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Investigation of Mechanical Properties of Layered Composites Formed from Glass, Carbon and Aramid Fibers and Aluminum Plates

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ABSTRACT

Technological developments and differences in application areas increase the importance of laminated composites. Laminated composites with complex properties exhibit features such as high strength, high corrosion and thermal resistance, low specific gravity, resistance to environmental conditions. These properties generally reflect components that make up laminated composite. In this study, effects of reinforcements on mechanical properties of laminated composites were investigated. In production of laminated composites, aluminum 5754 is used for metal layers, and aramid, glass and carbon fibers are used for fiber reinforcements. Epoxy was also preferred as resin. First of all, the resin was applied on the cleaned aluminum plate and the aramid fiber was added on it. By continuing the processes in this way, Arall laminated composite consisting of five layers was obtained. Similar processes were applied to carbon fiber and glass fiber materials, and Carall and Glare laminated composites were produced, respectively. In addition, by subjecting the fiber layers to a combination among themselves, Ar-Carall, Ar-Glare and Car-Glare laminated composites were produced. The produced laminated composites were subjected to tensile and bending tests and their strengths were compared. As a result of the experiments, the highest tensile and bending strength was obtained from the Carall laminated composite. The strength of the Ar-Carall and the Car-Glare laminated hybrid composites containing carbon fiber were better than the Arall and the Glare laminated composites.

1. INTRODUCTION

Layered composites consist of thin plates and panels with high strength in a certain direction. Very high strength values are obtained by combination of layers with different fiber orientations. FML (fiber metal laminated) composites are a good example. It is based on stacking thin metal plates with different properties and prepreg materials on top of each other [1]. Metal plate and prepreg forming FML layered composites are shown in Figure 1.

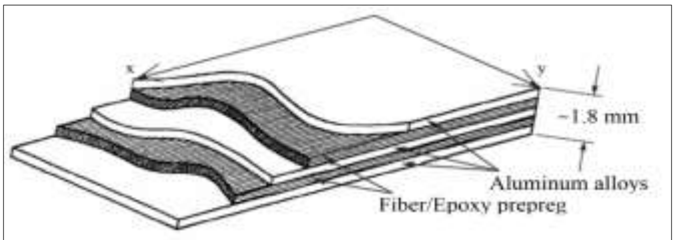

Figure 1. Fiber metal laminate (FML) laminated composite [1]

Arall (Aramid Reinforced Aluminum Laminates) was originally developed for applications in the airframe [2]. In later stages, two other variants of FML, Glare (Glass laminate aluminum reinforced epoxy) [3] and Carall (Carbon Reinforced Aluminum Laminates) [4], laminated composites began to be produced. These layered composites have been used in aircraft construction since 1980. In these composites, ductile aluminum alloy and linear elastic rigid fibers are in same material, and properties of layered composites bear characteristics of phases forming composite [5]. Arall, Glare and Carall laminated composites offer many advantages in industrial field, thanks to their low density, high strength to weight ratio and excellent corrosion resistance. Therefore, it has attracted attention of researchers. Wu and Yang (2005) stated that Glare layered composites offer a unique combination of properties such as outstanding fatigue resistance, high specific static properties, excellent impact resistance, good residue and blind notch strength, good corrosion properties and ease of fabrication/repair [6]. They also stated that Glare layered composites can be adapted to a wide variety of applications by changing the fiber/resin system, alloy type and thickness, stacking order, fiber orientation, surface pretreatment technique, etc. Armatlı Kayrak (2006) stated that specific elastic modulus, specific shear modulus and poison ratio in fiber direction and perpendicular to fiber direction of Arall

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plates have higher values than Glare and aluminum alloy materials [5]. It was emphasized that Glare, which has unidirectional layers, shows high properties comparable to aluminum alloys, and also has advantage of low density. Qaiser et al. (2015) stated that the curing process has an important effect on increasing strength of resin, but its effect on interface of layers is limited [2]. However, they emphasized that interfacial interaction of Arall composites could be improved after anodizing. Scanning electron microscope images and subsequent electron scattering spectrum data showed that adhesion on aluminum was much better in anodized and cured layers. Khalid et al. (2022) treated their manufactured composites with surface de-greasing, mechanical abrasion, and anodizing. In order to perform mechanical characterization, uniaxial tensile tests were conducted at various strain rates. The results revealed that, in the case of Carall, 1.7% increase in tensile strength and its tensile strength was increased from 741 MPa to 754 MPa. Whereas, Arall and Glare laminates exhibited high degree of strain rate-sensitivity. When the strain rate is the values are increased in the following patterns: 389 MPa, 411 MPa, and 475 MPa for Glare laminates (22% increase), and 253 MPa, 298 MPa 352 MPa for Arall laminates (39% increase) [7]. Asghar et al. (2017) stated that ultimate tensile strength of sheets is related to nature of their components [8]. They observed that Carall's tensile strength (215 MPa) and fracture toughness (87.554 MPa) were 50% higher than Arall's maximum tensile strength and 47% higher than fracture toughness, 22% higher than Glare's maximum tensile strength and 23% higher than fracture toughness. They also stated that Carall exhibited superior fatigue performance compared to Arall and Glare due to its fiber bridging effect. They emphasized that behavior of the experimental Paris curves also confirms the similar behavior. The most important disadvantage of composites is formation of cracks at matrix and fiber interface and propagation of this crack. It is stated that the most important reason for preference of laminated composites used in aircraft construction is low crack formation and low crack propagation characteristics. It is stated that the fibers were not damaged by arranging them in the load direction and the crack remains on the aluminum matrix plates and reduces stress intensity [2] (Figure 2).

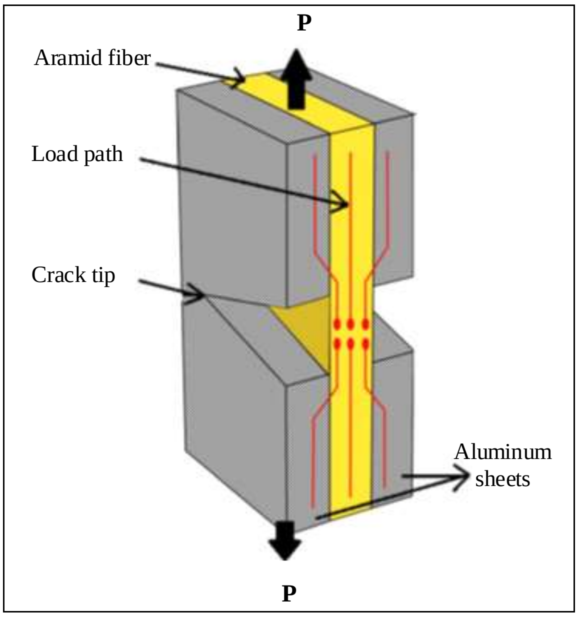

Figure 2. Crack-stopping mechanism of Arall [2]

It was seen that detailed analyzes were made on Arall, Glare and Carall layered composites in literature. In this study, in addition to Arall, Glare and Carall layered composites, Ar-Carall, Ar-Glare and Car-Glare layered hybrid composites were produced by combining the fibers in the layered composites. Tensile and bending strengths of the produced laminated composites were determined and compared with the each other.

2. MATERIALS AND METHOD

2.1. Production of Samples

In this study, metal sheet, different synthetic fibers, epoxy and hardener were used to produce laminated composite. Aluminum 5754 H111 alloy, purchased from Avas Metal, which has high corrosion and fatigue resistance, light weight, good weldability, resistant to industrial atmosphere and sea water, and suitable for coating, was preferred as metal sheet. The chemical composition of aluminum 5754 alloy, which has a thickness of 0.5 mm, is given in Table I, and some mechanical properties and hardness values are given in Table II.

TABLE I.
Chemical composition of aluminum 5754 H111 alloy (wt. %)

Fe	Si	Cu	Mn	Mg	Zn	Cr	Ti	Other	Al
0.4	0.4	0.1	0.5	3.1	0.2	0.3	0.15	0.15	Balance

TABLE II.
Mechanical properties of aluminum 5754 H111 alloy

Yield strength (MPa)		Tensile strength (MPa)		Elongation (%)	Hardness (Brinell (kg/mm^2))	
Min	Max	Min	Max	Max	Min	Max
80	100	190	215	24	50	55

Synthetic aramid, glass and carbon fibers, which are widely used in different fields and have become today's indispensable materials, have been used as fiber materials. Aramid, glass and carbon fibers which purchased from Dost Kimya, have the same weave and their weight is 200 gr/m^2. Arc 152 multi-purpose epoxy resin and W152 hardener, which purchased from Arc Marin, are specially designed for lamination and have protection and impermeability, are used as resin and hardener. Aluminum sheet cut by a saw and the fibers by a special scissors into dimensions of 120 mm x 20 mm. Epoxy and hardener were weighed on a precision balance at a ratio of 4/1 as written in the product introduction and mixed in a Heidolph brand MR Hei-Standard model magnetic stirrer for 15 minutes, at 50 °C table temperature and 750 rpm rotational speed. Epoxy resin was applied by hand lay-up method on the cleaned aluminum 5754 alloy sheet and aramid fiber was laid on it. An aluminum 5754 alloy plate was placed on aramid fiber again, on which the epoxy was impregnated, and the epoxy resin was applied on aluminum sheet. By adding aramid fiber on the resinized sheet, the resin was impregnated and the last layer of aluminum 5754 alloy sheet was placed on it and left to cure. Similar processes have also been applied to aluminum laminated composites using carbon and glass fibers. Thus,

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composites with aramid aluminum layer (Arall), carbon aluminum layer (Carall) and glass aluminum layer (Glare) were produced. In addition to these, Ar-Carall (one aramid fiber layer and one carbon fiber layer between three aluminum layers), Ar-Glare (one aramid fiber layer and one glass fiber layer between three aluminum layers) and Car-Glare (carbon aramid fiber layer and one glass fiber layer between three aluminum layers) layered composites were produced by combining fiber layers within themselves. All samples have 2 mm thickness and the other information including the layer types and numbers of produced laminated composites are given in Table III.

TABLE III.
Layer types and numbers of samples

Sample Number	Composite Name	Aluminum	Aramid Fiber	Carbon Fiber	Glass Fiber	Thickness (mm)
1 and 7	Arall	3	2	-	-	2
2 and 8	Ar-Carall	3	1	1	-	2
3 and 9	Ar-Glare	3	1	-	1	2
4 and 10	Glare	3	-	-	2	2
5 and 11	Carall	3	-	2	-	2
6 and 12	Car-Glare	3	-	1	1	2

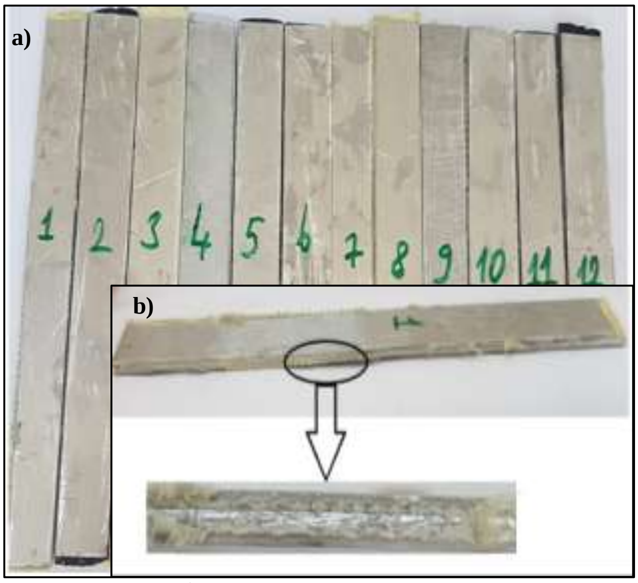

Figure 3. a) Image of produced laminated composite samples, b) Close-up view of the layers

Manufactured fiber metal laminated and hybrid fiber metal laminated samples image is given in Figure 3a. Close-up view of the layers of Arall is given in Figure 3b.

Manufactured samples were subjected to tensile test and bending tests with 250 kN capacity load cells in a Shimadzu brand universal test device to determine mechanical properties of the layered composite specimens. The test setup of the samples subjected to tensile and bending tests is given in Figure 4. The specimens were clamped to the jaws. Each jaw was given a clamping margin of 20 mm and the distance between the jaws was adjusted to 80 mm for the tensile test. The other hand the distance between the supports was kept at 80 mm and the center of the supports was adjusted to the force direction the bending test.

2.2. Mechanical Calculations and Experiments

Two samples were tested for each test. The force and elongation graphs were drawn by taking the average of two samples. Tensile and bending strengths of the laminated composites were calculated by considering the maximum forces in the force and elongation graph and the dimensions of the test specimens. The formula used for the calculation of the tensile strength is given in equation 1, and the formulas used for the calculation of the bending strength are given in equation 2-6.

$$\sigma_T = F/A \tag{1}$$

$$M = F * (L/4) \tag{2}$$

$$y = h/2 \tag{3}$$

$$I = (b * h^3)/12 \tag{4}$$

$$W = I/y = (b * h^2)/6 \tag{5}$$

$$\sigma_B = M/W \tag{6}$$

Here; σ_T: tensile strength, F: maximum applied load, A: sample cross-sectional area, M: moment, L: bending distance, h: sample thickness, b: sample width, I: moment of inertia, W: moment of strength and σ_B: bending strength.

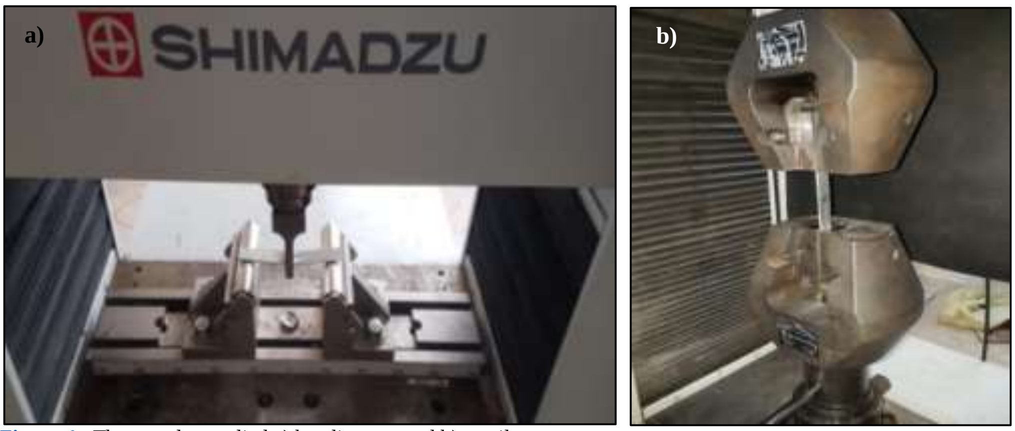

Figure 4. The samples applied a) bending test and b) tensile test

3. EXPERIMENTAL RESULTS AND DISCUSSION

In this study, tensile and three-point bending tests of Arall, Glare and Caral composites, and Ar-Carall, Ar-Glare and Car-Glare layered hybrid composites obtained by replacing the fibers were carried out with Schimadzu Universal test device. The Force (N) – Elongation (mm) graph as a result of the tensile test of Arall, Carall and Glare layered composites is given in Figure 5, and for Ar-Carall, Ar-Glare and Car-Glare layered hybrid composites in Figure 6.

For Arall composite, the maximum force was 12445 N and the maximum elongation was 6.2%. The tensile strength of Arall sample was calculated as 325.1 MPa by dividing the maximum tensile force obtained by the cross-sectional area of the sample. Although the calculated result is compatible with the literature data (390 MPa), the small differences are due to the strength-enhancing heat treatment of the aluminum alloy used in other studies [9].

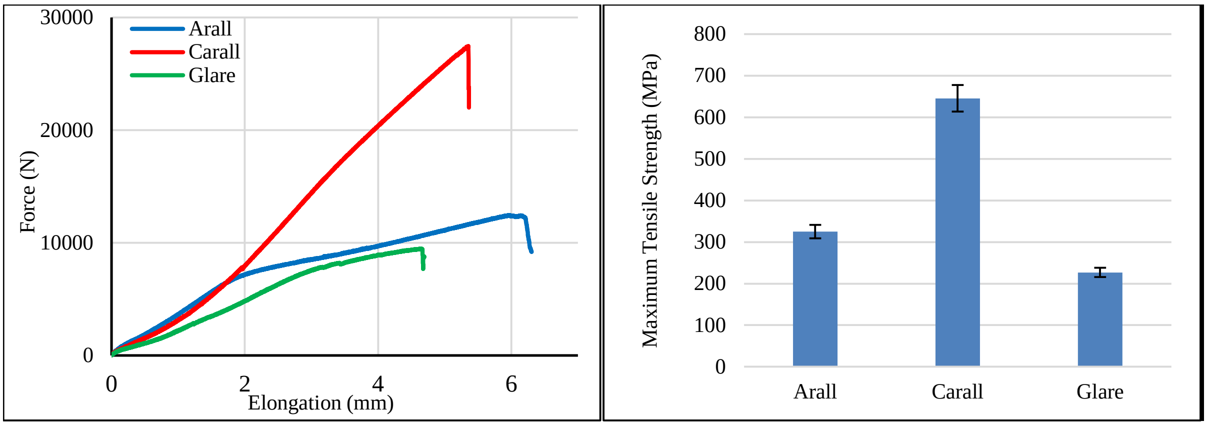

Figure 5. Tensile test graph of laminated Arall, Carall and Glare composites and their maximum tensile strengths

The tensile stress of Carall was calculated as 645.4 MPa by dividing the maximum force (27460 N at 5.3% elongation) by the cross-sectional area of the sample. In the literature, it was stated that the tensile strength of Carall at room temperature was 568±17 MPa as a result of the tensile test [10]. In the Glare layered composite, the maximum force was 9480 N and the maximum elongation was 4.6%. The tensile stress of the Glare sample was calculated as 226.9 MPa, and this value was found to be consistent with the data in the literature (~215 MPa) [11].

The maximum tensile strengths of Ar-Carall and Car-Glare laminated composites were very close to each other, measuring 16600 N and 16470 N, respectively, and their tensile strengths were calculated as 394.1 MPa and 397.2 MPa, respectively. If Figure 5 and Figure 6 are taken together, it is seen that the use of carbon fiber with other fibers leads to an increase in tensile strengths. In Arall composite, when a layer of carbon fiber is placed instead of a layer of aramid fiber (Ar-Carall), it has been determined that the tensile strength increases by 33%, and when the same process is applied in Glare composite (Car-Glare), it increases the tensile strength by 73%. The tensile strength of Ar-Glare composite was 22% lower than Arall and 11% higher than Glare.

The images of the fracture regions formed as a result of the tensile test of the laminated composites are given in Figure 7. As a result of the tensile test, it was observed that the fibers were separated from each other in a characteristic way by a mechanism in which the weave type and fiber orientation (0^0) were effective, showing similarity to the results found in the literature [12]. As shown in Figure 7a, it was determined that only the fibers in the tensile direction were separated from each other and damaged due to the anisotropic nature of the aramid fiber in the fracture regions of the aramid fiber reinforced laminated composites [13]. In the fracture regions of the carbon fiber reinforced laminated composites, in Figure 7b, the fibers are broken, similar to the studies in the literature, with the damage occurring in several regions, largely indented and protruding [14]. In the rupture regions of the glass fiber reinforced laminated composites, the glass fiber is separated from each other along a straight line perpendicular to the drawing direction (Figure 7c) [12].

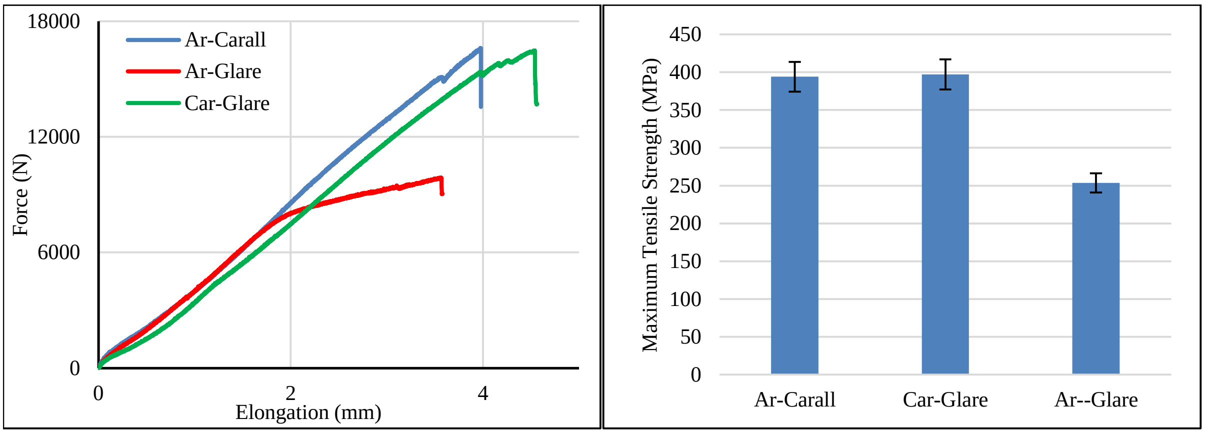

Figure 6. Tensile test graph of Ar-Carall, Ar-Glare and Car-Glare composites and their maximum tensile strengths

Figure 7. Fracture regions of Al layer composites a) Aramid Fiber Reinforced b) Carbon Fiber Reinforced c) Glass Fiber Reinforced

Force (N) – Deflection (mm) graph as a result of three-point bending test of Arall, Carall and Glare layered composites is given in Figure 8, and for Ar-Carall, Ar-Glare and Car-Glare layered composites in Figure 9.

As a result of the three-point bending test of Arall layered composite, the maximum bending force was measured as 190.6 N and the bending stress was calculated as 440.5 MPa. In research carried out in the literature, since the unit of measurement was given as force (N) in the bending test of the Arall layered composite, a comparison in MPa could not be made. In the same study, since the tensile test is given in MPa and it is compatible with the tensile test we have done, it is thought that the bending stress is also compatible [8]. As a result of the three-point bending test of Carall layered composite, the maximum bending force was measured as 456.2 N and the bending strength was calculated as 690.7 MPa. In the studies, the bending strengths for Carall were similar to the test results we performed and it was stated to be between 675-610 MPa [15]. As a result of the three-point bending test of Glare layered composite, the maximum bending force was measured as 232.8 N and the bending strength was calculated as 449.1 MPa. In the studies, the bending strengths for Glare are close to the test results we have done, and it has been stated to be between 520-690 MPa [16].

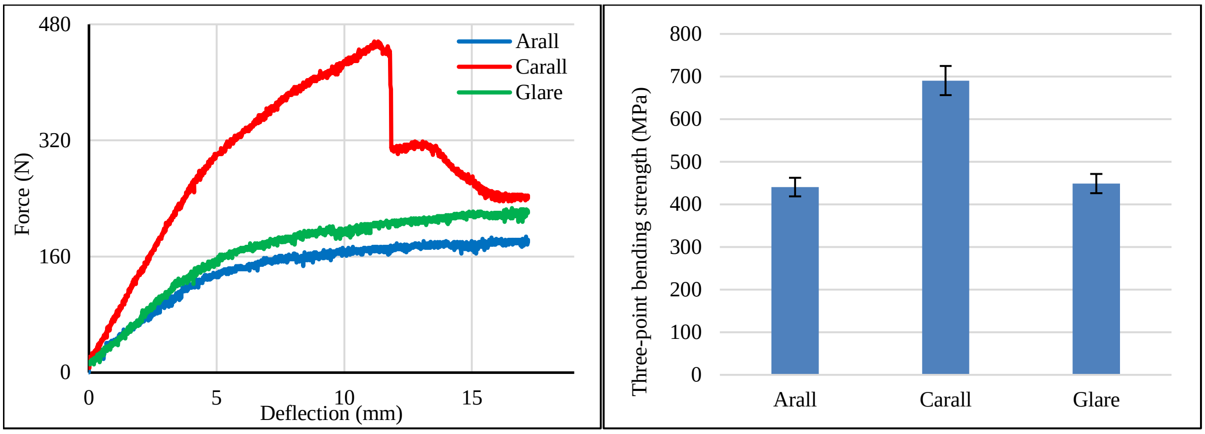

Figure 8. Three-point bending test graph of layered composites and their bending strengths

Ar-Carall and Car-Glare laminated composites have the highest and lowest bending strengths of the layered composites produced by adding binary combinations of aramid, carbon and glass fibers between aluminum plates. Ar-Carall layered composite was damaged at 382.2 N and Car-Glare layered composite was damaged at 341.1 N bending force. Ar-Glare layered composite, on the other hand, carried a maximum bending force of 277.2 N. The bending strengths of Ar-Carall, Ar-Glare and Car-Glare laminated composites were calculated as 518.9 MPa, 415.7 MPa and 501.7 MPa, respectively.

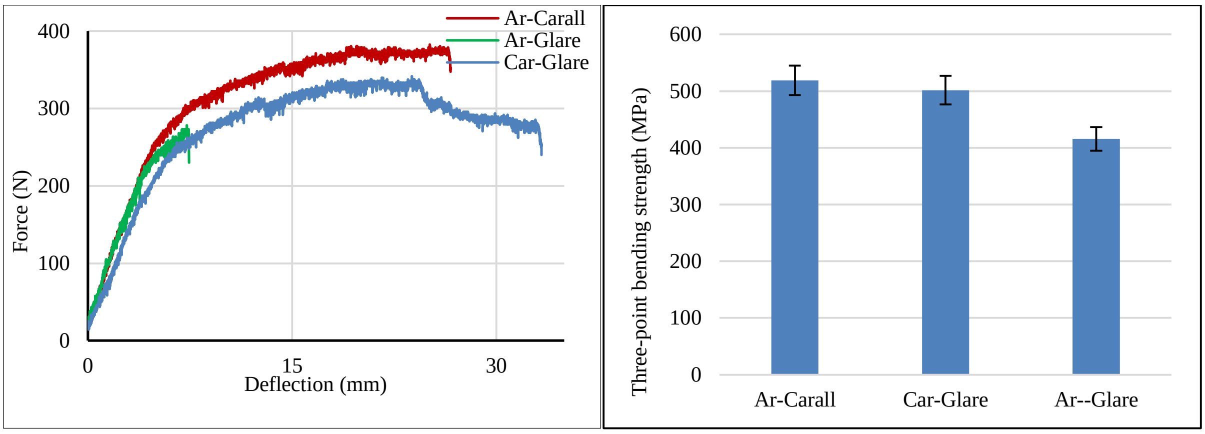

Figure 9. Three-point bending test graph of Ar-Carall, Ar-Glare ve Car-Glare laminated composites and their bending strengths

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4. CONCLUSION

In this study, Arall, Carall, Glare, Ar-Carall, Ar-Glare and Car-Glare layered composites were produced using aramid, carbon and glass fibers and aluminum laminates, and tensile and bending tests of these layered composites were performed. Obtained results are given below.

1. The highest tensile strength value was measured in Carall laminated composite (645.4 Mpa). It was determined that the result obtained was quite higher than Arall (325.1) and Glare (226.9 MPa) layered composites.

2. It has been observed that the tensile strength values of the layered composites with carbon fiber are higher than the layered composites without carbon fiber.

3. While the flexural strength was highest in Carall layered composite (690.7 MPa), it was close to each other in Arall (440.5 MPa) and Glare (429.1 MPa) layered composites.

4. In bending strength as well as tensile strength, layered composites with carbon fiber were obtained better than layered composites without carbon fiber.

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BIOGRAPHIES

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