Evaluation of the mechanical properties of chopped carbon fibre reinforced polypropylene, polyethylene, polyamide 6, and polyamide 12 composites

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ARI ALİ
BAYRAM ALİ
KARAHAN MEHMET
KARAGÖZ SEÇGİN

ABSTRACT – REZUMAT

Evaluation of the mechanical properties of chopped carbon fibre reinforced polypropylene, polyethylene, polyamide 6, and polyamide 12 composites

In this study, a comparative assessment of the mechanical properties of chopped carbon fibre (CF) reinforced polypropylene (PP), polyethylene (PE), polyamide 6 (PA6), and polyamide 12 (PA12) composites was performed. A variation in the composites was obtained by changing the fibre volume fraction of the composite elements under the same manufacturing method and conditions. After blending reinforcement and matrix materials using the extrusion method, the composite materials were manufactured in the shape of plates with thermoforming. The composites' tensile and 3-point bending tests were carried out, and the surface morphology of the fractured surfaces was examined by Scanning Electron Microscope (SEM). As the fibre content in all matrices increased, the efficiency of the fibre in the composites decreased. Finally, ANOVA analysis and mathematical model development by the least square optimization method were performed to analyse and fit experimental data. As a result of the ANOVA analysis, it was seen that the matrix type was more effective on the composite than the fibre type. The error of the modelling performed is less than 20% for the tensile and three-point bending tests.

Keywords: *polymer-matrix composites, carbon fibre, mechanical properties, ANOVA analysis, experimental data*

Evaluarea proprietăților mecanice ale compozitelor din polipropilenă, polietilenă, poliamidă 6 și poliamidă 12 armate cu fibre de carbon tăiate

În acest studiu, a fost efectuată o evaluare comparativă a proprietăților mecanice ale compozitelor din polipropilenă (PP), polietilenă (PE), poliamidă 6 (PA6) și poliamidă 12 (PA12) armate cu fibre de carbon (CF). S-au obținut diferite materiale compozite prin modificarea fracției de volum de fibre, utilizând însă aceeași metodă și aceleași condiții de fabricație. După amestecarea materialelor de armare și matrice prin metoda extrudarii, materialele compozite au fost fabricate sub formă de plăci cu termoformare. Au fost efectuate testele de tracțiune și îndoire în trei puncte ale compozitelor, iar morfologia suprafețelor fracturate a fost analizată cu microscopul electronic cu scanare (SEM). Pe măsură ce conținutul de fibre din toate matricele a crescut, eficiența fibrei din compozite a scăzut. În cele din urmă, analiza ANOVA și dezvoltarea modelului matematic prin metoda de optimizare a celor mai mici pătrate au fost efectuate pentru a analiza datele experimentale. Ca rezultat al analizei ANOVA, s-a observat că tipul de matrice a fost mai eficient pe compozit decât tipul de fibră. Eroarea modelării efectuate este mai mică de 20% pentru încercările de tracțiune și îndoire în trei puncte.

Cuvinte-cheie: *compozite polimer-matrice, fibră de carbon, proprietăți mecanice, analiză ANOVA, date experimentale*

INTRODUCTION

Polymer matrix composites are increasingly used in the plastics industry due to their high strength and low density [1]. Especially, chopped fibre-reinforced thermoplastic composites have become very appealing because of their ease of production, economy, and better mechanical properties and are widely used in many fields such as aircraft, aerospace, defence, and automotive industries [2]. In general, higher fibre volume fractions in composites are required to achieve a high-performance composite, and increasing the fibre volume fraction substantially increases the strength properties. Thus, the impact of fibre content on the mechanical properties of composites is significant [3]. Similarly, the mechanical properties of composites such as strength, modulus, and toughness usually up with increasing chopped fibre length; so, the mechanical properties of the composites are identified by the fibre volume fraction, as well as the size of the chopped fibre [4]. The properties of CF-reinforced polymers do not depend solely on the properties of the matrix and fibre; It also depends on the carbon fibre content, distribution, and fibre/matrix adhesion [1]. In the literature, it is reported that the mechanical performance of the composite increases with low and medium fibre content. However, high fibre content (more than 30 vol.%) indicates that the homogeneous distribution is impaired and weak fibre-matrix adhesion occurs. In this case, it is extremely important to achieve good fibre distribution to improve composite performance [5]. Moreover, the chemical structures of the fibre and the matrix determine the degree of interfacial adhesion. In this context, the fibre surface needs to be modified by chemical or plasma treatment [6]. Extrusion and injection moulding are the common methods to prepare CF reinforced polymer composites [7]. However, a significant amount of fibre breakage occurs during production, caused by the fibre-polymer, fibre-to-fibre, and fibre-processing equipment surface wall interactions. Fibre breakage resulting from these interactions causes a reduction in fibre length, which results in reduced fibre efficiency [8]. Therefore, the effects of fibre length and volume ratio, key factors that determine the final mechanical properties of composites, on CF reinforced polymer composites' mechanical properties are considered a combined impact [9]. Moreover, the mechanical behaviour of the fibre-reinforced composites mainly depends on the fibre's strength, chemical stability, matrix strength, and the interfacial bond between the fibre and the matrix to ensure stress transfer [10].

Relating CF reinforced polymer composites; there are various studies published in the literature [11, 12]. Zhou et al. investigated fibre breakage and dispersion for CF reinforced PA6/clay nanocomposites and drew attention to the effects of processing conditions on fibre breakage and dispersion [12]. Karsli and Aytaç prepared the chopped CF reinforced PA6 composites by injection method and investigated the effect of mixing ratios and fibre lengths on the mechanical properties of the composite [13]. Chen and Qiang produced PP and polyamide composites reinforced with CF by injection moulding. The study concluded that as the CF content of the composite increased, the tensile and impact strength increased [14]. Tiesong Lin et al. (2008) investigated the effects of 2 mm, 7 mm, and 12 mm CF reinforced geopolymer matrix composites on the mechanical properties and fracture behaviour. It was observed that the bending strength reached the highest value at 7 mm fibre length [15]. Based on the studies available in the literature, injection moulding is reported to be faster, easier to manufacture, and highly efficient [16, 17]. Sivas et al. produced fibre reinforced thermoplastic composite by injection and extrusion production method. Composites produced by extrusion showed a 17% superior performance [18].

In addition to experimental research, there are studies in the literature that expand experimental research by including correlation through numerical modelling. These models were used to predict the mechanical properties of fibre-reinforced composites, such as tensile strength, elastic modulus, and Poisson's ratio [19]. Cox published his work using the shear lag model for the interfacial strength between fibre and matrix [20]. Halpin and Kardos proposed a model to evaluate the properties of composites in terms of matrix and fibre properties. This model is based on the Halpin-Tsai equations, which are empirical type equations and are very often used to predict the tensile properties of composites [21]. Liang proposed a model to correlate the tensile strength of short fibre reinforced polymer composites. The model formulation was based on the force balance between matrix, fibre and composite [22].

The main objective of this work is to perform a comparative study for assessing the mechanical properties of chopped CF reinforced PP, PE, PA6, and PA12 composites. To do that, the focus is to gain a deep understanding of the tensile and 3-point bending properties of the CF-PP, CF-PE and CF-PA6, and CF-PA12 composites couples. In this context, 12 different composite materials were manufactured by adding 10 vol.%, 20 vol.%, and 30 vol.% chopped CF reinforcement materials to each PP, PE, PA6, and PA12 matrix elements under the same manufacturing method and conditions. To provide detailed and collective information to the literature, the rest of the paper is structured as follows: the material selection and production method explain why CF is chosen for this study. Next, the experimental design and ANOVA Analysis structure are introduced. Subsequently, in the results and discussion section, the comparative assessment of the mechanical properties of the fibre-polymer couples is performed by results tables, plots, SEM images, and ANOVA analysis. Finally, a least-square optimization study is carried out to obtain mathematical expression by fitting experimental data.

EXPERIMENTAL DETAILS

Materials and methods

For the experimental design, based on the literature survey, CF was preferred because of having a higher surface energy of 42.1 mJm^{-2} [23] compared to the other alternatives such as glass fibre (surface energy is 32.5 mJm^{-2}) [24] and aramid fibre (surface energy is 34.9 mJm^{-2}) [25]. In general, the main factors for good interfacial adhesion can be defined as the wettability between fibre-matrix and chemical bonding and mechanical interlocking on rough fibre surfaces [26]. Good wetting between the fibre and the matrix is required to achieve good interfacial adhesion and comprehensive and suitable interfacial contact. Wettability mainly depends on the surface energy of the two materials. The high surface energy of the fibre contributes to good adhesion and ensures good fibre-matrix interface compatibility [27, 28].

As a result, the high surface energy of the fibre has a positive effect on the performance of the composite. Since CF has the highest surface energy among the aforementioned fibres, its performance is expected to be higher than other fibres. On the other hand, the surface energy of the matrix should be low.

Molecules in a liquid with low surface energy are not strongly attracted to each other; instead, they tend to spread and adhere to the surface, so a liquid with high free energy will not bond to the fibre surface [29, 30].

In experimental studies, a 6 mm length of chopped fibre was used in the composites. Fibre volume fractions were determined as 10 vol.%, 20 vol.%, and 30 vol.%, and PP, PE, PA6, and PA12 were used as matrix materials. Mechanical properties of matrix and fibre materials were taken from catalogue values.

Preparation of test samples and all related tests were carried out in Bursa Technology Coordination and R&D Centre (Bursa, Turkey). A twin-screw extruder (Polmak Plastik 22 mm Lab type research extruder) was used to produce composites. The temperature values for the five zones in the extruder were determined using the literature and the product catalogue of the materials (195°C – 215°C – 225°C – 225°C – 240°C for PP, 170°C – 195°C – 220°C – 220°C – 230°C for PE, 240°C – 240°C – 250°C – 260°C – 285°C for PA6, 190°C – 200°C – 210°C – 220°C – 230°C for PA12) [31–34]. After the composites were obtained, they were granulated with a cutter.

500 mm × 500 mm composite plates were obtained by the granular press moulding method. Moulding consists of 3 stages, and all samples taken were kept in the first stage for 120 seconds, in the second stage for 180 seconds, and for 60 seconds in the third stage. The test samples were prepared by cutting the relevant moulds in standard sizes on the CNC machine.

Experimental design and ANOVA analysis

The experimental factors and levels shown in table 1 were selected. Sing these factors and levels; the experimental design was performed as illustrated in table 2 used to observe, achieve and interpret the impacts on the response variable by making the desired changes on the input variables [35].

Table 1

EXPERIMENT FACTORS AND LEVELS				
Factors	**1. Level**	**2. Level**	**3. Level**	**4. Level**
A – Matrix Type	PP	PE	PA6	PA12
B – Fibre volume fraction %	0*	10	20	30

Note: *0 represents the no fibre condition or matrix itself.

The analysis of variance shows to what extent the examined factors affect the output value chosen to measure quality and what kind of various levels cause. On top of that, the statistical reliability of the achieved results is also tested. For this purpose, firstly, the SS_T value (sum of total squares), which shows the total variability of the signal/noise (S/N) ratio, is calculated according to equation 1 [36].

$$SS_T = \sum_{i=1}^{n} (\eta_i - \eta_m)^2 \qquad (1)$$

$$SS_j = \sum_{i=1}^{n} \left[n_{ji} \times (\eta_{ji} - \eta_m)^2 \right] \quad j = A \text{ or } B \qquad (2)$$

$$F = \frac{SS_T/k-1}{SS_E/N-k} \qquad (3)$$

In equation 1, η_i is the signal-to-noise ratio calculated over the measured value, η_m – is the average of the signal-to-noise ratios calculated over the measured value, and n – the total number of experiments [36, 37]. The SS_T value is the sum of the squares of the two factors of SS_A (sum of squares of factor A) and SS_B (sum of squares of factor B), and the SS_E value is the sum of the squares of the margin of error. The sum of the squares of each factor was calculated separately by using equation 2.

In equation 2, k_j represents the number of levels of the A or B factor, n_{ji} – the number of experiments at the i level of the A or B factor, η_{ji} – the S/N ratio of the A or B factor at the i level, and η_m – the average S/N ratio [36,37]. For the next step, the F-Test is performed by calculating equation 3 to present how much each experimental factor affects the test results. For the next step, the F-Test is performed by calculating equation 3 to present how much each experimental factor affects the test results.

In equation 3, k–1 is the degree of freedom for the numerator by subtracting one from the number of groups, $N - k$ is the degree of freedom for the denominator, which is determined by subtracting the number of groups from the number of observations in all groups [38].

RESULTS AND DISCUSSION

Tensile properties and fractography

Tensile tests were carried out with Besmak-BMT 100E brand Universal Tensile Tester (100 kN). Tensile test samples were prepared according to TS EN ISO 527-2 type 2 standards. The tensile speed was set as 2 mm/min, and the pre-stress value was set as 10N. The measuring length was 50 mm for the video extensometer was. The tests were performed at 21°C. Fractured surface images of 30 vol.% fibre reinforced samples were examined with Hitachi TM3000 brand SEM at Bursa Technology Coordination and R&D Center (Bursa, Turkey).

It was observed that the tensile strength of all composite materials increased as the proportion of reinforcement material went up; so, the highest tensile strength values were achieved at the ratio of 30 vol.% reinforcement material. In terms of fibre efficiency factor, when the matrix materials are compared, 10 vol.% reinforcement PA12 shows the best performance, while the worst is seen in 30 vol.% reinforcement PE.

Table 2

EXPERIMENTAL DESIGN																
Experiment no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A – Matrix type	1	2	3	4	1	1	1	2	2	2	3	3	3	4	4	4
B – Fibre volume fraction	1	1	1	1	2	3	4	2	3	4	2	3	4	2	3	4

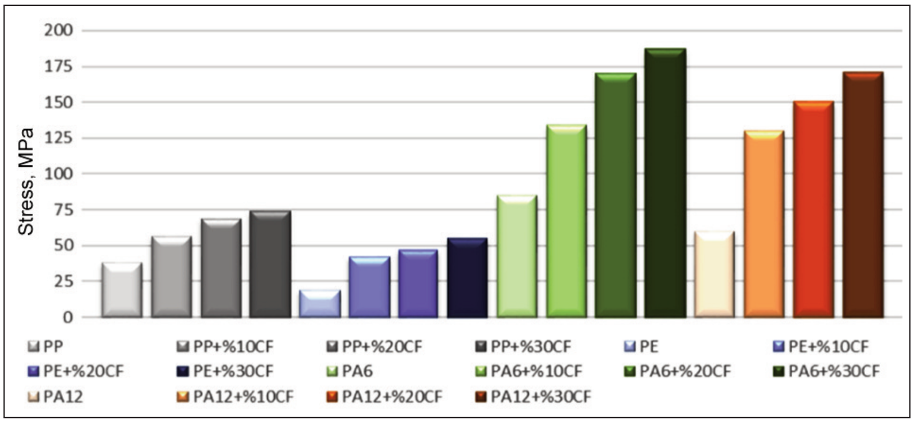


Fig. 1. Tensile test results of composites

S.Y. Fu and B. Lauke investigated fibre efficiency in chopped glass fibre and chopped CF reinforced PP composites. The tensile test of the composite materials with 8%, 16%, and 25% reinforcement materials was carried out. They concluded that the fibre efficiency in the glass and CF-reinforced composite decreased as the fibre volume fraction increased [8]. Choudhari and Kakhandki, on the other hand, investigated the mechanical properties of the chopped CF reinforced PA66 composite. It was observed that the tensile stress values decreased as the fibre volume fraction (10%, 20%, and 30% reinforcement materials used) increased on the matrix material. The SEM images of the 30% reinforced composite were examined, and it was observed that the fibres were not covered with the polymeric matrix, and most of the fibres were pulled out [39]. Karsli and Aytaç, on the other hand, investigated the mechanical properties of CF-reinforced PA6 composite material. It was determined that the amount of deformation in the matrix increased with the increase in the number of fibre rods in the matrix material, thus causing the fibres to pull out more easily [13]. Y. Zhang et al. interpreted the decrease in tensile strength and bending of the fibres as the fibre volume fraction increased as the fibre not being able to form a good interface with the matrix due to its smooth surface, thus causing the fibres to be stripped from the matrix [40]. The efficiency of fibres on matrix materials can be calculated using the Kelly–Tyson model [8, 31].

$$\sigma_c = \lambda_f \sigma_f V_f + \sigma_m (1 - V_f) \tag{4}$$

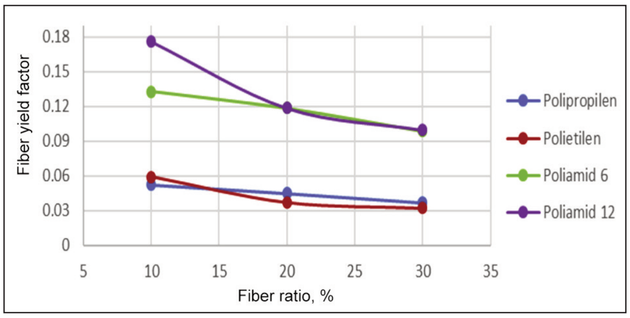


Fig. 2. CF efficiency factor in composites

In equation 4, σ_c (composite), σ_f (fibre), and σ_m (matrix) are the tensile strengths. V_f is the fibre volume ratio of the composite and λ_f – the fibre efficiency factor. When the tensile test results were inspected, it was clear that the mechanical properties of the matrix materials were greatly improved with the addition of fibres (figure 1). Nonetheless, fibre efficiency factors (figure 2) decreased with increasing fibre volume fractions [41]. SY Fu et al. explain this decrease in fibre efficiency: Average fibre length decreases as fibre volume ratios increase. This indicates that a higher fibre content causes significant damage to fibre length. The increased damage in fibre to length at higher fibre volume ratios is primarily attributed to the higher fibre-fibre interaction. It is also noted that the average length of CF is less than the average length of glass and aramid fibre. This is because carbon fibres are more fragile. Therefore, it is explained as being more easily broken during processing [8]. As the fibre volume fraction increased, the deformation ratio increased between the matrix and the fibre, and the weakening of the interface adhesion gave this result [25, 42]. In addition, another reason for the low fibre efficiency can be explained as follows; when figure 3 is examined, it is seen that the CF is not homogeneously dispersed in the matrixes. Wang et al. (2008) examined the effect of fibre dispersion on the mechanical properties of CFRC samples. They concluded that the inhomogeneity of the fibre dispersion negatively affects the strength of the composite [43]. Therefore, in our study, it can be supposed that while the fibre volume fraction increases in CF reinforced matrixes, one reason for the decrease in fibre efficiency is the deterioration of homogeneous distribution as this fibre percentage increases. Among the 30% CF reinforced composites, the lowest fibre efficiency was observed with those made with PE and PP. The main reason is that PE and PP have lower tensile strength than other matrices. Therefore, it is necessary to evaluate each fibre-matrix efficiency in itself. Normally, CF increases the tensile strength of PE by about 3 times. When the 30% fibre-reinforced composites were examined, the CF efficiency decreased as the fibre volume fraction increased in the four matrices. However, when we look at the highest-fibre efficiency, it is seen that the composite made with 10% CF added PA12. This means that as the CF ratio increases, the amount of deformation in the matrix increases, and the fibres do not provide the desired level of adhesion to the matrix. But CF showed the highest effect in PE. The 30% CF reinforcement increased the tensile strength of PE by 3 times, increasing it from 19 MPa to 56 MPa.

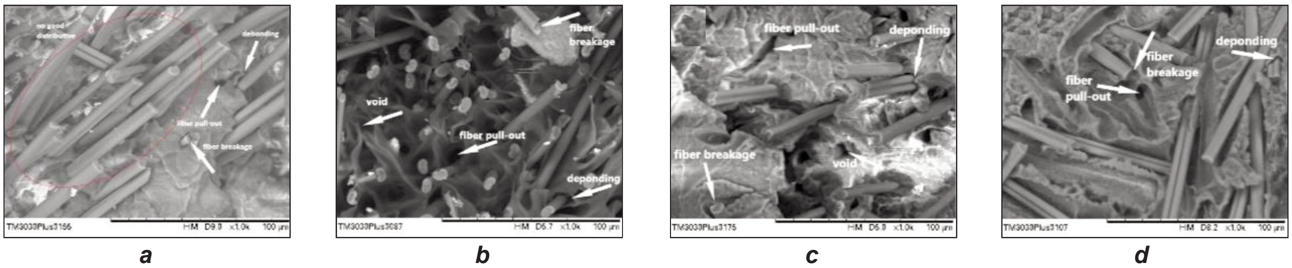


Fig. 3. SEM images of 30% CF reinforced composites: *a* – PP; *b* – PE; *c* – PA6; *d* – PA12 matrix

However, it only increased the tensile strength of PA6 by 2 times. It was observed that all samples had brittle fractures. This shows that damage occurred with fibre breakage.

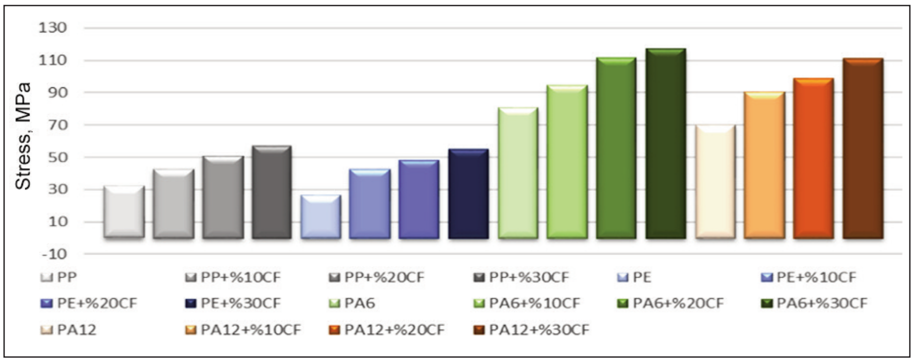


Fig. 4. Three-point bending test results of the composites

SEM images of 30% fibre-reinforced composites can be seen in figure 3, *a–d*. It is seen that the damage mechanism in composite materials occurs in three stages. In the first stage, micro cracks were formed in the matrix material. Then, the separation between the fibre and the matrix, and finally, the split at the interface and the breakage of the fibres caused damage. The physical adhesion between fibres and polymer matrices and the formation of voids at the interface between these two materials is controlled mainly by the wetting properties of the fibres [44]. Good wettability means that the reinforcing material that covers the rough surface of the matrix will flow over and take in all the air. Pull-out appears in the composites if good wetting does not occur between the matrix and the fibre [42]. When figure 3, *a–d* is inspected, it is observed that pull-out occurs in the fibres, and it is not covered with the polymeric matrix. This means poor interface adhesion between the fibre and the matrix [31]. Dark circles around the fibres show local deformation in the matrix around the fibres.

Additionally, these dark circles at the interface show the fibres have been unbonded with the matrix. The dark circle is because of the local deformation of the matrix around the fibre once the fibres separate from the matrix [25]. Some of the fibres were pulled from the matrix during deformation. It can be seen in figure 3, that the CF is not homogeneously dispersed in the PP matrix. When the fracture surfaces of 30% CF-reinforced composites in figure 3 were examined, it was seen that bending and crossing occurred in the fibres with the increase in fibre content, and the surface of the fibres was clean and smooth [40].

Three-point bending properties

The bending tests were carried out on a SHIMADZU brand three-point bending tester. According to TS EN ISO 178-3 three-point bending standards, the test samples were ready. The test conditions are set as the distance between the supports is 64 mm, the test speed is 2 mm/min, and the ambient temperature is 21°C. The 3-point bending test results are shown in figure 4. The results indicate that a higher bending strength ensures that the samples have better-bending strength. Moreover, it was observed that the bending stress of the composites increased, and the flexibility decreased as the fibre volume fractions increased. However, mechanical properties such as fibre-matrix interface adhesion levels and random dispersion of fibres were also adversely affected [39, 45]. In addition, molecules in a liquid with low surface energy are not strongly attracted to each other; instead, they tend to spread and adhere to the surface, so a liquid with high free energy will not bond to the fibre surface. To form a better bond, the matrix surface energy must be low [29]. Since the surface energy of the PE matrix is lower than other matrices, composites with the PE matrix performed better than the others [30]. The summary of the test results: (1) It was observed that the highest enhancement for each composite was obtained for 30% CF reinforcement cases, (2) 30% CF reinforcement increased the flexural strength of PP approximately 1.7 times by enhancing it from 32 MPa to 55.3 MPa, (3) 30% CF reinforcement increased the flexural strength of PE 2 times by enhancing it from 27 MPa to 55.1 MPa, (4) 30% CF reinforcement increased the flexural strength of PA6 1.4 times by enhancing it from 81 MPa to 117 MPa and (5) 30% CF reinforcement the flexural strength of PA12 1.6 times by enhancing it from 70 MPa to 110 MPa.

Analysis of experimental results

Signal value (S) stands for the actual value presented by the system and intended to be measured. The noise factor (N) represents the share of undesired factors in the measured value. In this method, the goal is to achieve higher S/N values, and the following equation 5 is used for the S/N ratio calculations [36, 38]. The S/N ratios of the test results are shown in table 3.

$$S/N = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \qquad (5)$$

where y is the measurement value, and n – the number of experiments.

In the next section, the impact of each factor at each level is investigated. For this aim, the average of the S/N ratios (table 3) is calculated for each factor level. When the S/N rates of the tensile and 3-point bending tests are analysed (figure 5), it can be observed that the mechanical properties increase significantly under the presence of fibre. The reason for this is that as the fibre percentage increase, the deformation energy of the composite rises, and the bond becomes stronger between the matrix and the fibre. In addition, molecules in a liquid with low surface energy are not strongly attracted to each other; instead, they tend to spread and adhere to the surface, so a liquid with high free energy will not bond to the fibre surface. To form a good bond, the matrix surface energy must be low [29]. Since the surface energy of the PE matrix is lower than other matrices, composites with the PE matrix performed better than the others [30]. On the other hand, it is observed that the effect in percentage decreases as the fibre percentage increases. As seen in figure 5, the matrix type significantly affected the mechanical properties of the composites. The highest effect was observed with composites made with PA6. This is because PA6 has the best mechanical properties among other matrices.

To explain to what length each experimental factor impacts the experiment results, the ANOVA analysis was performed for each factor. The calculated F values ensure the targeted 95% confidence level. The analysis details are shown in table 4. It can be observed from table 4 that matrix kind has the dominant impact on the mechanical properties. The second significant factor is fibre content s. However, It is seen that the impact on the matrix material increases as the fibre additive rate rises. It can be concluded that even though fibre addition has an enormous impact on the mechanical properties, of the composites, the mechanical properties of the composites have more sensitivity regarding the matrix type.

Mathematical modelling and data analysis by regression

This section has developed mathematical models to measure the relationship between input and output parameters. The model constants are obtained by the nonlinear multivariable optimization method. In the model, the fibre volume fraction (W) and the type of polymer matrix (P) are defined as the independent variable to result in dependent variables ($y(W,P)$ = the mechanical properties of the composites). The general representation of the proposed model equation is shown as follows:

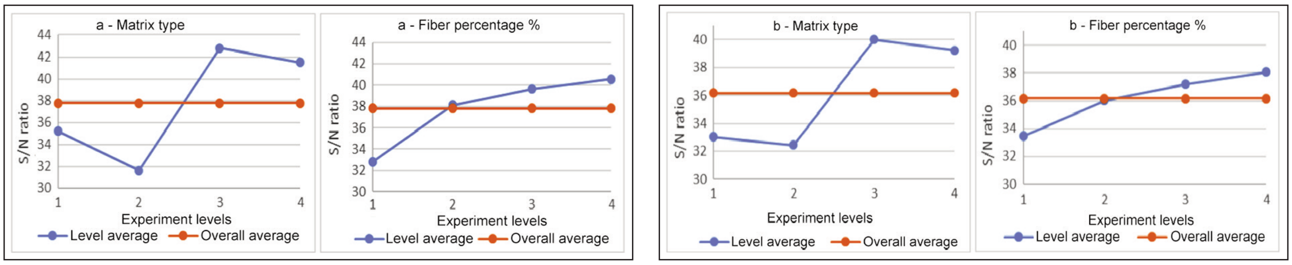
Nonlinear equation (NLE):

$$y(W,P) = a_0 \times W^{a_1} \times P^{a_2} \qquad (6)$$

where y is the model predicted outcomes and are the model coefficients (determined by the data fitting process) [46]. The above model constants are found by performing regression analysis shown in table 5 for mechanical properties of tensile, three-point, and bending respectively. In the modelling study, W and P are considered 4 levels. For W, the levels are

Table 3

S/N RATIOS OF EXPERIMENTAL RESULTS																
Experiment no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Tensile (MPa)	38	19	85	60	56.8	69.2	74.2	42.6	47.3	55.2	133.7	169.9	186.9	129.7	150.0	170.7
S/N	31.6	25.6	38.6	35.6	35.0	36.8	37.4	32.6	33.5	34.9	42.5	44.6	45.4	42.2	43.5	44.6
Three-Point Bend	32	27	81	70	42.9	51.2	57.4	42.9	48.2	55.0	95.0	111.1	117.0	90.7	99.1	111
S/N	30.1	28.6	38.1	36.9	32.6	34.2	35.1	32.6	33.6	34.8	39.5	40.9	41.3	39.1	39.9	40.9



a

b

Fig. 5. Graphical representation of: *a* – S/N ratios for tensile strength; *b* – Three-point bending

Table 4

ANOVA TABLE FOR TENSILE TEST

S/N ratio: 37.78	**Average S/N Values**								
	Degrees of Freedom	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Sum of Squares**	**Variance**	**F**	**Contribution (%)**
A- Matrix Type	3	35.22	31.63	42.79	41.5	333.27	111.09	137.8	69.58
B- Fibre volume fraction %	3	32.83	38.11	39.61	40.58	143.26	47.75	59.25	29.91
Error	8					6.45	0.81		0.5
Total	14					482.98	159.65		

ANOVA TABLE FOR 3-POINT BEND TEST

S/N ratio: 36,18	**Average S/N Values**								
	Degrees of Freedom	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Sum of Squares**	**Variance**	**F**	**Contribution (%)**
A- Matrix Type	3	33.03	32.44	40.00	39.22	190.88	63.63	155.93	79.45
B- Fibre volume fraction %	3	33.45	36.01	37.18	38.07	48.15	16.05	39.33	20.04
Error	8					3.26	0.41		0.51
Total	14					242.29	80.08		

Table 5

MATHEMATICAL MODELS FOR PREDICTING THE MECHANICAL PROPERTIES OF COMPOSITES

Model conditions			
Property	W	P	Model Equation
Tensile	1=0, 2=0.1, 3=0.2, 4=0.3	1=PE, 2=PP, 3=PA12, 4=PA6	$y(W, P) = 22.25175 \cdot W^{0.5764774} . P^{1.014976}$
Three Point Bending	1=0, 2=0.1, 3=0.2, 4=0.3	1=PE, 2=PP, 3=PA12, 4=PA6	$y(W, P) = 27.59192 \cdot W^{0.3237031} . P^{0.7525528}$

described as 1 = 0, 2 = 0.1, 3 = 0.2 and 4 = 0.3. On the other hand, the various type of matrixes used in this study is assigned to different levels to obtain more accurate model equations for the mechanical properties of the composites (table 5).

The comparative assessments' results between the experimental values and the model-predicted values are performed. The evaluation is carried out for tensile and three-point bending by taking into account the error between the experimental values, and the model-predicted values [38]. The obtained errors indicate that 75% are less than 20% of the tensile and three-point bending error. These results imply that the model (even though having a highly nonlinear nature) predictions against experimental values are very close and at acceptable levels [19].

CONCLUSIONS

In this study, a comparative assessment of the mechanical properties of chopped CF reinforced PP, PE, PA6, and PA12 composites was performed. It is concluded that the presence of reinforcement material, the type of matrix, the degree of adhesion between the matrix and the interface, matrix/fibre volume fraction, distribution, and orientation in the matrix are effective parameters in the mechanical behaviour of the composites.

The tests' results indicate that the mechanical properties increase significantly under the presence of fibre. On the other hand, it is observed that the effect in percentage decreases as the fibre percentage increases. Among the matrices of PE, PP, PA6, and PA12, CF-reinforced composites made with PA6 show the highest-fibre efficiency, but the PE matrix shows the highest performance improvement than the others because having the lowest matrix surface energy, which enables to form good form with the fibre. From the results of S/N ratios and ANOVA analysis, it can be seen that the percentage of the impact of matrix and fibre volume fraction on the mechanical properties of composite materials is various. It is observed that the matrix kind has the dominant impact on the mechanical properties.

Finally, nonlinear mathematical models to correlate the experimental values are developed. Based on the results, it is inferred that the predictions from the proposed models are found to be in good agreement with experimental data. Thus, it can be concluded that the proposed models are robust enough to correlate the experimental response of the polymer composites.

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Authors:

ARI ALİ[1], BAYRAM ALİ[2], KARAHAN MEHMET[3], KARAGÖZ SEÇGİN[4]

[1]OSTİM Technical University, Vocational School of Higher Education, Department of Weapon Industry Technician, 06374, Ankara, Turkey

[2]Bursa Uludag University, Department of Mechanical Engineering, 16059, Bursa, Turkey

[3]Bursa Uludag University, Vocational School of Higher Education, Department of Textile, 16059, Bursa, Turkey

[4]Qatar University, Department of Chemical Engineering, 2713, Doha, Qatar

Corresponding author:

ARI ALİ
e-mail: ali.ari@ostimteknik.edu.tr