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# Tensile, Impact and Interlaminar Shear Strength Behaviors of Basalt, Carbon and Aramid Fabrics Reinforcement Hybrid Textile Composites

Emel Ceyhun SABIR[1] 0000-0002-2385-1524
Çiğdem SARPKAYA[2] 0000-0001-7710-1035

[1] Department of Textile Engineering, University of Çukurova, Adana, Turkiye
[2] Department of Fashion Design, Karabuk University, Karabük, Turkiye

**Corresponding Author:** Çiğdem Sarpkaya, csarpkaya@karabuk.edu.tr

**ABSTRACT**

In this study, selected mechanical properties of carbon, aramid and basalt plain woven fabric reinforced epoxy composite plates were investigated. The composites were designed as hybrid form (two- and three-layered structures) with different orders and a total of six composite samples were produced. Selected mechanical properties are impact strength, tensile strength, tensile elongation (%) and interlaminar shear strength (ILSS). The layer order in the composite material affected the impact, tensile and ILSS mechanical strengths were determined. It was observed that the impact strength increased in the arrangement where the carbon fabric was in the upper layer, and the presence of aramid in the upper layer decreased the impact strength. The highest impact strength belongs to the Carbon/Aramid/Basalt composite. Aramid/Basalt composite was found to have the best tensile strength and % tensile elongation values. The highest ILSS value was obtained in the Basalt/Carbon hybrid composite structure without aramid fabric.

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**KEYWORDS**

Tensile strength, Impact strength, Interlaminar shear strength (ILSS), Hybrid textile composite

## 1. INTRODUCTION

Composite materials are superior materials designed to treat people, nature and the world better and are used in applications requiring high strength/weight ratios. Polymer-based composites are lighter materials compared to structural materials such as steel and aluminum. As a matrix element, particles, short fibers, continuous fibers or woven fabrics are included in the composite structure to increase performance. Among these, carbon fibers and fabrics are generally widely used in applications requiring high strength and stiffness, while basalt fibers and fabrics have recently emerged as an alternative due to their superior thermal and mechanical properties. Single or multi-layer fabric structures can be used in composite structures. Layered composites are produced to combine the superior properties of reinforcement materials and create a structure with better properties. Increasing the number of layers increases the mechanical strength. The reinforcement material can be in the layers in the form of particles, fibers or fabric. From the literature, carbon/basalt (1–4), carbon/aramid (5) and basalt/aramid (6,7) hybrid composites have been investigated, and there are also studies on ternary hybrid composites containing glass fibers (8–12).

In previous studies, the effect of reinforcement fabrics with different hybrid combinations on mechanical performance has been investigated. For example, Karaçor and Özcanlı (2022-a) evaluated the mechanical properties of interlocking hybrid carbon/aramid composites and stated that the hybrid structure showed lower mechanical strength compared to composites with only carbon fibers; however, the stiffness property increased significantly (13).

The weave structure and area weight have a decisive effect on the mechanical performance of fabric-reinforced composites. In this context, plain weave structures generally offer superior mechanical properties compared to twill and other types of weaves. This is attributed to the higher number of intersections between warp and weft yarns, which provides a more homogeneous distribution of load transfer and inter-yarn friction. Gülcan (2019) demonstrated this situation by comparing plain and twill woven carbon fabrics with different area weights (200 g/m² and 600 g/m²) in epoxy-based composites. According to the findings, plain weave samples showed the highest tensile strength (14). These results reveal how decisive fiber architecture is in improving the mechanical performance of composite materials.

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Karaçor and Özcanlı (2022-b) studied hybrid composites produced from basalt/carbon, basalt/aramid and carbon/aramid fabrics produced in 6 and 12-layer configurations. Among them, 12-layer basalt/carbon hybrid composites showed the highest tensile strength (15). This shows that both the number of fabric layers and the specific fiber combination significantly affect the mechanical strength of the hybrid composites.

The incorporation of functional additives into the composite structure stands out as an effective strategy to increase material performance. In this context, Joshi et al. (2022) investigated the addition of zinc oxide (ZnO) nanoparticles to basalt fiber reinforced epoxy composites. The study findings revealed that ZnO addition provided positive effects on tensile strength and toughness up to 2%; however, mechanical performance decreased when this rate was exceeded (16). The results show that careful optimization of the filler ratio is critical to increasing composite performance without adversely affecting matrix-fiber interactions.

Interlaminar shear strength (ILSS) is a fundamental parameter in the evaluation of fiber-matrix interface and structural integrity in composite materials; increasing ILSS improves long-term mechanical performance by strengthening delamination resistance. In this context, it is aimed to increase the interface performance with various surface modification techniques. Indeed, Ou et al. (2020) obtained a 6.5% increase in ILSS value by applying carbon nanotube (CNT) coatings to the surface of unidirectional carbon fiber/epoxy composites and demonstrated the potential of nanomaterial-based surface modifications in this area (17).

Similarly, Acar et al. (2013) used graphene oxide (GO) additive synthesized by modified Hummers method to improve fiber-matrix interface bonding in carbon fiber/epoxy composites. This additive provided a 58% increase in interlayer shear strength (ILSS) by increasing the compatibility between fiber and matrix (18). The findings reveal that nanomaterial functionalization is an effective method to increase the load transfer efficiency in composite structures.

In addition, Altay and Sarıkanat (2019) applied chemical oxidation and silane coupling agents for the modification of carbon fiber surfaces. These processes increased the density of oxygen-containing functional groups on the fiber surface and strengthened the interface bond with the epoxy matrix. Thus, the wettability and adhesion ability of the fiber to the matrix were significantly improved; because of these improvements, a significant increase of 116% in interlayer shear strength (ILSS) was obtained (19). These findings clearly demonstrate that chemical surface modifications are a highly effective approach to increase the mechanical strength and structural reliability of fiber-reinforced composites.

In the study, selected mechanical properties of high-performance woven fabric reinforced epoxy composites, especially for the automotive industry, were investigated. Layered hybrid composite plates were produced using carbon, aramid and basalt fabrics. Then, the mechanical performance of these hybrid composites was evaluated.

## 2. MATERIAL AND METHOD

### 2.1 Material

In the study, fabrics were used as reinforcements and epoxy resin was used as matrix in the production of layered composite plates. No additional fillers or additives were used in the structure. The reinforcement component was three different plain woven fabrics, which were: 100% aramid (200 g/m²), 100% basalt (200 g/m²) and 100% carbon fabrics (200 g/m²). Figure 1 shows the schematic view of the sample composite plate layout and the actual images of the fabrics used. The matrix phase of the composite was composed of MGS Lamination Epoxy Resin L160 and hardener MGS H160, and the mixing ratio was 100:25 by weight. The curing time was 40 minutes at room temperature (≈23 °C). The reinforcement-resin weight ratio was kept constant in all composite samples and was 70:30.

### 2.2 Method

#### *Experimental Design*

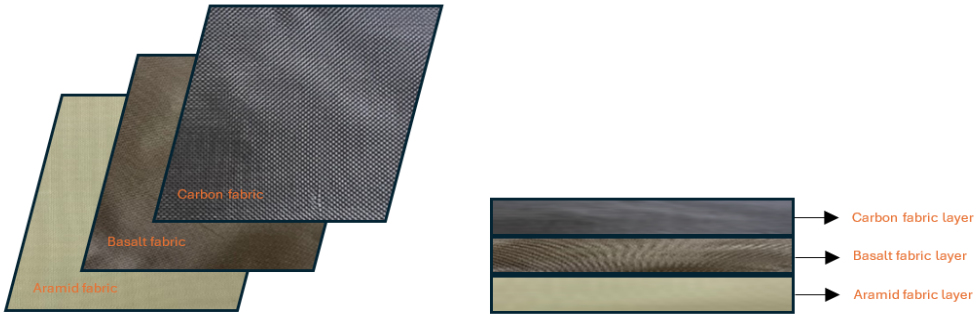
In this study, composite plates were produced in a layered structure. These layered hybrid structures are designed as 2-layer and 3-layer. A different fabric is used on each layer. The mechanical properties of the fabrics selected in the experimental study are different. It was thought that the mechanical properties of the designed composite would change when the fabric that first encountered the load, the second and/or third fabric to which the load was transmitted, were changed. For this reason, a different fabric placement was made in each layer. In 3-layer structures, the 1st layer is the front face, the 3rd layer is the back face, and in 2-layer structures, the 1st layer is the front face, the 2nd layer is the back face. The designed experimental plan consists of 6 different hybrid composite plates, as seen in Table 1.

#### *Manufacturing Procedure*

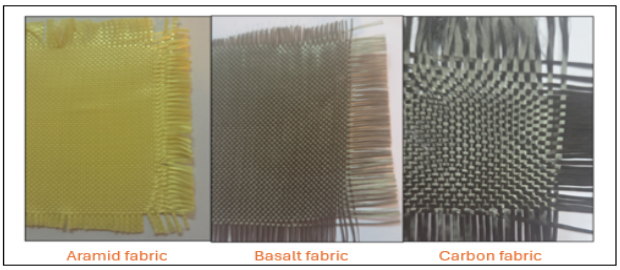
The hand lay-up method and vacuum infusion method were used together as a composite manufacturing method. The hand lay-up method was used to impregnate the resin between the fabric layers and the vacuum infusion method was used to combine all layers homogeneously. These methods were applied under laboratory conditions. The application surface was cleaned, and mold release agent was applied for the composite plates to be produced. The 1st layer of fabric was placed on the surface, the epoxy/hardener mixture was poured and spread on the fabric surface with a brush and/or squeegee. The 2nd layer of fabric was laid, and these processes are repeated according to the test plan for each sample. The separator fabric, peelply, and flow net were placed on the fabrics, respectively. The entire test sample was fixed to the surface with tape and the spiral hose was placed at the inlet and outlet of the vacuum. The vacuum bag was laid so that it was covered with all the materials. The vacuum inlet-outlet connectors were placed on the spiral hose by piercing the bag. The connector perimeter and the entire vacuum bag were fixed to the surface with sealing tape. The infusion hose was fixed by passing it through the connector. The hoses were connected to the vacuum and resin infusion ends, the connections were closed with sealing tape and pressure control was performed under vacuum.


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After these preparation stages, the vacuum pump was started, and the resin was absorbed into the composite plates. It was left at room temperature for 5 hours for curing and thus the hybrid composite plate production was completed. Figure 2 shown preparation of the samples and application of the vacuum infusion method as schematic and real views.




(a) Schematic view




(b) Used fabrics in the study

**Figure 1.** Aramid, basalt and carbon fabrics used in the experimental study a) Schematic view, b) Used fabrics 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 | - |

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

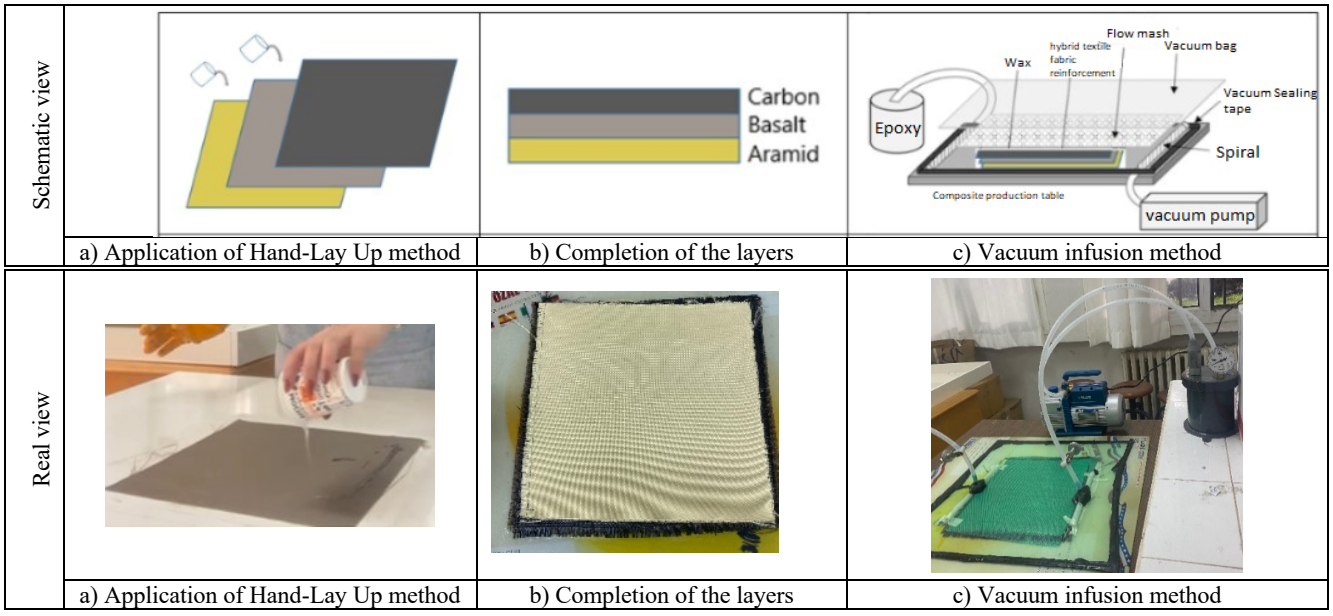



**Figure 2.** Preparing and producing (Schematic and real view) of Hybrid composite by methods with hand-lay up (a), sample 3: Aramid, basalt, carbon, ABC (b), and vacuum infusion method (c)


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*Mechanical Testing*

Tensile, impact and interlaminar shear strength tests were applied to composite panels. The standards are ASTM D256 for notched Izod impact strength, ASTM D 638M for tensile strength and TS EN ISO 14130 for interlaminar shear strength. Tensile strength was performed on a Shimadzu AGX series 50 kN testing machine at a test speed of 8 mm/min, tensile strength tests were performed with 10 N preload, and impact strength was performed on a Zwick Roell Hit5.5P testing machine with 5 J energy.

## 3. RESULTS AND DISCUSSION

### 3.1 Unnotched Izod impact strength test

Impact strength is a mechanical property that reflects the toughness of the material and is especially prominent in the transportation and construction sectors. A higher impact value indicates better toughness. The unnotched Izod impact strength test results for six composite plates were given in Figure 3. When the 3-layer composite plates were examined, aramid/carbon/basalt had the lowest value, while carbon/aramid/basalt had the highest value. The fact that the first layer to withstand the impact load was carbon has increased the impact resistance by 47% compared to the aramid/carbon/basalt sample. Lower values were obtained in 2-layer composites compared to 3-layer composites. Aramid/basalt had the lowest value, while carbon/aramid had the highest value. Again, here, the fact that the first layer to withstand the impact load was carbon had increased the toughness value by 44% compared to the aramid/basalt sample. When all samples were evaluated together, the carbon/aramid/basalt sample had the highest impact resistance value with 33.31 kJ/m$^2$, provided that the carbon was the first layer. Studies in the literature show that carbon fiber structure has a positive effect on impact load. Alshgari et al. (2022) showed that more carbon fiber structure significantly improves the mechanical properties of hybrid composites reinforced with carbon/basalt epoxy polymer matrix (3). In our study, aramid/basalt had the lowest impact strength value in 2-layer composite structure. However, in a study conducted in basalt/aramid (not included in this study), aramid/basalt 2-layer composite arrangement, better impact strength was obtained compared to basalt/aramid composite with aramid as the first layer (7).

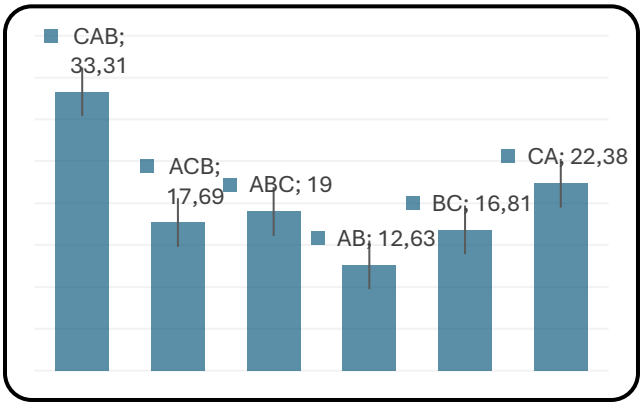
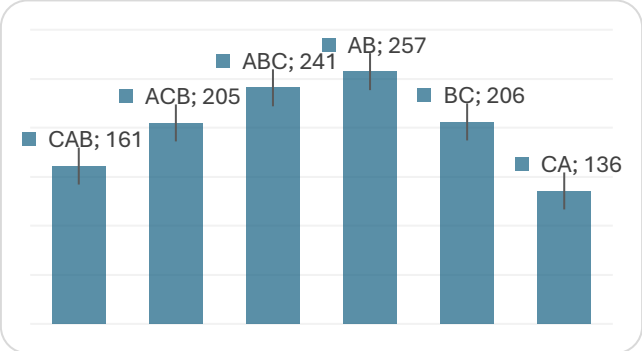


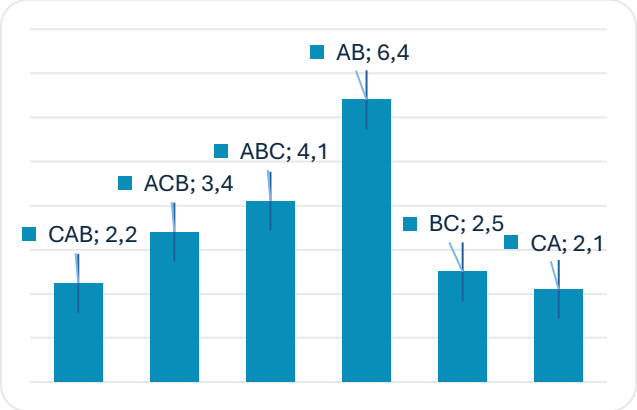

**Figure 3.** Distribution of unnotched Izod impact strength test results (kJ/m$^2$)

### 3.2 Tensile Strength Test

In composite plates, tensile strength and tensile modulus are important mechanical properties. In layered structures, since the tensile strength of the reinforcement material in each layer is different, different layer arrangements will change the tensile strength. Figure 4 shows the tensile strength and tensile modulus of 6 different composite plates.




a) Tensile strength (N/mm$^2$)




b) Tensile elongation (%)

**Figure 4.** Distribution of tensile strength test results

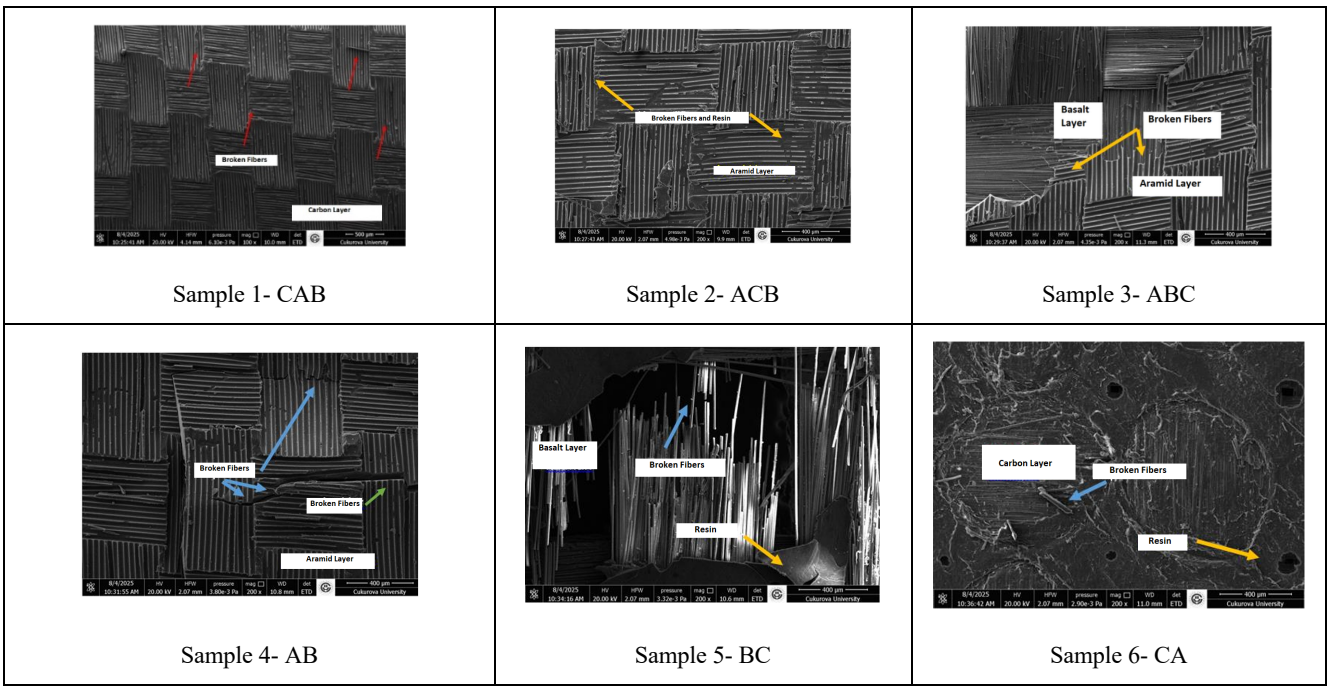
Here, in three-layer structures, carbon/aramid/basalt sample number 1 had the lowest tensile strength, and aramid/basalt/carbon sample number 3 had the highest tensile strength. It was observed that the use of basalt fabric instead of aramid in the middle layer in three-layer structures increased the strength by 33%. It was determined that carbon should be the last layer, not the first layer in the structure. When two-layer samples were examined, the sample with the highest tensile strength value was aramid/basalt (number 4), and the sample with the lowest tensile strength value was carbon/aramid (number 6). It was noteworthy that basalt was in the lower layer in sample number 4, which had the highest tensile strength. Sun et al. (2018) also showed in their study that the tensile strength was higher when basalt was on top in basalt/carbon and carbon/basalt combinations (2). In double-layered structures, sample number 6 was the one without basalt and had the lowest tensile strength. When all composite samples were examined, it was seen that sample number 4 in


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aramid/basalt arrangement had the highest tensile strength and % elongation value. It had been determined that basalt fabric reinforcement was a layer that improves the tensile strength of the composite. The combination of aramid and basalt fabrics was effective in increasing the tensile strength and flexibility of the composites. These results were consistent with similar studies in literature. For example, Karaçor and Özcanlı (2022-b) stated in the literature that basalt had a positive effect on hybrid structure tensile strengths and % elongations with aramid and that basalt/aramid hybrid samples showed higher tensile strength than basalt composites (15). Evaluations regarding tensile strength are similar for % elongation. SEM images of the tensile samples have been given in Figure 5. Important points were marked on the figures. It was determined from the SEM image of sample 4 that a more stable structural image was obtained as a result of the tensile test. When the SEM image of sample number 6, which has the lowest tensile strength value, was examined, fiber breaks, resin cracks and tribologically excessive surface roughness on the surface, which were the reasons for reducing the strength, were remarkable.

### 3.3 Interlaminar Shear Strength (ILSS) Test

The ILSS test results of 6 different composite plates were given in Figure 6. As stated in the literature, interlaminar shear strength largely depends on the surface properties of the fibers and their chemical and mechanical bonding capacity with the resin (17, 18). Especially the smooth surface and low surface energy of the aramid fibers caused the ILSS values to be lower than the basalt/carbon composite sample number 5, which was the only sample without aramid fabric reinforcement, due to the inability to establish sufficient bonding with the epoxy resin. This finding in the ILSS test of aramid fiber was also consistent with the literature (21, 22). This situation, in the combinations containing aramid in the study, the ILSS values remained in the range of 2.7–6.4 MPa. In the study, the Basalt/Carbon combination without aramid showed the highest ILSS value with 13.1 MPa. The highest ILSS value with aramid fabric was found to be 6.4 MPa in the three-layer structures, but the highest ILSS value was found to be 13.1 MPa in the structure without aramid, despite being 2 layers. The absence of aramid improved the ILSS value by 2 times. Altay and Sarıkanat (2019) showed that carbon and basalt fibers tend to adhere better to the epoxy matrix, especially without the need for surface modification (19). This finding showed that the interface formed by carbon and basalt fibers provides more effective load transfer and creates a structure that is more resistant to delamination (20). When previous studies were examined, ILSS values in basalt/epoxy composites were obtained as 35–44 MPa when used as basalt fiber, 23 MPa when used as fabric, approximately 23 MPa in carbon/epoxy systems, and up to 50 MPa after plasma surface treatment in aramid/epoxy composite (20, 22, 25). The 13 MPa value obtained in this study was not obtained from the basalt fabric reinforced composite alone, but from the basalt/carbon fabric reinforced composite. Although it was a value below these references encountered in practice, the resin type, whether or not the surface treatment was applied and the number of layers affect this feature. The ILSS value might be sufficient for applications requiring low to medium strength in doors, automotive interior panels.




Sample 1- CAB | Sample 2- ACB | Sample 3- ABC

Sample 4- AB | Sample 5- BC | Sample 6- CA

**Figure 5.** SEM images of the samples after tensile testing (100x)


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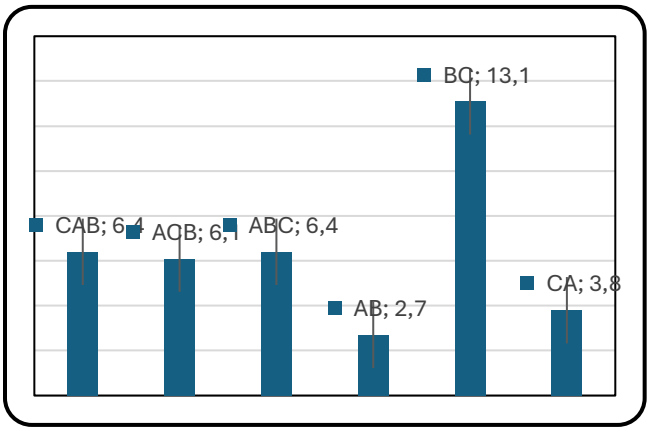



**Figure 6.** Distribution of Interlaminar shear strength (ILSS) test results (MPa)

## 4. CONCLUSION

In this study, the mechanical properties of composite plates designed by reinforcing with carbon, aramid and basalt fabrics in different arrangements were analyzed. This study, in which basalt, aramid and carbon fabric were investigated as 2 and 3 layers and in different layout designs, was evaluated together with other studies in the literature. It was observed that the order of the material layers played a critical role in energy absorption against impact loads, that the presence of carbon fabric on top significantly increased the impact resistance, whereas the presence of aramid in the outer layer decreased the impact resistance, that the 3-layer structure showed better performance than the 2-layer structure and that the highest impact resistance was Carbon/Aramid/Basalt. It was observed that the reinforcement fabric placement order had a direct effect on the tensile strength. It was determined that the Aramid/Basalt fabric reinforcement showed the best tensile performance. While the addition of carbon fabric reinforcement to the structure increased the tensile strength, it caused a decrease in the % elongation (more rigid). The Basalt/Carbon fabric reinforced composite had the best interlayer shear strength (ILSS) value. Aramid fabric reinforcement has a negative effect on ILSS properties. It cannot be said that the ILSS values in the study are mechanically very strong. In the industry, layered fabric reinforced composite structures that can be an alternative to structures with high mechanical properties such as steel; can meet different material expectations for not reducing natural resources, lighter materials, higher strength and many other expectations. Automotive and construction sectors are looking for new materials that will reduce weight but have high mechanical strength. In this direction, the study provides important data that can guide future research for the design and application of composite materials with high impact and tensile strength. The main purpose of the study is to determine suitable material combinations for areas where lightness and durability are of great importance, such as the transportation sector. By evaluating tensile, impact, and ILSSS tests together, it was determined that hybrid structures of carbon, aramid, and basalt fabrics can be used for applications requiring low and medium strength in the transportation sector, such as automobile doors, interior panels, and bumpers. A carbon/aramid/basalt hybrid structure can be recommended for automobile bumpers, basalt/carbon for interior panels, and carbon/aramid/basalt or aramid/basalt hybrid structures for doors.

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