calculated method | 14 | $R_W$ | $W_W/T_W$ | 17 | $R_{WWA}$ | $W_W/W_A$ | 20 | $R_{TWH}$ | $T_W/T_H$ |
| | 15 | $R_A$ | $W_A/T_A$ | 18 | $R_{WWH}$ | $W_W/W_H$ | 21 | $R_{HWA}$ | $H_W/H_A$ |
| | 16 | $R_H$ | $W_H/T_H$ | 19 | $R_{TWA}$ | $T_W/T_A$ | 22 | $R_{HWH}$ | $H_W/H_H$ |

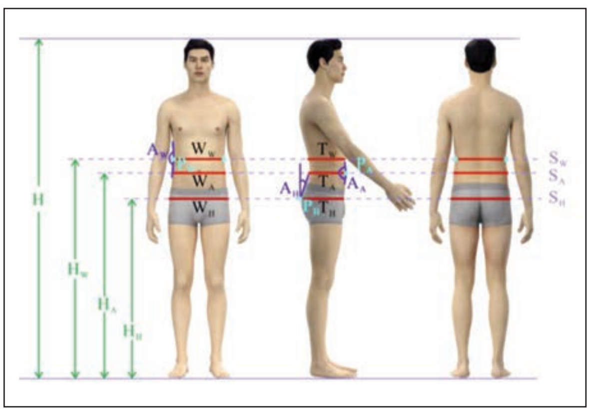


Fig. 1. Measurement methods

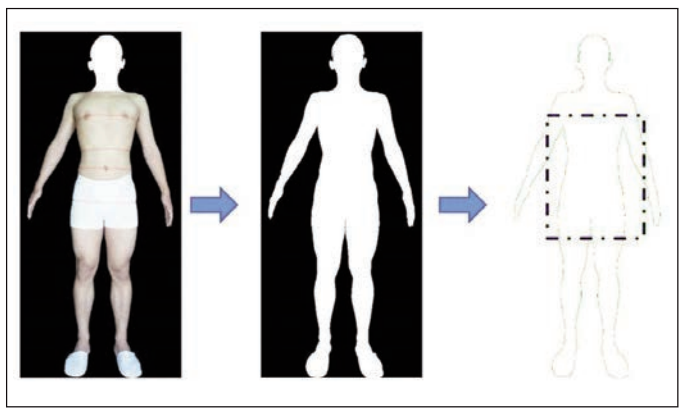


Fig. 2. Original photo, photo binarization and body silhouette

according to the grey level, and then the Optimum Thresholding (OTSU) [20] method was used to find a suitable threshold to convert the original RGB photo into a binary photo, as shown in figure 2. To make the target contour smooth and eliminate holes, the opening operation was used with the imopen function to eliminate the cluttered and small areas in the binary image caused by the original image noise, and the filling holes method was used with the imfill function to turn all non-boundary areas in the binary image into the background colour. Finally, the body silhouette was extracted, and the dotted box area was located to recognize the feature points at the waist-abdomen-hip part, as shown in figure 2.

## RESULTS AND DISCUSSION

To ensure the accuracy and reliability of the measurements, all the data were firstly pre-processed, and 173 valid samples were determined. The measured data were tested for normal distribution and descriptive statistics, and all 22 parameters were distributed normally. Therefore, a subsequent analysis of the sample data could be performed.

### Cluster analysis

The major problem of using the K-means algorithm in data mining is the choice of variables [21]. If all 22 variables were extracted, the high dimensional space would be formed with poor clustering results. Therefore, it is important to determine the appropriate variables.

To avoid the repeatability of the variables, the calculated variables (such as the ratio between the widths and thicknesses) and the angles were analysed, and the coefficient of variation [22] was used to determine the appropriate variables. The larger the coefficient of variation (standard deviation/mean), the bigger the difference between the data, and the greater influence on the waist-abdomen-hip shape.

Table 2

| STATISTICAL ANALYSIS OF RELATED VARIABLES | | | | | | |
|---|---|---|---|---|---|---|
| **Variables** | $A_H$ (°) | $A_A$ (°) | $A_W$ (°) | $R_W$ | $R_A$ | $R_H$ |
| SD | 3.640 | 6.221 | 4.982 | 1.879 | 0.090 | 0.075 |
| Mean | 12.370 | 168.60 | 164.787 | 1.364 | 1.430 | 1.418 |
| CV(%) | **29.423** | 3.690 | 3.023 | **7.222** | **6.298** | 5.294 |
| **Variables** | $R_{WWA}$ | $R_{WWH}$ | $R_{TWA}$ | $R_{TWH}$ | $R_{HWA}$ | $R_{HWH}$ |
| SD | 0.044 | 0.048 | 0.053 | 0.065 | 0.024 | 0.030 |
| Mean | 0.924 | 0.798 | 0.970 | 0.832 | 1.079 | 1.238 |
| CV(%) | 4.793 | 6.067 | 5.419 | **7.862** | 2.224 | 2.402 |

Note: SD means standard deviation. CV means coefficient of variation.

Descriptive statistics such as the standard deviation (SD), Mean and coefficient of variation (CV) of each parameter are listed in table 2. According to table 2, the coefficient variation of $A_H$, $R_{TWH}$, $R_W$, $R_A$, $R_{WWH}$ is significantly higher than other characteristic variables, indicating that the five characteristic variables have a greater degree of dispersion and impact on the waist-abdomen-hip shape. By comparing the correlation of five variables, the correlation coefficient between $R_{TWH}$ and $R_{WWH}$ is 0.748, which shows that there is a high correlation between the two variables. Therefore, four variables including $A_H$, $R_{TWH}$, $R_W$ and $R_A$ were selected as the variable subsets for the K-means cluster.

Since the reasonable cluster number will also affect the cluster effect, Elbow Method [23] and Silhouette Coefficient Method [24] were both used to determine the cluster number.

The core indicator of the Elbow Method is the sum of squares due to error (SSE), and its calculation formula is the following:

$$SSE = \sum_{i=1}^{k} \sum_{p \in C_i} |p - m_i|^2 \quad (1)$$

In formula 1, $C_i$ represents the $i$-th cluster, $p$ is the sample point in $C_i$, $m_i$ – the centroid of $C_i$, and $SSE$ – the clustering error of all samples, representing the quality of the clustering effect.

In addition, the Silhouette Coefficient is also a way to evaluate the quality of the clustering results. The silhouette coefficient of the sample point $X_i$ is defined as follows:

$$S = (b - a)/\max(a,b) \quad (2)$$

In formula 2, $a$ means cohesion which represents the average distance between $X_i$ and other samples in the same cluster, and $b$ is the average distance from all samples in the nearest cluster, named the degree of separation. The value of the Silhouette Coefficient is between [–1,1]. The larger the value, the better the cohesion and separation.

Combing the results of figures 3 and 4, when the cluster number is two, the classification effect is the best, and when the number is four, the classification result is better. Considering that the complexity of human body shape, two kinds of body shapes cannot reflect the difference in body shape, and it is difficult to meet the requirements of subsequent personalized clothing customization for fit. Therefore, the cluster number was set as four to carry on the K-means cluster analysis by using four variables, including $A_H$, $R_{TWH}$, $R_W$ and $R_A$.

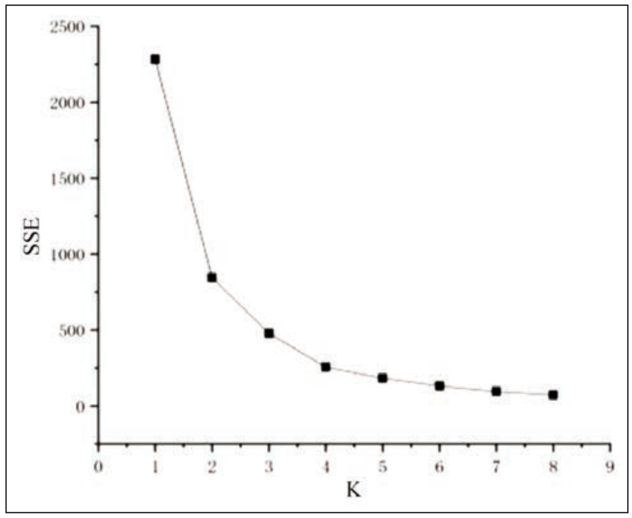



Fig. 3. Elbow method

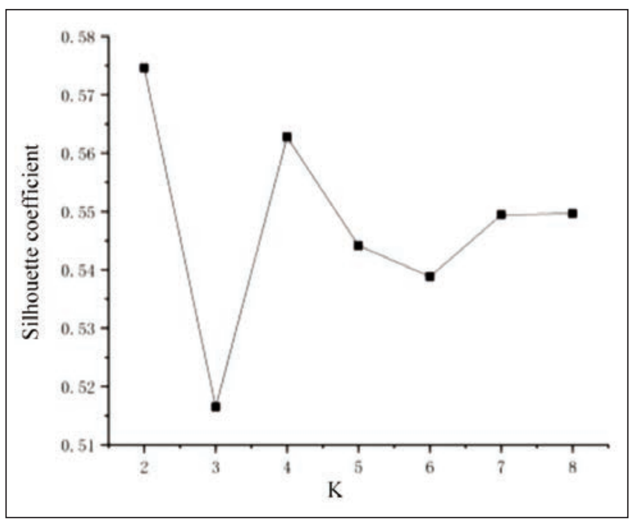



Fig. 4. Silhouette coefficient method

### Shape classification

The waist-abdomen-hip shape of 173 young men was divided into four categories, and the results are shown in table 3. The number of the first and fourth types is relatively even, and the third body type accounted for a relatively small proportion of less than 10%.

There are certain differences between body types, especially the value of $A_H$, and the values differ significantly between the first and the third types.

To analyse the four different body types of waist–abdomen–hip shape more intuitively, the front, side and sectional shapes of the four types were compared, and it is found that the shape difference is more obvious from the side and sectional view, as shown in figures 5 and 6.

Figure 5 shows the side view extracted between the waist and crotch lines, the hip and abdomen curves are landmarked to represent the hip and abdomen convex respectively, which are drawn by two red curves. The vertical distance between the abdomen and hip lines can reflect the differences among the four body types, and the $D_{WH}$ value of each body type, which means the horizontal distance between the left side points at the waist and hip position from the side view, is also significantly different. From the side view, the body shape of the first type is slightly fatter, though the abdomen and hip convex are not obvious. The second type is well-proportioned and the abdomen is flat. The third type has a raised hip, with a sunken back waist, and the whole waist-abdomen-hip leans forward. The fourth type has a plump hip and higher abdomen with a significant protrusion, the whole waist-abdomen-hip shape is round from the overall view.

Figure 6 shows the sectional view of the waist, abdomen and hip which can also reflect the difference between each type. The point cloud data of the cross-sectional curves were extracted to be moved and rotated as shown in figure 6, *a* and then the

Table 3

| FINAL CLUSTERING CENTER | | | | | | |
|---|---|---|---|---|---|---|
| **Clustering type** | **Number of samples** | **Proportion (%)** | $A_H$ (°) | $R_{TWH}$ | $R_W$ | $R_A$ |
| 1 | 36 | 20.81 | 7.75 | 0.832 | 1.365 | 1.419 |
| 2 | 74 | 42.77 | 11.38 | 0.850 | 1.341 | 1.420 |
| 3 | 15 | 8.67 | 19.88 | 0.793 | 1.410 | 1.482 |
| 4 | 48 | 27.75 | 15.02 | 0.816 | 1.383 | 1.473 |

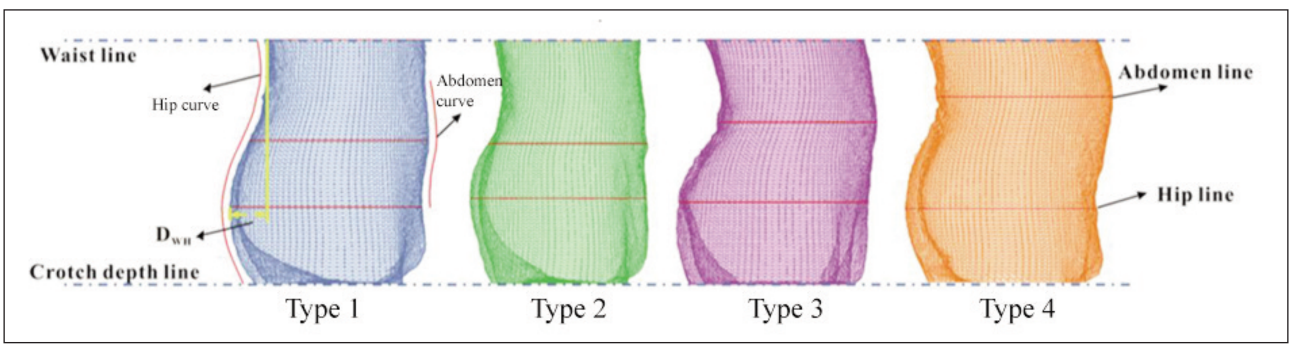
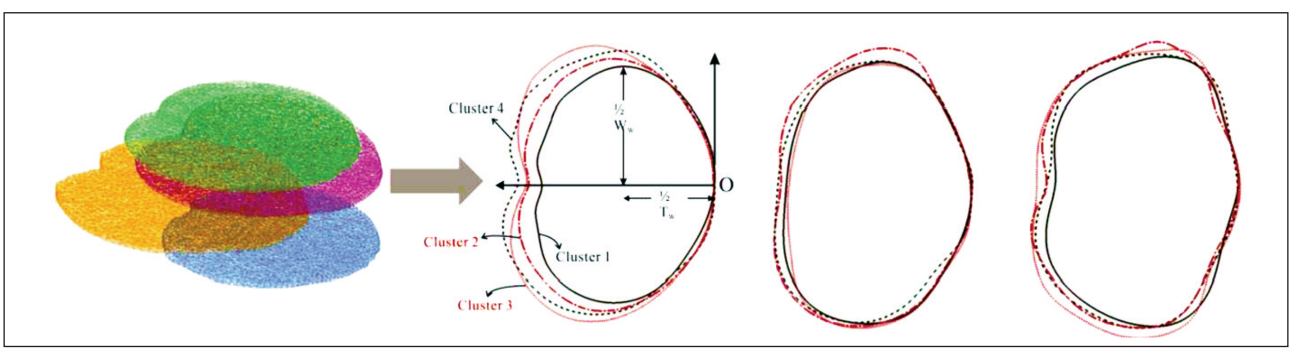



Fig. 5. Side view of the waist-abdomen-hip shape




*a* *b* *c* *d*

Fig. 6. Sectional view of the waist-abdomen-hip shape:
*a* – messy point cloud; *b* – waist section; *c* – abdomen section; *d* – hip section

curves of the four body types were overlapped at the convex points of the waist, abdomen and hip, as shown in figure 6, *b, c* and *d*.

By comparison, there are significant differences among the cross-sectional curves of the waist, which is related to the $R_W$ of each body type. Take the $R_W$ value of cluster one as an example, the value can be calculated by (1/2) $W_W$/(1/2) $T_W$, as shown in figure 6, *b*. From the perspective of the cross-sectional curve, the depth of the waist curve of the third and fourth types is larger than others, and the curve shape of the second type is relatively round.

Therefore, with the combination of the differences at the side and sectional views of the four types, the first type is named fat body, the second type is the normal body, the third type is the forward fat body, and the fourth type is the obese body respectively.

The discriminant rules were finally established to identify the four body types based on four parameters including $A_H$, $R_{TWH}$, $R_W$ and $R_A$, and the results are shown in table 4.

Table 4

DISCRIMINANT RULES OF THE FOUR WAIST-ABDOMEN-HIP TYPES

| Clustering type | Classification rules |
|---|---|
| 1 | F1>F2,F1>F3,F1>F4 |
| 2 | F2>F1,F2>F3,F2>F4 |
| 3 | F3>F1,F3>F2,F3>F4 |
| 4 | F4>F1,F4>F2,F4>F3 |
| **Discriminant formula** | |
| $F1 = 5.47*A_H + 859.55*R_{TWH} + 417.35*R_W + 212.34*R_A - 815.47$ | |
| $F2 = 7.96*A_H + 868.60*R_{TWH} + 416.19*R_W + 213.12*R_A - 846.40$ | |
| $F3 = 13.66*A_H + 865.32*R_{TWH} + 419.29*R_W + 208.28*R_A - 930.16$ | |
| $F4 = 10.41*A_H + 864.32*R_{TWH} + 420.00*R_W + 206.97*R_A - 871.59$ | |

The discriminant rules were also verified with 173 samples, and 172 samples were correctly classified to show the accuracy ratio reaches 99.4%, indicating that the classification rules are effective.

**Body type recognition based on body photos**

According to the contour curve characteristics of the body's front and side body shape, the typical height range for the limits was analysed to look for a landmark, and then the shape characteristics were used to determine the actual position [25]. To obtain the four parameters in the discriminant rules, the main feature points including waist point ($P_W$), abdomen point ($P_A$), and hip point ($P_H$) ought to be identified, as shown in figure 7, *a*.

Take the abdomen landmark as an example. Through the statistical analysis of the basic body proportion, the abdomen height is between 40% and 47% of the body height. As shown in figure 7, *b* the line *LA* is the upper limit, and the line *LB* is the lower limit. The line *L* represents the random line between the line *LA* and the line *LB*.

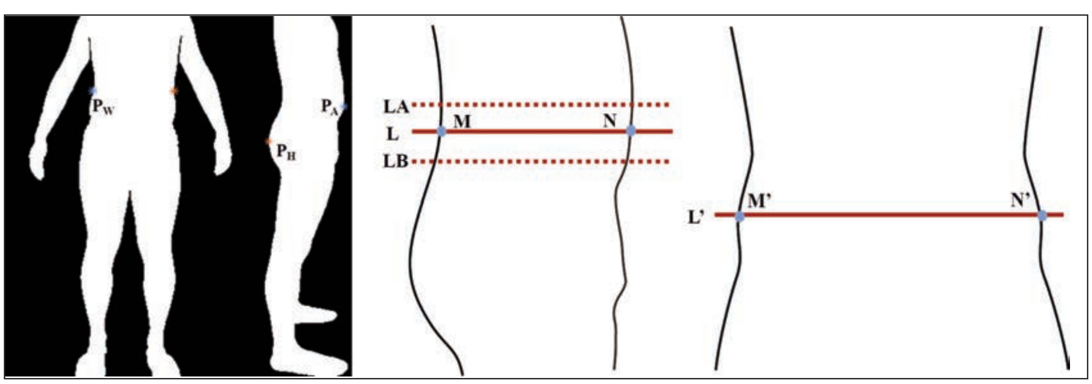
From the side view of the human body, the most prominent point on the right side at line *L* was searched from *LA* to *LB* with a line spacing of one pixel and was marked as point *N*. Then the left point *M* at line *L* was also obtained, and the distance between point *M* and *N* on line *L* was the abdomen thickness ($T_A$).

From the front view, *L′* could be determined by using the height of line *L*, as shown in figure 7, *c*. The left and right points at the line *L′* with the intersection of the body contour were marked as the points *M′* and *N′*, and the distance between them was the abdomen width ($W_A$). The determination method of the other points was similar, and the corresponding parameters such as angles and ratios were calculated.

**Error analysis**

To verify the accuracy of this body-type identification method based on body photos, the body photos of 30 samples were obtained to extract the four variables, and according to the established discriminant rules, the body type was automatically classified.

Compared with the classification results of the 3D measurements, the results are shown in figure 8. Among the 30 samples, 28 are correctly classified to show the accuracy ratio reaches 93.3%, with a 3.3 percent increase by comparing with the results in Cai's [26] paper.




*a* *b* *c*

Fig. 7. Graphical representation of: *a* – feature points; *b* – abdomen thickness; *c* – abdomen width

Table 5

| ERROR ANALYSIS BETWEEN THE PHOTO AND THE 3D MEASUREMENTS | | | | | | | |
|---|---|---|---|---|---|---|---|
| Variable name | Type | Mean | Standard deviation | Error range | Mean absolute error | Sig of t-test | Correlation coefficient |
| $A_H$ | 2D extracted | 10.937 | 2.931 | –1.16~1.34 | 0.541 | 0.143 | 0.982 |
| | 3D measured | 10.533 | 3.372 | | | | |
| $R_{TWH}$ | 2D extracted | 0.817 | 0.052 | –0.10~0.03 | 0.016 | 0.129 | 0.901 |
| | 3D measured | 0.827 | 0.044 | | | | |
| $R_W$ | 2D extracted | 1.375 | 0.085 | –0.09~0.10 | 0.027 | 0.344 | 0.904 |
| | 3D measured | 1.364 | 0.076 | | | | |
| $R_A$ | 2D extracted | 1.411 | 0.089 | –0.12~0.09 | 0.037 | 0.637 | 0.837 |
| | 3D measured | 1.416 | 0.075 | | | | |

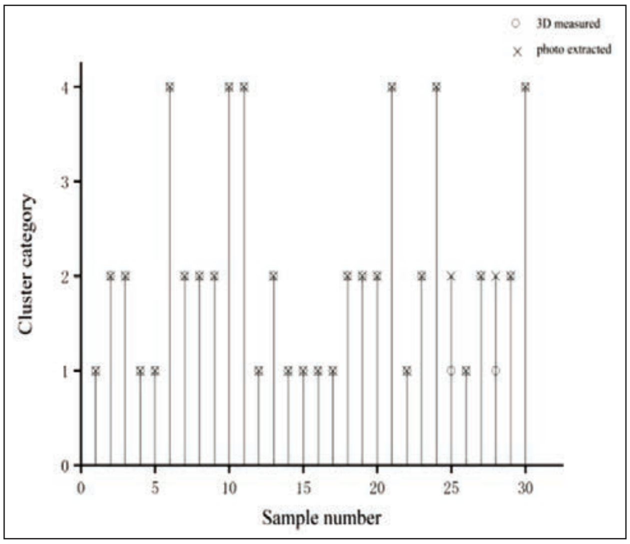



Fig. 8. Recognition result of 30 samples

The photo and 3D measurements were also compared and analysed to verify the accuracy, and the error results are shown in table 5. The difference in the mean and standard deviation between the photo extracted value and the 3D measured value is not significant, and the correlation coefficient of each variable is high, indicating that there is a high consistency between the two methods. However, the correlation coefficient of $R_A$ is 0.837, since the position of the abdomen was difficult to be determined, influencing the accuracy of the width and thickness at the abdomen position.

The photo-based extracted values and the 3D measured values were further paired with the t-test, and the results are shown in table 5.

The Sig. value of the t-test is greater than 0.05, indicating that there is no significant difference between the 3D measured and the photo-based extracted values, and the error ranges of the ratio values almost are all within ±0.1. Therefore, it can be considered that the automatic recognition method of the waist–abdomen–hip shape based on the body photos is feasible.

## CONCLUSIONS

In this study, the automatic recognition method of the waist-abdomen-hip shape based on body photos was proposed. 180 male college students aged 20–25 were selected to obtain human body data through 3D measurement, photo measurement and manual measurement. Based on the analysis of the shape parameters extracted from 3D point cloud data, the waist-abdomen-hip shape was divided into four types, including the fat type, normal type, forward fat type and obese type, and the corresponding classification rules for the four types were established based on the four parameters (such as $A_H$, $R_{TWH}$, $R_W$ and $R_A$). The automatic extraction of the parameters based on body photos was realized through feature point recognition, and the waist-abdomen-hip shape recognition system was developed with the classification rules. The verification results show that the accuracy of automatic recognition was 93.3%, and the significance (Sig) of the t-test was greater than 0.05, indicating that there is a good consistency between the photo extracted and 3D measurements to show that the method is feasible and effective. This research results can provide the basis for the pattern design of young men's trousers, and the method proposed in this research can be extended to other parts of the body and enrich the body type classification of young men even children and young females.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# Sensory analysis and Principal Component Analysis: a sustainable approach for quality control of stretch denim fabrics

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**ABSTRACT – REZUMAT**

**Sensory analysis and Principal Component Analysis: a sustainable approach for quality control of stretch denim fabrics**

*This study proposes a simplified approach to optimise the portfolio of denim manufacturers by reducing the cost of unattractive or undifferentiated assortments for future consumers based on their ability to perceive and discriminate sensory comfort. A key factor in a successful textile value chain is end consumers, who can be considered naive evaluators when it comes to sensory analysis, as they tend to touch apparel fabrics to perceive the sensory comfort they feel when wearing them. In this context, 16 naive assessors were recruited to quantitatively characterise six bipolar sensory attributes as hand descriptors of an assortment of five washed stretch denim fabrics based on tactile properties. Statistical analysis of the extensive data was performed using the multivariate technique PCA. Two principal components that explained 70.46% to 76.67% of the total observed variance for the five washed denim fabrics provided an adequate summary of the sensory data reported, so relationships between sensory attributes as hand descriptors and ratings given by the 16 untrained assessors were examined. Statistical tests showed that all six bipolar attributes were important for sensory analysis and that inter-rater agreement was low. However, considering the sensory perception of the untrained evaluators (i.e., consumers), it was concluded that four of the five washed stretch denim fabrics could be an option for product portfolio diversification. Thus, from a strategic and sustainability perspective, PCA for sensory analysis may be helpful in the quality control of washed stretch denim.*

***Keywords:*** *stretch denim, sensory analysis, fabric hand, assessors, PCA, quality control, sustainability*

**Analiza senzorială şi Analiza Componentelor Principale: o abordare sustenabilă pentru controlul calităţii ţesăturilor denim elastice**

*Acest studiu propune o abordare simplificată a unui aspect din activitatea producătorilor de țesături denim: optimizarea portofoliului și reducerea costurilor cu articole neatractive pentru viitorii consumatori, pe baza capacității acestora de a percepe și diferenția confortul senzorial al țesăturilor. Consumatorii finali, factor cheie al lanțului valoric textil de succes, pot fi considerați evaluatori naivi atunci când vine vorba de analiza senzorială deoarece au tendința de a manipula intuitiv țesăturile din produsele vestimentare, pentru a percepe confortul senzorial pe care l-ar putea simți la purtarea acestora. În acest context, 16 evaluatori fără experiență în evaluare senzorială au fost recrutați pentru a analiza un sortiment de cinci țesături denim elastice finisate și spălate, prin evaluarea cantitativă a șase atribute senzoriale bipolare – descriptori ai confortului senzorial. Analiza statistică a volumului mare de date experimentale a fost efectuată utilizând tehnica multidimensională PCA (Analiza Componentelor Principale). Contribuția fiecărui descriptor la diferențierea țesăturilor a fost sintetizată adecvat prin două componente principale care au explicat 70,46% până la 76,67% din variația totală observată pentru cele cinci țesături denim. Astfel a fost posibilă examinarea relațiilor dintre atributele senzoriale bipolare ca descriptori ai confortului senzorial și evaluările raportate de cei 16 evaluatori neexperimentați. Testele statistice au arătat că toate cele șase atribute bipolare au fost importante pentru analiza senzorială deși corelația dintre raportările evaluatorilor a fost la un nivel scăzut. Oricum, având în vedere percepția senzorială a evaluatorilor neinstruiți (consumatori obișnuiți), s-a ajuns la concluzia că doar patru din cele cinci țesături denim elastice ar putea reprezenta o opțiune pentru diversificarea portofoliului de produse. Dintr-o perspectivă strategică și sustenabilă, utilizarea PCA pentru analiza rezultatelor evaluării senzoriale poate fi de ajutor în controlul calității țesăturilor denim supuse tratamentelor de finisare-spălare în scopul diversificării gamei sortimentale.*

***Cuvinte-cheie:*** *denim elastic, analiză senzorială, confort senzorial țesătură, evaluatori, PCA, control de calitate, sustenabilitate*

## INTRODUCTION

Sensory comfort is one of the most challenging and complex issues in textile quality control. It is becoming increasingly important to designers and manufacturers in the development of fabric assortments and apparel collections, primarily because it is a key factor in understanding and measuring the preferences of consumers who are willing to purchase a garment. Regardless of the source of supply or market niche, apparel consumer lifestyle surveys have shown that consumers not only follow the latest fashion trends when purchasing apparel but are also willing to pay more for comfort than any other product feature designed to meet consumer values [1–3].

The global denim market landscape has changed with the introduction of more comfortable garments made from stretch denim fabric, as this property is already considered during fabric development. Manufacturers of denim fabrics and denim clothing are therefore committed to innovating their products and adapting them to consumer needs. This strategy also includes a wide range of finishing and washing techniques used in the various stages of processing [3–7].

Due to the increasing trend of giving a special look to denim products, some studies have been conducted to investigate the effects of finishing and washing processes on the physical and mechanical properties of fabrics based on subjective evaluation [8–11]. For garments, sensory comfort is based on individual perception of textile materials and can be evaluated using sensory analysis to assess physical human interaction with fabrics, which in laboratory practice is associated with the fabric hand. This concept, used in the textile industry, refers to the sum of sensations experienced by humans when handling the fabric and perceiving its tactile properties as a sensory response. Sensory analysis is thus a science that deals with the evaluation of the physical properties of a product through the human senses [12–19]. Sensory analysis, as a subjective evaluation technique, is considered a widely used practice to assess the sensory comfort of clothing to improve the design phase for both fabrics and garments. On the other hand, when buying a garment, consumers, with or without experience with textiles, tend to hold it in their hands to get an idea of the quality of the fabric and the sensory comfort they might enjoy when wearing the garment [15, 20, 21]. In this respect, sensory analysis by default uses the human senses as a "measuring tool", and variability in sensory responses is inherent in any group of raters participating in a sensory test, even in a homogeneous, trained panel [13, 15]. This situation can also occur with the sensory properties that are altered by the finishing and washing of denim [8, 9, 17, 18].

The planning and implementation of the sensory analysis for the perception of tactile properties must be ensured according to the standard guidelines for the field of sensory analysis, also considering the AATCC procedure for the subjective evaluation of the fabric hand. These reference documents specify the requirements and conditions under which fabrics should be evaluated for their sensory properties as descriptors of the fabric hand, including details on the selection and training of evaluators [12, 22–25].

Regarding the skills of the evaluators, the standards provide that sensory analysis can be performed by three categories: sensory assessors, selected assessors, and sensory experts. Sensory assessors may be "naive" evaluators who do not have accurate selection criteria and/or are not trained. The success of a sensory evaluation is highly dependent on the reliability of the evaluators, and this requires intensive training. However, the literature shows that sensory results reported by untrained evaluators (i.e., consumers), as opposed to those reported by evaluators with expertise, are relevant in determining actual product preferences in the marketplace [20, 21].

In evaluation trials, descriptive analysis can be used to quantitatively characterize specific sensory attributes perceived by a panel of evaluators for new product development and/or consumer testing and reported as intensity scores [15, 22–25]. In terms of constraints, it is to be expected that for certain fabrics and when looking for the effects of a variety of treatments on the fabric hand, some of the hand descriptors will be more difficult to assess and quantify by scores than others. Therefore, subjective evaluation of washed stretch denim fabrics can be very challenging for a panel of evaluators, especially naive evaluators who are considered regular wearers of denim garments. Accordingly, validation of rater performance is mandatory and involves techniques such as univariate or multivariate analysis of results reported as sensory data. As described in the literature, univariate analysis of rater performance focuses on individual attributes, while multivariate analysis focuses on the consistency of ratings within panellists and the entire set of sensory results [8, 10, 11, 17, 21]. Since it is a multivariate method to study the interaction between all sensory attributes and to highlight the similarities or differences between products, Principal Component Analysis (PCA) is recommended for descriptive analysis as one of the test methods for comparing competing products in terms of sensory differences and acceptability [23, 26, 27].

Sensory analysis of stretch denim fabrics, which now account for a significant share of the global denim market, has been studied to a limited extent. Despite the many studies on the tactile properties of fabrics, the multivariate technique based on PCA has not yet been applied to investigate the discriminative ability of a panel of naive assessors in evaluating the sensory properties of a range of washed stretch denim fabrics.

This study was conducted to establish a protocol for sensory analysis and the use of PCA as a statistical technique to support quality control of washed stretch denim fabrics and product portfolio diversification in denim companies from a strategic and sustainable perspective.

## EXPERIMENTAL

### Materials and methods

For this study, five stretch denim fabrics subjected to different washing treatments were blindly evaluated for their tactile sensory properties.

The 3/1 twill samples were woven on a PICANOL OMNI PLUS 800 air-jet loom using carded cotton yarns as warp threads and core-spun yarns as weft threads (with elastane as the core and combed cotton as the sheath). In the loom condition, 4 finishing treatments were conducted followed by 5 washing procedures (which are common in the denim industry) to produce an assortment of five washed stretch denims (D1 ÷ D5) [19]. The specifications of the fabric samples are listed in table 1 and the appearance of the five washed denims subjected to sensory analysis is shown in figure 1.

For this study, a group of 16 women aged 20–22 years were recruited as "naive"/untrained evaluators and participated in the subjective assessment panel. The "naive" evaluators, who had not previously participated in sensory training or sensory trials, received minimal instruction in blind manipulation of samples to quantify their perceptions by rating six bipolar attributes: stretchy/non-stretchy (St/N); soft/hard (So/H); flexible/stiff (F/S); thin/thick (T/Tk); slippery/rough (Sl/R); light/heavy (L/He).

As a principle of the scoring technique, numerical values were assigned to the two extremes of the bipolar attributes on the rating scale, quantifying the intensity of each attribute from 1 to 10 (e.g., for *soft/hard*, coded So/H: 1 for softest, 5 for medium, 10 for hardest).

Sensory analysis experiments were performed as described in previous work [19] and accordance with AATCC Procedure and current regulations [12, 22–24].

**Statistical analysis of sensory data for a new quality control procedure**

Following the sensory analysis experiments, the multivariate PCA technique was used to investigate the interaction between the sensory attributes indicated by the intensity ratings and to highlight similarities or differences between the five washed stretch denim fabrics as perceived by the 16 naive raters. The goal was to establish a protocol for sensory analysis and to use PCA as a statistical technique to support quality control of washed stretch denim fabrics and diversification of the product portfolio.

Given a large amount of information, this article will only address the general aspects of using PCA to analyse sensory data reported by naive assessors.

The following conventions were followed in applying the PCA algorithm:

– The intensity scores reported by the raters were observations belonging to the 16 individuals coded as E01 to E16.

– The six bipolar sensory attributes analysed as descriptors of the fabric hand were variables and were coded as St/N, So/H, F/S, T/Tk, Sl /R, L/He.

As shown in table 2, the comprehensive data processing with the PCA statistical tool consists of nine steps, each of which entails an important result [26, 27].

Table 1

STRUCTURAL PROPERTIES OF 3/1 TWILL GREIGE DENIM FABRIC

| **Material (%)** | | **Yarn count (tex)** | | **The density of yarn systems (per cm)** | | **Mass per unit area (g/m$^2$)** |
|---|---|---|---|---|---|---|
| Warp | Weft | Warp | Weft | Ends | Picks | |
| Cotton | 98/2 Cotton/Elastane | 57 | 63 | 27 | 20 | 317±16 |

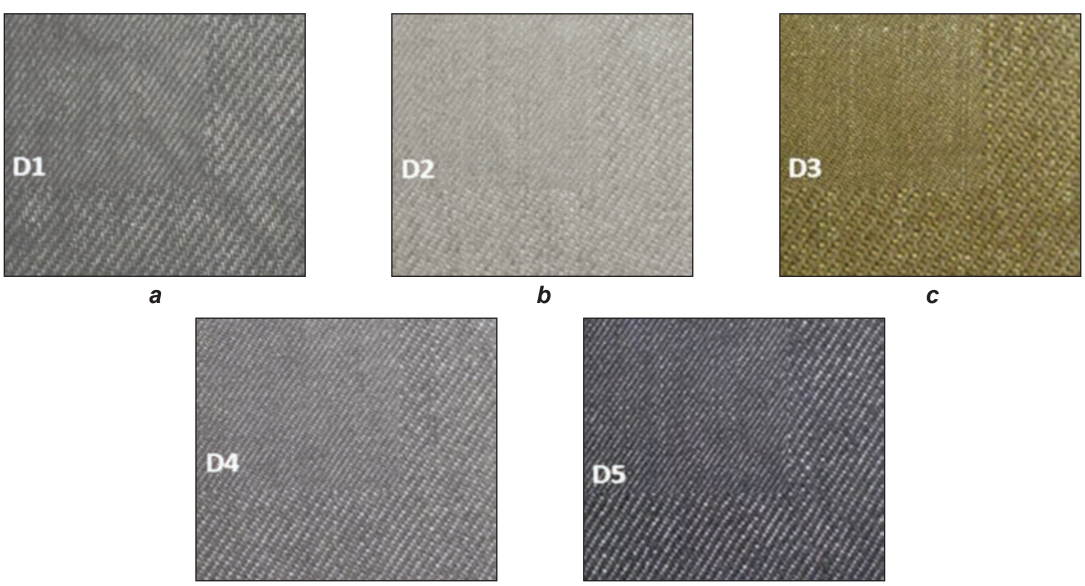



Fig. 1. Expected effects on the surface of stretch denim fabric after finishing and washing:
*a* – shiny for a leather look (D1); *b* – matte (D2); *c* – soft and shaded (D3); *d* – fuller and faded for a worn look (D4);
*e* – wrinkle-free and semi-glossy (D5)

Table 2

| PCA INFORMATION FLOW FOR SENSORY DATA OF WASHED STRETCH DENIM | | | | |
|---|---|---|---|---|
| **Purpose** | **Step** | **Item** | **Practical meaning** | **Relevant information** |
| Study of correlations between variables/ sensory attributes | 1 | *Eigenvalues* | Reflects the quality of the projection from the six-dimensional tables (for six variables) to a lower dimension by counting the total variability of the sensory data and making a quantitative assessment of how significantly a component represents the data | Assuming that there are six components/factors for six variables, eigenvalues above 1 have a larger share of the variance than any single variable, and principal components should account for more than 70% of the variance |
| | 2 | *Loading matrixes with components / factors loadings* | Understand the importance of principal components and sensory data for each variable and visualize correlations between variables and components | Note the values corresponding to the principal component for each variable with a factor loading greater than 0.4 |
| | 3 | *Squared cosines of the variables* | To interpret both correctly, the representation of the variables on the coordinate axes and the correlations between the variables | The values above 0.4 confirm that the variables are well enough connected to the principal components' axis |
| | 4 | *Communalities of variables* | Highlights the ratio of the variance of each variable to the total variation | Values above 70% are considered significant |
| Study of correlations between observa-tions/ individuals | 5 | *Squared cosines of the observations* | Highlights the quality of a representation of individuals in a point cloud in the new PCA space | For each observation, values greater than 0.4 match the factor for which the squared cosine is largest |
| | 6 | *Communalities of observations* | Underlines the quality of the representation of the individuals on the coordinate axes of the principal components and the correlations between individuals and factors | The higher indicators calculated for individuals (above 70%) allow the interpretation of the visual aspect of the correlation patterns between raters |
| Study of correlations between variables and observations | 7 | *Circles of correlation of variables* | Visualizes the correlations between variables / sensory attributes and factors for each sample, using eigenvectors related to the preferred directions of the sensory data as eigenvalues that quantify the relative importance of the directions | Assuming that the principal component/factor is the direction along which the sensory data have the greatest variance, the larger the eigenvector, the greater the significance of the variable |
| | 8 | *Scatter plots of observations* | Indicates the quality of the representation of the observations/ individuals in the PCA space shaped by factors | Allows identifying the trends of the raters in the performed sensory analysis |
| | 9 | *Biplots* | Very comprehensive charts with simultaneous representations of variables and observations in PCA space, providing visual access to results | Visualizes the sensory data reported for each bipolar attribute as a complete set of variables (by eigenvectors), with the raters as individuals (by data points) |

## RESULTS AND DISCUSSIONS

As described in table 2, all processing steps were completed for PCA to examine correlations between variables (sensory attributes), between observations (individuals), and correlations between sensory attributes and individuals using specific plots.

In this paper, the PCA of XLSTAT® Statistical Software for Windows [27] was used and the work started with the overall presentation of the sensory data in tables for each stretch denim fabric (D1 to D5). These tables contain the intensity scores assigned by the 16 raters (E01 to E16) for each of the six bipolar attributes: stretchy/non-stretchy (St/N); soft/hard (So/H); flexible/stiff (F/S); thin/thick (T/Tk); slippery/rough (Sl/R); light/heavy (L/He).

To determine the variances and correlations in the sensory data, the Pearson correlation matrices were calculated, corresponding to the correlation coefficients for all variables. For each of the five fabrics, the relationship between every two corresponding variables was indicated and allowed estimation of the degree of redundancy between the variables. Positive and negative coefficients were identified in the matrices obtained, with no extreme values and no values that would reflect the absence of correlation. Accordingly, there was no reduction, and the number of principal components was six. Thus, in the sensory analysis of the five fabrics, all six variables proved to be important hand descriptors to highlight the sensory comfort of washed stretch denim. This situation confirmed that the list of descriptors selected for the sensory analysis experiments was appropriate for this case study.

For the entire set of sensory data, the eigenvalues and the corresponding six principal components were determined and ordered from the highest to the lowest value, as shown in figure 2 with the scree plots of the eigenvalues with the cumulative percentage of the total variance of the sensory data.

Thus, of the six potential components/factors corresponding to the six variables F1 – F6, two principal components/factors, F1 and F2, were selected to explain most of the variance in the sensory data (table 3). The first and second principal components, F1 and F2, provided a reasonable summary of the sensory data reported by the 16 naive raters and explained more than 70% of the total observed variance for each of the five samples: D1 (74.55%), D2 (76.67%), D3 (70.46%), D4 (76.63%), and D5 (75.75%).

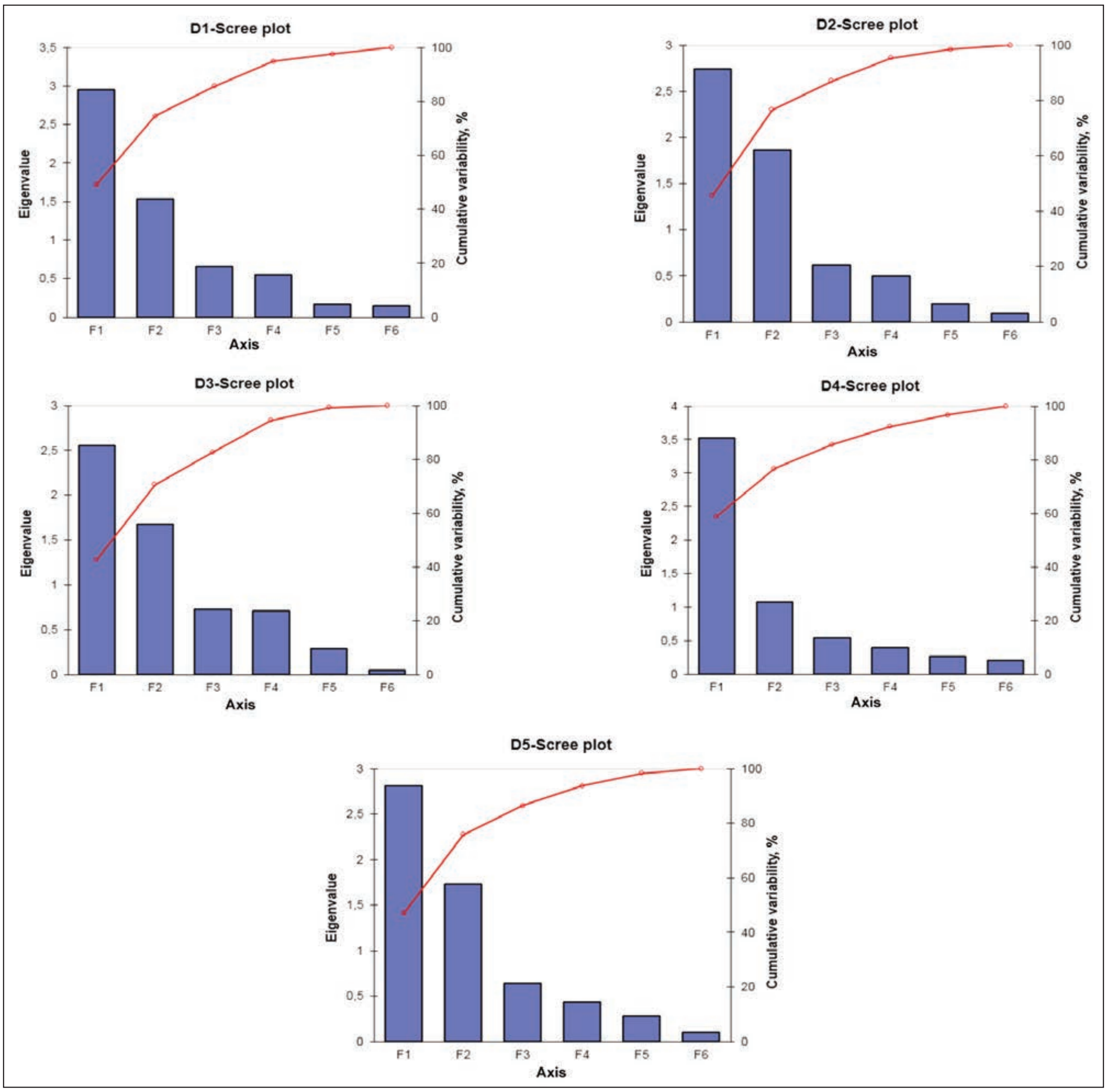



Fig. 2. PCA plots of eigenvalues to determine the number of components to keep

Table 3

| PCA FOR SENSORY ANALYSIS: THE PRINCIPAL COMPONENTS REPRESENTING THE OVERALL VARIABILITY | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Principal components** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** |
| **Washed stretch denim fabric** | **D1** | | **D2** | | **D3** | | **D4** | | **D5** | |
| Eigenvalue | 2.95 | 1.53 | 2.74 | 1.86 | 2.56 | 1.67 | 3.52 | 1.08 | 2.81 | 1.73 |
| Variability (%) | 49.09 | 25.47 | 45.64 | 31.03 | 42.59 | 27.88 | 58.67 | 17.95 | 46.88 | 28.87 |
| Cumulative % | 49.09 | **74.55** | 45.64 | **76.67** | 42.59 | **70.46** | 58.67 | **76.63** | 46.88 | **75.75** |

Table 4

| PCA: CORRELATION BETWEEN VARIABLES AND FACTORS IN THE LOADING MATRIX | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Principal components** | | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** |
| **Washed stretch denim** | | **D1** | | **D2** | | **D3** | | **D4** | | **D5** | |
| Variables | St/N | **0.871** | –0.055 | **0.676** | –0.387 | **0.702** | 0.378 | **0.880** | 0.043 | **0.486** | **0.743** |
| | So/H | **0.915** | –0.192 | **0.901** | –0.170 | **0.680** | **0.655** | **0.824** | –0.166 | 0.296 | **0.885** |
| | F/S | **0.864** | –0.093 | **0.909** | –0.060 | **0.642** | **0.433** | **0.713** | –0.412 | **0.868** | –0.022 |
| | T/Tk | **0.745** | 0.168 | **0.648** | **0.480** | **0.474** | –0.552 | **0.886** | 0.080 | **0.697** | –0.532 |
| | Sl/R | 0.220 | **0.838** | –0.189 | **0.925** | **0.601** | –0.646 | 0.251 | **0.928** | **0.703** | –0.338 |
| | L/He | –0.006 | **0.865** | **0.433** | **0.770** | **0.776** | –0.437 | **0.844** | 0.105 | **0.870** | 0.005 |

* The values in bold correspond for each variable to the principal component for which the factor loading is greater than 0.4 (highly positively correlations) [26, 27].

Table 5

| PCA: SQUARED COSINES OF THE VARIABLES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Principal components** | | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** |
| **Washed stretch denim** | | **D1** | | **D2** | | **D3** | | **D4** | | **D5** | |
| Variables | St/N | **0.759** | 0.003 | **0.457** | 0.150 | **0.492** | 0.143 | **0.774** | 0.002 | 0.236 | **0.552** |
| | So/H | **0.837** | 0.037 | **0.812** | 0.029 | **0.463** | **0.429** | **0.679** | 0.028 | 0.087 | **0.783** |
| | F/S | **0.747** | 0.009 | **0.826** | 0.004 | **0.412** | 0.188 | **0.508** | 0.169 | **0.753** | 0.000 |
| | T/Tk | **0.554** | 0.028 | **0.420** | 0.231 | 0.225 | 0.305 | **0.785** | 0.006 | **0.485** | 0.283 |
| | Sl/R | 0.048 | **0.702** | 0.036 | **0.856** | 0.361 | **0.417** | 0.063 | **0.861** | **0.494** | 0.114 |
| | L/He | 0.000 | **0.749** | 0.188 | **0.593** | **0.603** | 0.191 | **0.712** | 0.011 | **0.757** | 0.000 |

* The values in bold correspond for each variable to the principal component for which the squared cosine of variables is greater than 0.4 [26, 27].

**PCA to study the correlations between variables**

To interpret the significance of the principal components and the sensory results about each variable and to visualize the correlations between the variables and the principal components, the loading matrices with the components (i.e., the factor loadings) were calculated. Given the significant values of the factor loadings obtained for the five stretch denim items, presenting the variables in plots with two principal components is an appropriate choice (table 4).

For a proper interpretation of both the representation of the variables on the coordinate axes and the correlations between the variables, the squared cosines of the variables were calculated, as shown in table 5.

As for the values calculated for the five stretch denim fabrics, most of the variables listed in the loading matrix analysis appeared to be strongly associated with the F1 and F2 axes, with a few exceptions.

The above structures led to other different structures of correlations between the variables shared by the communalities of the variables, as shown in table 6.

Table 6

| PCA: COMMUNALITIES OF THE VARIABLES | | | | | | |
|---|---|---|---|---|---|---|
| **Washed stretch denim** | | **D1** | **D2** | **D3** | **D4** | **D5** |
| Variables | St/N | **0.762** | 0.607 | 0.635 | **0.776** | **0.788** |
| | So/H | **0.873** | **0.841** | **0.892** | **0.706** | **0.870** |
| | F/S | **0.756** | **0.830** | 0.599 | 0.678 | **0.754** |
| | T/Tk | 0.583 | 0.650 | 0.529 | **0.791** | **0.768** |
| | Sl/R | **0.751** | **0.892** | **0.778** | **0.923** | 0.608 |
| | L/He | **0.749** | **0.781** | **0.794** | **0.723** | **0.757** |

* The values in bold correspond for each variable to the principal component for which the communality of variables is greater than 70% [26, 27].

Table 7

| PCA: SQUARED COSINES OF THE OBSERVATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Principal components** | | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** | **F1** | **F2** |
| **Washed stretch denim** | | **D1** | | **D2** | | **D3** | | **D4** | | **D5** | |
| Naive assessors | E01 | **0.707** | 0.152 | **0.706** | 0.198 | **0.413** | **0.464** | 0.281 | **0.428** | 0.076 | **0.570** |
| | E02 | **0.363** | 0.015 | **0.458** | **0.493** | 0.391 | 0.190 | **0.796** | 0.169 | **0.910** | 0.059 |
| | E03 | **0.731** | 0.046 | 0.013 | 0.298 | **0.468** | 0.008 | 0.312 | 0.332 | 0.044 | 0.086 |
| | E04 | 0.008 | **0.617** | **0.521** | 0.400 | 0.000 | **0.942** | **0.731** | 0.017 | **0.783** | 0.118 |
| | E05 | **0.736** | 0.085 | **0.742** | 0.034 | **0.737** | 0.000 | **0.841** | 0.003 | 0.114 | 0.123 |
| | E06 | 0.042 | **0.734** | 0.001 | 0.001 | 0.000 | 0.000 | **0.442** | 0.020 | 0.349 | **0.593** |
| | E07 | **0.875** | 0.005 | **0.912** | 0.005 | **0.912** | 0.001 | **0.928** | 0.023 | 0.163 | 0.004 |
| | E08 | **0.763** | 0.105 | 0.100 | **0.806** | 0.099 | 0.013 | 0.170 | **0.461** | 0.024 | **0.453** |
| | E09 | 0.059 | **0.666** | 0.188 | 0.022 | 0.013 | 0.023 | **0.691** | 0.282 | **0.902** | 0.046 |
| | E10 | **0.869** | 0.029 | 0.062 | 0.124 | **0.413** | 0.033 | **0.460** | 0.062 | **0.494** | 0.388 |
| | E11 | 0.004 | **0.872** | 0.010 | **0.669** | **0.804** | 0.045 | 0.056 | 0.307 | **0.843** | 0.043 |
| | E12 | **0.515** | 0.078 | 0.008 | 0.106 | 0.343 | 0.122 | 0.073 | 0.048 | **0.817** | 0.091 |
| | E13 | **0.493** | 0.205 | 0.184 | **0.613** | **0.485** | 0.320 | 0.052 | **0.613** | 0.016 | **0.880** |
| | E14 | 0.229 | 0.360 | 0.138 | **0.682** | **0.713** | 0.037 | 0.204 | **0.651** | **0.436** | 0.000 |
| | E15 | 0.271 | 0.225 | 0.010 | 0.375 | 0.186 | 0.008 | 0.165 | 0.047 | 0.198 | 0.001 |
| | E16 | **0.532** | 0.140 | **0.739** | 0.049 | 0.353 | 0.156 | **0.713** | 0.003 | 0.003 | 0.063 |

* The values in bold correspond for each observation to the principal component for which the squared cosine of observations is greater than 0.4 [26, 27].

When considering the total sensory data obtained for the five stretch denim fabrics, the interesting information was that some of the values calculated for the communality variables were below the restricted threshold of 70%, in the range of 60–70%, and cannot be interpreted as meaningful correlation patterns between the group of six variables. Consequently, the values and the representation of the squared cosines of the variables in the PCA field with F1 and F2 retrospectively required a new explanation for an important part of the variables evaluated during the sensory analysis of the five stretch denim fabrics.

## PCA to study the correlations between observations

To highlight the quality of a different representation of the individuals (i.e., intensity values) from each naive rater in a scatter plot in the new PCA space, the squared cosines of the observations were calculated (table 7), representing the square of the cosine of the angle between an individual and a component.

As with the variables, the quality of the representation of the individuals on the coordinate axes F1 and F2 and the correlations between individuals and components had to be analysed based on the communalities of the observations. The correlation patterns allow interpretation for only some of the raters' observations, as in a situation with higher communality indicators for individuals (table 8).

As shown in table 8, for the higher communality indicators calculated for individuals, it is possible to interpret the visual aspect of the correlation pattern between the group of sixteen raters. The correlations between individuals and components and the common variation of the components with the given observations allow us to highlight the quality of the sensory results and consequently the quality of the evaluation panel.

Table 8

| PCA: COMMUNALITIES OF THE OBSERVATIONS | | | | | | |
|---|---|---|---|---|---|---|
| **Washed stretch denim** | | **D1** | **D2** | **D3** | **D4** | **D5** |
| Naive assessors | E01 | **0.859** | **0.904** | **0.877** | **0.709** | 0.645 |
| | E02 | 0.378 | **0.951** | 0.581 | **0.965** | **0.968** |
| | E03 | **0.778** | 0.311 | 0.477 | 0.644 | 0.129 |
| | E04 | 0.625 | **0.921** | **0.942** | **0.747** | **0.901** |
| | E05 | **0.821** | **0.776** | **0.737** | **0.843** | 0.237 |
| | E06 | **0.776** | 0.003 | 0.000 | 0.463 | **0.941** |
| | E07 | **0.880** | **0.917** | **0.913** | **0.952** | 0.167 |
| | E08 | **0.868** | **0.906** | 0.112 | 0.630 | 0.477 |
| | E09 | **0.725** | 0.210 | 0.036 | **0.973** | **0.948** |
| | E10 | **0.897** | 0.185 | 0.446 | 0.522 | **0.882** |
| | E11 | **0.876** | 0.680 | **0.848** | 0.363 | **0.886** |
| | E12 | 0.594 | 0.114 | 0.465 | 0.121 | **0.907** |
| | E13 | 0.697 | **0.797** | **0.806** | 0.664 | **0.897** |
| | E14 | 0.589 | **0.820** | **0.750** | **0.856** | 0.437 |
| | E15 | 0.496 | 0.385 | 0.194 | 0.212 | 0.199 |
| | E16 | 0.672 | **0.788** | 0.509 | **0.716** | 0.066 |

* The values in bold fit for each observation to the principal component for which the communality of the observations is greater than 70% [26, 27].

**PCA biplots to study the correlations between variables and observations**

To determine the links between the hand attributes and the ratings, the information from the separate correlation circles between the variables and the components and the scatter plot of the observations can be combined into corresponding PCA biplots. Table 9 summarizes the final PCA results using biplots generated for the sensory data of the 16 naive raters for the five washed stretch denim fabrics: the loading of each variable was plotted on the first component F1 in the horizontal dimension and on the second component F2 in the vertical dimension.

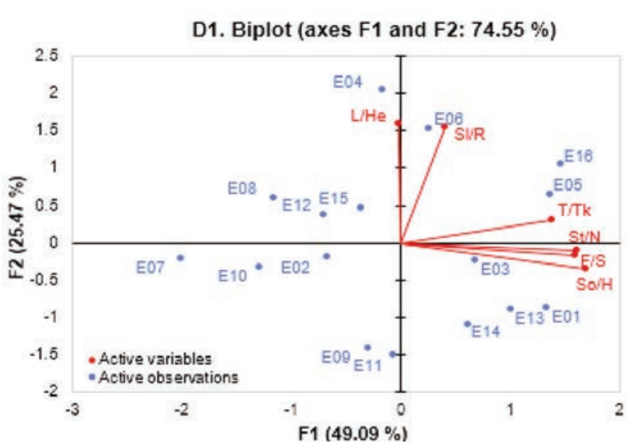
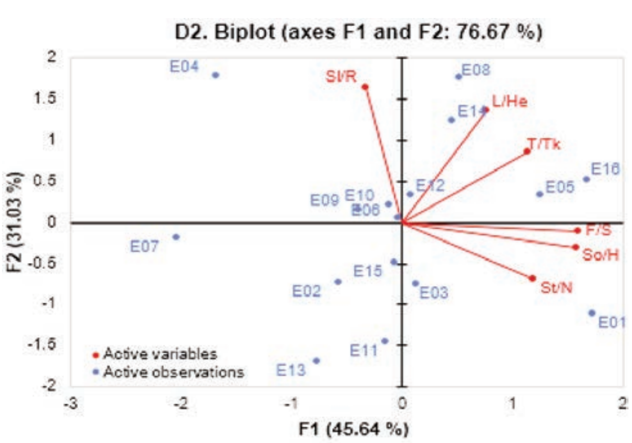
For the following discussions, it should be noted that the discriminatory attributes to be considered in this study were not always six. Considering the information in table 2, some calculated values of the communalities were smaller than the restricted limit and the interpretation of the squared cosines of these variables was limited. As with the variables, the observations reported by some assessors had lower values for the communality of the observations, which limited the interpretation of the squared cosine values calculated for these scattered individuals.

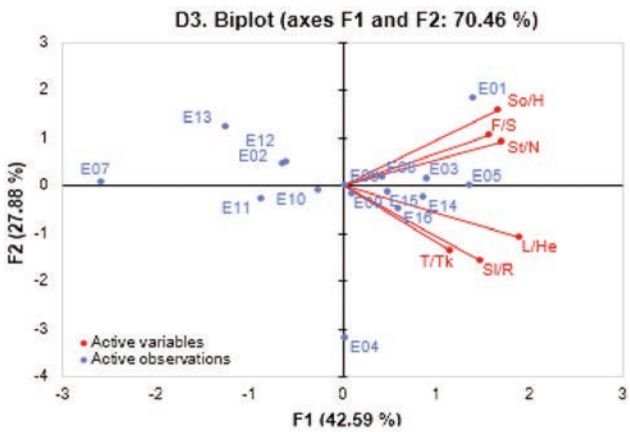
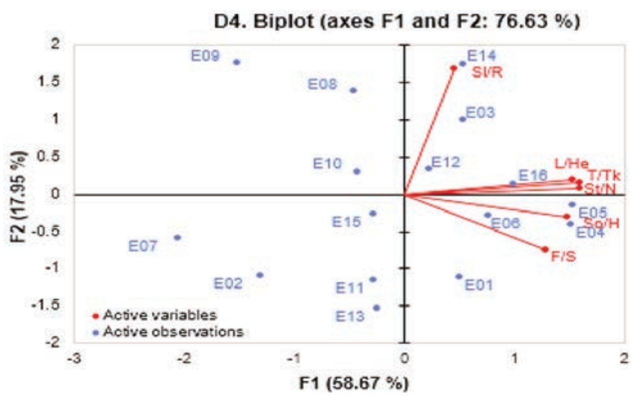
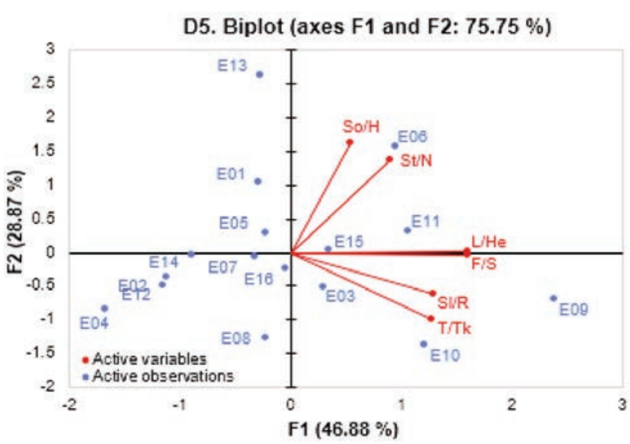
In addition to PCA, Kendall's concordance coefficient (W) was calculated to assess the extent to which the 16 naive assessors ranked the five stretch denim fabrics separately for each bipolar sensory attribute as a hand descriptor for fabrics. According to the results of the Chi-Squared significance test comparing the calculated values with the critical value, the concordance coefficients were found to be statistically significant at the 95% confidence level only for the bipolar attributes flexible/stiff ($W_{F/S}$ = 0.210) and slippery/rough ($W_{Sl/R}$ = 0.207). However, there is insufficient evidence to support the hypothesis that there is significant agreement between the sixteen raters on the two bipolar sensory attributes. This detail is somewhat consistent with the information previously obtained in the interpretation of the PCA results (table 9).

Considering the expected effects on the surface of stretch denim fabrics after washing (figure 1) and the PCA results (interpreted in table 9) for the sensory

Table 9

PCA BIPLOTS FOR A COMPREHENSIVE OVERVIEW OF SENSORY DATA CORRELATIONS REPORTED BY NAIVE RATERS FOR THE WASHED STRETCH DENIM RANGE

| PCA biplot of each washed stretch denim sample | Discussions for the five fabrics (D1-D5) |
|---|---|
|  | The biplot for the washed stretch denim D1 represents 74.55% of the total variance of the sensory data and shows the following correlation patterns: the attributes stretchy/non-stretchy, soft/hard, and flexible/stiff, which seem to be strongly associated with the axis of the first component F1; for the attributes slippery/rough, light/heavy, which seem to be strongly associated with the axis of the second component F2.<br>The variables St/N, So/H and F/S are strongly positively correlated with the observations of evaluators E01, E03 and E05, while the variables Sl/R and L/He are strongly positively correlated with the observations of evaluators E04 and E06.<br>In the study of the influence of washing treatments on the sensory comfort of D1 stretch denim, the naive assessors rated only 5 of 6 attributes, and there were only 5 of 16 raters whose tactile perceptions were strongly correlated with bipolar sensory attributes. |
|  | The biplot for the washed stretch denim D2 represents 76.67% of the total variance of the sensory data and shows visual correlation patterns: for the soft/hard and flexible/stiff attributes, which seem to be strongly associated with the axis of the first component F1; for the slippery/ rough and light/heavy attributes, which seem to be strongly associated with the axis of the second component F2. At the same time, the variables So/H and F/S are strongly positively correlated with the observations of assessors E01, E05 and E16, while the variables Sl/R and L/He are strongly positively correlated with the observations of assessors E08 and E14.<br>The discriminative attributes to be considered regarding the influence of washing treatments on the sensory comfort of D2 stretch denim were only 4 out of 6, and there were only 5 out of 16 assessors whose tactile perceptions correlated strongly with bipolar sensory attributes. |

<table>
<tr><th>PCA biplot of each washed stretch denim sample</th><th>Discussions for the five fabrics (D1-D5)</th></tr>
<tr><td>
</td><td>The biplot for the washed stretch denim D3 represents only 70.46% of the total variance of the sensory data, and a visual correlation pattern emerges for the light/heavy and slippery/ rough attributes, which appear to be strongly associated with the axis of the first component F1.<br>At the same time, the variables L/He and Sl/R are strongly positively correlated with the observations of assessor E14. The visual correlation pattern relates to only 2 of 6 variables, and at the same time, it was only one assessor out of 16 whose tactile perceptions when handling sample D3 were strongly correlated with bipolar sensory attributes.</td></tr>
<tr><td>
</td><td>The biplot for the washed stretch denim D4 represents 76.63% of the total variance of the sensory data and shows visual correlation patterns: for the attributes stretchy/non-stretchy, soft/hard, light/heavy, and thin/thick, which seem to be strongly associated with the axis of the first component F1; for the attribute slippery/rough, which seems to be strongly associated with the axis of the second component F2. The variables St/N, So/H, L/He and T/Tk are strongly positively correlated with the observations of evaluators E04, E05 and E16, while the variable Sl/R is strongly positively correlated with the observations of assessor E14. Among the discriminative attributes to be considered about the influence of washing on sensory comfort in the D4 sample, there were 5 out of six and only 4 out of 16 raters whose tactile perceptions were strongly correlated with bipolar sensory attributes.</td></tr>
<tr><td>
</td><td>The biplot for the washed stretch denim D5 represents 75.75% of the total variance of the sensory data and shows visual correlation patterns: for the attributes flexible/stiff, light/heavy, and thin/thick which seem to be strongly associated with the axis of the first component F1; for the attributes stretchy/non-stretchy and soft/hard, which seem to be strongly associated with the axis of the second component F2. The variables F/S, L/He and T/Tk are strongly positively correlated with the observations of evaluators E09 and E11, while the variables St/N and So/H are strongly positively correlated with the observations of evaluator E06. In the study of the effect of washing on sensory comfort of D5 stretch denim, naive evaluators rated 5 of 6 attributes, and there were only 3 of 16 assessors whose tactile perceptions correlated strongly with bipolar sensory attributes.</td></tr>
</table>

data perceived by the 16 untrained assessors (i.e., consumers) about the six bipolar attributes of the fabric hand, we can conclude the following: denim D3 can be excluded from the portfolio because its relevance to a potential customer, who will certainly handle the fabrics to perceive the sensory comfort he/she might feel when wearing a garment made of denim, is questionable compared to other four fabrics subjected to sensory analysis. To diversify the appearance of stretch denim fabrics through washing processes, only four stretch denims (D1, D2, D4 and D5) can remain reliable options for the manufacturer's portfolio.

Although the evaluation showed lower agreement among naive panellists, as inexperienced evaluators, this study can be the starting point for providing a readily available method to help denim manufacturers select the optimal wash treatment, which is undoubtedly important for future market success.

## CONCLUSIONS

This study proposes a simplified approach to optimise the portfolio of denim manufacturers by reducing the cost of unattractive or undifferentiated assortments for future consumers based on their ability to perceive and discriminate sensory comfort.

Therefore, a quantitative descriptive sensory evaluation method was used to investigate six sensory properties of washed denim and interpret the comfort perceptions of untrained evaluators (i.e., consumers).

The use of descriptive analysis as one of the test methods for comparing competing products in terms of sensory differences and acceptability involved the multivariate statistical technique Principal Component Analysis (PCA) for sensory data processing. When using the PCA technique to examine sensory data reported by a group of 16 naive assessors in blind ratings of washed stretch denim fabrics, good agreement was found for only a few raters and only for certain bipolar attributes as fabric hand descriptors. Overall, the results showed that the raters were sufficiently able to distinguish between the sensory properties of different denim fabrics, as the different washing processes had an impact on the perceived ratings.

Considering the observations of atypical individuals, who could be consumers without background knowledge of textiles, a procedure should be initiated by denim manufacturers to establish a sensory analysis program for the quality control strategy even closer to reality: to ensure that the expected effects of washing processes on stretch denim fabrics are perceived by potential customers, otherwise, a restriction of the offer is recommended. Of course, the PCA approach to sensory analysis can also be used to improve the quality control strategy with a panel of experts or selected assessors. It should be noticed that the relevance of sensory analysis in the quality control strategy to be applied alongside existing practices has been ensured by the publication of the first edition of the international standard ISO 20613:2019.

Washing processes add value to stretch denim fabrics and are important for designers and manufacturers looking to diversify their fabric offering and improve sensory comfort, as these are key factors in the market success of any garment. On the other hand, the issue of sustainability is becoming more acute in the textile industry today and requires a new approach to new product development and quality control. A strategy aimed at reducing the fabric assortment and producing only what is perceived as specific sensory comfort by a larger mass of consumers can also help reduce the carbon footprint. The carbon footprint of textiles is critical to the management of environmental pollution, making sustainability an important issue of our time. In this context, reducing the environmental impact of washing stretch denim fabrics is an important step for 3 R.

Ultimately, in addition to improving quality control, the interest of denim manufacturers in developing a product portfolio should not focus on an oversized fabric range, but on choosing optimal washing treatments in line with a sustainable policy: less waste of resources is more valuable for all.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# Collar style design of women's suit based on Kansei engineering

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**ABSTRACT – REZUMAT**

**Collar style design of women's suit based on Kansei engineering**

*To understand the influence of flat collar, closure collar, and shawl collar on the perceptual impression of women's suits, 12 pairs of adjectives used to describe the collar type of suits were determined by using the method of perceptual engineering and semantic difference. With the help of virtual fitting technology, 22 kinds of suit simulation pictures were drawn. Through the questionnaire survey, this paper studied the perceptual evaluation of different collar types of women's suits and then used the mean statistics and corresponding factor analysis to process the survey data. The results show that 1) the factors of stability, elegance, and style have influenced the collar design of women's suits; 2) different collars brought consumers different emotional feelings, for example, the shawl collar was simple and soft, the flat collar was professional, closure collar was elegant. The results can be used to guide the design of the female suit collar.*

***Keywords:*** *3D simulation, collar type, Kansei Engineering, Kansei Evaluation, women's suit*

**Designul gulerului pentru costumul de damă bazat pe ingineria Kansei**

*Pentru a înțelege influența gulerului plat, a gulerului cu rever ascuțit și a gulerului tip șal asupra impresiei perceptive a costumelor de damă, au fost determinate 12 perechi de adjective folosite pentru a descrie tipul de guler al costumelor, prin utilizarea metodei ingineriei perceptive și a diferenței semantice. Cu ajutorul tehnologiei de simulare virtuală, au fost create 22 de tipuri de imagini virtuale ale costumului. Prin aplicarea unui chestionar, această lucrare a studiat evaluarea perceptivă a diferitelor tipuri de guler al costumelor de damă, apoi a folosit statisticile medii și analiza factorială corespunzătoare pentru a procesa datele sondajului. Rezultatele arată că: 1) factorii de stabilitate, eleganță și stil au influențat designul gulerului costumelor de damă; 2) diferitele gulere le-au adus consumatorilor diferite sentimente emoționale, de exemplu, gulerul tip șal este simplu, moale, gulerul plat este profesional, gulerul cu rever ascuțit este elegant. Rezultatele pot fi folosite pentru a ghida designul gulerului costumului de damă.*

***Cuvinte-cheie***: *simulare 3D, tip guler, inginerie Kansei, evaluare Kansei, costum de damă*

## INTRODUCTION

Kansei Engineering, which appeared in the 1970s, is committed to quantifying customers' psychological needs and transforming them into product design elements [1]. This technology was first applied in the automobile industry [2], and then it also achieved success in the service industry [3], product design industry [4, 5], web page optimization field [6], colour research field [7], etc. With the development of society and economy, consumers' needs become more and more personalized, so only to meet the needs of consumers can they occupy an advantage in the market [8], especially in the clothing industry. Only by understanding the aesthetic needs of customers can precision marketing be carried out [9]. At present, with the help of the method of Kansei Engineering, some scholars have studied the field of personalized recommendation [10], functional design [11], women's suit vest design [12], e-commerce fabric retrieval [13], and fabric comfort [14]. These studies above profoundly impact the whole process of clothing design, production and sales, and provide a new method for garment industry practitioners to serve consumers better.

Kansei engineering can break the limitations of traditional methods and fully consider the psychological demands of consumers. With the deepening of research, scholars try to combine Kansei Engineering with other technologies to explore the potential needs of consumers better. For example, Dong et al. [15] realized interactive recommendations for clothing based on perceptual evaluation and fuzzy technology. Liu et al. [16] developed the knowledge base of fashion design by using perceptual evaluation and fuzzy logic. Zhang et al. [17] applied Kansei engineering technology to construct the performance evaluation system of virtual fashion design. The studies above transform the aesthetic and emotional needs of consumers into consideration elements in the process of fashion design or sales and achieve the purpose of improving customer satisfaction and meeting personalized needs, which can increase the competitiveness of clothing enterprises.

To sum up, as a branch of ergonomics, Kansei Engineering, which originated in Japan, and quantifies the user's emotion [18], has been widely used in the design and has gradually attracted the attention of interdisciplinary researchers. Kansei engineering design process is divided into three stages: emotional image acquisition, model building, and design optimization. Perceptual images can be obtained by indirect methods such as questionnaires, semantic difference methods, or direct methods such as testing the physiological indexes of subjects. In the modelling stage, researchers usually use linear processing technology [19], nonlinear processing technology [20] or reasoning prediction technology [21] to analyse and quantify the collected perceptual images. With the development of artificial intelligence technology and machine learning, researchers use genetic algorithm [22] and other intelligent algorithms to optimize the model's prediction accuracy. From the perspective of the perceptual image, the perceptual images obtained by perceptual engineering are mainly produced by vision, and other auditory and olfactory images [23] are less involved. The application scope of Kansei engineering is wider and wider. More and more intelligent algorithms are applied to Kansei Engineering, which improves the prediction performance of the model.

The suit has become a vital clothing category for women to attend business and leisure occasions because of its tailored, diverse and beautiful styles. The collar is located in the centre of the line of sight. Its modelling changes often have a significant impact on the style. To meet the consumers' personalized needs, collar style design is critical. A lapel collar is an important collar type for a suit. According to the shape of the collar mouth, the lapel collar can be divided into the flat collar, shallow collar, and closure collar. At present, some scholars used Kansei engineering technology to study flat lapel and closure lapel, looking for customers' favourite combinations [24].

Generally speaking, there is less research on women's suits, and the women's suits in the market cannot meet the personalized needs and aesthetic needs of modern women. This paper takes women's suit lapel as the research object, with the help of virtual fitting technology for suit modelling, using the method of Kansei Engineering for data analysis. The research results provide some guidance for suit collar design to produce clothing that meets the aesthetic needs of consumers, and to improve the market satisfaction and competitiveness of enterprises.

## METHOD

This paper first analyses the style elements of lapel collars of women's suits, then 100 samples of women's suits are collected on the Internet, and six professionals in fashion design are invited engaged to screen the samples. According to the modelling elements of lapel collars, similar collar styles are removed, and 22 representative women's suits are selected finally. We use virtual fitting technology to model 22 kinds of women's suits. Except for the collar, other design elements of these model components are consistent to ensure the accuracy of the experimental results. This paper only discusses the perceptual impression of the collar type on the overall style of the suit and does not discuss the influence of colour, fabric and other factors.

Next, we select words from fashion magazines and periodicals to describe women's suits' collar shapes, remove words with similar meaning and colloquialism, and finally select 12 pairs of adjectives. We use the semantic difference method to design the questionnaire, sort out the collected results and conduct factor analysis.

### Lapel collar style

Many factors affect the shape of the lapel, such as the height of the lapel point, the width of the lapel head, and the position of the serial line. The folding point's height directly affects the length of the collar and the visual centre changes with the position of the folding point. The width of the lapel plays a key role in collar design and overall style. The position of the serial line determines the proportion between the roll and the lapel. The structure of the shawl collar, flat collar, and closure collar is shown in figure 1.

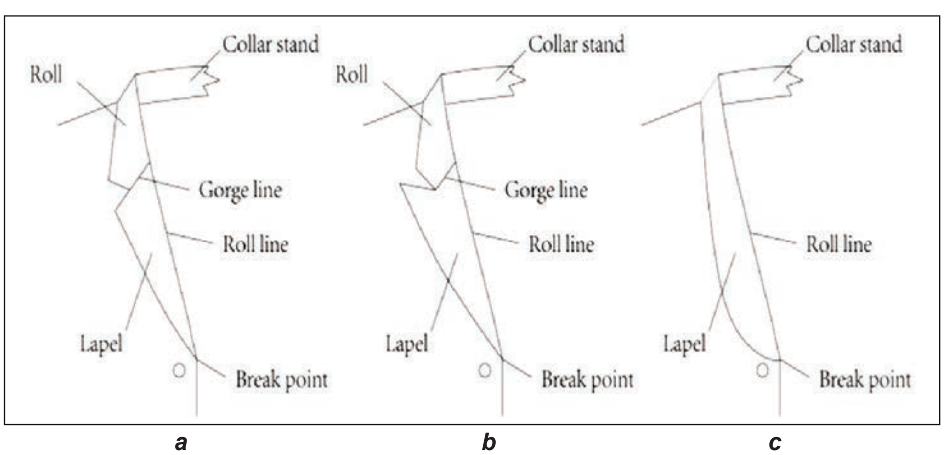


Fig. 1. Three common collar types of suits: *a* – flat collar structure; *b* – closure collar structure; *c* – shawl collar structure

## Stimulus mapping

We collect 100 samples of women's suits and invite six professionals engaged in fashion design professionals select 22 different types of women's suits referring to the shawl collar, flat collar, and closure collar modelling design elements. These 22 women's suits include nine closure collars, ten flat collars, and three shawl collars. To ensure preciseness and accuracy, we need to keep the fabric, colour, shape and other variables unchanged during the experiment, and only change the collar type.

The virtual fitting technology can stitch two-dimensional panels into three-dimensional clothing. Its simulation is quite realistic and its operation is convenient [25, 26]. According to the steps above, the 22 stimulus maps are numbered from 1 to 22, as shown in figure 2.

## Choice of perceptual vocabulary

After consulting a large number of fashion magazines and literature, we collected perceptual words to describe the collar of a suit. Six professionals engaged in clothing were invited to investigate and screen these words. Professionals eliminate adjectives with similar meanings, screen out words with vague or similar meanings, and then classify and rescreen the collected perceptual words based on the influence relationship between the remaining perceptual words and the stimulus map. Finally, 24 adjectives are determined from the aspects of use occasion, acceptance, structural characteristics and temperament. We number the 12 pairs of words from a to L number from A to L, as shown in table 1.

## Questionnaire development

First, each suit is evaluated with 12 pairs of adjectives. The evaluation method is the five-scale method


Fig. 2. Stimulus map

Table 1

ADJECTIVE PAIRS

| Number | Adjective | Score | | | | | Adjective |
|---|---|---|---|---|---|---|---|
| A | Professional | –2 | –1 | 0 | 1 | 2 | Leisure |
| B | Female | –2 | –1 | 0 | 1 | 2 | Neutral |
| C | Popular | –2 | –1 | 0 | 1 | 2 | Individual |
| D | Elegant | –2 | –1 | 0 | 1 | 2 | Casual |
| E | Modern | –2 | –1 | 0 | 1 | 2 | Retro |
| F | Exaggerated | –2 | –1 | 0 | 1 | 2 | Introverted |
| G | Soft | –2 | –1 | 0 | 1 | 2 | Stiff |
| H | Complex | –2 | –1 | 0 | 1 | 2 | Simple |
| I | Vivid | –2 | –1 | 0 | 1 | 2 | Inflexible |
| J | Plain | –2 | –1 | 0 | 1 | 2 | Gorgeous |
| K | Edgy | –2 | –1 | 0 | 1 | 2 | Outdated |
| L | Pretty | –2 | –1 | 0 | 1 | 2 | Ugly |

in the semantic difference method [27]. The score is set at five: –2, –1, 0, 1, and 2. As shown in table 1. Taking the adjective "female – neutral" as an example, the closer the score is to –2, the stronger the female feeling is; the closer the score is to 2, the stronger the neutral feeling is; 0 is the centre of the number axis, indicating that the feeling is unbiased. Next, the 22 women's suits collar type stimulus map is sorted out. Finally, the subjects scored each pair of adjectives in 22 stimulation maps according to their feelings.

## RESULTS

### Sample mean and analysis

A total of 106 questionnaires were collected, of which 100 were valid, 85% were female, and 15% were male. After examinees scored 22 samples of female suit collar stimulus maps, the average value was taken as the final score, as shown in table 2.

After the absolute value of the value in table 2 is taken, the larger absolute value is taken as the representative perceptual word of the stimulus graph. Then, the stimulation maps were classified according to different collar types. Stimulation maps 1, 4, 8, 10, 14, 15, 17, 20 and 22 were the closure collar, Stimulation figures 2, 3, 6, 7, 12, 13, 16, 18, 19, 21 are flat collar, Stimulation figures 5, 9 and 11 are shawl collar. Finally, it can be concluded that the subjects generally believe that the shawl collar is relatively simple and soft among the three collar types. When the shawl collar is relatively short, it seems inflexible. The suit with a flat collar makes people feel more professional. The collar with a larger lapel shows the characteristics of neutral and inflexible, while the collar with a thinner lapel gives a strong female feeling. When the closure lapel's angle is sharp, it has a sense of edgy and exaggeration; when the collar is too small, such as in the fourth and eleventh stimulus pictures, the subjects feel that it is not good-looking.

### Factor analysis

*KMO and Bartlett test*

As shown in table 3, the results of the KMO test and Bartlett test show that there is a correlation between variables. KMO test coefficient is 0.685, which is greater than 0.5, and Bartlett test significance is 0.000, which is less than 0.001, indicating that the questionnaire results can be further factor analysis.

The sample correlation matrix obtained by factor analysis is shown in table 4. When the absolute value of the table's value is closer to 1, it means that the two pairs of adjectives are more related. For example, there is a high correlation between exaggerated – introverted and plain – gorgeous, complex – simple

Table 2

SAMPLE MEAN SCORE

| **Stimulus map number** | **Adjective pairs number** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L |
| **1** | –0.45 | –0.3 | –0.12 | –0.42 | 0.03 | –0.52 | –0.03 | 0.64 | –0.27 | -0.3 | –0.24 | –0.55 |
| **2** | –1.03 | 0.58 | –0.79 | –0.03 | –0.48 | 0.58 | 0.45 | 0.79 | 0.48 | -0.7 | 0.45 | –0.06 |
| **3** | –0.73 | –0.58 | –0.85 | –0.21 | –0.67 | 0.55 | –0.36 | 0.91 | –0.21 | -0.7 | –0.33 | –0.55 |
| **4** | –0.06 | –0.03 | –0.06 | –0.09 | –0.21 | –0.18 | 0.12 | –0.03 | –0.3 | -0.09 | –0.24 | –0.3 |
| **5** | 0.42 | –0.3 | 0.39 | –0.09 | 0.12 | 0.18 | –1.12 | 0.91 | –0.58 | -0.52 | –0.48 | –0.55 |
| **6** | 0.55 | –0.27 | 0.09 | 0.27 | –0.76 | –0.21 | –0.39 | –0.18 | –0.42 | 0.03 | –0.52 | –0.03 |
| **7** | –0.58 | –0.06 | 0.09 | –0.52 | –0.64 | –0.06 | 0.15 | –0.36 | –0.3 | 0 | –0.58 | –0.64 |
| **8** | –0.36 | 0.27 | 0.36 | –0.18 | –0.27 | –0.79 | 0.39 | –0.21 | –0.33 | 0.18 | –0.64 | –0.55 |
| **9** | 0.36 | –0.58 | –0.24 | –0.18 | –0.21 | 0.21 | –1 | 0.67 | –0.67 | -0.52 | –0.46 | –0.73 |
| **10** | 0.15 | 0.06 | 0.3 | –0.33 | 0.06 | –0.7 | –0.12 | –0.42 | –0.18 | 0.18 | –0.48 | –0.64 |
| **11** | 0.52 | 0.88 | –0.12 | 0.42 | 0.21 | 0.64 | –0.85 | 0.94 | 0.55 | -0.88 | 0.52 | 0.33 |
| **12** | –1.12 | 0.21 | –1.09 | –0.09 | –0.64 | 0.52 | 0.06 | 0.73 | 0.24 | -0.61 | –0.24 | –0.73 |
| **13** | –0.09 | 0.09 | 0.21 | –0.03 | –0.3 | –0.15 | –0.03 | –0.09 | 0.03 | -0.33 | –0.21 | –0.39 |
| **14** | –0.55 | 0.03 | 0.42 | –0.24 | –0.12 | –0.18 | 0.03 | –0.64 | –0.55 | 0.03 | –0.64 | –0.7 |
| **15** | –0.39 | –0.45 | –0.36 | –0.36 | –0.7 | 0.15 | –0.09 | 0.24 | –0.18 | -0.52 | –0.52 | –0.52 |
| **16** | 0.27 | 0.24 | –0.12 | 0.55 | –0.27 | 0.15 | –0.24 | 0.64 | 0.39 | -0.76 | 0.18 | 0.09 |
| **17** | –0.06 | –0.27 | 0.27 | –0.58 | 0.12 | –0.45 | –0.58 | –0.76 | –0.58 | -0.21 | –0.58 | –0.79 |
| **18** | –0.88 | –0.64 | –0.82 | –0.27 | –0.88 | 0.48 | –0.67 | 0.58 | –0.21 | -0.64 | –0.42 | –0.52 |
| **19** | –0.36 | 0.64 | –0.76 | 0 | –0.76 | –0.06 | 0.45 | 0.55 | 0.52 | -0.76 | 0.15 | –0.09 |
| **20** | –0.33 | –0.12 | 0.09 | –0.33 | –0.09 | –0.55 | –0.06 | –0.09 | –0.61 | 0.12 | –0.97 | –0.61 |
| **21** | –0.27 | 0.09 | –0.94 | 0.12 | –0.82 | 0.3 | –0.03 | 0.48 | 0.27 | -0.55 | 0 | –0.21 |
| **22** | 0.27 | 0.27 | 0.58 | –0.15 | –0.21 | –0.76 | 0.3 | –0.3 | –0.42 | 0.15 | –0.73 | –0.82 |

and popular – individual, which means that the more gorgeous, complex, and individual perceptual impression of the stimulus map, the more exaggerated it is. On the contrary, the more plain, simple, and popular the perceptual impression of the stimulus map, the more introverted it is.

Table 3

| KMO AND BARTLETT'S TEST | | |
|---|---|---|
| **Kaiser-Meyer-Olkin measure of sampling adequacy** | | 0.685 |
| **Bartlett's sphericity test** | **Approximate chi-square** | 253.416 |
| | df | 66 |
| | Sig | 0.000 |

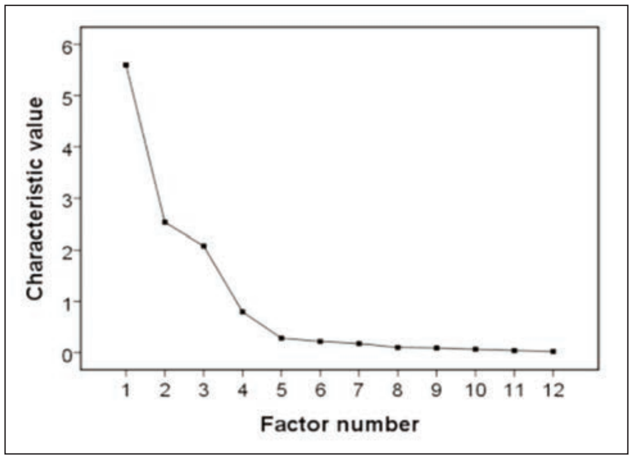


Fig. 3. Sample gravel map

Table 4

SAMPLE PERCEPTUAL VOCABULARY CORRELATION MATRIX

| Adjective pairs | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A** | 1.000 | 0.060 | 0.594 | 0.416 | 0.493 | –0.281 | –0.483 | –0.120 | –0.203 | 0.161 | –0.031 | 0.263 |
| **B** | 0.060 | 1.000 | 0.000 | 0.506 | 0.164 | 0.022 | 0.461 | 0.060 | 0.706 | –0.133 | 0.603 | 0.551 |
| **C** | 0.594 | 0.000 | 1.000 | –0.172 | 0.676 | –0.735 | –0.081 | –0.662 | –0.585 | 0.717 | –0.515 | –0.269 |
| **D** | 0.416 | 0.506 | –0.172 | 1.000 | –0.084 | 0.394 | –0.144 | 0.444 | 0.606 | –0.448 | 0.647 | 0.826 |
| **E** | 0.493 | 0.164 | 0.676 | –0.084 | 1.000 | –0.398 | –0.310 | –0.188 | –0.290 | 0.261 | –0.085 | –0.120 |
| **F** | –0.281 | 0.022 | –0.735 | 0.394 | –0.398 | 1.000 | –0.351 | 0.750 | 0.518 | –0.859 | 0.617 | 0.424 |
| **G** | –0.483 | 0.461 | –0.081 | –0.114 | –0.310 | –0.351 | 1.000 | –0.361 | 0.301 | 0.319 | 0.037 | –0.015 |
| **H** | –0.120 | 0.060 | –0.662 | 0.444 | –0.188 | 0.750 | –0.316 | 1.000 | 0.510 | –0.848 | 0.627 | 0.434 |
| **I** | –0.203 | 0.706 | –0.585 | 0.606 | –0.290 | 0.518 | 0.301 | 0.510 | 1.000 | –0.658 | 0.892 | 0.726 |
| **J** | 0.161 | –0.133 | 0.717 | –0.488 | 0.261 | –0.859 | 0.319 | –0.848 | –0.658 | 1.000 | –0.758 | –0.510 |
| **K** | –0.031 | 0.603 | –0.515 | 0.647 | –0.085 | 0.617 | 0.037 | 0.627 | 0.892 | –0.758 | 1.000 | 0.801 |
| **L** | 0.263 | 0.551 | –0.269 | 0.826 | –0.120 | 0.424 | –0.015 | 0.434 | 0.726 | –0.510 | 0.801 | 1.000 |

*Main factor selection*

In this study, principal component analysis is used to extract factors, and the total variance table of adjective pair interpretation is obtained, as shown in table 5. Principal component analysis (PCA) reduces the dimension of variables and uses relatively few variables to replace the original variables while retaining more than 85% of the original information. The cumulative contribution rate of the first three common factors is 85.038%, so first, the three common factors' choices can explain most of the information of 22 stimulus graph adjective pairs.

Figure 3 is the gravel map of the sample. The first factor has the highest eigenvalue and makes the greatest contribution to explaining the original variables. From the fourth point, the broken line gradually tends to be flat, and the final eigenvalue is almost close to 0, that is, from the fourth point, it has little contribution to the overall variable. The broken line of the gravel diagram shows that principal components 1, 2 and 3 can describe the perceptual design of women's suit collar.

Table 5

TOTAL VARIANCE

| **Ingredients** | **Initial eigenvalue** | | |
|---|---|---|---|
| | **Total** | **Variance/%** | **Cumulative variance contribution rate/%** |
| 1 | 5.597 | 46.643 | 46.643 |
| 2 | 2.531 | 21.089 | 67.732 |
| 3 | 2.077 | 17.306 | 85.038 |
| 4 | 0.795 | 6.621 | 91.659 |
| 5 | 0.282 | 2.354 | 94.012 |
| 6 | 0.219 | 1.826 | 95.838 |
| 7 | 0.176 | 1.469 | 97.307 |
| 8 | 0.100 | 0.835 | 98.143 |
| 9 | 0.090 | 0.750 | 98.893 |
| 10 | 0.067 | 0.557 | 99.450 |
| 11 | 0.042 | 0.348 | 99.798 |
| 12 | 0.024 | 0.202 | 100.000 |

*Naming and analysis of principal factors*

To get the components of each factor, rotate the component matrix to get the rotating component matrix table, as shown in table 6. This paper analyses the composition and connotation of public factors.

It can be seen from table 6 that the following five groups of adjective pairs, namely female – neutral, vivid – inflexible, pretty – ugly, edgy – outdated, elegant – casual, have a greater load on the first factor. According to the meaning of these five pairs of adjective pairs, the first factor is named the "elegant factor". The following four adjective pairs, namely exaggerated – introverted, plain – gorgeous, complex – simple, soft – stiff, have a greater load on the second factor. According to the meaning of these four pairs of adjective pairs, the second factor is named "style factor". The following three pairs of adjectives, namely professional – leisure, modern – retro, and popular – individual, have a greater load on the third factor. According to the meaning of these three pairs of adjectives, the third factor is named the "occasion factor".

Table 6

ROTATING COMPONENT MATRIX

| Adjective pairs | Factor | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Female-neutral | 0.898 | –0.244 | - |
| Vivid-inflexible | 0.848 | 0.316 | –0.351 |
| Pretty-ugly | 0.826 | 0.353 | 0.132 |
| Edgy-outdated | 0.802 | 0.494 | –0.109 |
| Elegant-casual | 0.752 | 0.363 | 0.276 |
| Exaggerated-introverted | 0.196 | 0.876 | –0.263 |
| Plain-gorgeous | –0.343 | –0.871 | 0.178 |
| Complex-simple | 0.256 | 0.846 | –0.114 |
| Soft-stiff | 0.357 | –0.640 | –0.638 |
| Professional-leisure | 0.152 | - | 0.912 |
| Modern-retro | - | –0.251 | 0.732 |
| Popular-individual | –0.159 | –0.643 | 0.692 |

### Discussion

Women's suits, as a necessary item for professional women to attend business and leisure places, are a popular choice for fashion talents to match clothes, which plays an important role in the clothing category. The collar is located in the visual centre of the clothing, which has a relatively great impact on the overall style of the clothing, but there is not much research on the collar type of women's suits at present. Because of this, the authors choose a flat collar, closure collar and a shawl collar to study the influence of these three common collar types on the overall perceptual impression of suit style.

With the development of society and the economy, the consumers' personalized demand is increasing. Only to meet consumers' needs and achieve the purpose of improving customer satisfaction, enterprises can better survive in the market [8, 9]. Authors use the semantic difference method to investigate the perceptual impression of the subjects on the collar type and make mean statistics and factor analysis on the survey data. The results show that the perceptual impression of the three different collar types is different, which had an impact on the perceptual impression of the overall style of the suit. This study can provide a reference for consumers to buy suits, and a guide for enterprises to design suits.

Due to the limited time, this paper only discusses the perceptual impression of the collar type on the overall style of the suit and does not discuss the influence of colour, fabric and other factors. Different colours bring different sensory experiences to consumers, such as warmth, cold, distance, and weight [28]. The softness, texture, drape and lustre of fabrics also affect the appearance, width and clothing style [29]. Style, colour and fabric are three important factors in fashion design. In the process of women's suit design, in addition to considering style design, research should also comprehensively refer to the two elements of colour and fabric, to produce clothing more in line with consumers 'aesthetic needs and personalized needs.

## CONCLUSION

This study takes the female suit collar type as the evaluation object, uses the semantic difference method, and draws the stimulus map with the help of virtual fitting technology to investigate consumers' perceptual impression of the collar type. Finally, the author processes the data and makes factor analysis, and obtains the following conclusions:

- Three main factors influencing the collar shape of women's suits are obtained: "style factor", "elegance factor" and "occasion factor".
- The three different collar types, closure collar, flat collar, and shawl collar, are the overall perceptual impression of the suit. The designer should carefully choose the collar type to match the suit according to the style.
- The perceptual impression of the shawl collar is relatively simple and soft. The flat collar is relatively professional, a lapel with a wide lapel shows neutral and inflexible characteristics, collar with a thin lapel gives people a strong feeling of being female. A closure collar with a round shape line makes people feel very elegant.

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# Reduction of non-conforming through statistical process control charts in textile industry

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**ABSTRACT – REZUMAT**

**Reduction of non-conforming through statistical process control charts in textile industry**

*The textile industry of Pakistan is a growing sector that contributes to the economy. Pakistan exports depend heavily upon textile goods. A minor defect in the finished good can cause a major loss of the export goods. Due to the involving the number of workers checking the product repeatedly can be very expensive therefore the quality engineering techniques of Statistical Control Charts are used in the textile industry. This research study aims at developing process control charts for the textile industry in Pakistan. For this purpose, the textile industry was taken into consideration. P-chart was developed to monitor the variation in the process with a Six Sigma standard deviation. The collection of data was for six months from various departments of the textile industry. The attribute data were collected for the analysis from 4 different units of the industry. The construction of the P-Chart includes the Control Limits (CL), Upper Control Limits (UCL), 3 sigma deviations from the mean Control Limit (CL), Lower Control Limits (LCL), –3 sigma deviation from the mean Control Limit (CL). The result showed that the processes of the production units were under control, however, the mean was not centred which was due to some common cause of the process which is acceptable. The P-chart can serve as a standard for the new process to be developed.*

***Keywords:*** *statistical process control, attribute charts, process monitoring, Control Limits, Six Sigma*

**Reducerea neconformităților prin diagrame de control statistic al proceselor în industria textilă**

*Industria textilă din Pakistan este un sector în continuă dezvoltare, care contribuie cu o cotă importantă în economie. Exporturile din Pakistan depind în mare măsură de produsele textile. Un defect minor al bunului finit poate cauza pierderi majore ale mărfurilor de export. Pentru că numărul de muncitori care se ocupă de verificarea produsului în mod repetat, poate fi foarte costisitor, prin urmare, tehnicile de inginerie a calității Diagramelor de control statistic sunt utilizate în industria textilă. Acest studiu de cercetare își propune să dezvolte diagrame de control al procesului pentru industria textilă din Pakistan. În acest scop, a fost luată în considerare industria textilă. Diagrama P a fost dezvoltată pentru a monitoriza variația procesului cu deviația standard Six Sigma. Colectarea datelor a durat șase luni de la diferite departamente ale industriei textile. Datele atributelor au fost colectate pentru analiza din 4 unități diferite ale industriei. Construcția diagramei P include limitele de control (CL), limitele superioare de control (UCL), abateri de 3 sigma de la limita medie de control (CL), limitele inferioare de control (LCL), abaterea de –3 sigma de la limita medie de control (CL). Rezultatul a arătat că procesele unităților de producție erau sub control, totuși, media nu a fost centrată, ceea ce s-a datorat unei cauze comune a procesului care este acceptabilă. Diagrama P poate servi ca standard pentru noul proces care urmează să fie dezvoltat.*

***Cuvinte-cheie:*** *controlul statistic al procesului, diagrame de atribute, monitorizarea procesului, Limite de control, Six Sigma*

## INTRODUCTION

Asian countries are the largest exporters of textile products. In Pakistan textile sector is defined as a backbone for economic price growth and it contributes the most to other sectors [1]. The total contribution to the GDP of Pakistan's textile sector shares more than 60% of the economy [2]. Textile companies are striving hard to maintain their growth but the increase in the manufacturing overheads is causing difficulties and making it very hard for the sector to survive and provide the best product at a minimal cost. With the increase in the commodity and the service price, industries have shifted their focus from being a production-oriented manufacturing organizations to quality-oriented manufacturing to eliminate the non-value-added activities and provide the best quality product to the consumers at the best possible cost [3, 4]. Due to the involving the number of workers checking the product repeatedly can be very expensive therefore the quality engineering techniques of Statistical Control Charts are used [5].

The implementation of statistical process control has been in many industries, for example, Health care industries including hospitals, clinics etc., automobile industries, defence industries, chemical and electronic industries and food chains as well [6]. Statistical quality control identifies the process improvement methods and provides the most economical, sustainable solution. Statistical Quality Controls are widely used for the sampling plan, identifying the conformance of the process or the process deviation for achieving the required quality [7].

The deviation in the process or the variability of the quality is caused due to the common causes and specific causes [8]. The common causes are the natural cause which cannot be eliminated until the business module of the production environment has been changed in terms of large investment. These are the reasons occurred during the condition of working, raw material nature or the technological level requirement. Specific reasons are caused by unexpected process deviation. Specific variation is not related to the worker ergonomics, raw material compliance or machine settings. They are variations which can only be determined by statistical process control [9].

Statistical Process Control charts are developed by obtaining the observations for the calculations. The process mean is calculated for developing the centre line (CL), and the standard deviation is calculated for the development of the Upper Control Limit (UCL) and Lower Control Limit (LCL) which are plus and minus 3-sigma. The observation points are then connected to plot the process characteristics [10]. The SPC charts are useful as they provide the direction of the process upward and downward from the origin due to the non-conformance produced during the production operations, which fails the final product [11].

To identify the area of improvement and severity of the process deviation, analysis is performed by using the statistical tools of control charts which establish the process deviation during a certain period and also determine the limits of deviations are under the control limits or exceeding the limits [12]. To analyse the deviation in the process from its mean position the design of the experiment is based on the collection of data from the real-time production. The experiment data was collected for six months through check sheets in which real-time data was recorded by the in-line quality controllers. Collected data is then analysed and interpreted to obtain the capability and the deviation of the process.

Every textile company aims to provide quality products and on-time deliveries to achieve the highest level of customer satisfaction. For that company is striving to enhance its process and product quality to eliminate the additional cost of reworking and rejection of customer complaints/claims which will be resulting in lower manufacturing costs and an increase in production levels. The research which will be conducted in an industry is the manufacturers and exporters to the different countries of the world in home textile products of bedding and curtain. It is a vertical industry consisting of in-house capacity from dyeing to packaging and shipping.

## METHODOLOGY

The methodology which will be used in this study is based on Statistical Process Control (SPC). The scientist Walter A. Shewhart at Bell Laboratories developed that the process should be in statistical control chart [13].

Statistical Process Control (SPC) is a methodology used by industries for measuring and controlling the quality of ongoing manufacturing processes [14]. Quality data in the form of check sheets of a Product or Process is measured in real-time during manufacturing. The collected data is then used for plotting the graphs with pre-determined control limits. Process capability defines the limits of the process whereas the specification limits are determined by the client's standards. Data measured falls within the control limits to determine the process is in control and any variation within the process can be due to the common cause of the natural variation which is expected throughout the process. Whereas if the process falls outside the control limits indicates the process variation and is likely to deviate from its mean position causing defects during production [15]. The selection criteria for control charts are shown in figure 1.

### X-R Chart

Control charts are used to understand the inside variation of the process. There are diverse types of control charts depending upon the factor on which the data is collected. It is used for the variable data when the information is available. This chart usually consists of two parameters

- The X chart shows the amount of variation in the process during the interval of time.
- The R chart shows the variation that occurred in the different sub-groups. A process of the r chart has the control limits the upper control limit and the lower control limit.

When XR charts are under control limits the distribution of the subgroup is steady and the process reliable. Control limits are not the same as the specification limits of control charts but it is both critical to performing analyses.

Control limits are the normal range. The minor deviation is monitored and recorded. It is observed that variety can be considered as the normal distribution which lies within the location between the three layers of standard deviation. The +3sigma and the –3sigma deviation.

To decide the control limit of the XR chart and to analyse the process variation [16].

$$\text{Range} = (X\text{max} - X\text{min}) \tag{1}$$

$$UCL = X + AR \tag{2}$$

$$LCL = X - AR \tag{3}$$

$$UCL = DR \tag{4}$$

$$LCL = DR \tag{5}$$

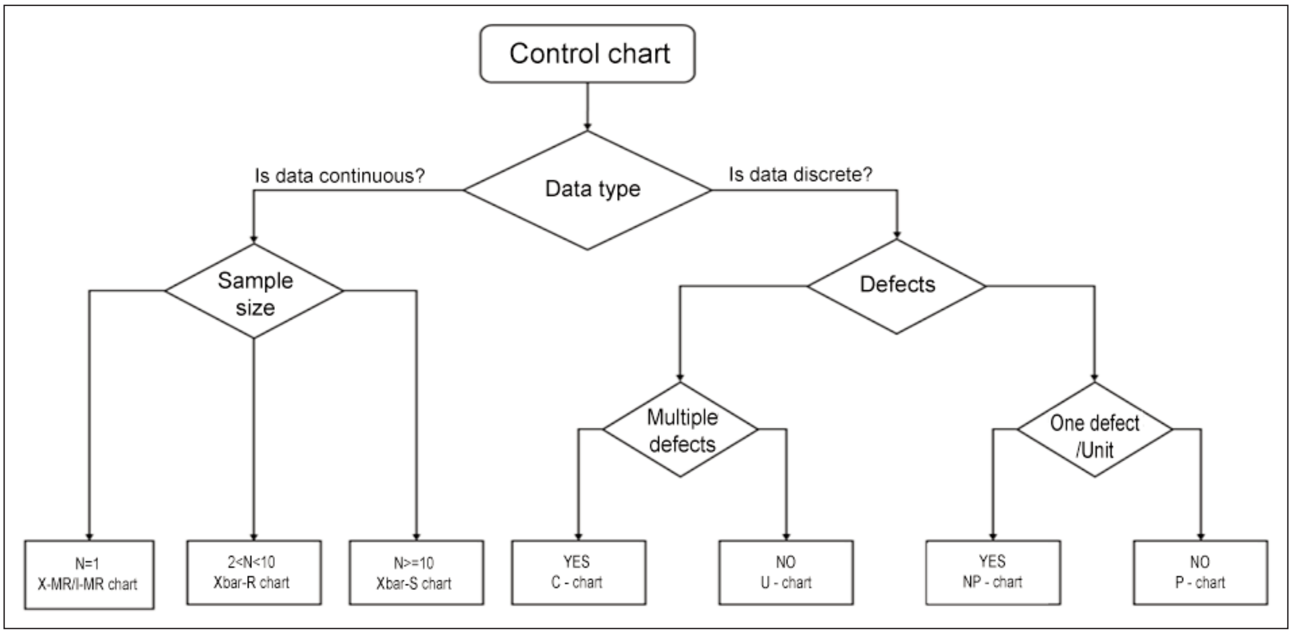


Fig. 1. Selection criteria of Control Charts

**C Charts**

C Chart are used to analyse the quantity of the defects on a unit of process against the total number of units taken against the process. It is used to monitor the number of defects in the process and the control limits are created to evaluate the process. It helps to identify the variation in the process and when the control chart is set up and any point which goes outside the control limit shows that the process has a variation which caused the non-conformance on the individual point [16].

$$c = \frac{\sum Di}{\sum K} \quad (6)$$

$$LCL = c - m\sqrt{c} \quad (7)$$

$$UCL = c + m\sqrt{c} \quad (8)$$

**NP Charts**

NP charts are used to monitor the quantity of non-conforming products during production for which samples can be taken on an hourly basis, shift-wise, day-wise, weekly or monthly. Once the data is collected and the control charts are set up the situation of the control chart is monitored and at the point, and if the point is outside the control limits it represents the quantity of the defectives that occurred at that point during the process [16].

$$\text{Control Limit} = np \quad (9)$$

$$LCL = np - m\sqrt{(np(1-p))} \quad (10)$$

$$UCL = np + m\sqrt{(np(1-p))} \quad (11)$$

**P-Chart**

P-Charts are defined as Attribute control charts having discrete data. P-Charts are selected based on sample size variation in the process and display the proportion of defective products, conforming or non-conforming. P-chart identifies the process variation and the variability over the period within the process. The process deviation is monitored by the control limits and the shifting of the process through its mean position [16].

P-charts are based on the variable sample size. To obtain the P-bar [10].

$$P = \frac{\sum number\ of\ defectives\ in\ deliveries}{\sum sample\ size} \quad (12)$$

For the sample size variation Upper limit

$$\sigma = p + 3 * \sqrt{\frac{P(1-P)}{n}} \quad (13)$$

For the sample size variation Lower limit

$$\sigma = p - 3 * \sqrt{\frac{P(1-P)}{n}} \quad (14)$$

**Sigma Levels in Control Charts**

The process mean or the centre line of control charts is always divided into three standard deviations i.e., +3σ the Upper Control Limit (UCL) and –3σ (Lower Control Limit), these limits are considered as the boundaries of the control charts and the process deviated if any of the plot points stands outside the limits. The level close to 3σ is +2σ and –2σ and next to the mean position lies the +σ and the –σ levels. This in combination states that the mean is dived into 3σ levels [17].

In the identification of the process and the capability of the control charts, some standards have been defined for the σ-level deviation [18].

1. If one data point is outside the ±3σ level the process is considered unstable.
2. If the two data points are outside ±2σ level the process is considered unstable.
3. If four or five data points are outside the ±σ level the process is considered unstable.

4. If eight continuous data points plot on the same σ level.
5. If five data points are in the continuous decrease the process is considered unstable.
6. If two data points out of three are outside the process needed to be monitored but are in control.

The statistical process has a normal distribution. A rule of 68%–95%–99.7% is applied to the control charts ±1σ fall in the 68% of the normal distribution, ±2σ lies in the 95% of the normal distribution and 99.7% will fall within ±3σ [19].

## RESULTS

The industry consists of four production units (figure 2); each unit receives raw material. The cutting department is where fabric batches are sized into the finished product, which then proceeds to the stitch department and operations are performed. During the stitching operation, the process of random inspection (figure 2 - Point; A D G J) is carried out to make sure the requirements and specifications are met to produce a quality product. After the stitching process products are moved to the quality control department where all the physical characteristics of the product are inspected, during the inspection process random (figure 2 - Point; B E H K) samples are picked to confirm the products are being checked as per the required quality. Inspected products are then processed for packing as per the customer's requirement and style. Some random inspection (figure 2 - Point; C F I L) samples from the packing process are taken to inspect that it meets the customer requirements. The data of the random inspections from each section of the production units are collected in the form of check sheets, these check sheets are then fed into the MS Excel format for storing and gathering data in the form Excel Workbook. The data in the MS Excel sheet is extracted and used on the Minitab software from which statistical control charts are developed to analyse the process capability.

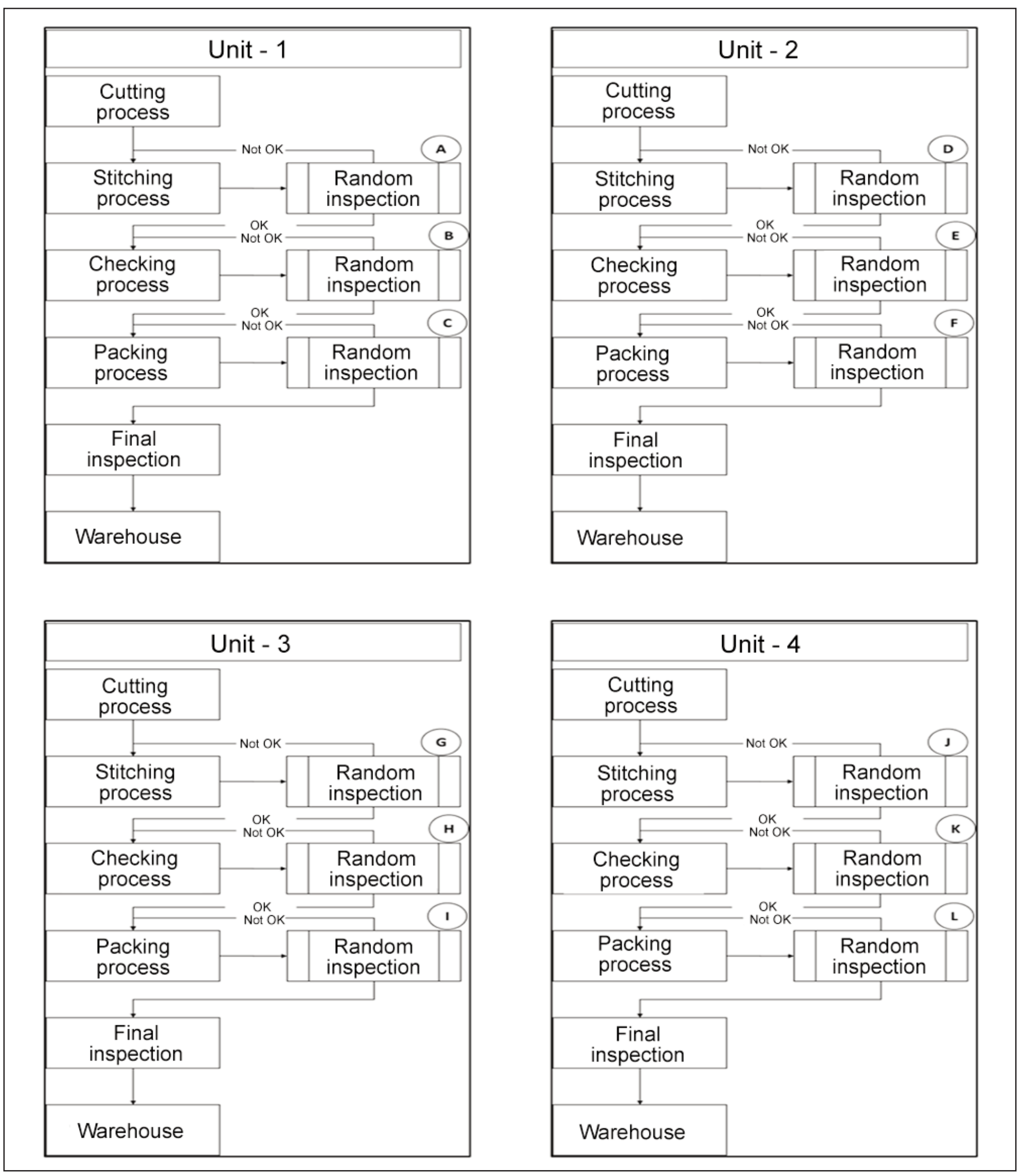


Fig. 2. Process flow of production units

## Production Floor Unit-1

The production process consists of the Stitching Section (figure 3), Checking Section (figure 4) and the Packing Section (figure 5). The collection of data on the production floor in real-time shows that the process of the Production floor Unit-1 is under control as per the conditions mentioned above. Although the process seems to be under control but not centred because they might be some special or common cause affecting the process.

The process in figure 3 shows the deviation but the process is well within the control limits according to the conditions mentioned above. The process in figure 4 seems to be well within the limit and there is no significant deviation from the analysis. The chart in figure 5 shows that the process is stable and well within the control limits.

## Production Floor Unit-2

The process of the Production Floor Unit-2 Stitching Section (figure 6), shows the deviation in the process but it is well within the control limits. The Checking Section (figure 7), of unit-2, is the most stable section as the deviation of the process points is minimum. Packing Section (figure 8), is also under control but not centred.

There is no significant deviation found in figure 6, from the mean and the process is under the UCL and LCL. The process is stable. Therefore, in figure 7, the process is not in any of the conditions mentioned above, therefore the process is well-centred and found stable in figure 8.

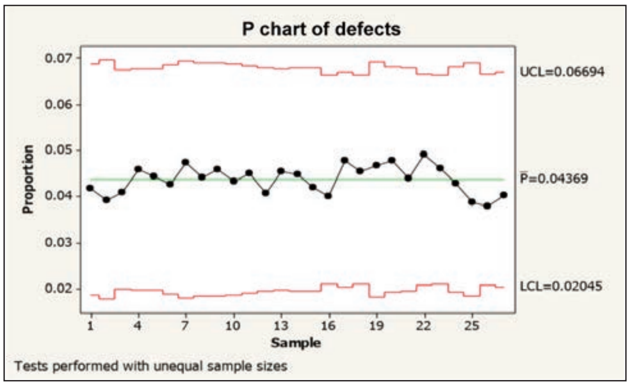


Fig. 3. Stitching Section Unit-1

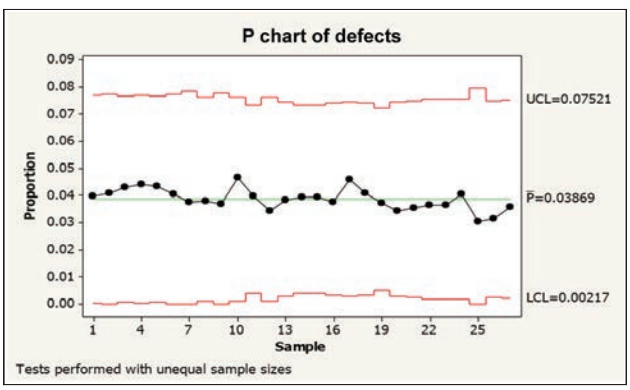


Fig. 4. Checking Section Unit-1

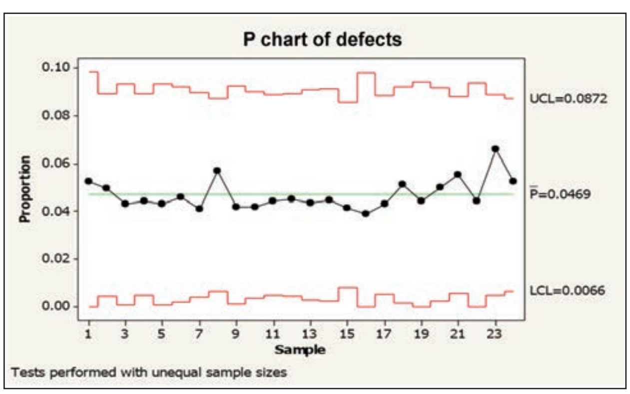


Fig. 5. Packing Section Unit-1

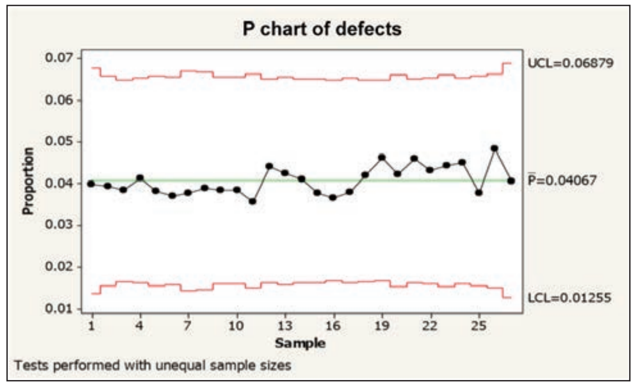


Fig. 6. Stitching Section Unit-2

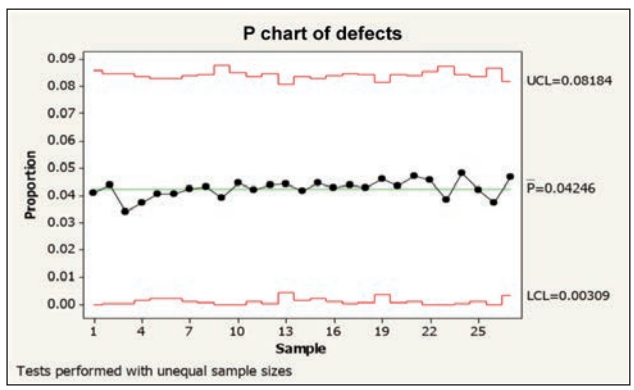


Fig. 7. Checking Section Unit-2

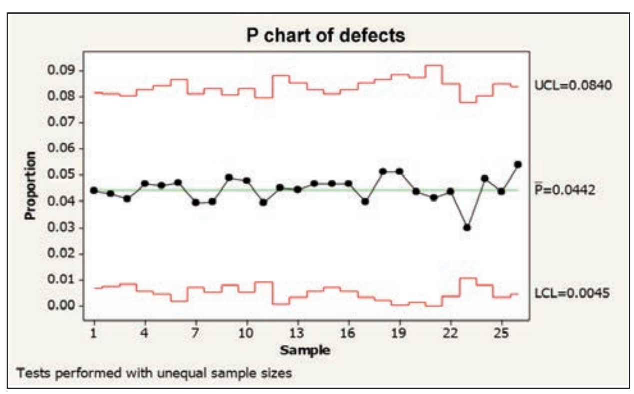


Fig. 8. Packing Section Unit-2

**Production Floor Unit-3**

The data points for Stitching Section (figure 9), show that the process is well within the control limits and the process is capable. The Checking Section (figure 10), also shows the control deviation in the process. Packing Section (figure 11), is under control and there is no significant deviation over the period.

All the data points are in the centreline and under the control limits in figure 9, figure 10 graph shows that the data is distributed on its mean position, and in figure 11, point number 21 has deviated from its mean position but the process is well controlled.

**Production Floor Unit-4**

The results from the analysis of the Stitching Section (figure 12) Checking Section (figure 13) and the Packing Section (figure 14) determine that the process is stable but there are some deviations in the mean point of the control chart which can be due to the special causes and can be removed by process improvement.

The process of all the units is well within statistical control. During the analysis, there is no significant deviation found throughout the process but the statistical control charts show the controlled deviation present in the process at every section of each production floor. These deviations can be due to the natural cause that exists within the system which cannot be eliminated but can be minimized or some special causes have caused the deviation of the process for example unqualified workers or malfunctioning machines etc. these are the causes which can be eliminated and the process can be stabilized.

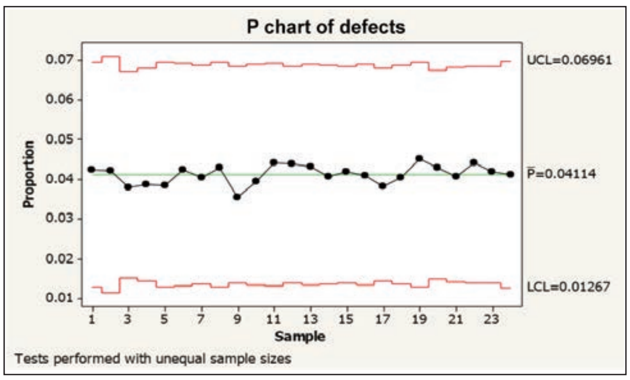


Fig. 9. Stitching Section Unit-3

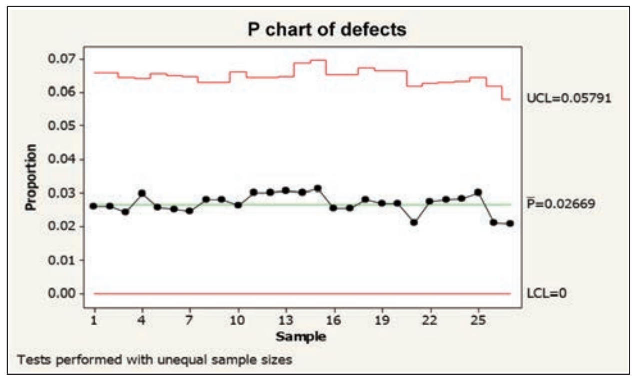


Fig. 12. Stitching Section Unit-4

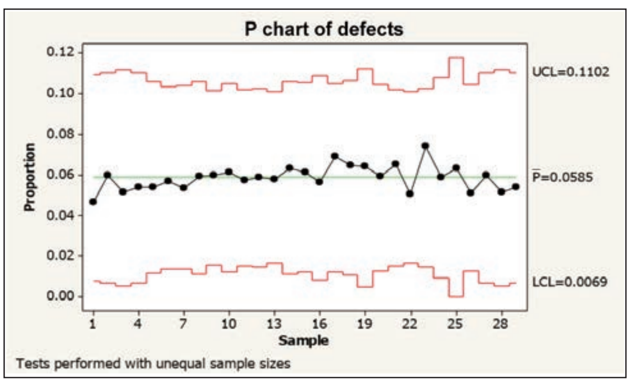


Fig. 10. Checking Section Unit-3

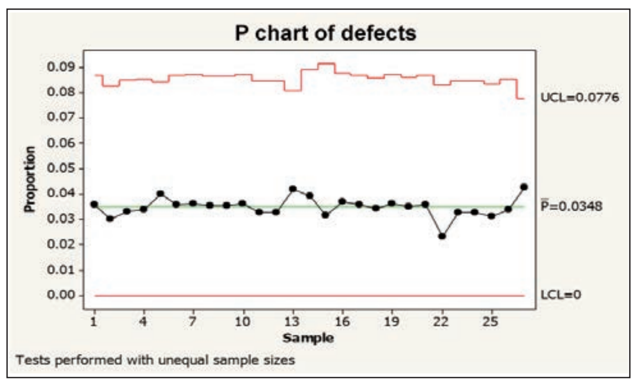


Fig. 13. Checking Section Unit-4

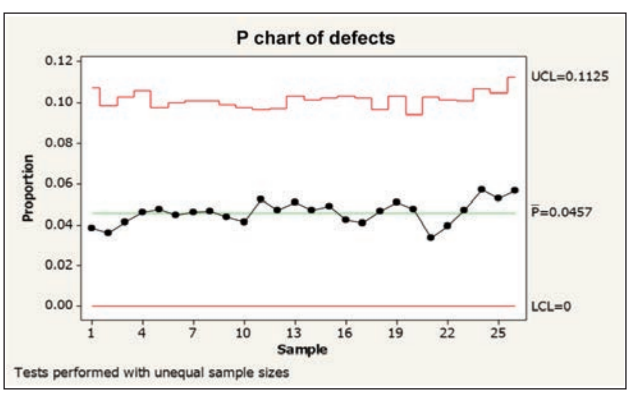


Fig. 11. Packing Section Unit-3

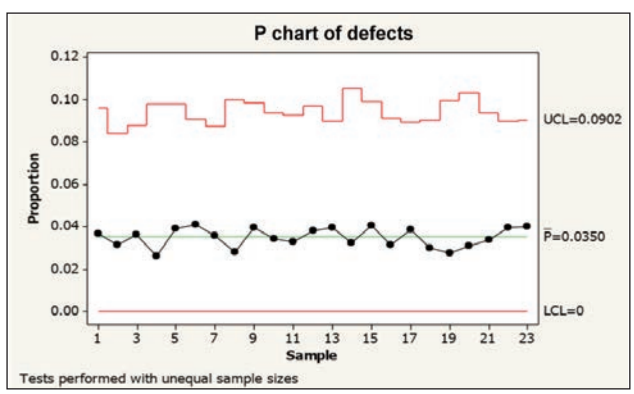


Fig. 14. Packing Section Unit-4

## CONCLUSION

Statistical process control allows an organization to identify the process deviation which results in the product's non-conformance and failure. The technique of SPC can be opted by the organization to identify the process capability and allows for to eliminate the non-value-added activities during the process. Implementation and the development of the process control charts improve the quality of the process by identifying the capability of the process. The analysis was performed in an organization by collecting the real-time data of the production units to identify the capability and the deviation in the process. Results of the analysis conclude that no significant deviation was found with in the process and satisfies the points of the section above, although the process was not centred at any production unit but is stable and each section of all the production units was found to be under the 99.7% of the normal distribution. The deviations within the process are due to the special cause or common cause depending upon the factors for example man factor, machine factor or the material factor and these can be eliminated by training or the awareness of the process thus resulting in a stable production process and eliminating failures.

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# Effect of wearing and washing temperature on the performance of compression socks

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ENGIN AKÇAGÜN


ABSTRACT – REZUMAT

**Effect of wearing and washing temperature on the performance of compression socks**

*Compression socks regulate blood flow in venous systems and are used for therapeutic purposes. The present study, it was aimed to analyse the influence of multiple levels of wearing and washing temperature on compression pressure. 9 pieces of compression socks samples with 3 different combinations (with different polyamide/ elastane body and inlaid yarn) were developed using compression socks knitting machine with a 1×1 laid in, 1×1 knit-miss structure. After the production of the samples, to simulate the "wearing and washing effect" a test protocol was designed. Compression pressure values were measured by using MST Professional II Medical Stocking Tester in different phases and results were evaluated statistically. The results show that when compression socks are worn for 15 days and washed 5 times, their compression pressure and graduation values change. After wearing compression socks on wooden leg pressure values shows a slight decrease due to a long period of stretching. In addition, after wearing and washing cycles it is seen that the pressure values increase as the washing temperature increases. 50˚C results show the highest increase at compression pressure. Statistical results show a correlation between temperature and compression pressure. Many researches were carried out on the production factors of compression socks, however, there are very few research studies on the usage performance of socks. The study contains results for both the literature and the producers/end users.*


***Keywords:*** *compression socks, washing of compression socks, pressure*


**Influența timpului de purtare și a temperaturii de spălare asupra performanței șosetelor de compresie**

*Șosetele de compresie reglează fluxul sanguin în sistemele venoase și sunt utilizate în scop terapeutic. În studiul de față, s-a urmărit analiza influenței nivelurilor multiple ale purtării și temperaturii de spălare asupra presiunii de compresie. 9 probe de șosete de compresie cu 3 combinații diferite (conținut diferit de poliamidă/elastan) au fost dezvoltate folosind o mașină de tricotat șosete de compresie cu structură 1 × 1 laid in, 1 × 1 knit-miss. După producerea probelor, pentru a simula „efectul de purtare și spălare", a fost conceput un protocol de testare. Valorile presiunii de compresie au fost măsurate prin utilizarea dispozitivului MST Professional II Medical Stocking Tester în diferite faze, iar rezultatele au fost evaluate statistic. Rezultatele arată că atunci când șosetele de compresie sunt purtate timp de 15 zile și spălate de 5 ori, presiunea de compresie și valorile gradației acestora se modifică. După purtarea șosetelor de compresie pe piciorul din lemn, valorile presiunii arată o scădere ușoară datorită perioadei lungi de întindere. În plus, după ciclurile de purtare si spălare se observă că valorile presiunii cresc pe măsură ce temperatura de spălare crește. Rezultatele la 50˚C arată cea mai mare creștere pentru presiunea de compresie. Rezultatele statistice arată o corelație între temperatură și presiunea de compresie. Au fost efectuate multe cercetări asupra factorilor de producție ai șosetelor de compresie, cu toate acestea există foarte puține studii de cercetare privind performanța de utilizare a șosetelor. Studiul conține rezultate atât pentru literatura de specialitate, cât și pentru producătorii/utilizatori finali.*


***Cuvinte-cheie****: șosete de compresie, spălarea șosetelor de compresie, presiune*

## INTRODUCTION

Compression socks are commonly recommended to exert maximum compression at the lower part of the leg at the ankle position to mitigate the intensity of venous-related disease efficiently [1]. The working method of this action is the exertion of compression pressure while gradually decreasing pressure, starting from the lowest girth point called ankle at position "b" to the maximum girth point called the calf "c" position (ankle to calf portion) of the leg. The compression pressure decreases from the ankle to the calf in the leg, regulating blood flow. By this way muscles will be kept in the proper alignment to reduce the risk for injury. It also provides relief to varicose patients and is used in the treatment as shown in figure 1 [2–4]. Compression pressure can be classified as moderate ranging from 20 to 30 mm Hg and firm ranging from 30 to 40 mm Hg compression. In addition to important diseases such as chronic varicose veins, these pressure ranges can also be applied to different symptoms such as fatigue, discomfort and soreness in the legs [5–8]. In theory, the pressure value seen on the leg is contingent upon the radius R of the leg and the reverse force T (N) exerted around the leg [9].

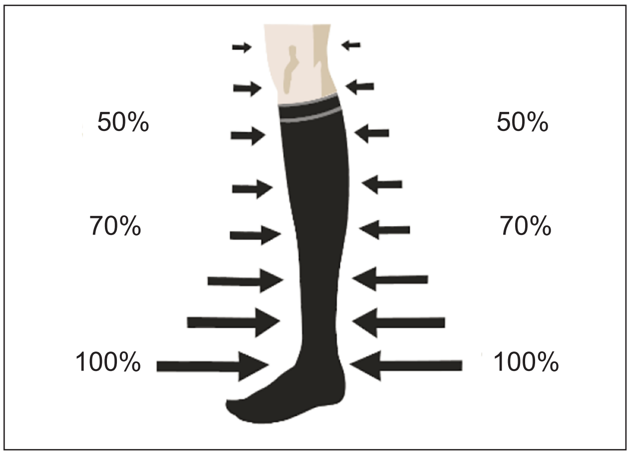


Fig. 1. Graduation of compression pressure

As described by Laplace's Law:

$$P(\text{Pa}) = \frac{T(\text{N})}{R(\text{cm})} \quad (1)$$

$$P(\text{Pa}) = \frac{T(\text{N}) \times 2\pi}{C(\text{cm})} \quad (2)$$

where $P$ is pressure (Pa), $T$ – Reverse fabric force (N), and $R$ – radius of the leg (cm). Graduation percentage ($G$ %) is a particularly important factor to keep in mind as it is helpful to regulate blood flow. The most famous standard method for the evaluation of compression socks is RAL GZ-387-1. According to this standard, the graduation percentage values must lie between 50–80% (Knee High). Graduation percentage ($G$ %) from ankle to calf portion is calculated using the formula:

$$(G\ \%) = (P^c \div P^a) \times 100 \quad (3)$$

where $P^c$ is the pressure at the calf portion, $P^a$ – the pressure at the ankle portion [10]. Utilizing Laplace formula, applied pressure should be highest at the narrowest radius of leg and gradually decreasing towards the areas with the maximum radius. Also, the circumference of the leg requires optimal pressure on the skin layers according to Laplace's Law, equation 2 [11].

Nowadays, the studies on compression stockings continue and researches usually focus on the effects of raw material characteristics, fabric constructions or manufacturing factors on pressure characteristics. Based on scientific literature review, it is observed that a few studies exist in which the performance of compression socks had been analysed after multiple wearing, machines washing and their influence on compression pressure.

More than 200 brands exist around the globe developing and selling their products ultimately recommending handing the socks samples at 40°C rather than washing on washing machines and drying them by placing them between two layers of towels avoiding any external force deteriorating compression socks. A few brand manuals are mentioned here for reference purposes [12–17].

In addition, Siddique et al. investigated the performance of compression stockings. After washing the same sock sample at 30°C first, he washed the same sock at 50°C and finally at 75°C. In this study, the products were washed without being worn between washes. He concluded that there is a significant increase in compression pressure as the wash temperature level increases [18].

RAL-GZ 387/1 standard quality evaluation protocol of compression socks recommends that before testing, compression socks should be washed once according to DIN EN 26 330/6 A. The test samples must be spun dry for two minutes and dried flat according to DIN EN 26 330, Method C, after washing, conditions the socks samples by spreading out after drying for a minimum of 12 hours in a standard atmosphere according to DIN EN 20139 [10].

According to guidelines for the use and prescribing of compression hosiery recommended by NHS subjected to care of compression socks. According to the manual, compression socks should be hand-washed at 40°C, but some garments may be suitable for gentle machine washing with mild detergent.

Compression socks should not be wrung out, twisted or tumble-dried. They should be dried flat away from direct heat and when dry should not be ironed [19].

Liu et al. developed heterogeneous hybrid knitted structures to enhance the stability of knitted panels. Thermoplastic polymer threads were plated with ground threads, which were then heated at 40°C and reset upon cooling. He recommended routinely washing commercial elastic compression stockings to eliminate hysteresis and refresh their mechanical performance. He concluded that such heterogeneous fabrics can be washed 50 times with controlled tension loss of less than 6% and exhibit relatively balanced elasticity and shape retention in cycles of stretch loading at 70% of tensile strain [20].

Maleki et al. investigated the pressure change effect due to repeated washing of different knitted fabrics. As the results of statistical analysis, repeated washing and repeated usage have a significant effect on interfacial pressure and pressure reduction of both fabrics [21].

Harpa et al. introduced a new approach to determine the capacity of medical compression hosiery to retain its designated gradual compression after repeated wearing and washing cycles. For his research, 2 pairs of sock samples were used for their evaluation for 15 and 30 days. All the socks' samples were tested before washing, after 15 and 30 wearing and washing. It was concluded that after repeated washing there is a decrease in compression pressure due to different levels of wearing and washing [2].

Based on the above scientific literature review, it is observed that there are few studies in which compression socks are purely analysed for their performance characterization based on wearing and different washing levels. This research aims to analyse the performance behaviour of compression socks after wearing and washing at different temperatures.

## MATERIALS AND METHODS

### Materials

In this research work, nine pieces of compression socks samples with three different combinations were developed using the MERZ compression socks knitting machine. Machine properties are type (SC or DC) and model/year (CC4 II, 2015), cylinder diameter of 4.75-inches, machine gauge of E28, four systems and 420 needles. These socks samples were comprised of body yarn (BY) and inlaid yarn (IL). Both body and inlaid yarns are double covered except for varying twist per meter (TPM) range.

Body yarn (BY) was purchased that contains an elastane (EA) core of linear density (50 dtex) sheathed with polyamide (PA) multifilament yarn exhibiting the linear density (44 dtex).

Three different types of inlaid yarns (IY1, IY2 and IY3) were purchased comprised of elastane (EA) as core material and polyamide (PA) materials as sheathed material simultaneously. Here; IY1 contains elastane (EA) core of linear density (285 dtex) sheathed polyamide (PA) yarn of linear density (33 dtex), IY2 contains elastane (EA) core of linear density (475 dtex) sheathed polyamide (PA) yarn of linear density (33 dtex), IY3 contains elastane (EA) core of linear density (570 dtex) sheathed polyamide (PA) yarn of linear density (78 dtex). The microscopic internal view and technical specifications of inlaid double-covered yarns are given below in figure 2 and table 1.

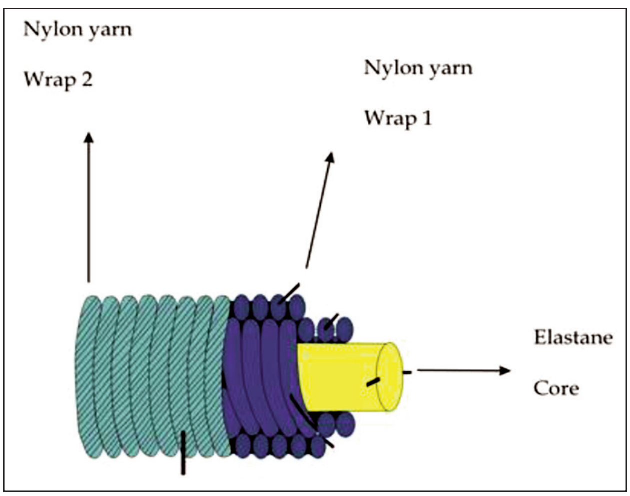


Fig. 2. Double covered Nylon filament yarn [22]

The structure [1×1 Laid in, 1×1 knit-miss structure] and machine settings of all the three socks' samples are fixed and produced three pieces from each sample code for a different level of washing temperature. Moreover, the microscopic structures of the developed compression socks are shown below in figure 3. Table 2 represents the technical and physical properties of the compression socks samples.

### Methods

Nine pieces of compression socks samples were tested at different washing temperatures. The aim was to simulate 'wear' and 'washing' of compression socks during the usage. The test protocol consists of 6 steps listed below and shown in figure 4.

Production of sock samples. Nine samples were produced with a different combination.

Pressure measurement before wearing.

In vitro-wearing simulation. In each case to simulate the "wearing effect" all socks were put on the wooden leg for 2 days (48 h).

Pressure measurement after wearing.

Washing the samples at three different levels of temperatures as seen in table 3.

Pressure measurement after washing.

This cycle is repeated five times for analysing and simulating the daily usage (wearing and washing) of people. It took fifteen days to compare the compression pressure results measured at 1st washing and then 5th washing cycle.

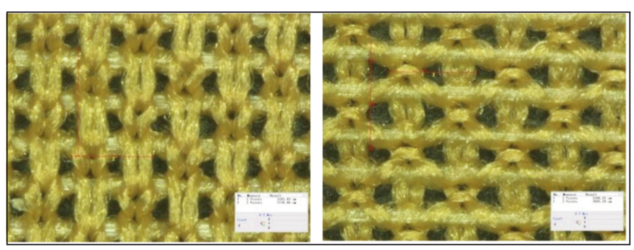

Fig. 3. Microscopic views of compression socks structure

Table 1

| SPECIFICATIONS OF INLAID YARNS (IY) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sample codes | Yarn codes | Yarn type | Fibre type | Linear density | Resultant count (dtex) | Fibre composition (%) | Draft |
| S1 | IY1 | Core | EA | 285 dtex | 275/48f/1 dtex | Polyamide: Elastane 80:20 | 4 |
| | | Sheath | PA 6.6 | 33 dtex (24 f) | | | |
| S2 | IY2 | Core | EA | 475 dtex | 450/48f/1 dtex | Polyamide: Elastane 70:30 | 2.9 |
| | | Sheath | PA 6.6 | 33 dtex (24 f) | | | |
| S3 | IY3 | Core | EA | 570 dtex | 550/48/1dtex | Polyamide: Elastane 60:40 | 1.95 |
| | | Sheath | PA 6.6 | 78 dtex (24 f) | | | |

Table 2

| TECHNICAL SPECIFICATIONS OF COMPRESSION SOCKS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample code** | **S1** | | | **S2** | | | **S3** | | |
| | **S1-30** | **S1-40** | **S1-50** | **S2-30** | **S2-40** | **S2-50** | **S3-30** | **S3-40** | **S3-50** |
| Measurement points and parameters | 50-285 (dtex) DCV | | | 50-475 (dtex) DCV | | | 50-570 (dtex) DCV | | |
| B-Ankle Wales density (stitches/cm) | 28 | | | 26 | | | 26 | | |
| B-Ankle Courses density (stitches/cm) | 12 | | | 11 | | | 11 | | |
| B-Ankle Stitches density (stitches/cm$^2$) | 336 | | | 286 | | | 284 | | |
| C-Calf Wales density (stitches/cm) | 22 | | | 21 | | | 20 | | |
| C-Calf Courses density (stitches/cm) | 12 | | | 11 | | | 11 | | |
| C-Calf Stitches density (stitches/cm$^2$) | 264 | | | 231 | | | 220 | | |
| Thickness (mm) | 0.54 | | | 0.63 | | | 0.87 | | |
| Fabric mass per unit area (g/m$^2$) | 270 | | | 305 | | | 360 | | |
| Fiber analysis (%) [Elastane: Polyamide] | 20:80 | | | 25:75 | | | 30:70 | | |
| Ankle Width – b (cm) | 8.5 | | | 8.5 | | | 9.2 | | |
| Calf width – c (cm) | 12.5 | | | 13 | | | 14 | | |
| Calf width – c (cm) | 12.5 | | | 13 | | | 14 | | |

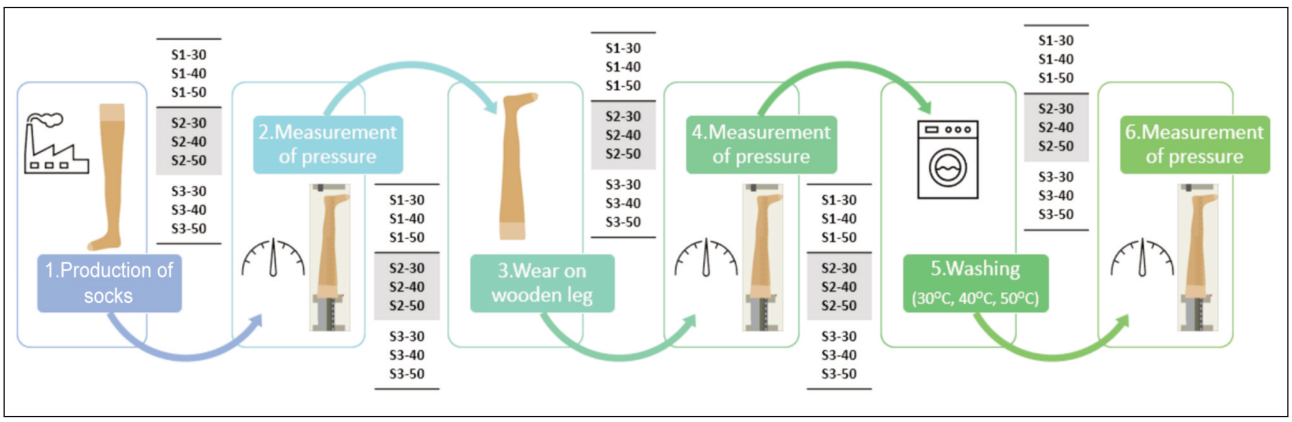


Fig. 4. Wearing & washing steps and measurement of compression pressures of socks

Table 3

| PARAMETERS OF WASHING TYPES | | | |
|---|---|---|---|
| **Washing type parameters** | **Time (minutes)** | **Temperature (°C)** | **Machine type** |
| 1st Washing Type | 30 | 30 °C | Front Loading Washing Machine |
| 2nd Washing Type | 30 | 40 °C | |
| 3rd Washing Type | 30 | 50 °C | |

**Measurement of compression pressure**

Currently, there are two major methods used for the determination of compression performance: the direct in vivo method and the indirect in vitro method. In this research, we performed the in vitro method for indirect evaluation of compression pressure using MST Professional II Medical Stocking Tester (Salzmann AG, St Gallen, Switzerland). It comprises a thin plastic sleeve. Sensors are located on the medial side of a linearly moveable attachment at a constant rate. The placement of sensors between the to and from the movement of the back side of the leg simulates the muscle's stretch and relaxation as shown in figure 5. The mechanical movement of the leg part possessing 10 sensors (depending on the length and longitudinal stretch of socks) from the ankle to calf portion measures the average exertion of compression pressure at the ankle and calf along with graduation percentage values as shown in figure 5. The air pump inflates the envelope until the contacts open. When the contacts open, the transducer reads the pressure at located measuring points and displays it digitally with 1-mmHg resolution.

Evaluation of compression measurement was performed under the standard test method RAL-GZ 387/1. Each sample was tested according to CEN 15831 in standard laboratory conditions (RH, 65±5%, temperature, 20±2°C). Tests were repeated five times for each sample.


Fig. 5. MST Professional II medical stocking tester

## RESULTS AND DISCUSSION

### Effect of wearing and washing on compression pressure

In this part of the study, we can see the compression pressure measurement results of the samples. Table 4 shows the compression pressure values of socks at the ankle before wearing, after wearing for two days and washing and after fifteen days of wearing and washing.

### 1st cycle of measurement of compression pressures at ankle and calf

Figure 6 and table 4 portray that samples 1 (S1-30, S1-40 and S1-50) after knitting (before wearing) pertain to equal compression pressure values of 23.7 mmHg at the ankle and 14.35 mmHg at the calf.

While samples S1-30, S1-40 and S1-50 after two days of wearing on wooden leg portray a different trend of exertion of compression pressure. S1-30 sample 23.43 mmHg in the ankle and 14.2 mmHg in the calf area, S1-40 sample 23.40 mmHg in the ankle and 14.20 mmHg in the calf area, S1-50 sample in the foot applies 23.45 mmHg pressure on the wrist and 14 mmHg in the calf area.

The sample socks (S1-30, S1-40 and S1-50) were also evaluated for the intensity of compression pressure after two days of relaxation and were again washed at three levels of temperatures (30˚C, 40˚C and 50˚C). Figure 7 and table 4 show that at 30˚C, 40˚C and 50˚C washing found a slight increase in compression pressure to 25 mmHg (S1-30), 25.3 mmHg (S1-40) and 25.5 mmHg (S1-50) at the ankle and 15.1 mmHg (S1-30), 15.2 mmHg (S1-40) and 15.23 mmHg (S1-50) at calf respectively. The reason for this slight increase in compression pressure after relaxation of two days of wearing on the wooden leg was due to a long time stretching and then quick contraction after washing at various levels of washing. It was also observed that their circumference increased when the socks were taken off from the wooden leg.

For S2-30, S2-40 and S2-50, the results of compression pressure after knitting (before wearing) were almost similar (figure 6 and table 4). After the socks were worn on wooden legs for two days, pressure values were measured as follows, respectively; 32.10 mmHg in the ankle and 18.7 mmHg in the calf in sample S2-30, 32.3 mmHg in the ankle and 18.3 mmHg

Table 4

COMPRESSION PRESSURE RESULTS OF ANKLE (B) AND CALF (C) AFTER WEARING AND WASHING

| Samples | Measurement position | Before wearing (mmHg) | After 2 days of wearing (mmHg) | After 2 days wearing & washing (mmHg) | After 15 days wearing & washing (mmHg) |
|---|---|---|---|---|---|
| S1-30 | ankle (b) | 23.7 | 23.43 | 25 | 23.7 |
| | calf (c) | 14.35 | 14.2 | 15.1 | 14.1 |
| S1-40 | ankle (b) | 23.7 | 23.4 | 25.3 | 23.9 |
| | calf (c) | 14.35 | 14.2 | 15.2 | 14.4 |
| S1-50 | ankle (b) | 23.7 | 23.45 | 25.5 | 25.5 |
| | calf (c) | 14.35 | 14 | 15.23 | 15.2 |
| S2-30 | ankle (b) | 32.4 | 32.10 | 34.4 | 33.2 |
| | calf (c) | 19.1 | 18.7 | 19.8 | 19.4 |
| S2-40 | ankle (b) | 32.4 | 32.3 | 34.5 | 33.6 |
| | calf (c) | 19.2 | 18.3 | 19.9 | 19.5 |
| S2-50 | ankle (b) | 32.4 | 32 | 35.1 | 35.2 |
| | calf (c) | 19.2 | 17.8 | 20.4 | 20.3 |
| S3-30 | ankle (b) | 33.8 | 33.36 | 37.2 | 35.4 |
| | calf (c) | 20.3 | 20.5 | 21.7 | 21.5 |
| S3-40 | ankle (b) | 33.8 | 33.7 | 37.3 | 37.5 |
| | calf (c) | 20.2 | 20.06 | 22 | 22.4 |
| S3-50 | ankle (b) | 33.8 | 33.45 | 38.3 | 38 |
| | calf (c) | 20.3 | 20.5 | 22.1 | 23.2 |

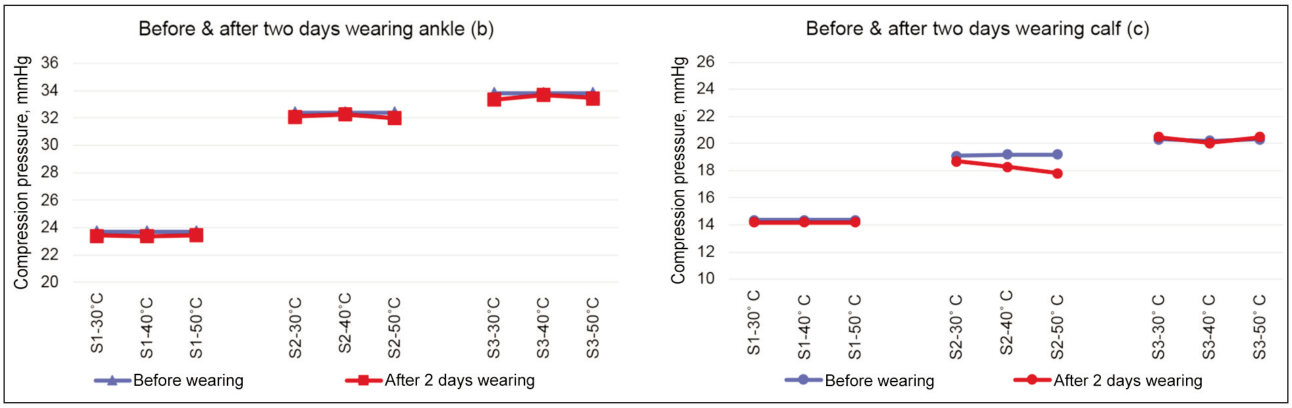


Fig. 6. Pressure comparison of the ankle (b) and calf (c) before and after two days of wearing

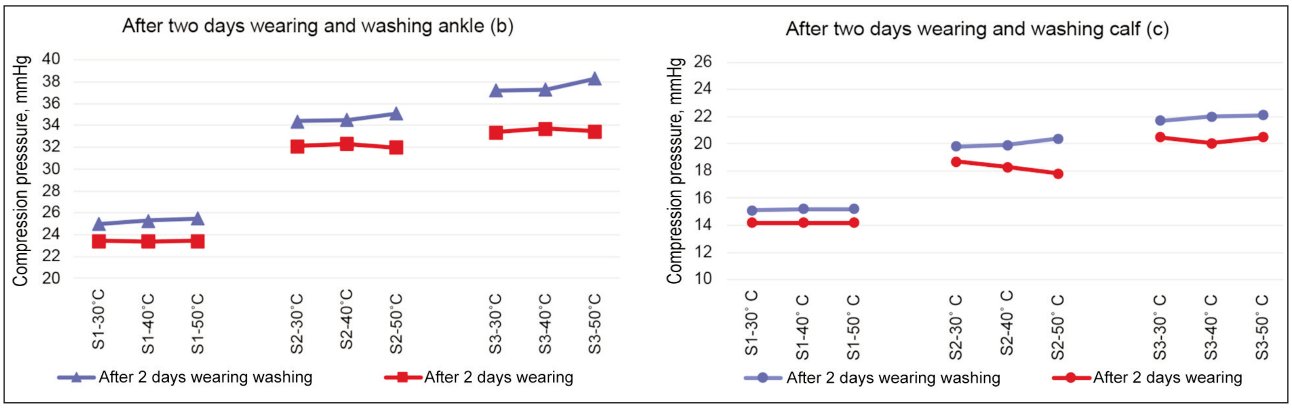


Fig. 7. Compression pressure change of ankle (b) and calf (c) after two days of wearing and washing

in the calf in the sample S2-40, 32 mmHg in the ankle and 17.8 mmHg in the calf in the sample S2-50. These worn sock samples were taken off from the wooden leg and again relaxed. It was then washed simultaneously at three different levels of temperatures 30˚C, 40˚C and 50˚C. When the pressure values in the ankle were examined after washing at different temperatures, an increase was observed at the ankle and calf. These values were measured at the ankle as respectively, from 32.10 mmHg to 34.4 mmHg after 30°C washing, from 32.30 mmHg to 34.5 mmHg after 40°C washing, from 32 mmHg to 35.1 mmHg after 50°C washing. At calf, portions were measured as 19.8 mmHg in the sample S2-30, 19.9 mmHg in the sample S2-40 and 20.4 mmHg in the sample S2-50.

As far as the S3-30, S3-40 and S3-50 are concerned, the compression pressure exerted by the S3 sample at the ankle was 37.2 mmHg after 30℃ washing (S3-30), 37.3 mmHg after 40℃ washing (S3-40) and 38.3 mmHg after 50℃ washing (S3-50) as shown in table 4. At calf, portions were measured as 21.7 mmHg in sample S3-30, 22 mmHg in sample S3-40 and 22.1 mmHg in sample S3-50.

The reason for the successive increase in compression pressure by increasing temperature is when the socks samples are worn to fixed-sized wooden legs they are stretched and when they are taken off their circumference increases. Again, when it was washed at different levels of temperature (30˚C, 40˚C and 50˚C) it shrinks more due to generated voids in the knitted structure of socks and higher regain the value of nylon material. The same trend and reason were for all of these socks' samples at successive temperatures.

Statistical analysis of all three socks' samples at three different levels of washing temperature was made using simple linear regression analysis as given in figure 8. The statistical significance of effect of different levels of temperature was fixed on the basis of coefficient of determination values (R-square) ((S1-30, S1-40, S1-50) = 0.98, (S2-30, S2-40, S2-50) = 0.85 and (S3-30, S3-40, S3-50) = 0.82). The statistical portrays that the influence of three different levels of temperatures exists but is not symmetric or consistent around the simple regression line. At calf portion coefficient of determination values (R-square) ((S1-30, S1-40, S1-50) =0.91, (S2-30, S2-40, S2-50) =0.87 and (S3-30, S3-40, S3-50) = 0.98) as shown in figure 8. Correlation values in both the ankle (0.9, 0.92 and 0.99) and calf (0.95, 0.93 and 0.99) portion explain the increase in pressure values as the temperature increases.

### 5th cycle of measurement of compression pressures at ankle and calf

Figure 9 shows the effect of five times wearing and washing on compression pressure at the ankle and calf portion of compression socks. As seen in figure 9,

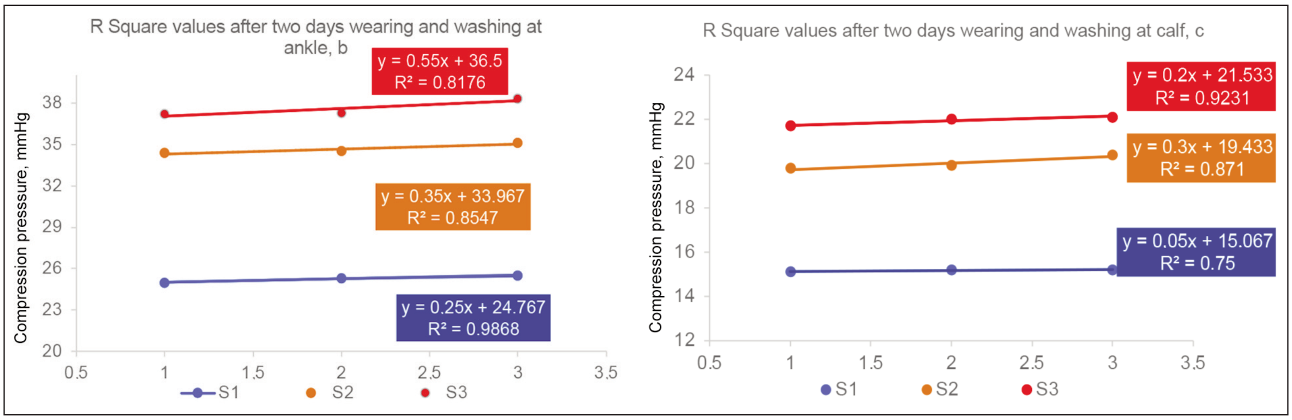


Fig. 8. R Square values of tests after two days of wearing and washing at the ankle (b) and calf (c)

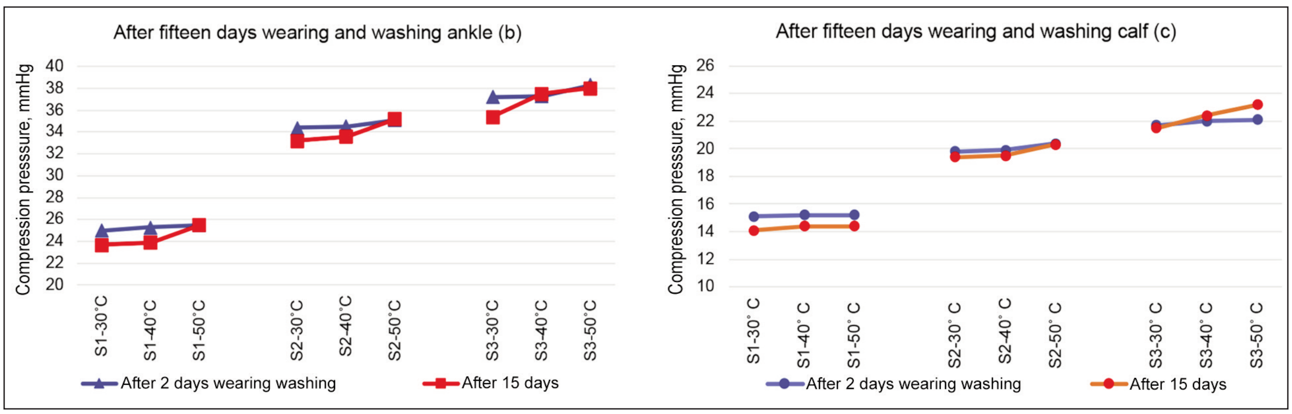


Fig. 9. Pressure comparison of the ankle (a) and calf (b) after fifteen days of wearing and washing

after five washing cycles, it is seen that the pressure values increase as the temperature increases. When the results after the 5th wearing and washing in the calf portion are examined, 14.1 mmHg in the S1-30 sample, 14.4 mmHg in the S2-30 sample, and 15.2 mmHg in the S1-50 sample were measured.

It was measured that the S1-30 sample applied 23.7 mmHg after 30°C washing, the S1-40 sample 23.9 mmHg after 40°C washing, and the S1-50 sample applied 25.5 mmHg after 50°C washing. In the S2-30 sample in the calf area 19.4 mmHg, 19.5 mmHg in the S2-40 sample, and 20.3 mmHg in the S2-50 sample were measured.

In addition, 33.20 mmHg in the S2-30 sample after 30°C washing, 33.60 mmHg after 40°C washing in the S2-40 sample and 35.2mmHg after 50°C washing in sample S2-50 were measured. Finally, when the pressure values of S3 samples in the ankle area were measured, respectively, the pressure results were obtained as follows: S3-30 35.40 mmHg after washing at 30°C, S3-40 after washing at 40°C 37.50 mm Hg and 50°C after washing S3-50 38 mm Hg. If we compared the results of sample S3-50 between 1st (33.8 mmHg) and 5th (38 mm Hg) wearing washing, there is a significant increase in compression pressure after multiple wearing and machine washing that is maximum for the sample S3-50 washed at 50°C.

The statistical significance of effect of different levels of temperature was analysed on the basis of coefficient of determination values (R-square) ((S1-30, S1-40, S1-50) = 0.83, (S2-30, S2-40, S2-50) = 0.88 and (S3-30, S3-40, S3-50) = 0.89) as shown in figure 10 at ankle portion. At calf portion coefficient of determination values (R-square) ((S1-30, S1-40, S1-50) = 0.93, (S2-30, S2-40, S2-50) = 0.84 and (S3-30, S3-40, S3-50) =0.98). The value of the coefficient of determination values of the socks sample (S3-30, S3-40, S3-50) is 89% which portray that the independent variable (x) which is different levels of temperatures is more significantly influencing the intensity of compression pressure. The reason behind this sort of trend is due to the heavier linear density of inlaid yarns used in samples (S3-30, S3-40, S3-50), heavier linear density of inlaid yarn used, and more draft required that permits the socks to shrink more. If the shrinkage increases, more reversal pressure on the surface wooden human leg is exerted. The significance of the input variables can also be judged on the basis slope value equation of the regression line. The slope value is the ratio of the rise (y-axis) to run (x-axis) and in the equation of the regression line, it is found as the coefficient of independent variable value (x) that the different levels of temperatures (30°C, 40°C and 50°C). Here the slope value of (S3-30, S3-40, S3-50) is (b=0.89) which is toward 1 that represents the steepness in the regression line. The

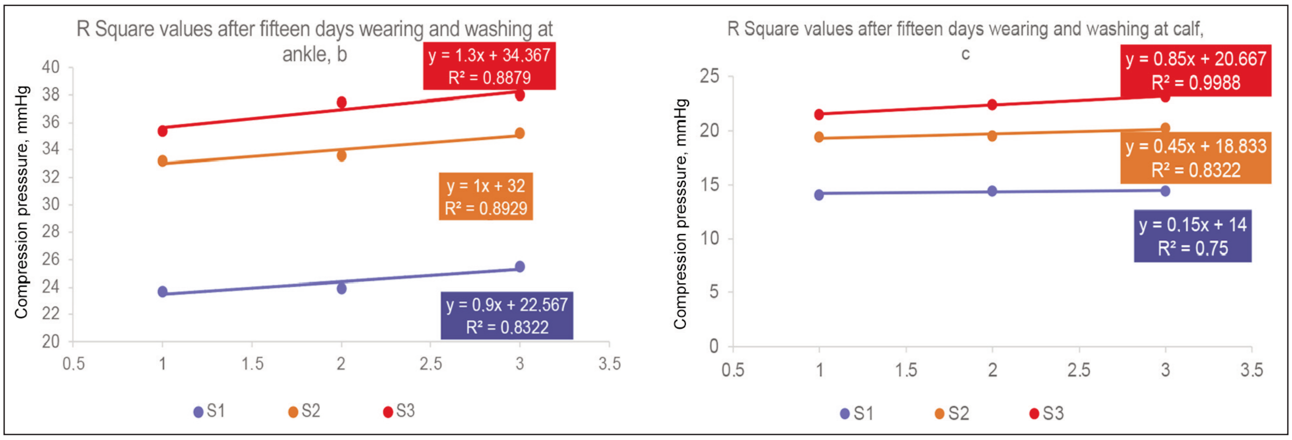


Fig. 10. R Square values of tests after fifteen days of wearing and washing at the ankle (b) and calf (c)

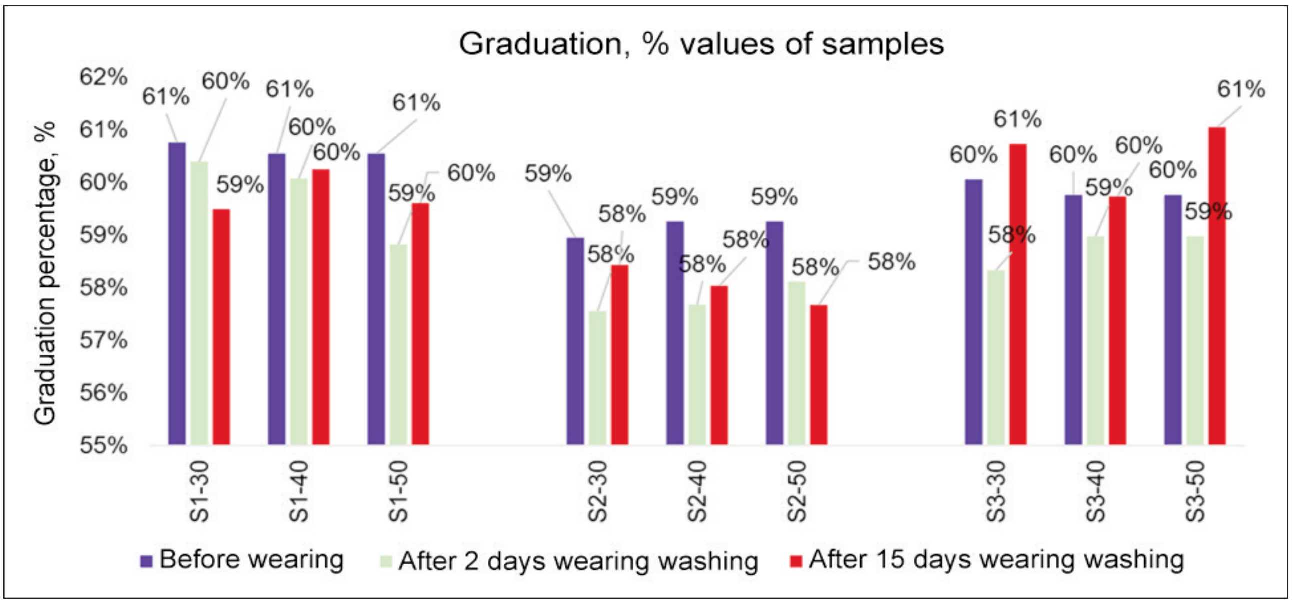


Fig. 11. Graduation values of compression socks

more steep the value, the higher the slope. The higher the slope, the more significant of the independent variable (x) influences the dependent variable (y).

### Graduation values of compression socks at calf

Figure 11 shows the graduation percentages (G%) of the c point before, after two days and fifteen days of wearing and washing. The gradation values of our all samples before wearing and after fifteen days exhibit the values within the standard values as mentioned above.

In figure 11, we see that the graduation values of each sample that the graduation percentage (G %) (after two days) are slightly decreasing. As for S1-30, S1-40 and S1-50 are concerned that the graduation percentage (G %) after 30°C, 40°C and 50°C washing slightly decreases to 60%, 60% and 59%. For samples (S2-30, S2-40, S2-50) the G % values after 30°C, 40°C and 50°C washing are slightly decreased to 58%. For sample 3 (S3-30, S3-40, S3-50), the G % values after 30°C, 40°C and 50°C washing are slightly decreased to 58%, 59% and 59% respectively.

In figure 11, we see that the graduation values (G %) of each sample S1, S2 and S3 that the graduation percentage (G %) (after fifteen days of wearing and washing) is slightly increasing as the temperature increases. As for S1 (S1-30, S1-40, S1-50) is concerned that the G% (after fifteen days) after at 40°C and 50˚C washing slightly increases to 60%. As for (S2-30, S2-40, S2-50) is concerned that the G% (after fifteen days) after 30°C, 40°C and 50°C washing remains the same, 58%. Because the material has no capacity for shrinkage due to its compact structure [1×1 Laid in, 1×1 knit-miss structure]. As for S3 is concerned that the G% (after fifteen days) after 30°C, 40°C and 50°C washing is slightly increasing to 61%, 60% and 61% respectively.

## CONCLUSIONS

This study aims to analyse the influence of wearing and washing cycles on the compression pressure of the socks. According to the results, it was observed that the washing temperature has a significant influence on the compression pressure for all samples.

It is concluded that the effect of temperature on the pressure of all the socks samples is different.

The socks sample S3-30, S3-40, and S3-50 exhibit the highest compression pressure as compared to S1 and S2 at the ankle and calf portion after wearing and washing. In addition, it can be said that the increase of linear density of inlaid yarns is more effective in pressure increase with the effect of temperature. The effect of temperature on the intensity of compression pressure for all three samples has a negligible increase/decrease in compression pressure.

As for graduation results G% it can be concluded that the effect of temperature (30°C, 40°C and 50°C) and wearing and washing cycles (after two and fifteen days) the graduation percentage (G%) values lie within the standardized values (50% – 80%).

Secondly, there is observed a slight increase/ decrease in graduation percentage (G%) measured between two and after fifteen days at the ankle and calf portion.

As a general result of the study, wearing/washing test results for the use simulation show us that there is a decrease in the pressure values as a result of wearing, but that the pressure values can be maintained by providing recovery after washing. In addition, it was understood that the washing temperature values are effective on the pressure values.

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# The effect of loop length, yarn twist and dyeing process on seam strength of knitted fabrics

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**ABSTRACT – REZUMAT**

**The effect of loop length, yarn twist and dyeing process on seam strength of knitted fabrics**

*Seam strength is a key factor both in terms of aesthetics and the life of the apparel. There are many factors affecting seam strength, some of which are relevant to fabric construction and treatment, and the others are about sewing thread and sewing parameters. This research paper focuses on the effects of fabric construction, sewing parameters and the dyeing process on the seam strength of knitted fabrics. For this purpose, seven single jersey knitted fabrics were produced, differing in loop length and yarn twist. The samples were dyed and then sewn with different sewing parameters. The seam strength values were calculated and statistically evaluated. The results showed that fabric construction, sewing thread type and count, stitch density and dyeing process profoundly influence the seam strength of single jersey fabrics. When comparing the effects of dyeing, it was found that dyeing leads to a decrease in seam strength values.*

***Keywords:*** *seam, seam strength, knitted fabric, loop length, yarn twist, dyeing*

**Influența lungimii buclei, torsiunii firului și procesului de vopsire asupra rezistenței asamblării tricoturilor**

*Rezistența asamblărilor prin coasere este un factor cheie atât în ceea ce privește estetica, cât și durata de viață a îmbrăcămintei. Există mulți factori care afectează rezistența asamblării prin coasere, dintre care unii sunt relevanți pentru construcția și tratarea materialului textil, iar ceilalți se referă la ața de cusut și parametrii de coasere. Această lucrare de cercetare se concentrează asupra influenței structurii materialului textil, parametrilor de coasere și procesului de vopsire asupra rezistenței asamblărilor prin coasere ale tricoturilor. În acest scop, au fost produse șapte tipuri de tricot glat, care diferă prin lungimea buclei și torsiunea firului. Probele au fost vopsite și apoi asamblate cu diferiți parametri de coasere. Valorile rezistenței asamblărilor prin coasere au fost calculate și evaluate statistic. Rezultatele au arătat că structura tricotului, tipul și finețea aței de cusut, desimea cusăturii și procesul de vopsire au o influență importantă asupra rezistenței asamblărilor prin coasere ale tricoturilor glat. Când se analizează influența vopsirii, s-a constatat că vopsirea duce la o scădere a valorilor rezistenței asamblărilor prin coasere.*

***Cuvinte-cheie****: asamblare prin coasere, rezistența asamblării prin coasere, tricot, lungimea buclei, torsiunea firului, vopsire*

## INTRODUCTION

The insertion of needle and thread into several layers of fabric must be regarded as the most complex phenomenon in the textile process from the conversion of the raw fibres to the finished garment. Textile consists of a long series of manufacturing processes and making-up are usually the last process. A garment that is spoiled at this late stage represents a waste of time, effort and material [1]. Therefore, sewing is both the most labour-intensive process and one of the critical processes in determining the productivity and quality of the finished garment [1, 2]. In cut and sewn apparel products, seams are formed when two or more pieces of fabric are held together by stitches [3]. The main function of a seam is to ensure an even transfer of load from one piece of fabric to another, thus maintaining the overall integrity of the fabric assembly. For proper appearance, the seam should not have any defects such as skipped stitches, unbalanced stitches, seam grin, puckering, unsteadiness, improper drapeability, uneven seam density and yarn severance or damage [4].

Since the seam is one of the basic requirements for garment construction, seam quality is an important parameter that determines garment performance [3, 5]. Apparel manufacturers focus on seam quality during the manufacturing and production of garments [4]. Objective and efficient evaluation of seam quality is of paramount importance for the apparel industry [6].

In the apparel industry, overall seam quality is defined by various functional and aesthetic performances desired for the apparel product during its end use [7]. The performance and quality of seams depend on various factors such as seam strength, slippage, puckering, appearance and yarn severance [8]. For better seam quality, it is important to consider the complete harmony of the main fabric properties, sewing thread properties and sewing conditions used. Adjustment of all sewing parameters is necessary to ensure quality [7, 9].

Despite the very high level of technology and automation in the processes of garment manufacturing, the desired sewing quality cannot always be achieved in the production of knitwear. One reason for this is that insufficient attention is paid to the quality of the material, in this case, knitwear. Such inferior quality seams in knitwear cause major defects that may be detected too late. This results in greater financial expenses and marketing risks [10].

Therefore, it is very important to be able to identify and be aware of yarn, fabric and sewing parameters that cause faults in the sewing of knitwear.

Various studies have been carried out to investigate the factors which affect the seam performance of woven fabrics. However, studies on knitted fabrics within this scope are limited. Bansal et al. studied the effects of sewing needle size, seam angle and sewing needle type on seam strength and seam efficiency of knitted fabrics. The test results revealed that with an increase in seam angle and needle size, seam strength decreases. However, with the sewing needle type, an increase in seam strength was observed for all tested fabrics. It is noted that seam efficiency increases with seam angle and sewing needle type [11]. Nassif investigated the effects of loop length, yarn twist factor and number of washing cycles on seam elongation, seam strength and efficiency. The results of this study revealed that both loop length and number of washing cycles had a positive effect on fabric dimensional stability at all twist factors. It is also found that loop length and yarn twist factor had a positive effect on seam elongation. On the contrary, both factors have a negative influence on seam strength and efficiency [12]. Wang et al. investigated the influences of stitch density on the strength, extensibility, and stress with stand retention of three types of stitches commonly used for knitted fabrics [13]. Rajput et al. investigated the influence of weft knitted fabric structures, sewing thread types and stitch types on seam strength and efficiency of superimposed seam type for cotton garments. The test results revealed that polyester-wrapped threads with a polyester filament core thread show better seam strength and seam efficiency [14]. Farhana et al. compared the seam strength and seam performance between dyed and un-dyed gabardine garments. For this purpose, different stitch classes, seam types, stitch densities, sewing thread linear densities and needle sizes were used. It can be concluded that the seam strength of dyed fabrics is lower than that of undyed fabrics due to the different stages of the dyeing process [15].

The related studies on knitted fabrics are limited and further investigation is required. Therefore, in this paper, more parameters, such as yarn twist and loop length of knitted fabric, dyeing process, sewing thread type and count, and stitch density were explored to provide a more detailed study. As fabric type, we focused on a single jersey, the most widely used knitted fabric, which is widely used in the apparel industry, such as T-shirts, underwear, cardigans and leggings.

## MATERIALS AND METHODS

### Sample preparation

Seven single jersey fabrics with different structural properties were produced on an E28 gauge, 32” diameter Pailung circular knitting machine, at constant machine settings. The fabric samples were produced from 30/1 Ne 100% cotton yarns with two twist factors and four different loop lengths, as listed in table 1. The samples were produced with four different loop length values of 2.6, 2.9, 3.2, and 3.6 mm to obtain tight, medium and loose fabrics, respectively.

After the knitting process, the fabrics were subjected to dry and wet relaxation treatments. Firstly, the fabrics were laid on a flat surface for 24 hours for dry relaxation. The wet relaxation of the samples was performed as reported in the literature [16]. After the relaxation process, half of the fabrics were bleached and then dyed with reactive dyes. All the samples were dyed in the same bath to eliminate variations due to the process.

The undyed and dyed fabric samples were sewn using SES 80/12 needle size on an overlock sewing machine. ISO 504 stitch type was used with three different stitch densities (3, 4 and 5 stitches/cm). All fabric samples were tested coursewise. During the sewing process, the sewing speed, thread tension

Table 1

PHYSICAL PROPERTIES OF FABRICS

| Properties | Fabric code | | | | | | |
|---|---|---|---|---|---|---|---|
| | F1 | F2 | F3 | F4 | F5 | F6 | F7 |
| Yarn linear density (Ne) | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| Loop length (mm) | 2.6 | 2.9 | 3.2 | 2.6 | 2.9 | 3.2 | 3.6 |
| Yarn twist | Low | Low | Low | Medium | Medium | Medium | Medium |
| Wales/cm | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| Courses/cm | 22 | 19 | 17 | 22 | 19 | 17 | 14 |
| Thickness (mm) | 0.56 | 0.57 | 0.63 | 0.59 | 0.60 | 0.64 | 0.74 |
| Mass per unit area (g/m$^2$) | 147 | 140 | 132 | 154 | 149 | 142 | 123 |
| Tightness factor (Tex/mm) | 1.71 | 1.53 | 1.39 | 1.71 | 1.53 | 1.39 | 1.23 |

Table 2

| PROPERTIES OF SEWING THREADS | | | | | | |
|---|---|---|---|---|---|---|
| **Properties** | **Sewing Thread Code** | | | | | |
| | **ST1** | **ST2** | **ST3** | **ST4** | **ST5** | **ST6** |
| Thread type | Mercerized cotton | Mercerized cotton | PES-PES core-spun | PES-PES core-spun | PES-Co core-spun | PES-Co core-spun |
| Yarn count (tex) | 30 | 35 | 24 | 30 | 24 | 30 |
| Twist (TPM) | 795 | 753 | 1010 | 945 | 1210 | 1098 |
| Breaking strength (CN/tex) | 23.93 | 28.43 | 54.63 | 55.37 | 41.88 | 40.33 |
| Elongation at break (%) | 4.51 | 6.42 | 19.43 | 20.67 | 21.25 | 20.15 |

and other settings were kept constant. Three types of sewing threads with two different yarn counts were selected. Table 2 shows the characteristics of the sewing threads used.

### Testing

Based on the parameters used in this study, an experimental plan was developed using a full factorial experimental design. The input variables of sewing thread type, sewing thread count, and stitch density, each at different levels, were used to create an experimental design. The variables and their values were selected based on the literature review and the general requirements of the apparel industry. By using these variables during the sewing process, undyed and dyed 252 fabric samples were prepared as a whole.

The loop lengths were measured by counting the loop numbers knitted by a predetermined yarn length and dividing this yarn length by the loop numbers. The tightness factor was calculated according to the given formula:

$$\textit{Tightness Factor} = \frac{\sqrt{\text{tex}}}{L} \qquad (1)$$

where $L$ is loop length in mm.

Seam strength is the crucial index to represent the mechanical properties of the seam [17]. The seam strength test was performed on a Zwick Roell ZO10 tensile tester, in accordance with the standard TS EN ISO 13935-1. The test speed specified in the standard is 50 ± 10 mm/min. However, this speed is not sufficient to cause the knitted fabric to break at the seam. Preliminary tests showed that breakage at the seam occurred at a test speed of 200 mm/min. For this reason, the device setting was kept constant for all tests: The set distance between jaws was 100 mm and the test speed was 200 mm/min [18].

Measurements were made with five repetitions. By averaging five readings for each sample, the average seam strength value was obtained.

Analysis of variance (ANOVA) was used to analyse the test results using SPSS software. To derive whether the group means were significantly different, the significance level (p-value) was determined. In this analysis, only those cases that showed statistical significance beyond the 5% level were considered significant.

## RESULTS AND DISCUSSION

Statistical results related to p-values are given in table 3. For Tamhane's T2 and Duncan tests, the mean values are followed by letters. Any values followed by the same letter are not significantly different ("a" shows the lowest value and "c" shows the highest value).

Table 3

| STATISTICAL ANALYSIS RESULTS FOR SEAM STRENGTH VALUES | | | | | |
|---|---|---|---|---|---|
| **Parameters** | | **Un-dyed** | | **Dyed** | |
| | | **p-value** | **Seam strength** | **p-value** | **Seam strength** |
| Fabric type | F1 | 0.006* | 75.01 ab | 0.036* | 57.39 a |
| | F2 | | 80.40 ab | | 61.55 a |
| | F3 | | 88.32 bc | | 65.91 ab |
| | F4 | | 82.02 ab | | 59.62 a |
| | F5 | | 92.07 c | | 71.5 ab |
| | F6 | | 94.22 c | | 76.03 b |
| | F7 | | 71.68 a | | 61.39 a |
| Sewing thread type | ST1 | 0.113 | 78.81 | 0.023* | 59.11 ab |
| | ST2 | | 87.59 | | 69.96 bc |
| | ST3 | | 86.14 | | 64.19 abc |
| | ST4 | | 77.82 | | 56.01 a |
| | ST5 | | 77.75 | | 64.96 abc |
| | ST6 | | 92.23 | | 74.74 c |
| Stitch density | 3 | 0.000* | 50.96 a | 0.000* | 35.42 a |
| | 4 | | 72.29 b | | 53.37 b |
| | 5 | | 126.92 c | | 105.54 c |

Note: * Statistically significant ($p < 0.05$).

### Effect of the dyeing process

The test results and statistical analysis of the samples are given in table 3 and figure 1. The statistical analysis showed that the difference between the seam strength values of the undyed and dyed samples was significant. As shown in figure 1, the seam strength values measured before dyeing were higher than the values measured after dyeing for each fabric type. This is due to the mechanical effects that occur during dyeing. Dyeing abrades the fabric, the sewing thread and the sewing area, resulting in lower seam strength. As stated by Nurrunnabi et al., the seam strength decreases at different rates during dyeing with all dyestuffs (direct, reactive, vat and pigment dyes) [19].

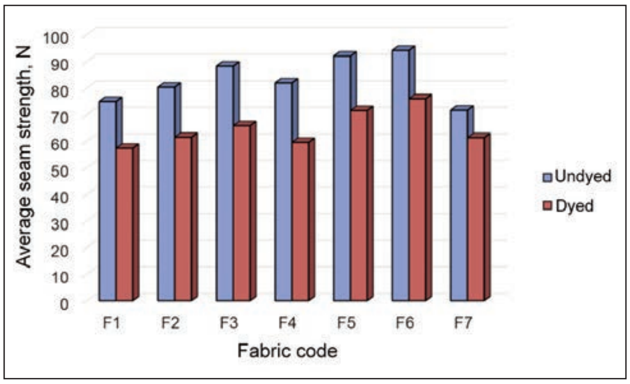


Fig. 1. Effect of dyeing process on seam strength

### Effect of the fabric structure

As can be seen in figure 1, the highest seam strength value was measured at F6 before dyeing. The lowest seam strength values were measured at F7 and F1, respectively. However, the statistical test results show that the differences between the lowest values are insignificant. A similar situation was observed after the dyeing process.

Moreover, it was observed that the seam strength values of the fabrics with higher yarn twist and loop length were higher. When the effect of yarn twist in fabrics with the same loop length is examined, it can be seen that the value of seam strength tends to increase with higher yarn twist in all fabric types (figure 2). However, the statistical test results show that the differences between the results are insignificant. In general, it is found that yarn twist has a positive effect on seam strength. As the yarn twist increases, so does the fabric strength, which results in better seam strength values.

Comparing the loop lengths of fabrics with the same twist value, it is found that the seam strength increases with increasing loop length for F1, F2 and F3. However, the difference between them was found to be insignificant. Comparing the medium-twisted fabrics (F4, F5, F6 and F7), it can be seen that seam strength increases between F4 to F6 and decreases very sharply at F7. This means when the loop size increases more than a certain amount, at some point the fabric becomes too loose and it becomes much more sensitive to deformations (figure 3).

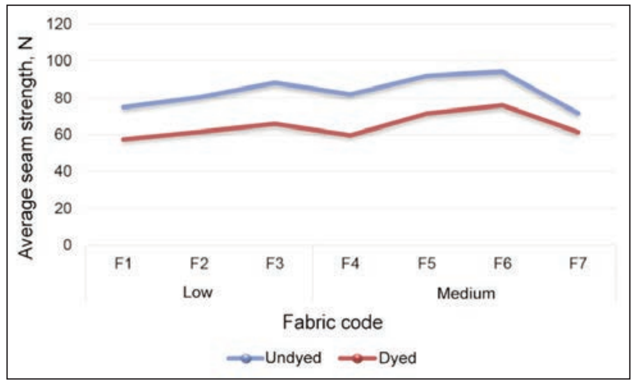


Fig. 3. Effect of loop length on seam strength

### Effect of sewing thread

The seam strength values of the fabrics sewn with different sewing threads are presented in figure 4. As can be seen from figure 4, the highest value for seam strength was calculated with ST6 and the lowest with ST4 and ST5 before dyeing. However, the difference between the results is not statistically significant. After dyeing, the samples sewn with ST6 had the highest average seam strength values, whereas those sewn with ST4 had the lowest values.

When the sewing threads are evaluated by sewing thread type, it is found that the seam strength increases with increasing sewing thread count (tex) for PES-Co core-spun thread and mercerized cotton thread. However, an opposite trend was observed for the samples sewn with PES-PES core-spun thread.

There is an interesting phenomenon that occurs in samples sewn with different types of sewing threads. It is known that the PES-PES core-spun sewing thread is the strongest among the others used in the study. However, the lowest value for seam strength was measured with PES-PES core-spun thread both before and after the dyeing process. This can be

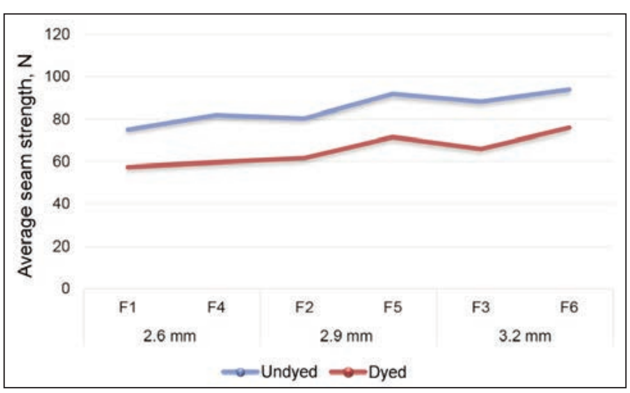


Fig. 2. Effect of twist factor on seam strength

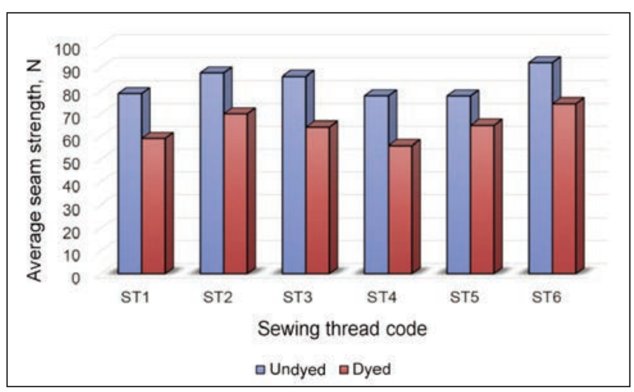


Fig. 4. Effect of sewing thread on seam strength

attributed to the interactions between fabric and sewing thread composition [18].

### Effect of stitch density

Statistically, a significant difference was found between the seam strength values of the specimens sewn with different stitch densities. In figure 5, an increasing trend was observed that as the stitch density increased, the seam strength followed the same manner. As mentioned in the literature, as the stitch density increases, the number of contact points between the sewing thread and the fabric yarns increases, resulting in a denser surface [20, 21]. Consequently, the tensile force is distributed to a larger number of points and the resistance is higher. In addition, as the stitch density increases, the sewing thread consumption increases, so the seam resistance becomes higher.

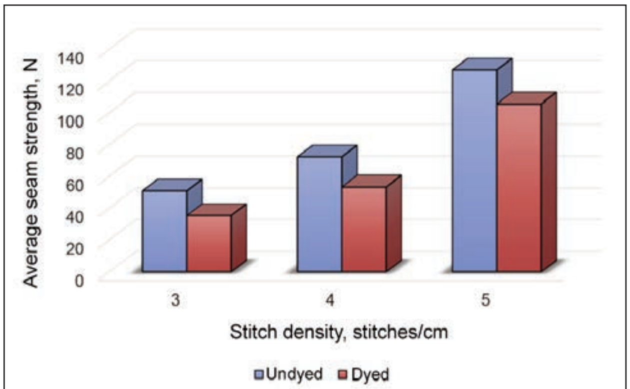


Fig. 5. Effect of stitch density on seam strength

## CONCLUSION

In this study, single jersey knitted fabrics were produced with different yarn twist and loop length. Then half of the fabrics were dyed. Dyed and undyed fabric samples were sewn with selected sewing parameters. As mentioned earlier, there are few studies on the seam performance of knitted fabrics. The related studies on knitted fabrics are limited and require further investigation. Therefore, this study focused on the effects of fabric parameters (yarn twist and loop length), sewing parameters (sewing thread count, sewing thread type, stitch density) and dyeing process on seam strength of knitted fabrics. The data obtained from experimental studies were statistically evaluated and the factors affecting the seam strength were analysed.

The main results of these analyses are summarized below.

- The seam strength values of the samples after the dyeing process are lower than those measured before dyeing. This is due to the mechanical damage that occurs during dyeing.
- Fabric construction, sewing thread type, thread count, and stitch density have statistically significant effects on the seam strength values, whereas sewing thread type shows no such effect before dyeing.
- When analysing the results of the seam strength tests, the highest strength values were observed in fabrics sewn with PES-Co core-spun thread at 5 stitches/cm.
- In general, it is found that yarn twist has a positive effect on seam strength. As the yarn twist increases, the fabric strength also increases, resulting in better values for seam strength.
- As the loop length increases, the seam strength increases, however at some point the fabric becomes too loose and the fabric becomes much more sensitive to deformation.
- The general perception is that the core-spun sewing thread is the strongest among the other sewing threads used in the study. However, the interactions between fabric composition and sewing thread may alter the results. For cotton fabrics, PES-Co core-spun and mercerized cotton threads are recommended to achieve the highest seam strength values, both before and after dyeing. This result shows that fabric composition is important in the selection of sewing thread types.

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# Investigating the impact of normal and abnormal loss factors in garment industry: A case study based on a jeans manufacturer in India

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**ABSTRACT – REZUMAT**

**Investigating the impact of normal and abnormal loss factors in garment industry: A case study based on a jeans manufacturer in India**

*This study aimed to analyse the normal and abnormal loss of a jeans manufacturing company in India. Personal interview and observation method are used in this study. Abnormal loss in quantity and rupee value is computed for 40 days of production based on the observed data. Mean abnormal losses are computed and one sample t-test is applied to test the hypotheses that the mean abnormal loss is not equal to zero. The study revealed that a normal loss of 3 to 5% is expected in any garment manufacturing company due to loss during the cutting and shrinkage process. The p-values of one sample t-test were less than 0.05 for all the tested hypotheses, hence, all the null hypotheses ($H_{01}$ to $H_{05}$ mean abnormal losses equal to zero) were rejected. Further, it was found that fabric is the big contributor in terms of abnormal loss. Hence, proper training for workers and recruiting of trained workers are advised to reduce abnormal losses.*

***Keywords**: jeans manufacturing, textile industry, abnormal losses, normal losses, garment, apparel, volatility, financial performance*

**Investigarea impactului factorilor de pierdere normală și anormală în industria de îmbrăcăminte: un studiu de caz bazat pe un producător de pantaloni tip jeans din India**

*Scopul acestui studiu a fost de a analiza pierderea normală și anormală a unei companii producătoare de pantaloni tip jeans din India. Interviul personal și metoda de observare sunt utilizate în acest studiu. Pierderea anormală în cantitate și valoarea rupiei este calculată pentru 40 de zile de producție pe baza datelor observate. Pierderile medii anormale sunt calculate și un test t pentru un eșantion este aplicat pentru a testa ipotezele că pierderea medie anormală nu este egală cu zero. Studiul a arătat că pierderea normală de 3 până la 5% este de așteptat în orice companie producătoare de articole de îmbrăcăminte din cauza pierderii în timpul procesului de tăiere și contracție. Valorile p ale testului t pentru un eșantion au fost mai mici de 0,05 pentru toate ipotezele testate, prin urmare, toate ipotezele nule ($H_{01}$ până la $H_{05}$ înseamnă pierderi anormale egale cu zero) au fost respinse. În plus, s-a constatat că țesătura contribuie cel mai mult la pierderile anormale. Prin urmare, se recomandă pregătirea adecvată a lucrătorilor și recrutarea lucrătorilor instruiți pentru a reduce pierderile anormale.*

***Cuvinte-cheie**: producție de pantaloni tip jeans, industria textilă, pierderi anormale, pierderi normale, îmbrăcăminte, modă, volatilitate, performanță financiară*

## INTRODUCTION

India is the world's second-largest garment and apparel producer. With its 5% contribution to global trade, India is the world's second-largest garment and apparel exporter. India's textile and apparel exports including handicrafts increased marginally from US$ 39.2 billion in 2017–2018 to US$ 40.4 billion in 2018–2019 which is 3%. However, India's global market share is well behind China which controls about 38% of the global textile and apparel trade. Textile and clothing exports accounted for 12% of India's overall exports in 2018–2019. In the fiscal year, 2018-2019 India's textiles industry contributed 7% of total industry production (by value). In the fiscal year, 2018–2019 the Indian textiles and apparel industry contributed 2% to Gross Domestic Product, 12% to export earnings and 5% to the global textiles and apparel trade. In the last 5 years, the textiles industry has seen a surge in investment. From April 2000 to September 2020 the industry received $3.46 billion in foreign direct investment [1].

Even though the Indian garment industry outlook is lucrative, the instability in the cost of production has made the companies disclose inconsistent numbers. Several business dailies and academic journal papers have discussed the impact of volatile raw material prices on the performance of textile and garment manufacturing companies in India. For example, Aggarwal [2], Hawaldar et al. [3], Jha [4], and

Meher et al. [5] stated that the textile and garment manufacturing companies are using petrochemical raw materials as their core material and as the crude oil price is highly volatile in the market, the garment and textile companies financial performance are not stable. Hence, an efficient cost management and cost control technique is the need of the hour for garment companies to manage to stabilize their financial performance. This work aims to analyse the normal and abnormal losses in the production process of garment manufacturing companies, jeans in particular.

## LITERATURE REVIEW

Keane and te Velde [6] stated that the textile and garment industries play a vital role in the development of emerging economies because they provide employment and income for both the male and female working population of the country. Abraham & Sasikumar [7] mentioned that the agreement on textile and clothing (ATC) of the world trade organization (WTO) has made both positive and negative impact on the Indian textile industry. To successfully compete in the international markets, textile markers in India have to focus on cost-cutting strategies and efficiency-building techniques. Cost management and product innovation are must for textile producers around the globe [8–10] opined that the unit cost is the major competitive factor for textile and garment manufacturing companies. He further stated that efficient utilization of raw material will yield profit, however, most textile entities are experiencing diseconomies of scale because of stringent labour laws. Choudhary [11] stated that production cost in textile companies has to be predicted and managed effectively to compete in the wholesale and retail markets. Using a case study and action research methodology, Becker [12] has tried reducing the cost variance. More accurate sketches and costing from the designers are advised to minimize the cost variance.

Akeem [13] and Stan et al. [14] stated that the proper budgetary control techniques may help manufacturing companies manage their cost-effectively. Aaron [15] has made a comparative cost analysis between the bundle and modular method of apparel production and the study revealed that modular production is better for apparel manufacturing, however, the commitment of supervisors and management is very much crucial. The cost analysis of textile industries using lean manufacturing systems was studied by some authors [16, 17]. The above-stated studies have discussed the need for cost analysis in the textile and garment business, and comparative cost analysis in different manufacturing systems. However, the study on normal and abnormal loss analysis in garment manufacturing companies is not covered so far in the academic literature. On the other hand, Ullal et al. [18] suggested that "future in the services industry belongs to Artificial Intelligence (AI) driven machines".

## DATA AND RESEARCH METHODOLOGY

Personal interview and observation methods were used to collect the primary data for this study. The production manager and supervisors are the key respondents for our production process and cost-related discussions. The daily production process was observed for 40 working days and the abnormal loss estimations were made at the end of each working day. The company manufactures five different sizes of jeans pants; they are 30, 32, 34, 36 and 38 inch in the ratio of 0.15:0.25:0.25:0.25:0.15 respectively. The installed capacity of the plant is to produce a maximum of 1000 pants per day, whereas the actual productions use to vary between 800 to 1000 pants on a daily base on the availability of workers. The normal loss was measured based on the standard expected loss % given by the production manager. In the cutting and washing process of the material, a normal loss of 3 to 5% is expected. Abnormal losses are estimated for 40 days of production and the mean abnormal loss values are computed for each size of pants. Further, one sample t-test is used to test the hypothesis that the mean abnormal loss is not equal to zero. In this study following hypotheses are developed and tested.

$H_{01}$: The mean abnormal loss value in 30-size jeans production is significantly equal to zero.

$H_{02}$: The mean abnormal loss value in 32-size jeans production is significantly equal to zero.

$H_{03}$: The mean abnormal loss value in 34-size jeans production is significantly equal to zero.

$H_{04}$: The mean abnormal loss value in 36-size jeans production is significantly equal to zero.

$H_{05}$: The mean abnormal loss value in 38-size jeans production is significantly equal to zero.

## ANALYSIS AND DISCUSSIONS

Figure 1 shows the production process of the selected jeans manufacturing company. The production manager stated that the normal loss of 3 to 5 % occurs in the shrinkage, cutting and sewing process which are the 2$^{nd}$ and 5$^{th}$ stages of the production

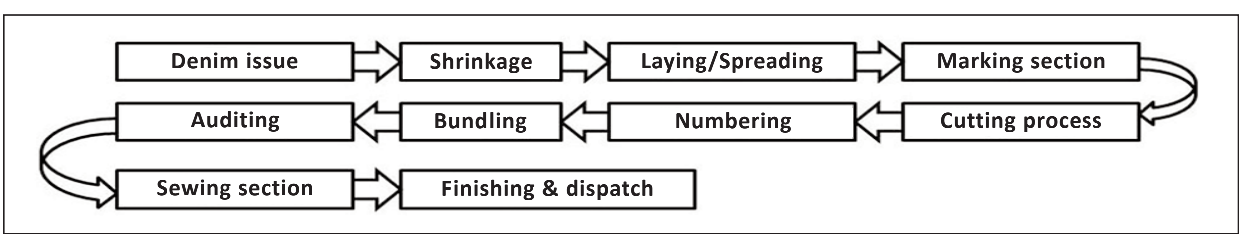


Fig. 1. The production process of the selected jeans manufacture

Table 1

| ONE SAMPLE T-TEST STATISTICS | | | | | | |
|---|---|---|---|---|---|---|
| **Pant size** | **Quantity/Value in Rs** | **t** | **df** | **p-value** | **Mean** | **Mean difference** |
| 30 | Abnormal loss in quantity | 3.365 | 39 | 0.002 | 0.30 | 0.30 |
| | Abnormal loss in value | 3.365 | 39 | 0.002 | 180.00 | 180.00 |
| 32 | Abnormal loss in quantity | 3.557 | 39 | 0.001 | 0.35 | 0.35 |
| | Abnormal loss in value | 3.557 | 39 | 0.001 | 210.00 | 210.00 |
| 34 | Abnormal loss in quantity | 2.726 | 39 | 0.010 | 0.20 | 0.20 |
| | Abnormal loss in value | 2.726 | 39 | 0.010 | 120.00 | 120.00 |
| 36 | Abnormal loss in quantity | 2.449 | 39 | 0.019 | 0.20 | 0.20 |
| | Abnormal loss in value | 2.449 | 39 | 0.019 | 120.00 | 120.00 |
| 38 | Abnormal loss in quantity | 3.557 | 39 | 0.001 | 0.35 | 0.35 |
| | Abnormal loss in value | 3.557 | 39 | 0.001 | 210.00 | 210.00 |

process. This normal loss is an unavoidable loss, which goes as a corner or border piece while cutting the denim material. The cutting process in the selected company is semi-automated; the hand scissors and computer-operated straight knife machine are used for the cutting purpose. The supervisors stated that the hand scissors are very much essential for a particular shape and pattern cuttings, however, the major errors which lead to abnormal loss come from this method of cutting. The sewing section also contributes to the abnormal loss; however, the errors in the higher size products will not go to waste because they can be adjusted with lower size pants. Hence, the abnormal loss contribution from this section is less compared to the cutting section:

The collected abnormal loss data and normal loss computations are presented in the annexure section. The one sample t-test statistics and mean values of all 40 days of abnormal loss in quantity and rupee value are presented in table 1. t is the t-statistic value, df is the degrees of freedom, and the p-value is the probability value.

The p-values of all one sample t-tests are less than 0.05 indicating that the abnormal loss values and quantity are significantly different from zero. As the test value was equal to zero, the mean and mean difference values for the entire test are equal. The proportions of different costs that add up to give the abnormal cost value in the analysis are 50 percent for raw materials, 20 percent for direct labour, 20 percent for indirect labour and 30 percent for factory overheads. Fabrics, sewing thread, trims and accessories (button, zipper, fusible interlining, embroidery, bidding, stickers, narrow fabrics, motifs and so on) are among the raw materials used in the garment. However, the fabrics account for 80% of the cost of raw materials. All other materials are also essential for the production of jeans, the fabric, as the most significant cost factor, must be properly handled. As cutting is the most common source of fabric waste in various garment manufacturing processes, this material has to be handled carefully. Much attention should be paid to the cutting room to reduce fabric waste.

## CONCLUSION

The objective of this study was to examine the normal and abnormal losses at selected jeans manufacturers in India. The direct interaction with the production manager revealed that the normal loss of 3 to 5% is common in any garment or textile manufacturing company, which is because of the cutting and shrinkage process. Further after 40 days of production observation, we have computed the abnormal loss in units and rupee value for each day's production. The defects caused abnormal losses were found on the majority of days. One sample t-test significantly proves that the abnormal loss is not equal to zero. Further, it was found that fabric is the big contributor in terms of abnormal loss. Specifically, the errors in cutting and sewing fabrics lead to abnormal losses. An in-depth examination of fabric losses during the cutting and sewing process may help in reducing material waste. Proper training for workers and recruiting trained workers may also help in reducing abnormal losses.

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# Determining the optimal product mix in multiple constraints manufacturing environment: an application in the textile industry

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**ABSTRACT – REZUMAT**

**Determining the optimal product mix in multiple constraints manufacturing environment: an application in the textile industry**

*Theory of constraints (TOC) is an approach to production planning and control by focusing on the constraints of an organization to increase throughput by effectively managing constraints. TOC approach has been applied in many sectors, and efficient results have been taken. One of the application areas of TOC is product mix decisions. Product mix decisions are important for multi-product manufacturing systems because they affect the performance measures of the companies. This study aims to present how TOC is applied to determine the optimum product mix in a multiple-constraint environment in the textile industry. To achieve this, we first select three basic products of a textile company and examine the production processes of these products from TOC perspective. Next, we perform a bottleneck process and identify three bottlenecks for the problem. Then, based on our bottleneck process results, we generate three scenarios. Upon assessing these scenarios, we determine the most appropriate product mix by implementing the TOC approach. Finally, we employ a goal programming approach to solve the product mix problem and compare its results with those obtained by the TOC.*

***Keywords:*** *theory of constraints, product mix, multiple constraints, goal programming, textile industry, Turkey*

**Determinarea combinației optime de produse în mediul de producție cu constrângeri multiple: o aplicație în industria textilă**

*Teoria constrângerilor (TOC) este o abordare a planificării și controlului producției prin concentrarea pe constrângerile unei organizații, pentru a crește randamentul prin gestionarea eficientă a acestora. Abordarea TOC a fost aplicată în multe sectoare și s-au obținut rezultate eficiente. Unul dintre domeniile de aplicare ale TOC este reprezentat de deciziile legate de combinația de produse. Deciziile privind combinația de produse sunt importante pentru sistemele de producție, deoarece afectează măsurile de performanță ale companiilor. Acest studiu își propune să prezinte modul în care se aplică TOC pentru a determina combinația optimă de produse într-un mediu cu constrângeri multiple din industria textilă. Pentru a realiza acest lucru, selectăm mai întâi trei produse de bază ale unei companii textile și examinăm procesele de producție din perspectiva TOC. Apoi, efectuăm un proces de blocaj și identificăm trei blocaje pentru această problemă. Apoi, pe baza rezultatelor procesului nostru de blocaj, generăm trei scenarii. După evaluarea acestor scenarii, determinăm cea mai potrivită combinație de produse prin implementarea abordării TOC. În cele din urmă, folosim o abordare de programare a obiectivelor pentru a rezolva problema combinației de produse și a compara rezultatele acesteia cu cele obținute prin TOC.*

***Cuvinte-cheie****: teoria constrângerilor, combinația de produse, constrângeri multiple, programarea obiectivelor, industria textilă, Turcia*

## INTRODUCTION

The theory of constraints (TOC) is a business management approach that evaluates firms as a system and states that each system has at least one constraint and that the power of the systems is as much as the strength of its constraint. For profitability, these constraints must be correctly identified, managed, and monitored continuously concerning different criteria [1].

Product mix decisions, which have a significant impact on the profitability of the company, are one of the most important decisions faced by production companies [2]. The product mix problem contains determining the quantity of each product within the product portfolio of the company. The main structure of the problem is to maximize profit from the mix of manufactured products linked to constraints on the available capacity of resources [3].

The product mix decision problem is one of the important applications of the TOC's ongoing improvement process. Extensive research has been performed to determine the best product mix for profit maximization [2]. A company has at least one constraint which limits the company from achieving the best performance and maximum profit. A constraint is defined as "a thing that prevents making money of a system/organization" [4]. When a company has capacity constraints, capacity is limited, it can't manufacture every unit of product that the market demands. In this case, the best action is to concentrate on the company's most profitable products and to utilize all of the company's available resources to produce these products. As a result, the company will be able to boost its profitability by utilizing its existing resources to develop the most profitable products [5].

The TOC approach is a widely used method to determine the product mix of a company. This approach was used in many sectors such as the TFT-LCD industry [6], furniture sector [7], birds' food production sector [8], etc. When the literature was investigated, there is not any study conducted in the textile industry on the product mix problem. Therefore, one aim of this study is to show how the TOC approach can be used in the textile industry to determine product mix.

Most of the studies related to product mix problems have used data provided from previous studies such as de Soza et al. proposing an approach [9] and testing this approach on data provided by Fredendall and Lea [5]. Sobreiro and Nagano evaluated the heuristics of Fredendall and Lea [10] and Aryanezhad and Komijan [11] and proposed a new heuristic [12]. Tanhaei and Nahavandi [13] used a goal programming approach for the product mix problem defined by Hsu and Chung [14]. Another aim of this study is to use real-world data provided by a textile company.

In the literature, many studies about product mix were performed in a single constraint environment. There exist only a few studies that incorporate multi-constraints [13, 15–17]. Another aim of this study is to contribute to the TOC applications performed in multi-constraint environments.

In this study, our main ambition is to investigate the impact of identifying and eliminating constraints that arise during the production process in terms of profitability. To achieve this, the application of a production company performing in the textile industry was questioned to determine whether (*i*) there exist constraints that limit the effectiveness of the company, (*ii*) these constraints that arise during the production process can be eliminated, and (*iii*) these constraints will affect the profitability of the company. In this study, we use the TOC methodology and goal programming approach in the context of a multi-constraint manufacturing environment.

## GENERAL INFORMATION

The basic argument of TOC is that constraints determine the performance of a firm, and each system has at least one constraint [18]. TOC is a management approach defending which constraints must be eliminated because of limiting the performance of enterprises, and that constraints have negative impacts on performance. TOC is a systematic approach focused on the identification and elimination of constraints for continuous development [19].

Goldratt defined a simple Five Focusing Steps (5FSs) process for achieving continuous improvement. These five steps are explained in detail in the literature [2, 19]. TOC's 5FS are as follows:

1. Identify the system's constraint(s).
2. Decide how to exploit the system's constraint(s).
3. Subordinate everything else to the above decision.
4. Elevate the constraint(s).
5. If, in the previous steps, a constraint has been broken, go back to Step 1.

There are different approaches in the literature regarding the classification of constraints. According to Louderback and Patterson [20], constraints are divided into two groups internal constraints and external constraints. Internal constraints are production capacity, operating policies, and the working environment. External constraints are market share, legal restrictions, etc. [20].

The new performance criteria are improved in cost distribution by changing cost and management conceptions in enterprises. Performance measures are divided into two groups; financial measures and operational measures. While financial measures are net profit, investment profitability, and cash flow, operational measures are throughput, inventory, and operating expenses [21].

Net Profit (NP): Net profit is an absolute measure of whether the firm makes money or not.

Investment Profitability (ROI): Investment profitability is a proportional measure of a firm's target of earning money.

Cash flow: The amount of money available for the company to meet its financial obligations.

Throughput (T): It is the money rate the firm gains through sales. Goldratt described throughput as the difference between the sales price of the unit product and the direct first material cost.

Inventory (I): Inventory "represents the whole money that the firm deposit to things bought to sell." Unlike other approaches, in TOC, inventory is described as an entity, not as a source. Inventories are evaluated by the cost of the raw materials. Labour costs and general production expenses are not included in variable costs. According to this, buildings, and vehicles are included in product and semi-finished product inventories [22, 23].

Operating Expenses (OE): Operating expenses represent the whole money that the firm spends to transform inventory into a product. In TOC, expenses are defined according to sales volume, not to production volume. Operating expenses include general administrative expenses, direct labour costs, general production expenses, marketing, sales, and distribution costs.

The product mix problem is widely acknowledged as one of the most critical decision problems of a production system. It is not possible to meet the demand for all items due to capacity limits.

Therefore, companies need to decide on the appropriate quantities of suitable products to participate in the production plan to achieve the desired profit [24]. The issue of product mix includes deciding the volume and mix of products to maximize profit within constraints of production resources and the capacity of constraints. Although the integer linear programming method can optimize the product mix, it is not always easy and fast to formulate and solve a mathematical model [25]. The product mix is an NP-hard problem because of the complexity of the product mix decision problem.

The TOC-based approach is frequently used in place of or in addition to optimization tools such as the contribution margin per constraint unit method or linear programming approaches as a tool for product mix selections. Many articles published since the early 1990s have been used in several similar examples to analyse the quality of the TOC-based approach for possible product mix decisions compared to other tools [26]. Table 1 provides a literature review of the product mix based on the TOC approach.

Table 1

LITERATURE SUMMARY ABOUT PRODUCT MIX BASED ON THE TOC APPROACH

| Author(s) of the study | The main scope of the study |
|---|---|
| Onwubolu | A heuristic approach to a Tabu search-based TOC to identify the nearly optimal product mix for minor problems [27]. |
| Onwubolu and Muting | A TOC procedure based on a genetic algorithm to solve product mix problems [28]. |
| Lea and Fredendall | Effects of production performance on management accounting systems and methods of determining product mix [29]. |
| Aryanezhad and Komijan | The TOC-heuristic method with Linear Programming, an algorithm that determines the product mix (TOC-AK) [11]. |
| Mishra et al. | A taboo search and simulated annealing hybrid approach to determine the product mix in a multi-constraint environment [30]. |
| Souren, Ahn and Schmitz | Several samples with modifications of the same basic sample, investigate optimal product mix decisions using a TOC-based approach [26]. |
| Wang, Du and Wen | Mixed Integer Linear Programming to define a product mix for the TFT-LCD industry, taking into account profit, efficiency, raw material supply, and market demand [6]. |
| Chaharsooghi and Jafari | A simulated annealing algorithm to determine the product mix [31]. |
| Hasuike and Ishii | A flexible mix of problems using TOC and an efficient solution method using two stochastic programming models, namely the probability fractional optimization model and the probability maximization model [32]. |
| Wang, Sun and Yang | An optimization approach based on an immunity algorithm and TOC for product mix on problems of small-scale or large-scale samples (100 items and 50 resources) [33]. |
| Ray, Sarkar, and Sanyal | The combined use of TOC and analytical hierarchy process in product mix problems [16]. |
| Susanto and Bhattacharya | Negotiated fuzzy multipurpose linear programming approach to determine the product mix of an eight-product chocolate production company by assuming the objective coefficients with fuzzy numbers [34]. |
| de Soza et al. | An algorithm that determines the initial solution based on the RTOC presented by Fredendall and Lea [9]. |
| Sobreiro and Nagano | Evaluated the heuristics of Fredendall and Lea [31] and Aryanezhad and Komijan [22] and proposed a new and better constructive heuristic based on the TOC and the Backpack Problem [12]. |
| Tanhaei and Nahavandi | The improved TOC approach determines the optimal product mix in a two-constraint resource environment [15]. |
| Badri, Ghazanfari, Shahanaghi | The product mix problem with range parameters and proposed a multi-criteria decision-making approach to determine the TOC-based product mix [25]. |
| Sobreiro, Mariano and Nagano | A throughput per day approach to define product mix by a constructive heuristic based on Integer Linear Programming and heuristics-based in TOC [10]. |
| Golmohammadi and Mansouri | A new mixed-integer programming (MIP) model by considering product mix problem and scheduling simultaneously (COLOMAPS) [35]. |
| Okutmus, Kahveci and Kartašova | The constraint-based resource utilization approach to determine the optimal product mix in the furniture sector [7]. |
| Tanhaie and Nahavandi | A methodology using of goal programming and pair-wise comparison to determine the product mix of the production system in multiple bottlenecks environment [13]. |
| Zhuang and Chang | A mixed-integer programming (MIP) model, based on the time-driven activity-based costing (TDABC) accounting system [36]. |
| Mohammed and Kassam | A Model using two linear programming models based on TOC to determine the product mix of a bird's food production facility [8]. |
| Wang et al. | They clarified the cases under which the AHP (Analytical Hierarchy Process) / TOC method can and cannot output the optimal solution in multi constraint environment [17]. |

## METHOD AND MATERIAL

### Method

The product mix was determined based on multiple objectives which were maximizing throughput and maximizing bottlenecks exploitation. Considering TOC's 5FS, to determine the optimal, the following steps should be performed [10, 37]:

1. Identify the system's constraint(s) by calculating the necessary capacity in each source to manufacture all products: the only constraint of the system is resources that its market demand to increase in capacity or its available capacity is smaller than its requested capacity.
2. Decide how to explore the system's constraint(s): the constraint should be explored by observing the throughput of each product for each consumed unit time of the constraint of the system.

The first, the TOC algorithm was suggested by Tanhaei and Nahavandi [15]. For the second step, the TOC algorithm and goal programming (GP) approach explained by Tanhaei and Nahavandi [13] were used in this study. The structural framework of the study is presented in figure 1.

Notations used in the methodology are presented in table 2.

Table 2

| PARAMETERS | |
|---|---|
| **Notation** | **Explanation** |
| $i$ | Product index $i$ = 1, 2, …, $n$ |
| $j$ | Resource index $j$ = 1, 2, ..., $m$ |
| $k$ | Bottleneck index $k$ = 1, 2, …, $r$ |
| $r$ | Number of bottlenecks |
| $X_i$ | Production quantity of product (unit) |
| $RM_i$ | Raw material cost of product *I* (₺/ unit) |
| $D_i$ | Demand of product *i* (unit) |
| $P_i$ | Selling price of product *I* (₺/unit) |
| $CP_j$ | Capacity of resource *j* (min.) |
| $L_j$ | Load (Required capacity) of resource *j* (min.) |
| $d_j$ | Difference between available capacity and required capacity of the resource (min.) |
| $t_{ij}$ | Unit production time of product i in resource *j* (min./unit) |
| $BN_k$ | Bottlenecks |
| $T_i$ | The throughput of product *i* (₺/unit) |
| $T_{i(B1k)}$ | The throughput per constraint resource time of BNk (₺/unit*min.) |
| $NP$ | Net profit (₺/unit) |
| $OE$ | Operating Expenses (₺) |
| $G_s$ | Objective functions for maximizing bottlenecks exploitation |
| $G_{r+1}$ | Objective function for maximizing throughput |
| $W_s$ | Importance of objective function |
| $f_s$ | Positive deviation from goal *s* |
| $s$ | Number of objective functions |

*TOC based product mix methodology*

Steps of the TOC-based product mix methodology adapted from Tanhaei and Nahavandi [15] for multiple constraints are presented as follows.

**Step 1.** Identifying system constraints.

Calculate the total load for each resource as follows:

$$L_j = \sum_{i=1}^{m} D_i t_{ij} \tag{1}$$

Then calculate $d_j$ which is the difference between a resource's capacity ($CP_j$) and its total load as follows:

$$d_j = CP_j - L_j \tag{2}$$

where If $d_j \leq 0$ or $d_j$ has a negative value and this resource has overload, it is a constraint, otherwise it is non-constraint. Determine the set of constraint resources (*CR*). Here *BN*1 is the main constraint, *BN*2 is the second constraint, etc. *CR* = {*BN*1,…, *BNk*}

**Step 2.** Decide how to exploit the system's constraint(s). Determine the throughput for each product i is determined as follows.

$$T_i = P_i - RM_i \tag{3}$$

Then, determine the throughput per constraint resource time of *BN*1 for each product *i* as follows:

$$T_{iBN1} = \frac{T_i}{t_{iBN1}} \qquad i = 1, 2, ..., n \tag{4}$$

determine the production priority of products by sequencing products according to $T_{iBN1}$ descending. Determine the production quantity of products ($X_i$) at the point of demand of each product and the available capacity of *BN*1. Calculate the load on *BNk*+1 for the product mix determined as follows:

$$L_{BNk+1} = \sum_{i=1}^{r} t_{BNk+1}\, x_i \tag{5}$$

If $L_{BNk+1} \leq CP_{BNk+1}$, the product mix determined is optimal and stopped. If $L_{BNk+1} > CP_{BNk+1}$, Repeat Steps 2 for *BNk*+1. Determine the throughput per constraint resource time of *BNk*+1 for each product *i* as follows:

$$T_{(iBNk+1)-} = \frac{T_i}{t_{iBNk+1}} \qquad i = 1, 2, ..., n \tag{6}$$

repeat Step 2 for *BNk*+1.

Calculate the profit of the company according to the determined product mix as follows:

$$NP = \sum_{i=1}^{n} (T_i\, x_i - OE_i) \tag{7}$$

*Goal programming model*

GP Model for the product mix suggested by Tanhaei and Nahavandi [13] is explained in the following. Equations 8 and 9 show how the product mix model maximizes bottleneck utilization and throughput 9. Equation 10 determines that the total process time of all products at resource *j* does not exceed resource *j*'s capacity, and equation 11 determines that the output amount of product *i* does not exceed the product *i*'s demand.

$$G_s = max\left(\sum_{i=1}^{n} x_i\, t_{ij}\right) \tag{8}$$

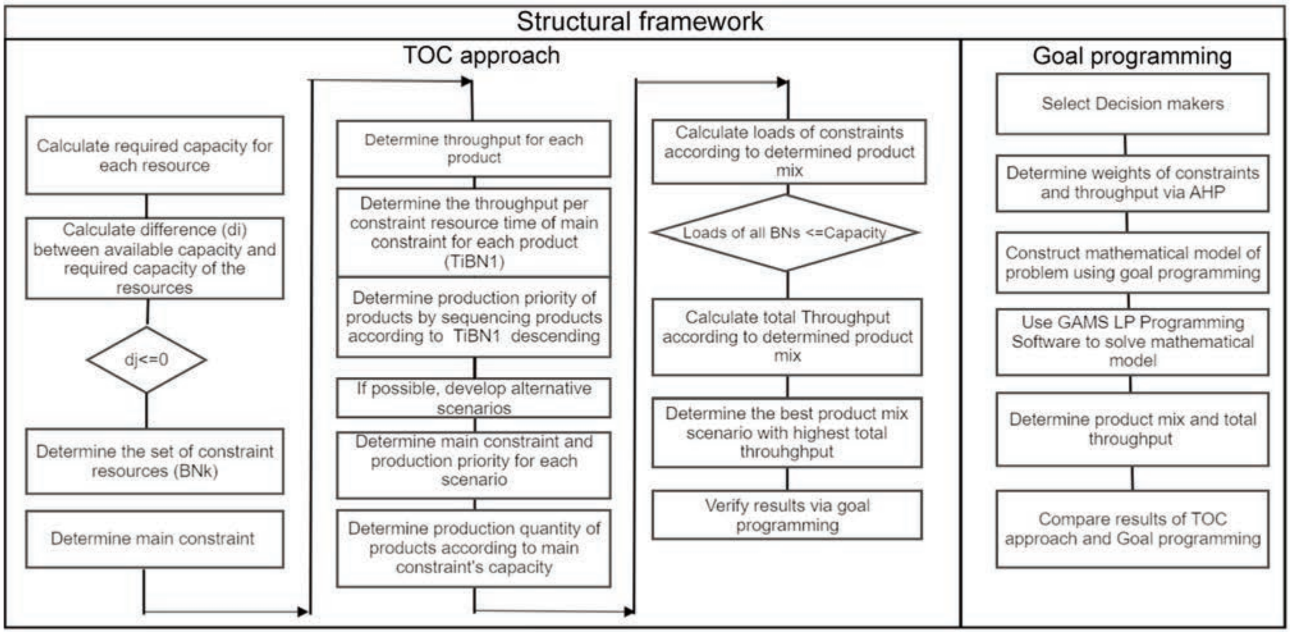


Fig. 1. The structural framework of the study

$$G_s = max\left(\sum_{i=1}^{n} x_i\, t_{ij}\right) \quad (9)$$

Subject to

$$\sum_{i=1} L_j \leq CP_j, \quad j = 1, 2, \ldots, m \quad (10)$$

$$0 \leq x_i \leq D_i \quad (11)$$

The model is solved by using GP, and fs refers to deviations from targets. Equation 12 demonstrates how deviation from objectives could be reduced by explicitly including the positive deviation in the model's objective function, that is, it means minimizing the sum of the deviations from the targets. $W_s$ demonstrates the weights of objectives that should be ascribed to variable $f_s$ as determined by the decision-maker. $W_s$ values can be determined via AHP.

Hence, the final model is given as follows: equation 13 determines the usage of constraints in possible maximum capacity. Equation 14 determines achieving to possible maximum throughput. Equation 15 determines that the total process time of all products at non-constraint resources. Equation 16 represents, the production quantity of product *i* does not exceed its demand.

$$min\left(\sum_{s=1}^{r+1} W_s\, f_s\right) \quad (12)$$

Subject to

$$\sum_{i=1}^{n} x_i\, t_{ij} + f_s = CP_s, \quad j, s = 1, 2, ..., r \quad (13)$$

$$\sum_{i=1}^{n} x_i\, L_i + f_{r+1} = \sum_{i=1}^{n} D_i\, T_i \quad (14)$$

$$\sum_{i=1}^{n} x_i\, t_{ij} \leq CP_j \quad if \;\; r < j < m \quad (15)$$

$$0 \leq x_i \leq D_i \quad (16)$$

**Material**

XYZ Company mainly manufactures three kinds of products including suits, jackets, and trousers in the Istanbul factory in Turkey. The firm manufactures about 19 products in different concepts as outsourced to the firms in domestic and abroad. At the same time, it also keeps under the control of the global brand products of Turkey, the Middle East, Africa, and Russian markets. The unit sales price of the suit, jacket and trousers are ₺700, ₺500 and ₺250 respectively while their weekly demand is 700, 800 and 600 units.

Cost information of the products manufactured in the factory is presented in table 3. According to TOC, all costs except direct raw materials and supplies are considered operating expenses. Direct raw material expenses of the products, direct labour expenses, operating expenses, sales prices, and demands of the products are given in table 3.

In XYZ Company, the production process contains eight steps which are Mold/Model Preparation, Slaughterhouse, Fusing/Labelling, Jacket Production, Pants Production, Ironing, Quality Control, and Mapping/Packaging. The processing times of each product in production processes are given in table 3.

## RESULTS

### Identifying the system constraints

Firstly, loads of resources are calculated, and then loads and available capacities are compared to identify the constraints. The required capacity of resources ($L_j$) to produce 700 suits, 800 jackets, and 600 trousers was calculated, and then, the difference ($d_j$) between the resource's available capacity and its required capacity is calculated. Resources which is $L_j > CP_j$ are determined as constraints or bottlenecks. As can be seen from table 4, the company has three constraints: Slaughterhouse (*BN*1), Model Preparation (*BN*2), and Ironing (*BN*3). The company will not be able to meet customer demands, because of these constraints. Slaughterhouse is the main

Table 3

| UNIT PROCESSING TIME IN PRODUCTION PROCESSES AND COST INFORMATION OF THE PRODUCTS | | | |
|---|---|---|---|
| **Processes** | **Suit** | **Jacket** | **Trousers** |
| Model preparation (min/unit) | 2.05 | 1.26 | 0.79 |
| Slaughterhouse (min/unit) | 2.01 | 1.54 | 0.47 |
| Fusing/Labelling (min/unit) | 0.99 | 0.65 | 0.34 |
| Sewing I (min/unit) | 1.54 | 1.54 | - |
| Sewing II (min/unit) | 1.23 | - | 1.23 |
| Ironing (min/unit) | 1.84 | 1.3 | 0.54 |
| Quality control (min/unit) | 1.5 | 0.95 | 0.55 |
| Combining/Packaging (min/unit) | 1.4 | 0.8 | 0.6 |
| Direct raw materials expenses (₺/unit) | 220 | 133 | 72 |
| Direct labour expenses ((₺/unit) | 67.2 | 44.5 | 32.0 |
| Variable operating expenses (₺/unit) | 134.3 | 79.3 | 55.0 |
| Fixed operating expenses (₺) | 119,000.0 | 75,250.0 | 41,750.0 |
| Sales price (₺/unit) | 700 | 500 | 250 |
| Demand (unit) | 700 | 800 | 600 |

constraint with the largest $d_j$ value (521) and the bottleneck. Firstly, the company should focus on Slaughterhouse (*BN*1). But Model Preparation (*BN*2) has very close values with Slaugherhouse (*BN*1), we have two alternatives to manage constraints.

**Decide how to exploit the system's constraints**

At this step, firstly, unit throughputs per product ($T_i$) are calculated and then throughput rates per constraint times ($Ti_{(BN1)}$) for products are calculated based on *BN*1. $Ti_{(BN1)}$ values are ordered in descending order. Thus production priorities of products are defined as Trousers, Suit, and Jacket accordingly based on $Ti_{(BN1)}$ values as seen in table 5.

Because $Ti_{(BN1)}$ values of Suit and Jacket are very close values, we have second alternative production priority as Trousers, Jacket and Suit.

According to tables 4 and 5, the above explanations, we determined three scenarios. Based on Scenario 1, the main constraint is Slaughterhouse (*BN*1), and the Production priority is Trousers, Suit, and Jacket. Based on Scenario 2, the main constraint is Slaughterhouse (*BN*1), and the Production priority is Trousers, Jacket and Suit. Based on Scenario 3, the main constraint is Model Preparation (*BN*2), Production priority is Jacket, Suit, and Trousers which are determined in table 6.

For three Scenarios, product mixes are determined as seen in table 7. The manufacturing quantity of the

Table 4

| DETERMINING SYSTEM CONSTRAINTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Model preparation** | **Slaughter house** | **Fusing/ Labelling** | **Sewing I** | **Sewing II** | **Ironing** | **Quality control** | **Combining/ Packaging** |
| $CP_j$ (min.) | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 | 2400 |
| $L_j$ (min.) | 2917 | 2921 | 1417 | 2310 | 1599 | 2652 | 2140 | 1980 |
| $d_j$ (min.) | -517 | -521 | 983 | 90 | 801 | -252 | 260 | 420 |
| CP Rate | 1.215 | 1.217 | 0.590 | 0.962 | 0.666 | 1.105 | 0.892 | 0.825 |
| Bottleneck | BN2 | BN1 | - | - | - | BN3 | - | - |

Table 5

| PRODUCTION PRIORITY OF PRODUCTS BASED ON BN1 | | | | | | |
|---|---|---|---|---|---|---|
| **Product (i)** | **$P_i$ (₺/unit)** | **$RM_i$ (₺/unit)** | **$T_i$ (₺/unit)** | **$t_{i(BN1)}$ (min.)** | **$T_{i(BN1)}$ (₺/unit*min.)** | **Production priority** |
| Suit | 700 | 220 | 480 | 2.01 | 238.806 | 2 |
| Jacket | 500 | 133 | 367 | 1.54 | 238.312 | 3 |
| Trousers | 250 | 72 | 178 | 0.47 | 378.723 | 1 |

Table 6

| PRODUCTION PRIORITY OF PRODUCTS BASED ON BN2 FOR SCENARIO 3 | | | | | | |
|---|---|---|---|---|---|---|
| **Product (i)** | **$P_i$ (₺/unit)** | **$RM_i$ (₺/unit)** | **$T_i$ (₺/unit)** | **$t_{i(BN2)}$ (min.)** | **$T_{i(BN2)}$ (₺/unit*min.)** | **Production priority** |
| Suit | 700 | 220 | 480 | 2.01 | 234.15 | 2 |
| Jacket | 500 | 133 | 367 | 1.54 | 291.27 | 1 |
| Trousers | 250 | 72 | 178 | 0.47 | 225.32 | 3 |

Table 7

| DETERMINING PRODUCT MIX FOR THREE SCENARIOS | | | | | | |
|---|---|---|---|---|---|---|
| **Parameter** | | **Suit** | **Jacket** | **Trousers** | **Capacities** | Demand:<br>Suit: 700 unit<br>Jacket: 800 unit<br>Trousers: 600 unit |
| Unit processing Times (min/unit) | BN1 | 2.01 | 1.54 | 0.47 | 2400 min. | |
| | BN2 | 2.05 | 1.26 | 0.79 | 2400 min. | |
| | BN3 | 1.84 | 1.3 | 0.54 | 2400 min. | |
| Scenario 1 | | | | | | |
| Main Constaint: BN1<br>Priority<br>1. Trousers<br>2. Suits<br>3. Jacket | Required capacity for 600 Trousers (min) | 600 × 0.47 | = | 282 | | Product Mix<br><br>Trousers: 600 unit<br>Suits: 700 unit<br>Jacket: 461.7 unit |
| | Left capacity of BN1 for suits (min.) | 2400 – 282 | = | 2118 | | |
| | Required capacity for 700 suits (min.) | 700 × 2.01 | = | 1407 | | |
| | Left capacity of BN1 for jacket (min.) | 1407 – 711 | = | 711 | | |
| | Jacket Quantity (unit) | 711/1.54 | = | 461.7 | | |
| Scenario 2 | | | | | | |
| Main Constaint: BN1<br>Priority:<br>1. Trousers<br>2. Jacket<br>3. Suit | Required capacity for 600 Trousers(min.) | 600 × 0.47 | = | 282 | | Product Mix<br><br>Trousers: 600 unit<br>Jacket: 800 unit<br>Suits: 440.8 unit |
| | Left capacity of BN1(min.) | 2400 – 282 | = | 2118 | | |
| | Required capacity for 800 unit jackets(min.) | 800 × 1.54 | = | 1232 | | |
| | Left capacity of BN1 to produce jacket(min.) | 2118 – 1232 | = | 886 | | |
| | Suit Quantity(unit) | 886/2.01 | = | 440.8 | | |
| Scenario 3 | | | | | | |
| Main Constraint: BN2<br>Priority:<br>1. Jackets<br>2. Suit<br>3. Trousers | Required capacity for 800 unit Jackets (min.) | 800 * 1.26 | = | 1008 | | Product Mix<br><br>Jacket: 800 unit<br>Suits: 679 unit<br>Trousers: 0 |
| | Left capacity of BN2 for suit (min.) | 2400 – 1008 | = | 1392 | | |
| | Suit quantity (unit) | 1392 / 2.05 | = | 679.0 | | |

products based on their priorities is determined concerning the available capacity of the main constraint and demand of each product.

In multi constraints environment, all constraints should be eliminated, and then total throughput and net profit should be calculated. From this viewpoint, three scenarios were evaluated if all constraints are eliminated or not with the determined product mix. Evaluations of three scenarios are presented in table 8. In table 8, according to the determined product mix, the required capacity is calculated for three constraints to understand if constraints remain as constraints or not. For Scenario 1, the product mix is determined as 600 Trousers, 700 Suits, and 461.7 Jackets. Based on Scenario 1, BN1 and BN3 are not constraints because their loads are lower than 2400. BN2 is still a constraint because its load is higher than its capacity (2772.7 > 2400). It needs 372.7 minutes of extra capacity. Therefore, total throughput does not be calculated.

For Scenario 2, the product mix is determined as 600 Trousers, 800 Jackets, and 440.8 Suits. BN1, BN2, and BN3 are not a constraint because their loads are lower than their capacities. The total throughput for Scenario 2 is calculated as ₺ 858560 (600 * 250 + + 800 * 500 + 440.8 * 750). For Scenario 3, the product mix is determined as 800 Jackets, 679 Suits, and 0 Trousers. We could not plan to produce any

Table 8

| COMPARISION OF SCENARIOS BASED ON TOC | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | | **$CP_k$ (min.)** | **$L_k$ (min.)** | **$d_k$ (min.)** | **Capacity Using rate** | **Production Priority** | **Product Mix** | **Total Throughput (₺)** |
| Scenario 1 | BN1* | 2400 | 2400.0 | 0.0 | 1.00 | 1.Trousers | 600 | N.S. |
| | BN2 | 2400 | 2772.7 | –372.7 | 1.16 | 2.Suit | 700 | |
| | BN3 | 2400 | 2212.2 | 187.8 | 0.92 | 3.Jacket | 461.7 | |
| Scenario 2 | BN1* | 2400 | 2400.0 | 0.0 | 1.00 | 1.Trousers | 600 | ₺ 612080 |
| | BN2 | 2400 | 2385.6 | 14.4 | 0.99 | 2.Jacket | 800 | |
| | BN3 | 2400 | 2175.1 | 224.9 | 0.91 | 3.Suit | 440.8 | |
| Scenario 3 | BN1 | 2400 | 2596.8 | –196.8 | 1.08 | 1.Jacket | 800 | N.S. |
| | BN2* | 2400 | 2400.0 | 0 | 1.00 | 2.Suit | 679 | |
| | BN3 | 2400 | 2289.4 | 110.6 | 0.95 | 3.Trousers | 0 | |

* Main constraint.

Table 9

| DMS' EVALUATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **DM1** | | | | | | **DM2** | | | | | |
| Parameter | BN1 | BN2 | BN3 | Throughput | Weights | Parameter | BN1 | BN2 | BN3 | Throughput | Weights |
| BN1 | 1 | 2 | 3 | 2 | 0.417 | BN1 | 1 | 1 | 3 | 1 | 0.300 |
| BN2 | 1/2 | 1 | 2 | 2 | 0.269 | BN2 | 1 | 1 | 3 | 1 | 0.300 |
| BN3 | 1/3 | 1/2 | 1 | 1/2 | 0.121 | BN3 | 1 | 1/3 | 1 | 1/3 | 0.100 |
| Throughput | 1/2 | 1/2 | 2 | 1 | 0.193 | Throughput | 1 | 1 | 3 | 1 | 0.300 |
| **DM3** | | | | | | **DM4** | | | | | |
| Parameter | BN1 | BN2 | BN3 | Throughput | Weights | Parameter | BN1 | BN2 | BN3 | Throughput | Weights |
| BN1 | 1 | 1 | 3 | 1 | 0.296 | BN1 | 1 | 1 | 2 | 1/2 | 0.233 |
| BN2 | 1 | 1 | 3 | 1 | 0.296 | BN2 | 1 | 1 | 2 | 2 | 0.346 |
| BN3 | 1/3 | 1/3 | 1 | 1/3 | 0.099 | BN3 | 1/2 | 1/2 | 1 | 1/2 | 0.135 |
| Throughput | 0 | 2 | 3 | 1 | 0.310 | Throughput | 2 | 1/2 | 2 | 1 | 0.330 |

Trousers. In this situation, BN1 is still a constraint because its load is higher than its capacity (2596.8 > 2400). It needs 196.8 minutes of extra capacity. Therefore, total throughput does not be calculated.

As a result, the best Scenario is Scenario 2.

The GP solution is as follows: Firstly, we define the four decision-makers (DMs) as the production manager, planning manager, planning chief, and accounting manager of the company. DMs performed pairwise comparisons to decide the importance of bottlenecks and throughput by employing AHP. Pairwise comparisons of bottlenecks and throughput are presented in table 9. The importance of bottlenecks and throughput is determined by the arithmetic mean of four DMs evaluations as W1: 0.312, W2: 0.303, W3: 0.114, W4: 0.283.

The maximum throughput of the system which is the goal of throughput is calculated as ₺749800 according to the $\sum_{k=1}^{3} D_k T_k$ $(600 * 178 + 800 * 375 + 700 * 490 = 749800)$.

Finally, using GP, the mathematical model for the product mix of the textile company is defined as follows.

$$\min Z = 0.312 f_1 + 0.303 f_2 + 0.114 f_3 + 0.283 f_4$$

$$2.01X_1 + 1.54X_2 + 0.47X_3 + f_1 = 2400$$ (for slaughterhouse)

$$2.05X_1 + 1.26X_2 + 0.79X_3 + f_2 = 2400$$ (for model preparation)

$$1.84X_1 + 1.3X_2 + 0.54X_3 + f_3 = 2400$$ (for ironing)

$$480X_1 + 367X_2 + 178X_3 + f_4 = 749800$$ (for throughput)

$$0.99X_1 + 0.65X_2 + 0.34X_3 \leq 2400$$ (for fusing/labelling)

$$1.54X_1 + 1.54X_2 + 0X_3 \leq 2400$$ (for Sewing I)

$$1.23 X_1 + 0X_2 + 1.23X_3 \leq 2400$$ (for Sewing II)

$$1.5X_1 + 0.95X_2 + 0.55X_3 \leq 2400$$ (for quality control)

$$1.4X_1 + 0.8X_2 + 0.6X_3 \leq 2400$$ (for combining/Packaging)

$$0 \leq X_1 \leq 700$$ (for the demand of Suit)

$$0 \leq X_2 \leq 800$$ (for the demand of Jacket)

$$0 \leq X_3 \leq 600$$ (for the demand of Trousers)

The above-mentioned GP Model is solved by GAMS LP Programming Software. Provided results are as follows: The product mix is determined as 600 Trousers, 800 Jackets, and 440.796 Suits. With these results, the total throughput is calculated as ₺ 612080. GP results are the same as the TOC-based Scenario 2's results.

## CONCLUSIONS

The current study described a methodology for determining the product mix of a manufacturing system utilizing the TOC approach based on developed scenarios and verifying TOC results with GP. The methodology presents a way for determining the product mix in a multiple bottlenecks environment in the textile industry. The proposed methodology can provide the optimum solution in product mix decisions by improving alternative scenarios provided from the results of the TOC approach and by verifying the results of the TOC approach via GP.

TOC algorithm can provide the best solution for product mix decisions in a single-constraint manufacturing environment. When multiple constraint resources exist, the TOC-based approach could not reach the optimal solution and it ran the risk of becoming infeasible. The current study demonstrated that the TOC had flaws when dealing with multiple-constraint resources. Therefore, we used the TOC algorithm suggested by Tanhaei and Nahavandi [15] for multiple-constraint resources. Firstly, we determined three bottlenecks, but the first and second constraints have close values for their loads. Therefore, we had two alternatives, we determined two production priorities of products based on 1st and 2nd bottlenecks. We calculated throughput per constraint time ($t_{i(BN1)}$) based on BN1 for each product. Values of $T_{2(BN1)}$ and $T_{3(BN1)}$ are very close, therefore we have two alternative production priorities for BN1. Thus, we provided three scenarios for the solution of TOC based product mix problem. As seen in table 8 we evaluated three scenarios and found that Scenario 2 is the optimal scenario, in which BN1 is the main constraint and the product mix is suggested as 600 Trousers, 800 Jacket and 441 Suits with a total throughput of ₺ 612080.

The TOC-based algorithm has several benefits: It removes the need for complicated mathematical expressions and it is easy to understand. However, the result of TOC can be infeasible for a multi-constraint environment. Therefore, to verify the TOC results, we employed a GP approach as also suggested by Tanhaei and Nahavandi [13] for product mix problems in multiple constrains manufacturing environments. In this model, DM can decide about the importance of throughput and Bottleneck priority by considering them in the decision matrix. According to the GP model, the product mix was determined as 600 Trousers, 800 Jacket and 441 Suits with ₺ 612080 total throughput. Both approaches produced the same results.

In this study, we attempted to optimize all constraints simultaneously and together within the 3 scenarios to generate feasible results. For this reason, we evaluated the capacity usage rate of all three constraints. If the capacity usage rate of constraints is higher than 1.00, we didn't calculate the total throughput of a scenario. Therefore, for Scenario 1 and Scenario 3, we could not calculate total throughputs because for Scenario 1, the capacity usage rate of the BN2 constraint is higher than 1.00, and in Scenario 3, the capacity usage rate of the BN1 constraint is higher than 1.00.

If we didn't take into account all constraints simultaneously, the total throughput would be calculated as ₺ 612243.9 for Scenario 1 and ₺ 619520 for Scenario 3. We would choose Scenario 3 because of its highest total throughput value. In this situation, we would make a wrong decision because the demand for constraints would continue higher than their capacities. By the scenario development approach, we make accurate decisions as seen from the results of the GP approach.

With the study, changing the company's current production mix and using the product mix created according to the TOC has resulted in positive results that the company can increase its profitability, continuity and sustainability.

This study has some limitations. One of the limitations of this study is that it is a preliminary study that is conducted in a particular sector. Additional analysis should be performed within a larger scope of sectors. Another limitation of this study is that only two methods, i.e. the TOC approach, and the GP, are implemented for determining the optimum product mix. For tackling such problems, there exist several other approaches in the literature that compare their results with that of the TOC. Data provided in this study can be evaluated by other methods such as genetic algorithm, immune system, simulated annealing, etc. and their results can be compared with the findings of this study.

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# Classic suturing materials overview

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**ABSTRACT – REZUMAT**

**Classic suturing materials overview**

*Sutures are used in surgery to approximate wounds for the healing purpose after injury or elective interventions or for hemostasis ligation. During the millennial evolution of sutures, natural fibres have been almost completely replaced by synthetic materials. Experience from the last years has shown that silk and catgut chromium threads are natural fibres still used in surgical theatres, but they might have registered a decrease in preferences due to inflammatory response. Despite the continuous improvement in this field, there is not a perfect universal suture affordable and right for every patient. There are rare, but possible complications such as local irritation, foreign body response, granulomas or fistulas. Various studies conducted over time, some presented in this paper, have shown that actual surgical threads are safe and taking into account the indications, we should obtain maximum results with minimum adverse reactions. An ideal combination of delayed absorption and elasticity allows a tension-free closure and supports the healing process of most tissues and makes the surgical thread a preferred option for surgeons. The purpose of this article is to overview the suturing materials and to optimise surgical techniques by increasing the benefits of each suture material with minimal adverse reactions.*

***Keywords**: natural fibres, synthetic sutures, absorption, monofilament, multifilament, tissular response*

**Prezentare generală a materialelor de sutură clasice**

*Suturile sunt folosite în chirurgie pentru aproximarea rănilor în scopul vindecării după traumatisme sau intervenții chirurgicale elective sau pentru ligaturi hemostazice. Pe parcursul evoluției de-a lungul a mii de ani a suturilor, fibrele naturale au fost aproape complet înlocuite cu materiale sintetice. Experiența din ultimii ani a arătat că firele de mătase și crom catgut sunt fibre naturale încă folosite în blocurile operatorii, dar care par să înregistreze o scădere a preferințelor datorită răspunsului inflamator.*

*În ciuda îmbunătățirii continue în acest domeniu, nu există o sutură universală perfectă, accesibilă și potrivită pentru fiecare pacient. Există complicații rare, dar posibile, cum ar fi iritația locală, răspunsul la corp străin, granuloame sau fistule. Diverse studii efectuate de-a lungul timpului, unele prezentate în această lucrare, au arătat că firele chirurgicale efective sunt sigure și ținând cont de indicații, ar trebui să obținem rezultate maxime cu reacții adverse minime. O combinație ideală de absorbție întârziată și elasticitate permite o închidere fără tensiune și susține procesul de vindecare a majorității țesuturilor și transformă firul chirurgical într-o opțiune preferată pentru chirurgi. Scopul acestui articol este de a prezenta materialele de sutură și de a optimiza tehnicile chirurgicale prin sporirea beneficiilor fiecărui material de sutură cu reacții adverse minime.*

***Cuvinte-cheie:** fibre naturale, suturi sintetice, absorbție, monofilament, multifilament, răspuns tisular*

## INTRODUCTION

The first texts, that tell of the use of suture threads, were found in ancient China and Egypt and date back to 2000 B.C. the first dated needles are from 20.000 B.C. and were made of bone [1–6]. A Sanskrit text, called Charaka Samhita, described the use of ants to approximate the wound margins. These are the army ants (known also as driver ants), more precisely the “soldiers” were used because they possess large mandibles. After the ant bites its body is then twisted off leaving the head in place [1, 2].

Sushruta was an ancient Indian surgeon known today as the “Father of Surgery” described around 600 B.C., in Sushruta Samhita, a variety of operations in which he used horse hair, cotton, flax, hemp, tree fibres and animal ligaments as threads and different types of round or triangular and curved or straight needles [1, 2, 4].

The Edwin Smith papyrus that dates back to 1600 B.C. tells of linen strips coated with honey and flour their properties are similar to modern-day closure strips [6].

In the year 175, Galen describes the use of “catgut”. The thread was at first obtained from the submucosal tunic of sheep or goats’ intestines or the serous tunic of bovine intestines [1, 5].

In the 16$^{th}$ century Hieronimus Ab Aquapendante from Paduia introduced the use of gold threads and in the year 1857, J. M. Sims described the use of silver threads [1].

Most of the suture materials described did not withstand the test of time. After Joseph Lister introduced sterilization methods for the catgut threads, they became the main absorbable suture material in use in the 19th century and chromic catgut is still in use to this day [1, 5, 6].

Another type of thread that is still in use today is silk. It's used for surgical wound closure and was first described around 1050. E. Th. Kocher is responsible for its widespread usage, especially in Europe. Because of its qualities, softness, elasticity and durability, it was considered the "gold standard" [1, 6].

By the end of the First World War, George Merson manufactured eyeless needles sutures where one end of the suture material is attached to the base of the needle. In 1960, the introduction of sterilization by irradiation meant that the eyeless needle and the thread could be sealed in their package and then sterilized, reducing the risk of contaminating the needle or the thread [6].

This article aims to overview the suturing materials and their particularities to have a better understanding of how and when should each one be used, thus optimizing surgical techniques by maximizing the benefits of each suture material and minimizing the postoperatory complications.

## GENERAL PRESENTATION AND CLASSIFICATION OF SUTURING MATERIALS

### Surgical threads

The main factors used to classify actual surgical threads types are:

- Absorbable vs. non-absorbable
- Synthetic vs. natural
- Monofilament vs. multifilament.

A relevant scheme of this classification is presented in figure 1.

Sutures are considered absorbable if they lose most of their tensile strength over variable periods ranging from a few weeks to several months.

Absorbable threads are classified as natural and synthetic sutures. Natural fibres are derived from purified animal tissues and are sometimes made of the purified serosa of bovine intestines. Silk and catgut (made from sheep submucosa) are all types of natural sutures. Natural threads are different from synthetic sutures in that they degrade by proteolysis, while synthetic sutures degrade by hydrolysis. Hydrolysis causes less of an inflammatory reaction than proteolysis, which is why natural sutures can be known for causing more inflammation at the suture site. Usually, sutures have a smooth surface but there are newer sutures manufactured with barbs. These barbs do not require knots for security [7].

Other suture category is monofilament and multifilament. Monofilament sutures are single fibers with less capillarity and less surface area than a multifilament. Monofilament sutures demand more handling care, and more knots to provide security, but tend to fracture less than multifilament sutures, they pass through tissues more easily and cause a less inflammatory reaction than their multifilament counterparts. Multifilament sutures are more malleable; they tie knots more securely and they are easier to handle by the surgeon. However, multifilament sutures also cause more friction through tissue and have increased capillarity and surface area, increasing their predilection to inflammation and infection. Multifilament sutures can be coated to make them slide through tissues more easily and have properties more similar to a monofilament suture. They can also be coated with antibiotics to make them more infection-resistant. However, they are more expensive than traditional sutures [8]. Table 1 presents mainly surgical threads with an individualized period of absorption, indications and broken-down mechanism.

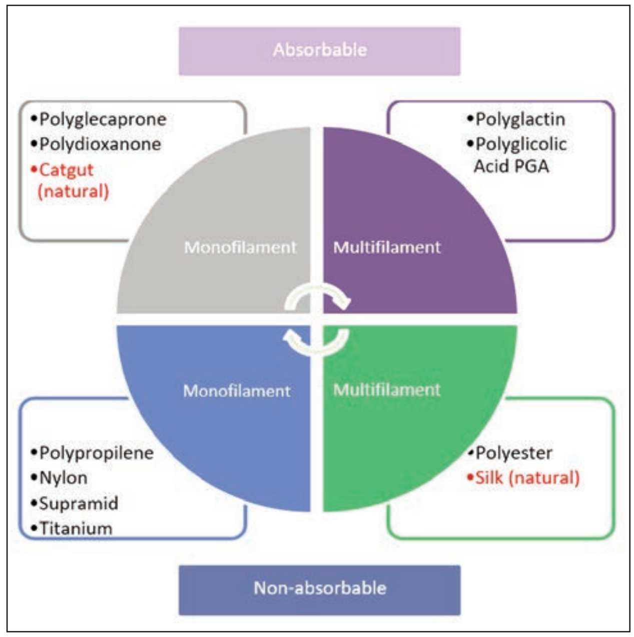


Fig. 1. Surgical threads general classification

From the surgical thread size point of view (transversal section), there is used the United States Pharmacopeia (USP) scale from 11-0 (the thinnest) to 5 (the thickest able to tow a car). In the USP scale, 1-0 is not included. Depending on these dimensions the wires are adapted to various tissues as presented in table 2.

For high infection risk, one should use monofilament absorbable sutures. For suturing the skin, the smallest suture for the area is preferable.

Regarding absorbable sutures, if more strength is required, slowly absorbable sutures are the best choice. For fascia and tendons low absorbable or non-absorbable sutures should be used while the stomach bladder or colon requires absorbable material [8, 9].

### Surgical needles

The needle is composed of three main segments – the base, body and point. The base could include the needle eye where the thread attaches manually to the needle (this type is mentioned for historical reasons, not in routine use), or a point where the suture

Table 1

| ABSORPTION TIME, INDICATIONS AND BROKEN-DOWN MECHANISM OF SUTURES | | | |
|---|---|---|---|
| **Material** | **Total absorption time** | **Indication** | **Broken-down mechanism** |
| Polyglactin | 50–70 days | Soft tissue closing and ligation | Hydrolysis |
| Polyglycolic acid | 60–90 days | Soft tissue closing and ligation | Hydrolysis |
| Polyglycolic acid – rapid absorption | Approximately 42 days | Superficial tissue and mucosa only | Hydrolysis |
| Poliglecaprone | 90–110 days | Superficial tissue and ligation | Hydrolysis |
| Polydioxanone | 180-210 | General soft tissue closing | Hydrolysis |
| Plain catgut | 63 days | General soft tissue closing and ligation | Phagocytosis |
| Catgut chromium | 90 days | General soft tissue closing and ligation | Phagocytosis |

Table 2

| UNITED STATES PHARMACOPEIA (USP) SCALE FOR THREADS AND USING DEPENDING ON TISSUE | | |
|---|---|---|
| **USP scale** | **Actual size (mm)** | **Tissue** |
| 11-0 & 10-0 | 0.01 & 0.02 | Ophthalmology, microsurgical repair |
| 9-0 & 8-0 | 0.03 & 0.04 | Ophthalmology, microsurgical repair |
| 7-0 & 6-0 | 0.05 & 0.07 | Small vessel repair/grafting for hand and face |
| 5-0 & 4-0 | 0.1 & 0.15 | Larger vessel repair, hand and face skin, tendon repair |
| 3-0 & 2-0 | 0.2 & 0.3 | Thick skin, fascia, muscle, tendon repair |
| 0 & 1 | 0.35 & 0.4 | Fascia, drains stitches |
| 2 & >2 | >0.5 | Large tendon repairs, thick fascia closure, orthopaedic surgery |

thread gets crimped onto the needle. The body is the most considerable segment of the needle and connects the base to the point and determines the shape of the needle. The needle can be straight or mainly curved in surgery. The circle of a curved needle comes in different lengths, but most curves are 1/4, 1/2, 3/8, or 1/3 of a circle. The curve is crucial in helping the surgeon know where the tip of the needle is at all times. Most skin closure sutures are curved, and usually 3/8 of a circle [7, 9].

There are different types of needles categorized by the appearance of the needle tip, mainly cutting or taper needles. Cutting needles have a tip with three sharp edges, with a regular cutting needle having the cutting surface inside the needle and a reverse cutting needle having it on the outside of the needle. Reverse-cutting needles are commonly used for sewing skin.

Taper needles are rounded and can be either sharp or blunt. They work by piercing the tissue without cutting it, and spreading the tissue as it passes through it. These are used for soft tissues. A useful needlepoint section classification is pictured in figure 2.

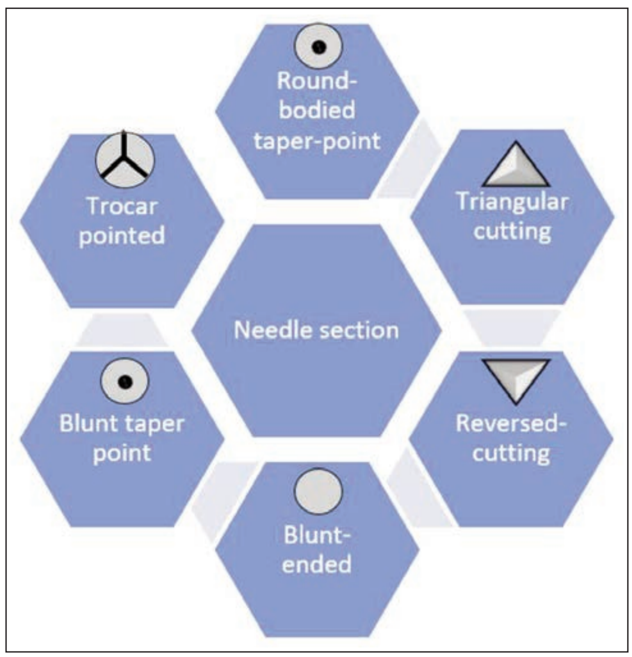


Fig. 2. Needlepoint section classification

## INDICATIONS AND COMPLICATIONS OF SURGICAL THREADS

### Absorbable materials

*Monofilament*

- **Polydioxanone** (PDS) – is generally used for soft tissue closing in General Surgery, Gastrointestinal Surgery, Orthopedics, Gynecology, Plastic surgery, Urology and Ophthalmic Surgery. This is not suitable for cardiovascular tissues, neurological tissues and microsurgery.
- **Plain surgical gut** – is generally used for soft tissue closing and ligation in General Surgery, Gastrointestinal surgery, Gynecology, Urology and Ophthalmic surgery. This is not suitable for Cardiovascular surgery and Neurosurgery. As an

absorbable material with quick absorption, it is contraindicated when extended wound support is needed with special precautions in patients with delayed wound healing and infected wounds.

- **Poliglecaprone** – is generally used for soft tissue closing and ligation in General Surgery, Gastric Surgery, Gynecology, Plastic Surgery and Urology. This material it is contraindicated in patients with allergies and known sensitivity of its components and for when wounds support is required for longer periods.
- **Polytrimethylene carbonate** – is generally used for soft tissue closing and ligation in General Surgery, Gastrointestinal Surgery, Gynecology, Urology, Plastic Surgery and peripheral Vascular Surgery. It is not intended for use in adult cardiovascular tissue, ophthalmic surgery and neurological surgery.
- **Glycomer** – is generally used for soft tissue closing and ligation in General Surgery, abdominal closure and Ophthalmic Surgery. It is contraindicated for use in cardiovascular and neurological surgery.

*Multifilament*

- **Polyglactin** – is generally used for soft tissue closing and ligation in General Surgery, Gastrointestinal surgery, Plastic Surgery, Gynecology, Orthopedics, Urology and skin closure. This material is not intended for cardiovascular and neurological surgery.
- **Polyglycolic acid** (PGA) – is generally used for soft tissue closing and ligation in General Surgery, Gastrointestinal surgery, Plastic Surgery, Gynecology, Orthopedics, Urology and skin closure. This material is not intended for cardiovascular and neurological surgery.

### Non-absorbable materials

*Monofilament*

- **Polypropylene** – is generally used for soft tissue closing and ligation in Cardiovascular surgery, Neurosurgery, Ophthalmic surgery, Microsurgery, Plastic Surgery, skin surgery, Orthopedics, Gynecology, General Surgery, Gastrointestinal surgery and in abdominal wall surgery.
- **Polyamide** – is generally used for soft tissue closing and ligation in General Surgery, Plastic surgery, Gastrointestinal surgery, Gynecology, Orthopedics, Ophthalmic surgery and skin closure.
- **Steel** – is generally used for closure of the sternum, abdominal wall closure, hernia repair and Orthopedics.

*Multifilament*

- **Polyester** – is generally used for soft tissue closing and ligation in Cardiovascular surgery, General Surgery, Ophthalmic surgery, Oral surgery, Gastrointestinal surgery, Gynecology and skin closure
- **Silk** – is generally used for soft tissue closing and ligation in General Surgery, Ophthalmic surgery, Oral surgery, Gastrointestinal surgery, Gynecology and skin closure. This material is not intended for urinary tract tissue, biliary tract tissue and known allergies and sensitivities.

**Complications and adverse reactions of suture materials might be:**

- Local irritation
- Transitory inflammatory foreign body response
- Erythema
- Induration during the absorption process of subcuticular sutures
- Suture materials may enhance an existing infection
- Wound dehiscence
- Granulomas
- Fistula formation.

## LITERATURE OVERVIEW

The probability of a complication to occur is low as demonstrated in a study in which a long period without any complications was presented data from 12 patients (1 in 2004 and 11 in 2005) who developed mild to moderate inflammation or fistula/infection (inflammation, granuloma, extrusion, fistula, abscess) after 3 to 8 weeks after clean operations (varicose vein, hernia, benign soft tissue tumour) in which they used Vicryl (Polyglactin 910) [10].

In a study in which were included 1000 plastic surgery outpatients it was demonstrated that there are no substantial differences between the different suture materials and suturing techniques, making the association of different suture materials, individual patient characteristics, surgeon skills and wound site and length with postoperative wound complications (tissue reactivity, infection rate and wound dehiscence). A moderate increase in the risk of tissue reactivity for silk and polyglactin 910 and a protective effect of thinner internal sutures were observed [11].

In a study in which polyglactin 910 and polyglycolic sutures were compared after layer closure of laparotomy wounds after 306 acute or elective operations. The total incidence of wound dehiscence and herniation was 0.65% with no significant difference between polyglycolic acid (0.6%) and polyglactin 910 (0.7%). The incidence of abscess, granuloma or sinus formation was 6.5% for polyglycolic acid and 11.3% for polyglactin 910, with the difference not being statistically significant [12].

In recent years, the minimally invasive approach to abdominal surgery has become increasingly established, but open surgery is still practised. Numerous studies addressed the question of the ideal suture material and the optimal suture technique for primary elective abdominal wall closure [13–18].

Based on current meta-analyses, the application of a monofilament, late-absorbable suture using a continuous suture technique with a suture-to-wound length ratio of at least 4:1 is the method of choice [19] A recommendation for this combination can also be found in the recently published European Hernia Society guidelines [20].

In 2009, a new monofilament, ultra-late-absorbable suture with high elasticity was developed for abdominal wall closure and introduced into the market [21]. The combination of delayed absorption and elasticity allows a tension-free closure and supports the healing process of the fascia.

One of the studies that evaluated the performance of Monomax suture was MULTIMAC study. The objective of this international, multi-centric, prospective, observational, single-arm cohort study was to analyse the performance of Monomax suture material under daily clinical routine in a non-selected patient population. The study followed a total of 200 patients undergoing a primary elective laparotomy using either a midline or transverse incision that were examined regarding the frequency of short-term complications (reintervention due to burst abdomen, wound infection, wound healing disorders)

The results of the MULTIMAC study indicate that the ultra-long-term absorbable, elastic monofilament suture is safe and efficient for abdominal wall closure performed under daily clinical routine.

## CONCLUSIONS

Surgical suturing materials were needed from ancient times and during technology evolution, the manufactures improved their characteristics. The perfect universal surgical thread doesn't exist, but there is a variety of sutures to choose from, depending on each patient, type of intervention or tissue. Regardless of threads' actual improved performances, there are possible complications such as local irritation, foreign body response, granulomas or fistulas. The multitude of studies conducted in the last 20–30 years established the indications and contraindications for each type of thread or needle, but there are expected new materials to be developed to improve the range of suturing materials or even replace the existing ones.

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# The effect of calcium carbonate content and particle size on the mechanical and morphological properties of a PVC foamed layer used for coated textiles

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### ABSTRACT – REZUMAT

**The effect of calcium carbonate content and particle size on the mechanical and morphological properties of a PVC foamed layer used for coated textiles**

*Due to recent developments in composite formulations and coating technology, polyvinyl chloride (PVC)-coated textiles are becoming increasingly popular in the textile industry. The most critical properties of PVC-coated textiles are their mechanical characteristics and morphological properties because they control their cost well. This study focuses on the impact of filler diameter and content on the mechanical properties of the PVC foam layer used for coated textiles stuffed with calcium carbonate ($CaCO_3$). The mechanical properties of the PVC foamed layer (breaking load, tearing strength and elongation at break) were studied. The applied contents were found to significantly influence the mechanical properties of the PVC foamed layer. The addition of $CaCO_3$ fillers improved their mechanical properties. The results also showed that mechanical properties were enhanced using calcium carbonate with different particle sizes; the smallest particle size gave the highest mechanical resistance. The morphology of the different samples showed that the employment of calcium carbonate increases foam formation. A higher $CaCO_3$ content can deteriorate the PVC foam layer structure. Using a small filler particle diameter decreased pore sizes and ameliorated the regularity in pore size distribution.*

***Keywords***: *coated fabric, filler, coating, PVC, $CaCO_3$, content, particle size*

**Influența conținutului de carbonat de calciu și al dimensiunilor particulelor asupra proprietăților mecanice și morfologice ale unui strat de spumă PVC utilizat pentru peliculizarea materialelor textile**

*Datorită dezvoltării recente în compozite și tehnologia de finisare, textilele peliculizate cu clorură de polivinil (PVC) devin din ce în ce mai populare în industria textilă. Cele mai importante proprietăți ale textilelor peliculizate cu PVC sunt caracteristicile lor mecanice și proprietățile morfologice, deoarece costul este ușor controlabil. Acest studiu se concentrează asupra impactului diametrului și conținutului de umplutură asupra proprietăților mecanice ale stratului de spumă PVC utilizat pentru textilele peliculizate îmbibate cu carbonat de calciu ($CaCO_3$). Au fost studiate proprietățile mecanice ale stratului de spumă PVC (sarcina la rupere, rezistența la rupere și alungirea la rupere). S-a constatat că acest conținut aplicat influențează semnificativ proprietățile mecanice ale stratului de spumă PVC. Adiția de $CaCO_3$ a îmbunătățit proprietățile mecanice. Rezultatele au arătat, de asemenea, că proprietățile mecanice au fost îmbunătățite folosind carbonat de calciu cu diferite dimensiuni ale particulelor; cea mai mică dimensiune a particulei a dat cea mai mare rezistență mecanică. Morfologia diferitelor probe a arătat că utilizarea carbonatului de calciu crește formarea de spumă. Un conținut mai mare de $CaCO_3$ poate deteriora structura stratului de spumă PVC. Folosirea unui diametru mic de particule de umplutură a redus dimensiunea porilor și a îmbunătățit regularitatea distribuției dimensiunii porilor.*

***Cuvinte-cheie***: *țesătură peliculizată, umplutură, acoperire, PVC, $CaCO_3$, conținut, dimensiunea particulelor*

## INTRODUCTION

Coated textiles represent a highly used group of textile materials. They are used in a variety of industries, including footwear, automobiles, upholstery, and clothing. These fabrics usually consist of a topcoat, a middle coat, and backing cloth. PVC-coated textiles are easy to process, low in cost, and have a consistent appearance [1–3].

Their main components include a polymer (PVC), a stabilizer, a plasticizer, and a filler. These components are uniformly mixed to form the plastisol. The different components are important for the general behaviour of the final product. However, the filler characteristics are a key issue in determining many of the technical properties of PVC-coated textiles.

Almost 80% of the fillers used in PVC-coated materials are based on calcium carbonate Titanium dioxide is the second most used filler, approximately 12%, followed by calcined clay approximately 5%. The remains are other materials, including glass and talc [4–6]. Calcium carbonate is an adequate filler for PVC-coated materials. The specific properties of this chemical, such as its low cost of production as well as its availability, encourage industries to enhance its performance and optimize its use. Traditionally, $CaCO_3$ filler was considered an additive, and because of its reduced surface area and unfavourable geometrical features, it was used to lower the cost, increase the melt viscosity and moderately increase the modulus of the PVC final product, whereas tensile strength and deformability remained unaltered or even reduced in some situations. Recently, the particle size and shape distribution, the dispersion degree, and the filler content have been reported to affect PVC material properties when filled with calcium carbonate [7, 8]. Thus, the applications of $CaCO_3$ particles on PVC product quality are determined by several parameters, including specific surface area, morphology, size, brightness, oil adsorption, and purity. Particle morphology and size play an important role in industrial applications, and control of crystal shape and size is therefore a basic requirement from the viewpoint of applications. The impact of calcium carbonate particles was attributed to their large interfacial surface and small particle size, which create a strong adhesion between the plastisol and the filler and enhance the van der Waals interaction force between them [9–11]. Numerous studies have been carried out to correlate the calcium carbonate content and particle size with the properties of PVC materials. Sun et al. [12] showed that the impact strength and the tensile strength of PVC increase considerably with decreasing $CaCO_3$ particle size. Nakamura et al. [13] observed that the yield stress of PVC composites decreases while increasing the filler content. The effect of calcium carbonate particle size on PVC foam was studied by Azimipour et al. [14] and Demir et al. [15].

In general, ample research has been conducted using PVC plastics and composites. However, few studies have been performed to study the effects of calcium carbonate concentration and particle size on the properties of PVC layers used for the production of coated textiles. The use of calcium carbonate with a small particle size may help increase the mechanical properties of PVC-coated textiles at a lower filler level, which may result in a lower formulation cost. Developing PVC-coated textiles with lower costs and improved quality will aid industry growth.

Several properties are required to improve the practical usability of PVC-coated fabrics as textile materials. This work aims to explore the effect of calcium carbonate content and particle size on microstructural properties, breaking load, tearing strength, and elongation to break the PVC internal layer used for coated textiles.

## EXPERIMENTAL PROCEDURE

### Raw materials

Commercial grades of PVC, diisononyl phthalate (DINP), mixed-metal heat stabilizer, kicker, azodicarbonamide, pigment, transfer paper and poly-cotton knitted fabric base were kindly provided by the Plastiss Company (Sayada, Monastir, Tunisia). $CaCO_3$ particles with different ground micron sizes were provided by the SOFAP Company (Sfax-Tunisia).

### Preparation of polymeric layer formulations

The formulations used to produce the PVC sheets (superficial and expanded layers) are shown in table 1. All the ingredients were blended using a mechanical stirrer until a homogenous mixture was obtained, with a desired viscosity level fixed by the company. To reach the desired viscosity, the amount of plasticizer was variable.

### Production of PVC leather fabric

We used the transfer coating technique for the production of PVC-coated textiles. On the first coating head, the plastisol is spread on the transfer paper using a blade while controlling the thickness. The formed layer, called the skin layer or superficial layer, is then dried at 140°C for 20 seconds and cooled. On the second coating head, the plastisol is spread on the first formed layer using a blade at a given thickness. This second layer forms foam after being dried at 200°C for 80 seconds and is called the bottom layer or expanded layer. Later, the knitted poly-cotton fabric is laminated to the resulting PVC layers, and the complex thus formed is passed through the main furnace where gelling and expansion of the cellular plastisol take place. After cooling, the paper and the formed PVC-coated textile are detached and rolled up separately.

Figure 1 shows some photographs of the prepared PVC leather fabric. Figure 2 presents the coating process.

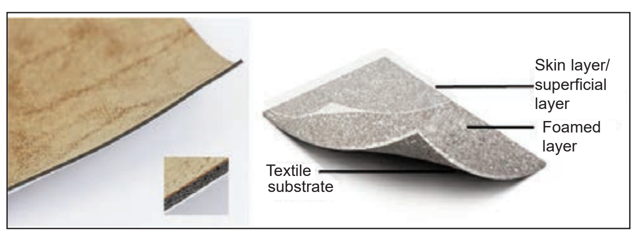


Fig. 1. PVC leather fabric

Table 1

| SUPERFICIAL AND EXPANDED LAYER FORMULATIONS | | | | | | |
|---|---|---|---|---|---|---|
| Layer | Ingredient contents expressed as parts per hundred of resin (phr) | | | | | |
| | PVC resin | Plasticizer | Stabilizer | Calcium Carbonate | Kicker | Azodicarbonamide |
| Superficial | 100 | X | 1.5 | Y | Ø | Ø |
| Expanded | 75 | Z | Ø | Y | 2 | 4 |

X = (70/80/82/94/102;114); Y = (0/25/50/75/100/125); Z = (37, 5/62, 5/76, 5/90, 5/102; 114).

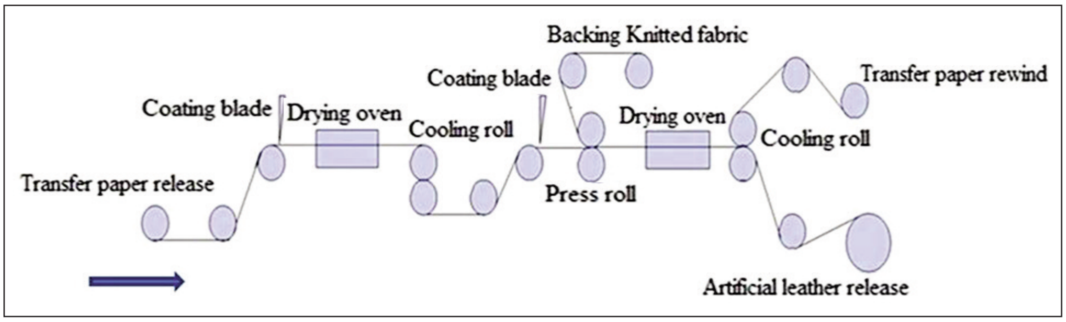


Fig. 2. Coating process

*Tensile and burst tests*

Tensile and burst tests were carried out according to NF EN ISO 1421-2017 standards using a testing machine (Zwich GmbH, Ulm, Germany) with a crosshead speed of 100 mm/min. Test specimens had dimensions of 50±0.5 mm in width with a sufficient length to obtain a distance of 200±1 mm between the jaws of the testing machine.

*Tearing strength*

The tearing strength test was performed according to NF EN ISO 4674-1-2017 using an ELMENDORF dechirometer. Tests were run in triplicate to avoid an experimental error.

*Optical microscopy*

The morphology and structure of the expanded PVC layers were observed using a Leica DM 500 optical microscope equipped with different objectives connected to a colour view camera and controlled by the analysis software. The materials were observed in transmission mode under different magnifications of the objective.

*Scanning electron microscopy (SEM)*

Detailed morphological investigations were carried out using a high-resolution FEIQ250 Thermo-Fisher ESEM with a resolution greater than 7 nm at 5–10 kV low working voltages. The cross sections of PVC foams were prepared by sharp bending and then covered by a gold layer.

## RESULTS AND DISCUSSION

### Mechanical properties

*The effect of calcium carbonate content*

Figure 3 illustrates the results of tearing strength, breaking load and elongation to break measurements

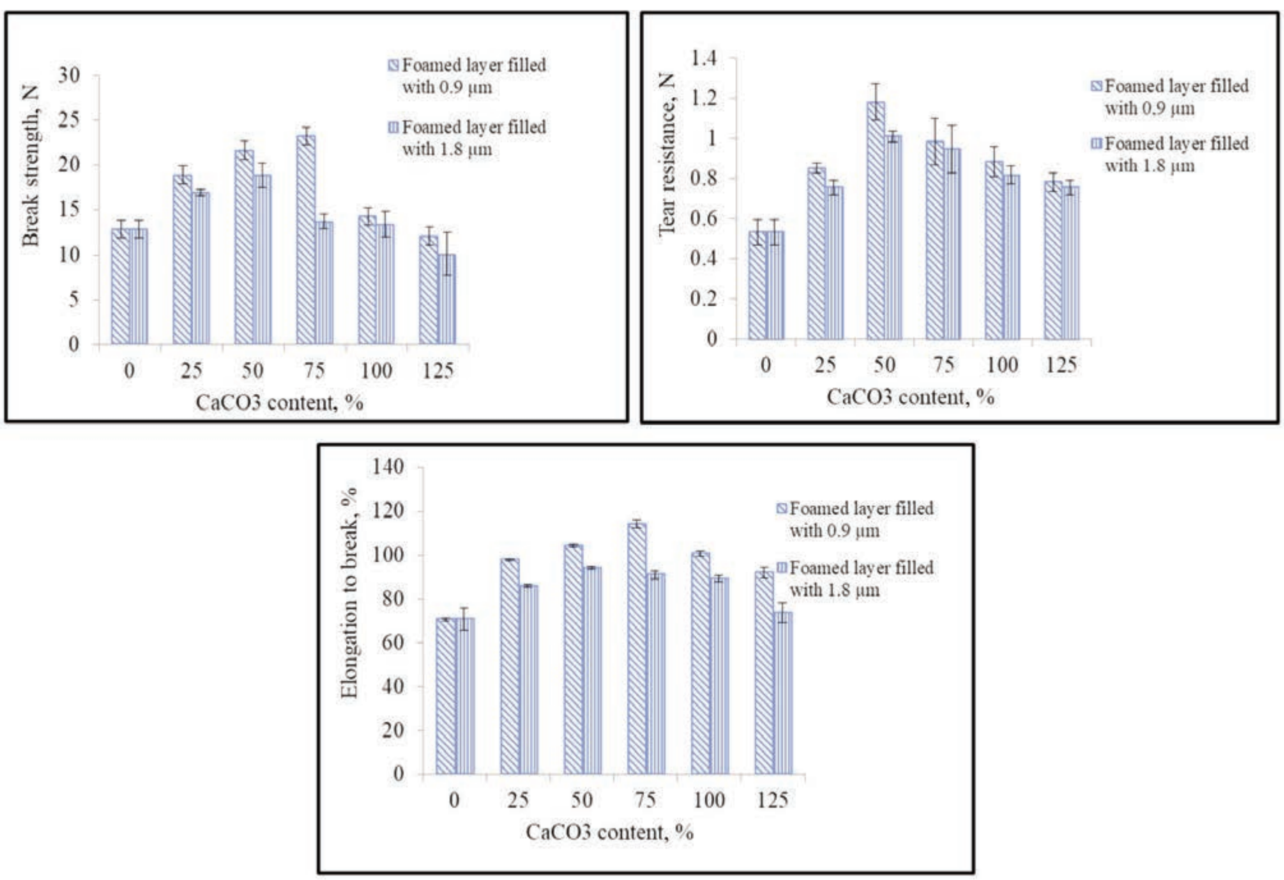


Fig. 3. Effect of $CaCO_3$ particle size and content on the mechanical properties of PVC internal layer used for coated textile

for internal layer samples at different amounts and particle sizes of calcium carbonate particles. The standard deviation of tearing strength values varies from 0.05 to 0.235, from 0.325 to 2.4 for the breaking load results and from 0.42 to 4.45 for the elongation to break measurements. The addition of $CaCO_3$ leads to an increase in the elongation at break, break strength, and tear resistance. The best results were obtained when the amounts of $CaCO_3$ reached 50 and 75%. The data suggested that the surface adhesion between $CaCO_3$ particles and the PVC matrix plays a crucial role in improving the mechanical properties of the prepared PVC layers. In fact, the stronger the interfacial adhesion is, the greater the stress moved to the $CaCO_3$ entities from the PVC matrix, leading to higher mechanical properties. However, an excess $CaCO_3$ content results in a low dispersion rate of particles in the PVC matrix. This indicates that there is an optimal amount of $CaCO_3$ to be added for the preparation of such a PVC layer. The interfacial adhesion between CaCO3 and the PVC matrix is then too weak, which causes a decrease in the breaking load, elongation to break and tearing strength of the PVC layers.

These outcomes agree with previous studies that have shown that an excess of $CaCO_3$ results in a decrease in the tensile strength of PVC and that the mechanical properties of PVC materials are influenced by the interfacial adhesion between the PVC matrix and the $CaCO_3$ particles [12–14]. Only a small amount of strain is likely to be transferred from the PVC matrix to the inorganic filler.

*The effect of calcium carbonate particle size*

Figure 3 also shows that the finer the filler particles are, the better the mechanical properties. The PVC layers filled with fine $CaCO_3$ have a higher elongation to break, tear resistance, and break strength.

The use of a small particle size results in an intense increase in the specific surface area of the filler particles, resulting in a rise in the interfacial contact area between the filler and the PVC matrix. The larger the interfacial contact area is, the better the transmission of stress from the PVC matrix to the filler particles, resulting in higher mechanical properties.

A literature survey shows that fine calcium carbonate particles significantly improve the mechanical characteristics of PVC matrices [12–15].

**Structural properties**

*The effect of calcium carbonate content*

The microscopic images of the PVC internal layer filled with different types of calcium carbonate particles at different contents are presented in figure 4. For the sample prepared without filler, the voids appear large, crowded, and very close to each other, and the presence of open cells is evident. These voids are a result of the foaming process, in which two main steps are included: bubble nucleation and growth. By adding the filler, the small voids start to move away from each other, the cell number increases, and closed cells are clearly observed, forming a regular pore shape and uniform structure. It can be concluded that the presence of calcium carbonate particles can promote foam formation by increasing the number of nucleation sites for bubble genesis. These outcomes have been confirmed by many researchers [12, 14, 15].

Using a content of 100% calcium carbonate can boost the liberation of decomposed gases, increase the nucleation sites and raise the total energy between the different bubbles. Therefore, there is a

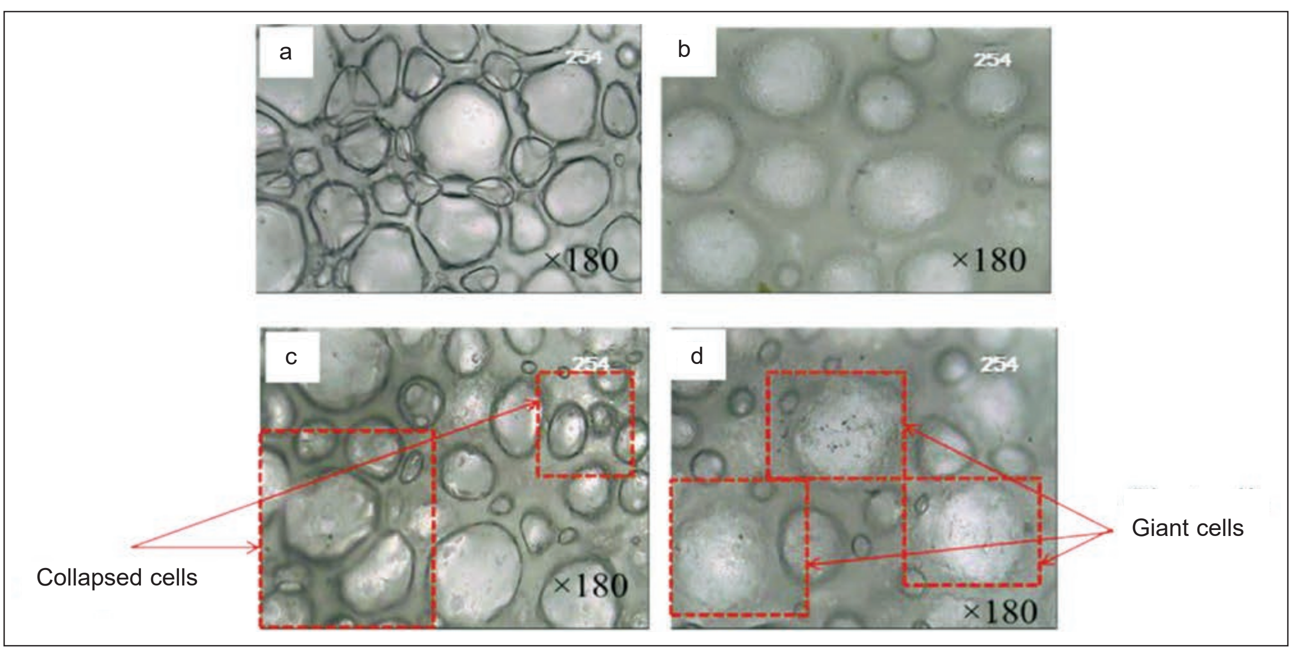


Fig. 4. Effect of $CaCO_3$ (0.9 μm) content on the structural properties of the internal layer: *a* – without filler; *b* – with 50% of $CaCO_3$; *c* – with 100% of $CaCO_3$; *d* – with 125% of $CaCO_3$

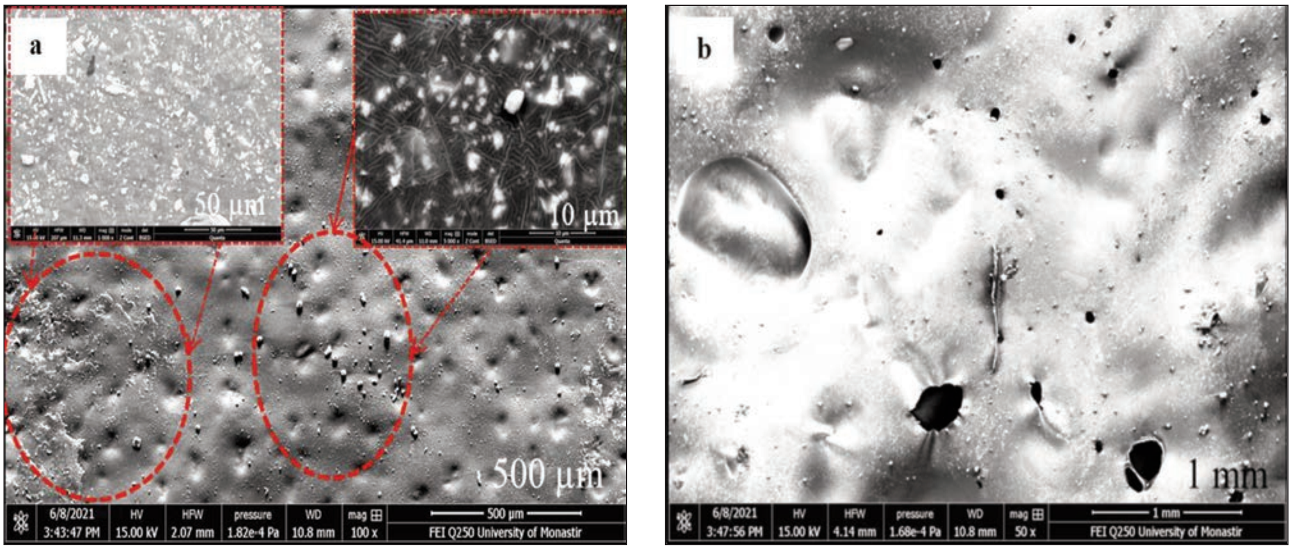


Fig. 5. SEM images of the internal layer prepared using 100% of $CaCO_3$ (0.9 µm) at different magnifications

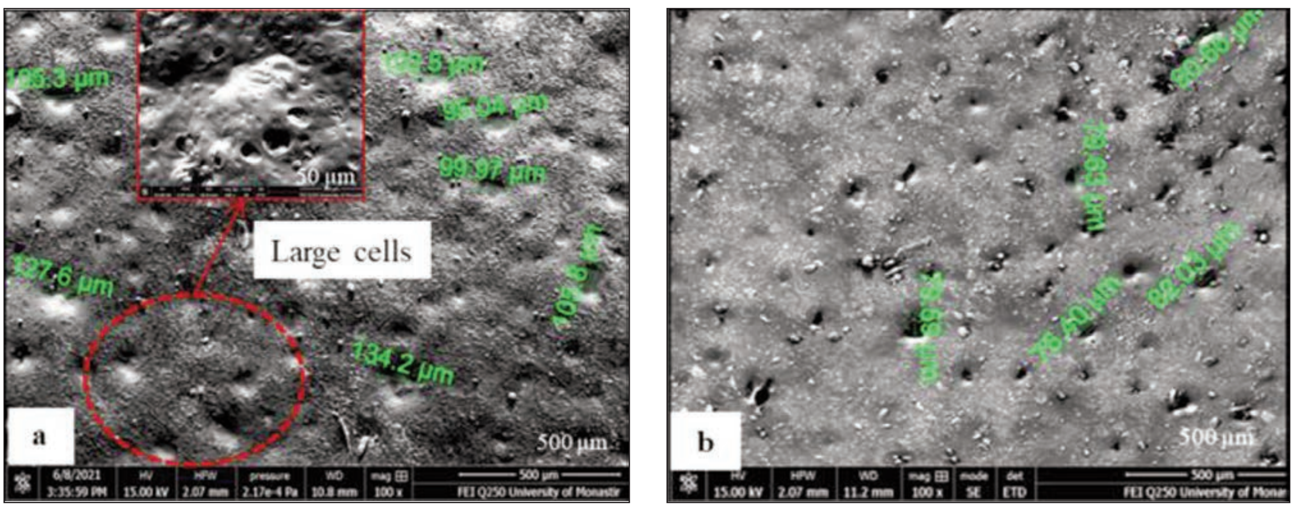


Fig. 6. SEM images of the internal layer prepared using 50% of CaCO3: *a* – 1.8 µm; *b* – 0.9 µm

higher possibility of forming collapsed cells, as observed in figure 4, *c*, which can create more gigantic cells, as evidenced in figure 4, *d*, so the foam structure begins to deteriorate.

These results confirm the poor mechanical quality previously observed for samples prepared without filler and for samples prepared with an excess of filler.

Figure 5 shows an SEM micrograph of the internal layer using 100% $CaCO_3$ (0.9 µm). From the images, it can be observed that $CaCO_3$ particles are scattered on the surface of the layer. We can also observe the irregular and rough surface of the samples. This result is due to the presence of an excess of calcium carbonate, which is poorly distributed in the PVC matrix. The poor dispersion of the filler results in poor adhesion between the PVC matrix and the filler.

Figure 5, *b* shows the appearance of microvoids and cracks, which are due to the poor dispersion of the filler. Several studies have shown that the poor dispersion of the fillers deteriorates the mechanical properties of the final materials [10–13].

*The effect of calcium carbonate particle size*

Figure 6 shows the pores forming the PVC foam of the internal layer. Using fine calcium carbonate particles (0.9 µm), the pores appear more uniform and smaller than those of the sample prepared using large calcium carbonate particles (1.8 µm). Using small filler particles, the liberation of the decomposed gases is better, which enhances the creation of additional nucleation sites for bubble formation, resulting in a uniform structure.

James Lee [17] confirmed these results and showed that the vast surface area of nanoparticles provides more intimate contact between the filler particles, PVC matrix, and gas, resulting in the enhancement of the foam structure and its mechanical properties.

The mechanical results are in good agreement with the morphological observations and are also in agreement with previous work by Azimipour et al. [14], who studied the effect of filler particle size on the morphological behaviour of the PVC foam.

## CONCLUSIONS

This research has been conducted to investigate the effects of calcium carbonate content and particle size on the mechanical and structural properties of the PVC foam layer used for coated textile production. It is important to know that calcium carbonate is the cheapest chemical among all the others used in the production of the polymeric layers used for PVC-coated textiles.

Through various analyses, we found that both the content and particle size of calcium carbonate have strong effects on mechanical and morphological properties. In particular, the most significant effect was detected when using fine calcium carbonate particles for the production of the PVC internal layer.

The low filler concentration of calcium carbonate resulted in positive changes in mechanical and structural characteristics. However, the structure of the PVC layers becomes mechanically poor at higher filler rates.

These outcomes have been confirmed by many studies that have investigated the effect of the content and particle size of calcium carbonate on the final properties of PVC materials.

Numerous authors [17–25] have studied the effects of calcium carbonate content and particle size on the behaviour of PVC in fires; thus, the effect of $CaCO_3$ content and particle size on the thermal characteristics of PVC-coated textiles will be evaluated in subsequent work.


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# Analysis of green consumer behaviour towards the intention to purchase upcycled fashion products

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IONICA ONCIOIU ANA MARIA IFRIM

**ABSTRACT – REZUMAT**

**Analysis of green consumer behaviour towards the intention to purchase upcycled fashion products**

*In recent years, the emergence of online platforms specializing in upcycling fashion marketing has provided affordable markets in line with the changing expectations of environmentally conscious consumers. This research applies questionnaires to collect data on consumers' intentions to purchase upcycling fashion products and aims to identify consumers' green behaviour. The results showed that there is a growing awareness among all generations of respondents about the use of upcycled fashion products and revealed that social influence, attitude, perceived risk, environmental concern, and usefulness have a significant positive impact on consumer purchase intention towards these products. This research can help the upcycling fashion business in Romania figure out how green consumer behaviour can improve the flexibility of specialized online platforms so that marketing strategies can be made.*

***Keywords:*** *circular economy, sustainability, textile waste, recycling, purchase behaviour*

**Analiza comportamentului ecologic al consumatorului față de intenția de a cumpăra produse de modă reciclate**

*În ultimii ani, apariția platformelor online specializate în marketingul produselor reciclate creativ în industria modei au oferit piețe accesibile, în conformitate cu așteptările în schimbare ale consumatorilor conștienți de mediu. Această cercetare aplică chestionare pentru a colecta date despre intențiile consumatorilor de a cumpăra produse de modă reciclate și are ca scop identificarea comportamentului ecologic al consumatorilor. Rezultatele au arătat că există o conștientizare tot mai mare în rândul tuturor generațiilor de respondenți cu privire la utilizarea produselor de modă reciclate și au relevat că influența socială, atitudinea, riscul perceput, preocuparea de mediu și utilitatea au un impact pozitiv semnificativ asupra intenției de cumpărare a consumatorilor față de aceste produse. Această cercetare poate ajuta afacerea de reciclare creativă din România să descopere modul în care comportamentul ecologic al consumatorilor poate îmbunătăți flexibilitatea platformelor online specializate, astfel încât să poată fi realizate strategii de marketing.*

***Cuvinte cheie:*** *economie circulară, durabilitate, deșeuri textile, reciclare, comportament de cumpărare*

## INTRODUCTION

The textile industry is one of the most polluting [1–3]. Famous clothing stores launch a new collection of clothing items on the market almost every two weeks. Basically, it is the continuous growth of items that are produced and thrown away, becoming waste in a very short time. The best solution is recycling any remaining textile material. Also, through the recycling of textiles, the mixing of all categories of waste, by default, and any form of pollution that may result from that mixture is avoided [4].

In addition to the long time required for the degradation of most textiles, when disposed of, they emit greenhouse gases and pollute the soil and water with chemicals and dyes [2]. At the same time, incineration for energy recovery is a method of disposing of municipal waste, including textile waste, in industrial combustion plants. Under European law, incineration is not a form of recycling but only a form of energy recovery or controlled waste disposal [5]. Although it is preferable to the method of waste disposal by storage, according to studies [6–8], the amount of energy used for fibre production is significantly higher than that recovered. For these reasons, incineration should be the last method used for the management of textile waste, after reuse and recycling. In this regard, there are even initiatives to ban the incineration and storage of unused textile stocks.

A solution to these problems could be upcycling recycling, which is an increasingly popular practice that transforms one textile product at the end of its life into another [1, 3, 4]. This process begins at the design stage, has a positive effect on the entire life cycle, and allows several actors to interact. The main feature of upcycling is that new products will have the same quality or better value than the original ones. Upcycling is also a method for companies and designers to be more efficient with surplus materials including upholstery scraps or old textiles [4]. In other words, they produce creative and frequently one-of-a-kind products from waste, and the process involves giving used materials a new use without investing much in new resources. This concept is well defined in the literature and, above all, very different from the better-known term recycling, which instead describes an industrial process of waste transformation [7–10]. Several authors [2, 4, 8] believe that research and innovation are needed to support the creation of a fully functional recycling sector for textiles while stimulating market demand for upcycling and recyclable fibres and yarns. Also, for more people to want to buy these products, companies in the field need to step up their social media campaigns to show how reused textiles might be better for your health than new textiles [11–15].

The motive to purchase upcycled fashion products is subjective, depending on whether it is in the person's best interests as an internal motivation (attitude toward upcycled fashion materials, environmental concern, usefulness) or is determined from the outside as an extrinsic motivation (social influence, perceived risk). In this context, social influence is defined as an individual's perception of people's behaviour that is important to them. Numerous prior research has also demonstrated that perceived risks have a negative effect on the behavioural intent and purchase behaviour of online consumers [3, 6, 11]. Users of online platforms specializing in upcycling fashion may face the perceived risk of using the app and purchasing services while leaking personal information. On the other hand, when customers develop a favourable opinion of upcycled fashion materials, they will create a desire to purchase these items considering their usefulness. Environmental concerns are often seen as major motivators for recycling, but consumer perception of how vital it is to conduct conscientious behaviour must also be investigated.

From the perspective of what has been presented, this research advances the following hypotheses:

H1: Social Influence has a significant impact on the intention to purchase upcycled fashion products.

H2: Attitude toward upcycled fashion materials has a significant impact on the intention to purchase upcycled fashion products.

H3: Perceived risk has a significant impact on the intention to purchase upcycled fashion products.

H4: Environmental concern has a significant impact on the intention to purchase upcycled fashion products.

H5: Usefulness has a significant impact on the intention to purchase upcycled fashion products.

The goal of this study is to find out what makes people want to buy upcycled fashion products from specialized online platforms. The results showed that social influence, attitude towards upcycled fashion materials, perceived risk, environmental concern, and usefulness have a significant positive impact on the consumer's intention to buy green compared to upcycled fashion products. Moreover, because social influence and attitude toward upcycled fashion materials have proven to have the greatest effect on buying intent, digital marketers need to focus on consumer perceptions when establishing promotional campaigns on online platforms specializing in upcycling. fashion. This research has the potential to improve existing analyses of the green consumer profile in Romania by providing actual evidence of the market's appetite for upcycled fashion products.

The rest of the paper is organized as follows: the research model is presented in the second section; the empirical results are described in the following sections, and the study's conclusions are presented in the last section.

## RESEARCH METHODOLOGY

To ensure the validity of the research, the questions of this study are based on previous related literature that has been revised by experts and correctly altered in line with the context of this study [7, 12, 14]. Table 1 contains descriptions of the research variables and theoretical frameworks that were used in this study. An anonymous online questionnaire was distributed through social networks to 420 people from January 2022 to March 2022. Data collected were analysed using the structural equation model (SEM).

Table 1

DEFINITIONS OF THE CONCEPTS AND VARIABLES USED IN THE STUDY

| Concepts and Variables | Definition |
|---|---|
| Social Influence (SI) | The choice of the media is not based on its subjective qualities but on other social elements, including organizations, peer groups, posts, and social networks, that have an impact on how individuals perceive, experience, and behave when using the media. |
| Attitude toward upcycled fashion materials (AUF) | Individuals' intentions to purchase upcycled fashion products can be predicted, in part, by their attitudes. |
| Perceived risk (PR) | It occurs when consumers just cannot see the consequence of their purchase and are scared about undesirable outcomes. |
| Environmental concern (EC) | This refers to an individual's strong attitude toward ecosystem protection and environmental issues. |
| Usefulness (UF) | Possibilities of the subjective personal opinion that one will engage in given behaviour in the future. |
| Purchase intention (PI) | This is a person's willingness to actively act. |

The respondent's level of agreement and disagreement on each item was described using a five-point Likert scale (1 = strongly disagree, 3 = uncertain, 5 = strongly disagree). To test the theoretical hypothesis, this study used Partial Least Squares (PLS). To eliminate the bias of the results, the snowball sampling method was used, which also allows equal chances to be given to all respondents who have the potential to be future customers of upcycling fashion products. The percentage of males and women in the surveyed population may be found to be fairly equal. The majority of participants were between the ages of 25 and 34 (40%) and 15 to 24 (34%). Approximately 10% of those polled were between the ages of 31 and 38, 8% were between the ages of 35 and 44, 6% were between the ages of 45 and 54, and 2% were between the ages of 55 and 70. Figure 1 illustrates the conceptual framework of the study.

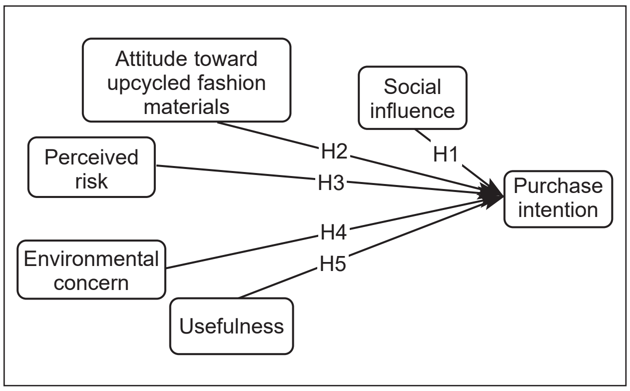


Fig. 1. Proposed research model

The reliability and validity of the measuring model were examined. In this study, the questionnaire's findings were examined using Cronbach's reliability of composition, and the validity analysis comprised assessments of convergence validity and discriminate validity. The convergent validity test was conducted using confirmatory factor analysis (CFA) and the average amount of variance extracted (AVE) in this study. The convergent validity was determined by comparing the AVE and the square of the correlation coefficient between the dimensions. The purpose of the structural model analysis was primarily to investigate the analytical outcomes of the routes between the assumptions. All of the AVE measures presented in table 2 exceeded 0.5, providing strong support for convergent validity.

## RESULTS

Following the verification of the measurement model, the structural model shown in table 3 was analysed for its accuracy. Overall model fit results ($\varkappa^2$/df = 1.521, NFI = 0.962, NNFI = 0.966, CFI = 0.978, RMSEA = 0.042, SRMR = 0.05) suggested that the hypothesized model as well as the observed data have been well. The estimated structural coefficients were then used to assess the individual hypotheses. Figure 2 demonstrates that the model's predictors account for 68% ($R^2$ = 0.68) of the variance in purchase intention. Social influence is found to have a significant influence on purchase intention with the highest coefficient ($\beta$ = 0.38, $p < 0.001$) that is subsequently followed by attitude toward upcycled fashion materials ($\beta$ = 0.29, $p < 0.001$), environmental concern

Table 2

SUMMARY OF MEASUREMENT SCALES

| Variable | Constructs items | Mean | Factor loading | Cronbach's α | AVE |
|---|---|---|---|---|---|
| Social Influence (SI) | SI 1 | 3.75 | 0.74 | 0.95 | 0.58 |
| | SI 2 | 3.79 | 0.75 | | |
| | SI 3 | 3.96 | 0.74 | | |
| Attitude toward upcycled fashion materials (AUF) | AUF 1 | 3.97 | 0.77 | 0.95 | 0.60 |
| | AUF 2 | 3.70 | 0.74 | | |
| | AUF 3 | 3.84 | 0.77 | | |
| Perceived risk (PR) | PR 1 | 3.85 | 0.79 | 0.85 | 0.56 |
| | PR 2 | 3.94 | 0.74 | | |
| | PR 3 | 3.87 | 0.74 | | |
| Environmental concern (EC) | EC 1 | 3.86 | 0.77 | 0.89 | 0.58 |
| | EC 2 | 3.85 | 0.81 | | |
| | EC 3 | 3.94 | 0.75 | | |
| Usefulness (UF) | UF 1 | 3.78 | 0.74 | 0.86 | 0.55 |
| | UF 2 | 3.73 | 0.74 | | |
| | UF 3 | 3.83 | 0.75 | | |
| Purchase intention (PI) | PI 1 | 3.81 | 0.74 | 0.94 | 0.55 |
| | PI 2 | 3.39 | 0.74 | | |
| | PI 3 | 3.69 | 0.75 | | |
| | PI 4 | 3.78 | 0.76 | | |

(β = 0.24, p < 0.001), usefulness (β = 0.22, p < 0.001), and perceived risk (β = 0.20, p < 0.01). As a consequence, the findings suggested that the proposed model is acceptable.

Table 3

| THE RESULTS OF STRUCTURAL MODEL PATH ESTIMATES | | | | |
|---|---|---|---|---|
| Hypothesized path | | β | t -value | Testing results |
| H1 | SI -> PI | 0.38 | 2.87* | Supported |
| H2 | AUF-> PI | 0.29 | 2.24* | Supported |
| H3 | PR -> PI | 0.20 | 2.05* | Supported |
| H4 | EC -> PI | 0.24 | 2.40* | Supported |
| H5 | UF -> PI | 0.22 | 2.10* | Supported |
| Model fit indices | | | | |
| NFI | | 0.962 | | |
| CFI | | 0.978 | | |
| RMSEA | | 0.042 | | |
| RMR and SRMR | | 0.05 | | |

Note: Significance of path coefficients: * p < 0.01.

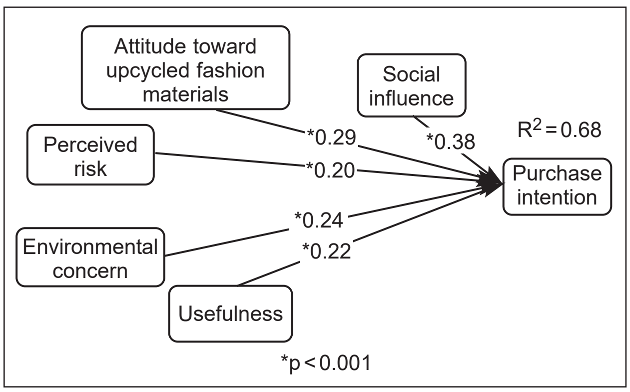


Fig. 2. Results of structural model testing

Most of the hypotheses of the model are strongly supported, but an important conclusion of this study is that social influence plays an important role in the process of expectation formation, and also in the intention to purchase upcycled fashion products. So, online platforms specializing in upcycling fashion marketing can direct their promotional campaigns to people with environmental concerns by entailing usefulness as a hedge against future uncertainty.

## CONCLUSIONS

To attract new consumers for upcycling fashion items, specialized online platforms must examine from the users' perspective and understand why users utilize the virtual community and what type of strategy should be implemented to increase the intention to purchase these products [16–18]. Furthermore, this study examined psychological and behavioural elements at the individual level while analysing the factors influencing customer behaviour toward upcycling fashion products. Since upcycling fashion inclination has stabilized, customers' consumption patterns have developed.

From the perspective of potential theoretical implications, this research adds to the body of knowledge and literature on sustainable and upcycled fashion. Because of the issues surrounding textile waste, many fashion firms are battling to attract and keep clients with sustainable fashion items, such as upcycling fashion products. Overcoming these preconceptions is a significant challenge for today's upcycling fashion marketers.

Several suggestions for managers and marketers are provided in light of the research's practical consequences. Thus, these results can act as a reference point for knowing the priorities or expectations of the Romanian customer for upcycled fashion products. For instance, the study's results show that behavioural factors are also linked to making financial decisions. This means that the current model could be improved by adding more features related to how people see financial risk.

Converting non-consumers of sustainable fashion products, on the other hand, can be challenging. On top of that, as mentioned previously, the phenomena of fashion are rather complicated. The current study evaluated only behavioural purchase intent, as opposed to actual consumption; it was conducted in an online format, and its participants were limited in terms of their geographic location. In future studies, we will use other individual characteristic variables, apart from personal values, which could shape the relationship with the consumption of upcycling fashion products.

In conclusion, it is important to take measures to prevent environmental pollution through the proper recycling of textiles. It is vital to remember that any company that generates waste, in this case, some textiles, are obliged and responsible to carry out their management. People's feelings about upcycled fashion materials are seen as the most important factor in determining whether or not they will buy these products [19, 20]. Online community platforms that focus on upcycled fashion can also do customer segmentation from the customer's point of view to better meet customer demand.


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