Investigation of sound and thermal properties of basalt, aramid and carbon reinforcement layered composites

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ABSTRACT – REZUMAT

Investigation of sound and thermal properties of basalt, aramid and carbon reinforcement layered composites

Especially for the construction and transportation sectors, layered composites are important in terms of heat and sound insulation, energy saving and cost reduction. This study aims to investigate the heat and sound insulation properties of textile-reinforced, layered designed hybrid composite materials. In the study, textile reinforcement is fabric, and high-performance fabrics such as basalt fabric, aramid and carbon are the main components of the layered design. The matrix component is epoxy. The hybrid composite manufacturing method is the combined use of hand lay-up and vacuum infusion methods. The layers are 3 and 2 layers, and a total of 6 samples were produced according to the test plan. In thermal insulation, the lowest heat transfer coefficient and in sound insulation, the highest sound transfer loss are taken into account. At the end of the study, the lowest heat transfer coefficient was obtained as 0.0341 W/mK in the Aramid/Basalt composite sample and 16 dB for sound transmission loss in the Carbon/Aramid/Basalt composite sample. In cases where insulation is not desired in heat conduction, the best composite plate is the Carbon/Aramid/Basalt hybrid composite, which has the highest heat conduction value, with a value of 0.0514 W/mK.

Keywords: *sound and thermal properties, basalt, aramid, carbon, hybrid composites*

Investigarea proprietăților acustice și termice ale compozitelor stratificate cu armătură din bazalt, aramidă și carbon

În special pentru sectoarele construcțiilor și transporturilor, compozitele stratificate sunt importante din punct de vedere al izolației termice și fonice, al economisirii energiei și al reducerii costurilor. Scopul acestui studiu este de a investiga proprietățile de izolare termică și fonică ale materialelor compozite hibride stratificate, armate cu materiale textile. În cadrul studiului, armarea textilă este reprezentată de țesături, iar țesăturile de înaltă performanță, precum țesătura de bazalt, aramidă și carbonul, sunt componentele principale ale designului stratificat. Componenta matricei este epoxidul. Metoda de fabricație a compozitului hibrid este utilizarea combinată a metodelor de stratificare manuală și infuzie sub vid. Compozitele sunt formate din 3 și 2 straturi, iar în total au fost produse 6 eșantioane conform planului de testare. În ceea ce privește izolația termică, se ia în considerare cel mai mic coeficient de transfer termic, iar în ceea ce privește izolația fonică, se ia în considerare cea mai mare pierdere de transfer fonic. La sfârșitul studiului, cel mai mic coeficient de transfer termic a fost obținut ca fiind 0,0341 W/mK în eșantionul compozit aramidă/bazalt și 16 dB pentru pierderea de transmisie a sunetului în eșantionul compozit carbon/aramidă/bazalt. În cazurile în care izolația nu este dorită în conducția termică, cea mai bună placă compozită este compozitul hibrid carbon/aramidă/bazalt, care are cea mai mare valoare de conducție termică, cu o valoare de 0,0514 W/mK.

Cuvinte-cheie*: proprietăți acustice și termice, bazalt, aramidă, carbon, compozite hibride*

INTRODUCTION

Reinforced, layered composites are used in many industries. They are especially used in the automotive and aviation transportation industries, where properties such as strength, heat insulation and sound absorption are primarily required. For the materials to remain strong under bending and impact loads, the durability of composite materials can be increased by making various reinforcements. The study aims to directly investigate the heat and sound insulation properties of layered composite materials. The current research covers the significant effect of carbon fabric and other high-performance fabrics with a layered design configuration on heat and sound insulation properties. For this purpose, some sources obtained the literature review conducted in recent years regarding the heat and sound insulation properties of the use of high-performance textile fabrics, such as carbon, basalt and aramid, in composite structures are given below.

In their study in 2009, Sapuan et al. developed a systematic route for the design of a fabricated car body. Carbon fibre reinforced polymer composite was preferred as the material in the body design of the car. The performance of the designed car body and the reliability of the body were evaluated through engineering analyses such as aerodynamics and stability [1].

Durgun (2014) used the vacuum infusion method, one of the production methods, in the production of composite materials to shorten the unit price and part production time and reduce mould costs. In the study, a prototype car hood was produced using this method. After the internal and external parts were produced, they were combined with the metal hood body. Measurement of the complete parts was carried out by optical scanning [2].

Ovalı developed polypropylene matrix composites reinforced with basalt fabric and pumice stone of different sizes as filling material. At the end of the study, the tensile strength, modulus of elasticity and elongation properties were negatively affected, but the heat and sound insulation properties of the composite were improved [3].

In their study in 2015, Cai et al., a type of surface aluminised thermally insulated composite fabric to prevent or minimise skin burn damage caused by high temperatures. In this study, the thermal insulation properties of aluminised aramid fabrics were investigated. Thermal insulation of aluminised fabrics and non-aluminised fabrics was measured using a dry hot plate device. Here, it has been observed that aluminised fabrics have higher thermal resistance than non-aluminised fabrics [4].

Bulut et al., in their study in 2016, investigated the damping and vibration properties of basalt-aramid/epoxy hybrid composites with different basalt/aramid fibre mixture ratios. It has been observed that the use of aramid fibres in composite laminates increases the damping properties of the laminates but reduces their strength values [5].

Korkut and Gören aimed to explore polymer-based composite reinforcements to improve the heat conduction performance of PV modules. For this purpose, carbon, glass fibre, and aramid (Kevlar) reinforcement materials were investigated under two different parameters. At the end of the study, they found the heat conduction performance of carbon fibre to be most effective, followed by glass fibre (0.013 W/mm^2) and aramid ($4 \cdot 10^{-4}$ W/mm^2) [6].

Özgür examined the heat and sound insulation properties and mechanical properties of composites reinforced with basalt and carbon fabric and reinforced with filling materials. The Taguchi Grey Relationship Analysis optimisation technique was used to determine the composite material that gives the best sound and heat-absorbing properties. As a result of the study, optimum samples were determined [7].

Özgür et al., in their study in 2023, examined the heat and sound insulation properties of basalt and carbon fabric reinforced composites according to the Taguchi Grey Relationship Analysis method. Accordingly, L18 (mixed 3–6 levels) was chosen as the experimental design. As a result of the study, they found an improvement of 0.15 in the validation test [8].

Mazur et al. produced PLA composites reinforced with aramid and basalt fibres. It was used in injection moulding with weights of 10%, 15% and 20%. Comprehensive analyses were done on mechanical, thermal, thermodynamic and structural studies. The results showed that the mechanical properties of the composites improved significantly as the fibre content in the composite increased [9].

Xue et al., in their study in 2023, suggested a method for the preparation of aerogel insulation materials. Specifically, by combining coating technology, SiO/PI/AF (aramid fibre) aerogel composite fabrics were successfully obtained. The results demonstrated that excellent heat transfer performance was exhibited by composite fabrics [10].

In Liu et al.'s study, the matrix material was Polyamide aerogel the reinforcement material was aramid fibre in the study. According to the results, increasing PI aerogel led was improved mechanical properties, flexibility and thermal insulation [11].

Deshmukh and Pai used the aramid/basalt/epoxy interlayer composite to investigate the importance of CAI and sound transmission loss under 3 different conditions (25°C, –10°C and in an environment). It was designed the samples they prepared as aramid in the first layer, basalt in the next 3 layers and aramid again in the last layer. It has been observed that humidity has a negative effect on these two properties [12].

Agarwal et al. examined the effect of carbon-Kevlar intraply layers on the sound transmission loss properties of basalt/epoxy composites. According to impedance tube test results, the hybrid composites exhibited a 54.71% increase in sound transmission loss compared to the basalt-only composites. This improvement indicates the superior sound insulation performance of the hybrid structures. The findings demonstrate that the inclusion of carbon-Kevlar intraply layers is effective in optimising the acoustic properties of composite materials, particularly in terms of vibration and sound transmission behaviour [13].

Raja and Devarajan investigate the effects of integrating porcelain filler particles into basalt fibre-reinforced polymer composites on their mechanical and thermal properties. A 37% improvement in thermal performance was achieved with the addition of porcelain fillers, with significant enhancements observed in parameters such as heat resistance, thermal conductivity, and the coefficient of linear thermal expansion [14].

In this study, the heat and sound insulation properties of layered composite materials were investigated for use in the transportation sector. Carbon fabric, which is widely used in the transportation sector in the layered structure, aramid fabric, which is good for impact resistance and heat insulation, and basalt fabric, which is known to have good heat and sound insulation properties, were designed as three and two layers. The effect of the layered design on heat and sound insulation properties was investigated. This study aims to reveal the best composite design in terms of heat and sound insulation in order to use three high-performance textile surfaces in hybrid form in industrial areas. For this reason, the fabrics were used in two and three-layer structures in different orders.

MATERIAL AND METHOD

Material

In composite materials, the reinforcement textile structure is typically formed by weaving filament fibre tows (e.g., 3K, 12K) into a fabric using a plain weave pattern. These woven fabrics are subsequently processed using various composite manufacturing techniques and find application across multiple industries such as textiles, construction, and aerospace. The diversity of these applications necessitates the prioritisation of specific composite properties depending on the intended use. Accordingly, in this study, aramid, basalt, and carbon-based materials were utilised in fabric form as reinforcement components (figure 1). All fabrics used in the study weighed 200 g/m^2 and were sourced from a domestic supplier (www.kompozitshop.com, Türkiye). The carbon fabric exhibited a thermal conductivity of 17 W/mK, a fibre diameter of 7 μm, and a density of 1.76 g/cm^3. The fabrics were produced using a plain weave configuration from filament tows, with the carbon and basalt fabrics having a fibre tow density of five 3K tows per centimetre. The aramid fabric consisted of Twaron fibres in both warp and weft directions, with a linear density of 930 dtex and a weave density of 10.5 × 10.5 ± 0.3 per centimetre. The thicknesses of the fabrics were measured as 0.75 ± 0.25 mm. Composite plates have a layered structure, and these structures have 2 or 3 layers, with a different fabric on each layer. The reason why different fabrics will be chosen for the layers is to monitor the effects of the different advantages of each fabric material on the layered composite design in engineering design.

The experimental plan is given in table 1. Six different layered composite plates were obtained. The front side is the 1st floor, the back side is the 3rd floor in a 3-layer structure, and the 2nd floor is in a 2-storey structure. This marking was deemed important in the implementation of sound and heat insulation tests.

MGS Lamination Epoxy Resin L160 and MGS Lamination Epoxy H160 hardener were used in the study.

Table 1

EXPERIMENTAL PLAN				
No	**Sample Code***	**1st Layer**	**2nd Layer**	**3rd Layer**
1	CAB	Carbon	Aramid	Basalt
2	ACB	Aramid	Carbon	Basalt
3	ABC	Aramid	Basalt	Carbon
4	AB	Aramid	Basalt	-
5	BC	Basalt	Carbon	-
6	CA	Carbon	Aramid	-

Note: * C: Carbon fabric, A: Aramid fabric, B: Basalt fabric.

Method

Composite plate preparation

As a composite manufacturing method, the hand lay-up method by brush was used to impregnate the resin between the layers and the vacuum infusion method was used when all layers were completed. The sheets produced with the vacuum infusion method can be ensured to have a more homogeneous structure. In this method, the resin system is subjected to vacuuming (degassing) in the vacuum chamber for one hour to completely remove the air gaps in the system. The application surface for the composite plates to be produced was chosen as a glass plate. After cleaning and drying, the mould release agent was applied. The 1st layer of fabric, which is the bottom layer of the composite, is placed in accordance with the test plan. It is used as an epoxy matrix together with its accelerator, and the epoxy/hardener ratio is prepared as 4/1 (25% hardener). The resin used in the composite has this composition. The reinforcement/resin ratio in the composite is 70%–30%. A small amount is poured onto the first layer by hand. It is spread on the fabric surface with a brush and/or squeegee. Then, another layer of fabric is laid, and this process is repeated until the layers are finished. Separating fabric, peel ply and flow net are placed on the last layer, respectively. The entire test sample is fixed to the glass surface with tape. The spiral hose is placed at the inlet and outlet parts of the vacuum. The vacuum bag is placed on top to cover the sample. The connector is placed on the spiral hose by drilling the bag. The connector surroundings and the entire vacuum bag are fixed with sealing tape so that there is no leakage. The infusion hose is passed through the connector, and the seal is provided with sealing tape. It is fixed onto the vacuum infusion device from the edges with sealing tape. Then, hoses are attached to the vacuum

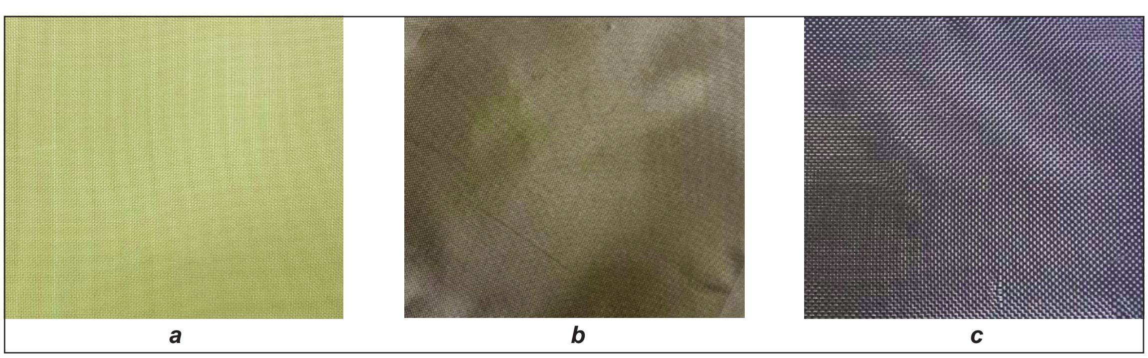

Fig. 1. Aramid, basalt and carbon fabric used in the experimental study:
a – Aramid fabric; *b* – Basalt fabric; *c* – Carbon fabric

and resin infusion ends, and the connection points with the mould are sealed with sealing tape. Pressure control is performed under vacuum in case there is an air leak in the mould. By operating the device, the resin is absorbed into the composite plates. In this way, layered composite plate production is achieved. The curing time of the composites is 24 hours at room temperature. The vacuum infusion application mentioned is given in figure 2.

After the layered composite plate production is carried out, samples are prepared to test the heat and sound insulation properties of the obtained plates, and the heat and sound insulation properties of the layered composites are investigated. Laser cutting was used in sample preparation. Sound transmission loss test (ASTM E-2611:2009) and thermal conductivity coefficient test (TS EN 12667) were performed in accordance with standards. Figure 3 shows the samples prepared according to the test sample sizes in laser cutting for the thermal conductivity coefficient test and sound transmission loss measurement of 6 samples [15, 16].

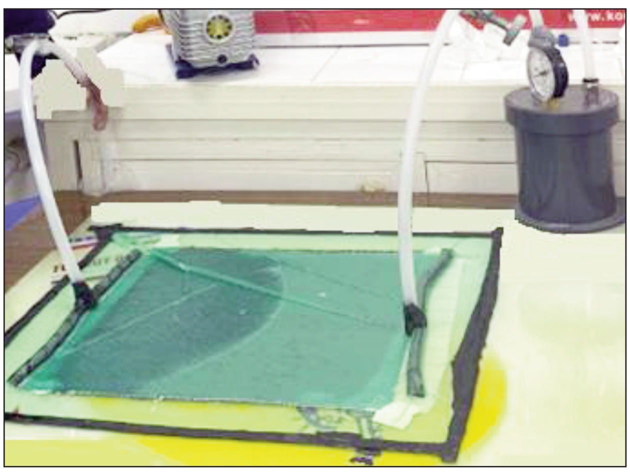

Fig. 2. Vacuum infusion method application

RESULTS AND DISCUSSION

Thermal conductivity coefficient test results

Figure 4 shows the test results for the thermal conductivity coefficient. In this test, the measurement results are expected to be as close to zero as possible. As shown in the table, all values are very close to zero. Among them, the sample with the lowest thermal conductivity coefficient is sample no. 4 (AB), with a value of 0.0341 W/mK, while the highest value belongs to sample no. 1 (CAB), with 0.0514 W/mK. Examining the graph, it can be observed that sample no. 3 (ABC) has the lowest value among the 3-layer sample structures. In the 2-layer sample structures, the lowest value belongs to sample no. 4 (AB). According to Aramid, Korkut, and Gören (2022), Barucci et al. (2005), and Ventura and Martelli (2009), the thermal conductivity coefficients of Aramid reinforcement materials range between $1 \cdot 10^{-5}$ and 4 W/mK [17–19]. For basalt, Moretti et al. stated that reinforced structures with a thermal conductivity coefficient of 0.031–0.034 W/mK have better thermal insulation properties [20]. Carbon fabric, on the other hand, has been seen in the literature as 260 W/mk by Korkut and Gören in 2022, Fukai et al. in 2000, Hong et al. in 2010, and as stated, its thermal conductivity is worse than Aramid and Basalt [17, 21, 22]. Therefore, in this study, it is seen that the thermal conductivity coefficient value increases in the samples (numbers 1 and 6) where the carbon fabric is in the upper layers. It has been determined that when carbon fabric is placed on the 2nd and 3rd layer, respectively, it has a positive effect on the decrease of the thermal conductivity coefficient. It is seen that aramid fabric has a positive effect on the thermal conductivity coefficient (good thermal insulation) regardless of the layer.

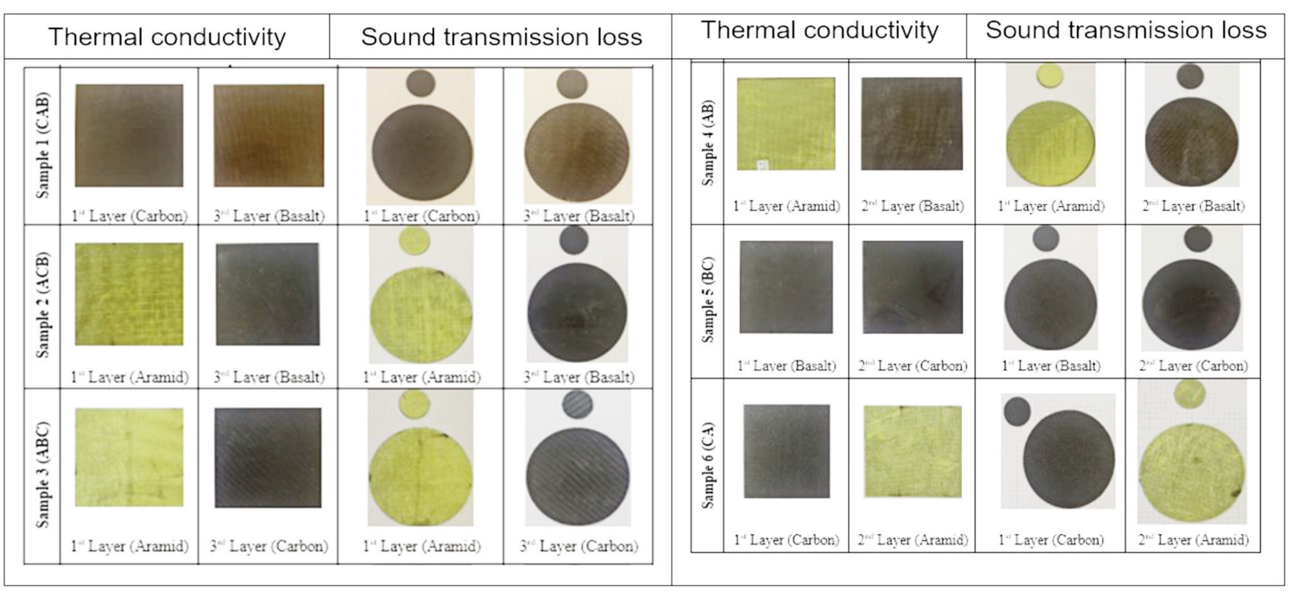

Fig. 3. Test samples for thermal conductivity coefficient and sound transmission loss tests of the 6 samples produced in the study

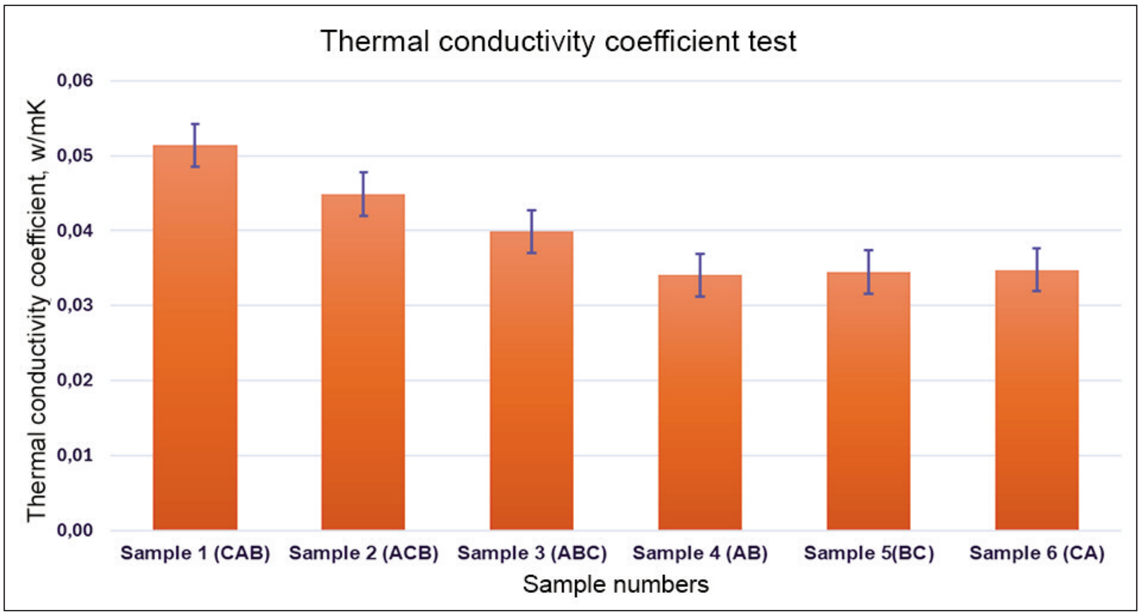

Fig. 4. Distribution of thermal conductivity coefficient test results according to composite samples

It can be said that the optimum thermal conductivity coefficient value is reached when Aramid-Basalt is included in the structure, respectively, in 3- and 2-layer structures.

Sound transmission loss test results

The average values of the sound transmission loss measurements for the samples are presented in figure 5. Higher sound transmission loss values indicate better sound insulation performance. Accordingly, the highest sound transmission loss was observed in Sample No. 1 (CAB), while the lowest was recorded in Sample No. 4 (AB). It was found that sound transmission loss increases when the carbon fabric is positioned in the uppermost and upper layers of the structure. This finding is supported by studies conducted by Sujon et al. and Wang et al. [23, 24], which reported that carbon fibres exhibit higher acoustic absorption coefficients than aramid fibres at low and medium frequencies, thereby providing better sound insulation properties. Additional studies investigating the use of aramid and basalt as layered fabric reinforcements and their corresponding sound transmission loss values were also examined. Deshmukh and Pai (2023) measured a sound transmission loss of 36.01 dB for an undamaged Aramid–3-layer Basalt–Aramid composite structure [12]. Moretti et al., in their study in 2016, stated that the sound transmission loss and acoustic performance of basalt fibres were excellent [20]. When sample number 5 (BC) is examined in this study, it is seen that it has the highest sound transmission loss in a 2-layer structure when basalt is placed on the upper layer. When the 2-layer and 3-layer structures are compared, the 3-layer sample number 1 (CAB) gave the

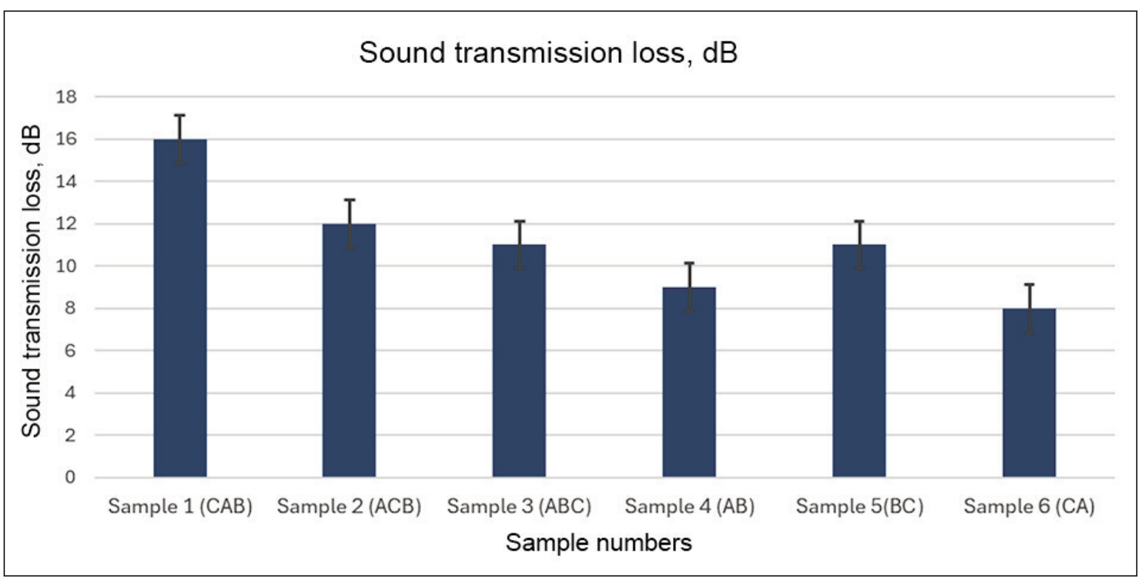

Fig. 5. Distribution of sound transmission loss test results according to composite samples

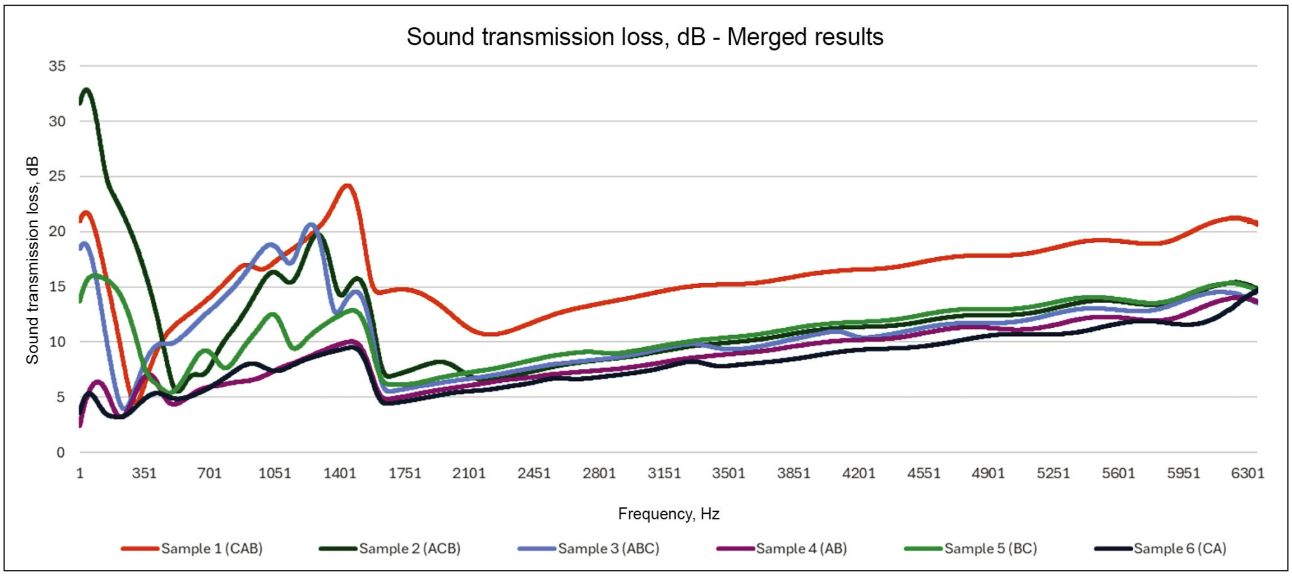

Fig. 6. Sound transmission loss values of samples in the frequency range of 50 Hz-6200 Hz

highest sound transmission loss and is the best sample in sound insulation.

Frequency range values must be considered when interpreting sound transmission loss. In figure 6, the sound transmission loss values of the samples in the frequency range of 0–6200 Hz are shown collectively. Generally, 2-layer samples exhibited a more stable behaviour at frequencies of 1600 Hz and above, while samples 1 and 2 of the 3-layer samples exhibited a more stable behaviour at 2300 Hz and above, and sample number 3 (ABC) exhibited a more stable behaviour at 1650 Hz and above.

CONCLUSION

In the study, the heat and sound insulation properties of layered composite materials were experimentally investigated using high-performance textile structures for use in the transportation sector. These structures in the form of Carbon, Aramid and Basalt were used layered within the composite in different layouts, contributing to the literature. The composite resin is epoxy, and the production method is the vacuum infusion method. Since lightness is an important parameter in these structures designed for transportation, a total of 6 different composite designs with as few layers as 2 and 3 layers were selected. Since in-vehicle sound insulation and heat insulation are of great importance for the transportation sector, these properties of the designed composites were examined comparatively for 2 and 3 layers. The results obtained from 6 different samples according to standard test methods are summarised below.

Evaluations on the thermal conductivity coefficient:

- Among 6 different composite designs, the sample with the lowest thermal conductivity coefficient value is sample 4 (AB: Aramid/Basalt) with a 0.0341 W/mK value, and the highest value is sample 1 (CAB: Carbon/Aramid/Basalt) with 0.0514 W/mK.
- In 2-layer sample structures, the lowest value belongs to sample number 4 (AB: Aramid/Basalt).
- In 3-layer sample structures, it is seen that sample number 3 (ABC: Aramid/Basalt/Carbon) has the lowest value in the group.
- In this study, it is seen that the thermal conductivity coefficient value increases in the samples (numbers 1 and 6) where the carbon fabric is in the upper layers.
- It has been determined that when carbon fabric is placed on the 2nd and 3rd layer, respectively, it has a positive effect on the decrease of thermal conductivity coefficients.
- Aramid fabric appears to have a positive effect on the thermal conductivity coefficient (good thermal insulation) regardless of its layer.
- It can be said that the most suitable thermal conductivity coefficient value is reached when Aramid-Basalt is included in the structure in the order of 2 and 3 layers.

Evaluations on the sound transmission loss:

- Among 6 different composite designs, the highest sound transmission loss belongs to sample no. 1 (CAB: Carbon/Aramid/Basalt) and the lowest belongs to sample no. 4 (AB: Aramid/Basalt).
- It is seen that the sound transmission loss value is higher in cases where the carbon fabric is in the uppermost and upper layers of the structure.
- When sample number 5 (BC: Basalt/Carbon) is examined, it is seen that basalt has the highest sound transmission loss in a 2-layer structure when placed on the upper layer.
- When 2 and 3-layer structures were compared, the highest sound transmission loss was obtained in the 3-layer composite sample number 1 (CAB: Carbon/Aramid/Basalt).
- When the sound transmission loss behavior of samples in the frequency range of 50–6200 Hz is examined, 2-layer samples exhibit a more stable behavior at frequencies of 1600 Hz and above,

while 3-layer samples no. 1 (CAB: Carbon/Aramid/ Basalt) and 2 (ACB: Aramid/ Carbon/Basalt) samples are more stable at 2300 Hz and above, and sample number 3 (ABC: Aramid/Basalt/Carbon) is more stable at 1650 Hz and above.

Generally, among all samples, the thermal conduction coefficient is the lowest for sample no. 4 (AB: Aramid/Basalt), which has a 2-layer, and can be used as an insulation material for the transportation industry. For sound transmission loss, the 3-layer sample number 1 (CAB: Carbon/Aramid/Basalt) has the best performance and can be used as a sound insulation material.

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