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Examination of Fiber Reinforced Composite Materials

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Highlights

- This article focuses on the hybridization of natural fibers with synthetic fibers.
- The effect of hybridization of flax fibers with glass fibers of different weights was observed.
- Important results were obtained in the effect of hybridization process on mechanical properties.

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Abstract

In recent years, various new and practical products have emerged thanks to rapidly developing science and technology to meet human needs and expectations. A variety of these products are new materials known as composites. The use of composites is also increasing, from the aircraft industry to the automobile industry, to other areas such as sports equipment, infrastructures. The goal of this research is to present a hybrid composite material that can be retainable and does not harm the environment that can be used in the automobile industry. This goal has been tried to be achieved by using natural fiber (flax fabric) reinforced glass fibers in different weights (86 gr/m² and 100 gr/m²). The vacuum assisted resin transfer molding (VARTM) system was used to fabricate the composite samples. Composite products produced during the study were tested with regard to mechanical (tensile strength, bending strength), hardness, and morphological (scanning electron microscopy). The results indicate that the tensile strength value of hybrid composites is 2.5 times and 1.7 times higher than that of homogeneous composites and flexural test results also 78% and 23% enhancement compared to single fiber composites. According to the hardness test measurement of hybrid composites, it was found that the hardness value changed with an increase of 14% and 33% compared to the homogeneous composite. Scanning Electron microscopy (SEM) analysis images also coincide with mechanical analysis results. The hybrid composites produced in the study have become a favorable option in diverse areas of use in the automotive industry, considering human health and environmental factors.

1. INTRODUCTION

Today, fiber reinforced polymer composites, with some of their features, have started to attract great attention globally with their unique and versatile characteristics compared to traditional construction and home materials such as metals, wood, and reinforced concrete. Among the versatile properties found in composite materials; high mechanical properties, low cost, good processing ability, lightness, ease of assembly, relatively good resistance to environmental factors and fatigue can be shown [1]. While these features provide advantages in different sectors, especially the fuel and weight savings provided by composite materials make them attractive not only for a single area but also for medical devices, military fields, civil aircraft, space, and automotive sectors [2]. Such improvements will become more common as the use of composite materials over traditional materials increases. For these application fields, polymer matrix composites are one of the most favourite materiels. Polymer matrix composites have become more preferable for high-strength and light applications, as they are a good alternative. With the ever-increasing demands, an increasing search is emerging in the field of composites in order to find the better and the substitute with newer dimensions [3, 4]. Most of the composites are produced depending on the desire to increase the properties such as hardness, toughness, and strength under environmental effects or at higher temperatures for improving the combination of mechanical features in materials [5]. This improvement is

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achieved through the hybridization of the material. Hybrid composites consist of a combination of two or more types of reinforcement. Hybrid composites benefited the features of each type of reinforcement [6]. Hybrid composites are designed to perform specific task applications. The properties of composites are improved with the design variations made in mixed combinations. Composites formed by the combination of two or more separate materials in a macroscopic structural unit are made from various combinations of polymer, metal, and ceramic materials. The basic structures make up the composites are matrix and reinforcement phases. In addition to distributing the applied load to the fibers, the matrix holds the fibers together in a structural unit and protects them from the environment. The reinforcements are the ones assume the essential role of providing strength and stiffness mainly in composite materials. Today, a wide variety of supplements, usually in fiber form, are available on the market [7, 8]. The mechanical properties in hybrid laminates are based on the length of the fibers, fiber orientation, and the type of matrix used. Hybrids have excellent tensile and compressive strength, corrosion resistance, very lightweight, and good dimensional stability compared to ordinary laminates [9]. In recent years, the use of natural fibers as reinforcement in polymer composites has raised substantially. While natural fibers are strong and light, they are also comparatively affordable. Compared to traditional reinforcement materials, natural fibers as abaca, jute, sisal, pineapple, and coconut have low abrasion and low density, acceptable specific strength features, good thermal properties, multi-functionality, advanced energy recovery and causes fewer health problems [10]. In the meantime, ecological awareness is forcing modern industries to make use of natural fibers as an alternate to traditional non-renewable synthetic reinforcement materiels [11]. One of the disadvantages of natural fibers is that besides their poor resistance to moisture absorption, their mechanical characteristics, e.g., shrinkage and bending, are considerably lower than conventional fibers. Therefore, the presence of natural fibers alone in the polymer matrix would be insufficient to meet all technical requirements in a fiber reinforced composite. With the properties of both, the optimum benefit is obtained by combining natural fiber with synthetic fiber in the same matrix material [12]. Since the stone age, flax has been one of the few plants that draw attention to produce very valuable products. Fibers obtained from flax plants are biodegradable meanwhile showing good mechanical properties. The suitable growing environment for flax is temperate and latterly, the major linen fabricating countries are Belarus, France, and China [13]. Linen is one of the most extensively utilized bio-fibers and also one of the first to be woven, spun, and extracted in textiles. The main components of a flax fiber come about varying amounts of pectin, lignin, wax, hemicellulose, and cellulose. The physical characteristics of fibers are identified by lignin, hemicellulose, and cellulose. It was observed that the tensile strength of the flax fibers changed between 1500 and 1800 MPa, and the compressive strength was around 1200 MPa. Table 1 indicates the physical and mechanical features of diverse natural fibers and glass fibers [14].

Table 1. *Physical and tensile characteristics of glass fibers and natural fibers [14]*

Fiber Type	**Relative Density(g/cm³)**	**Diameter (μm)**	**Tensile Strength (MPa)**	**Elongation at Failure (%)**	**Elastic Modulus (GPa)**	**Specific Modulus (GPa x cm³/g)**
Flax	1.4-1.5	12-600	343-2000	1.2-3.3	27.6-103	45
Abaca	1.5	-	400-980	1.0-10	6.2-20	9
Jute	1.3-1.49	20-200	320-800	1-1.8	30	30
Cotton	1.5-1.6	10-45	287-800	3-10	5.5-12.6	6
Coir	1.15-1.46	10-460	95-230	15-51.4	2.8-6	4
Hemp	1.4-1.5	25-600	270-900	1-3.5	23.5-90	40
Ramie	1.0-1.55	20-80	400-1000	1.2-4.0	24.5-128	60
Kenaf	1.4	-	223-930	1.5-2.7	14.5-53	24
Sisal	1.33-1.5	8-200	363-700	2.0-7.0	9.0-38	17
E-glass	2.5-2.6	<17	2000-3500	1.8-4.8	70-76	29

Linen fibers are at the forefront with their cost-effectiveness, nominal energy depletion during operating, and low specific gravity. Researches in the literature show that the characteristic surface morphology of flax provides well mechanical features to flax fiber reinforced composites. Nonetheless, it is stated that the weakness of flax fiber and polymeric resins in bonding with each other is the reason for the weak fiber-matrix interface bond strength [15]. Of all the reinforcing fibers, glass fibers are the most common for polymer matrix composites. The main benefits of glass fiber include low cost, high chemical resistance, excellent insulating properties, and high tensile strength. The drawbacks are the comparatively low tensile modulus and high density for commercial fibers, susceptibility to wear during processing, in some degree high hardness, and low fatigue resistance. Freshly drawn glass fibers can have mean tensile strength above 3.45 GPa. Nevertheless, surface damage caused by abrasion, tends to reduce this to values in the range 1.72–2.07 GPa, either by rubbing against each other or by contact with processing equipment [16]. In several implementations, it is seen that the share of use for glass fiber reinforced composites has increased. In general, depending on the area in which it is used, the material may encounter static loads and small dynamic mechanical loads. Especially in marine and construction areas, glass-reinforced polymer composites (GRP) are often used because they are exposed to significant hygrothermal conditions and can withstand static and very large dynamic loads [17]. Epoxy, often used as a matrix material in polymer-based composites, is a thermosetting polymer and is relatively easy to process. Epoxies are environmentally stable, have high hardness and specific strength, but are fragile due to their highly cross-linked network structure. Besides, epoxy has a wide range of uses as a preferred material in fiber reinforced polymer composite materials used in aviation design and production in many sectors [18, 19]. When producing composites, two classes of resin are used, fundamental resin (matrix) and side resin (hardener). Epoxy, polyurethane, and unsaturated polyester are among the basic resins with the highest usage rate. For curing purposes, a hardener is added as a secondary resin. Curing can be done at room temperature and high temperature. This is based on the composition of the resin and hardener [20]. In polymer matrix composites, it is post-cured at high temperatures to achieve better chemical and heat resistance and to improve mechanical properties and increase the amount of crosslinking. Each materiel has a separate post-curing process based on the raw material. Post-curing variables can be expressed as curing time, temperature, the time between initial curing and final curing, and temperature profile slope. When additional curing is applied, it has been observed that indirect and direct composite materials have an effect on the flexural strength and modulus of elasticity [21, 22]. Some researchers have studied woven fabric composites produced by the VARTM technique in the aerospace and defense industries. Compared to the RTM (Resin Transfer Molding) process, the VARTM process is advantageous in terms of cost-effectiveness of the tooling, machining at room temperature, shortening of the mold filling time, and easier scalability in large structures. With this technique, the amount of resin in the mold and adequate wetting of the fibrous preform are important parameters to determine product quality and process efficiency [23]. In a material, hardness is a measure of its stand to deformation caused by the compressive force applied with a keen object. In this search, GFRP (Glass Fiber Reinforced Polymer)/Jute/Linen hardness and GFRP/Jute composite materials hardness were encountered [24]. By measuring with Rockwell Hardness tests, the surface hardness of the conventional metal material to be used in the same application and the material produced in this study were compared. Glass/Linen/Epoxy composite plates were used in this study [25]. In another study, the mean Rockwell E hardness of the Carbon Fiber/Flax/Epoxy composite was 72.437 HRE. Forces applied to all specimens perpendicular to the test direction showed circular indentations on the specimen surfaces [26]. Although form-pressed petrochemical plastics reinforced with natural fibers are already used by default for components not visible in the automobile industry, it is noted that natural fiber reinforced biopolymers need further optimization to fit large product lines. In addition to the use of interior components in the automobile industry, natural fiber-reinforced polymers are also made use of demanding applications in building materials such as automobile exterior surfaces and bodywork components. The fender section of a passenger bus can be given as an example of this outer surface part. These parts are manufactured using the sheet molding compound technique using PTP (vegetable oil-based thermosetting resin) and hemp fiber bundle materials [27]. Over the past decade, the use of natural fiber composites with thermoset and thermoplastic matrix in instrument panels, headliners, package trays, seat backs, door panels, and interior parts has been adopted by European automobile suppliers and manufacturers. Natural fibers such as jute, flax, sisal, and hemp provide benefits like a decrease in CO_2, weight, expense, and less need for on oil sources, and recyclability, while at the same time qualifying these fiber sources as green or environmentally friendly [28]. Green composites are often used for applications in the construction and automotive industries. Green composites can also provide weight reduction and vibration damping in the automotive industry [29]. According to research, it appears that natural fiber reinforced PBS (polybutylene succinate) and PLA (polylactic acid) composites represent considerably less odor emission, which is suitable for automotive interior parts. In terms of the effect of compounding operations, compression molding also indicated comparatively fewer smell concentrations convenient for the automotive industry [30]. In the literature, some studies deal with natural fiber reinforced fabric used to produce composites. In these studies, the effects of fiber array, fabric weaving style, filling material, the use of a different number of fibers on mechanical properties, the effect of surface treatment applications on acoustics were studied and analyzed. Santulli et al. changed their order in composite materials produced by natural fiber fabric such as linen and jute and basalt made of mineral fibers. They hybridized these fabrics utilization of epoxy resin and glass fiber. They examined the effect of this change on tensile and elastic characteristics and concluded that there is a substantial alteration in the elastic modulus with a limited effect on tensile [31]. In a study by Kumar et al., glass and flax fabrics with vinylester resin were utilized to fabricate composite parts. The vacuum assisted resin transfer molding process was used. Produced parts were tested for mechanical properties an also thermal and water absorption analyses were applied. Results show that pure woven glass fibers have lower tensile strength than hybrid composites. It was understood that the strength of the products with glass-layered composites on the bottom surface was higher in the bending tests and the samples with glass-layered composites at both ends had higher values than the others in terms of impact resistance [32]. In another study of K. Mohan and T. Rajmohan [33], composites are manufactured applying altered epoxy resin mixed with different weight multi-walled carbon nanotube (MWCNT) with reinforcement materials such as glass and linen fiber. The samples were produced using the compression molding technique and the effect of the filling material was analyzed using compression, impact, tensile, bending, and hardness tests. The outcomes indicated an augment in tensile strength in glass and linen fiber reinforced composites with an MWCNT content of 0.5% by weight and 1% by weight. When the compressive strength is examined, the value decreases first in the composite with 0.5% MWCNT content by weight, as the value increases rapidly when the ratio is increased to 1% by weight filling material. C.M. Meenakshi and A. Krishnamoorthy [34] and I. Turkmen and N. S. Köksal [35] studied glass and flax fiber fabric with polyester resin via the hand-lay-up method. They examined the mechanical properties (flexural, tensile) and impact strength of the samples produced. They found that the augment in the number of fiber layers had a favorable effect on the mechanical characteristics and the hybrid composite performed equally well with the traditional glass fiber composite and generally had better values than the mono natural fiber composite. Cihan et al. [36] investigated damping features of glass/flax hybrid composites. They compared only flax fabric reinforced and different sequence glass/flax hybrid reinforced composites. Especially when linen laminas are settled on the exterior skin, hybridization of Linen and E-glass fibers has been found to result in an increment in damping from 1.97% to 2.63% in the optimum hybrids. In one of the searches, Saidane et al. [37] analyzed the laminar fracture toughness of the materials by applying the double cantilever beam (DCB) test to glass, flax, and hybrid glass-flax fibers. In order to determine the damage mechanisms in these composites, DCB tests were followed by applying the acoustic emission (AE) technique and different damage mechanisms were observed with the help of scanning electron microscope (SEM). As a result of the study, it was seen the toughness of glass fiber composites could be increased in a suitable combination with flax fibers, and it was revealed that the reduction of composite structure weight was an important advantage due to the low fiber density of flax. In these studies [38, 39], the sandwich structure model was created by using Flax/Glass/Epoxy materials. The effects of these structures on static and fatigue compressive properties and moisture diffusion behavior have been studied. B.A. Muralidhar [40] used a combination of linen plain-woven fabric and weft rib knit structures as reinforcement and production were made by hand lay-up technique. The samples produced were applied thermogravimetric analysis, dynamic mechanical analysis, tensile test, static compression test, and the surfaces were examined by scanning electron microscope model. It has been found preformed laminates knitted as a leather layer exhibit superior mechanical property, but the presence of different area weight preforms within the structure causes a significant deterioration in mechanical features. Fiore et al. [41] investigated how outer layers of glass woven fabric affect pinhole strength in linen/epoxy laminates. In the light of the tests performed, it has been found the outer layers of the glass fabric in the flax/epoxy laminate affect the mechanical performance of mechanically joined joints in a positive way. Zhang et al. [42] examined unidirectional linen and glass fiber reinforced hybrid composites in terms of tensile, fracture toughness, and laminar shear strength. They compared the results of the analysis with the theoretical calculation values. It was observed the tensile characteristics improved with the increment of glass fiber ingredients. In other works[43, 44], the results obtained by using glass and linen fabric as reinforcement elements for damage mechanisms were evaluated in terms of hybridization. In the study, the use of composites produced using glass fiber, epoxy and polyester resins in auto body panels was investigated. The analysis of the mechanical properties of the produced composites offered the possibility to determine the material performance in the vehicle under dynamic and static load conditions [45]. In another study, the use of sisal fiber instead of traditional materials in the production of light vehicles was investigated by taking advantage of the lightness, high specific strength and biodegradability properties that are evident in sisal fiber composites [46]. In another study investigating the use of composite materials in automotive, the use of banana-coconut fiber particle composites hybridization operation in automotive component design and production was examined. The results of the analyzes have been found that the materials produced do not pose any problems in the use of the car window regulator handle, as well as providing an extra weight advantage [47]. Getu et al. stated in the results of the study that the hybrid composite materials they produce from bamboo and sisal fiber can be used in the construction of light vehicles targeted by automotive manufacturers, as well as the potential to be used in automotive interior panels of recyclable materials that do not require high mechanical efficiency [48].

In this study, flax from natural fibers and glass fiber with two different weights (not found generally in previous studies) per square meter (86 gr/m² and 100 gr/m²) were used as reinforcements to build up environmentally friendly composite panels for the use of alternative material in automotive parts. Since the composite structures used in this study are promising in terms of both environment and cost compared to traditional materials used in automotive, studies on this subject are increasing. These types of composite structures have a widespread impact on today's material studies, with their potential to be the building blocks of future vehicles. While the matrix material is the epoxy resin from thermosets, the production is made by vacuum assisted resin transfer molding technique. Investigating and discussing the mechanical characteristics (bending, tensile strength, modulus of elasticity, elongation at break) and hardness performances of hybridized materials, the outcomes of hybrid composites were compared with the results obtained from lamina flax and lamina glass fiber reinforced composites. Composites produced with these analyzes will reveal the usability of the vehicle both in the exterior and interior. At the same time, the effect of glass fibers of different weights on mechanical properties in samples produced is presented. In addition, the morphology of the fractured surfaces was analyzed by SEM. Morphologically analyzed materials will be a guide for researchers in terms of chemical and physical structure in the production of new hybrid composite materials in future studies.

2. MATERIAL METHOD

2.1. Material

Two different glass fiber fabrics with different weights per square meter and 280 gr/m² linen fabric were used as reinforcement material supplied from companies in Istanbul. Table 2 shows the properties of these fabrics. The structure of these fabrics is plain weave. The fabric samples are indicated in Figure 1.

Table 2. *Properties of fabrics*

Fabric	Weight (gr/ m²)	Thickness of fabric(mm)	Warp	Weft
Flax	280	0.5	-	-
Glass Fiber	86	0.06	34x1	12x12.5
Glass Fiber	100	0.08	22x1	24x2.8

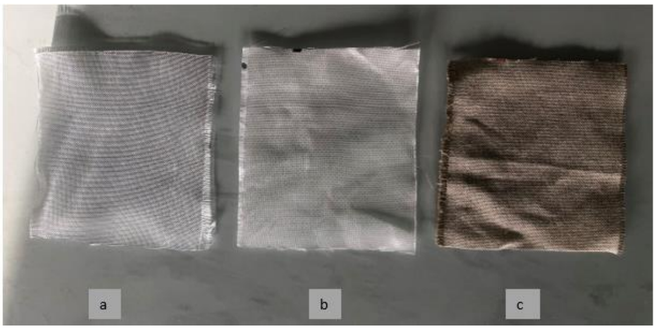

Figure 1. *Fabric samples: a) Glass fiber (86 gr/m²) b) Glass fiber (100 gr/m²) c) Flax*

As a matrix system, Epoxy resin (L160) and hardener (LH260S) supplied from Kompozitshop (Turkey) were used. While preparing the mixing ratio of resin and hardener, 100:36±2 by weight, as specified by the manufacturer, was taken into account. Table 3 gives the properties of the resin system. L160 Infusion epoxy resin systems are the products used in aviation, automotive, marine, aerospace, wind propellers, and defense industries, which are widely used in advanced composite parts manufacturing in the world. The L160 system, which has an aviation certificate, can be easily used in infusion applications that are not very large. It cures at room temperature and parts that meet civil aviation standards can be obtained by post curing [49].

Table 3. *Epoxy and Hardener Properties*

	L160 Infusion Epoxy	H260S Hardener
Operating temperature (° C)	-60 / +50 without heat treatment -60 / +80 by applying heat treatment	-
Process temperature (° C)	+10 / +50	-
Density (g / cm³)	1.13-1.17	0.93-0.97
Viscosity (mPas)	700-900	80-100
Refractor index	1.5480-1.5530	1.4980-1.4985
Amine value (mgr KOH / gr)	-	450-500
Measurement Conditions	25°C	25°C
Operating temperature (° C)	-60 / +50 without heat treatment -60 / +80 by applying heat treatment	-

Fifteen composite samples have different fabric stacking patterns and were produced for analysis throughout this study. Table 4 shows the reference codes for fabric layers in composite samples.

Table 4. *Codes of produced samples*

Composite Codes	Fabric Types
FL	Pure Flax fabric composite
G86	Pure Glass Fiber fabric composite (86 gr/m²)
G100	Pure Glass Fiber fabric composite (100 gr/m²)
FLG86	Flax/Glass Fiber (86 gr/m²) hybrid composite
FLG100	Flax/Glass Fiber (100 gr/m²) hybrid composite

2.2. Method

Composite specimens were produced using vacuum assisted resin transfer molding method (VARTM). Composite fabrication was carried out under room temperature conditions (20°C±2°C). This manufacturing technique involves dispersing the resin into the fabric and using a vacuum pump to remove air pockets. At first, the specified area was cleaned and then applied a releasing agent. Then the fabrics were arranged in the determined order, the peel ply and the infusion mesh were placed on the fabric. The determined area was surrounded by a vacuum sealing band. After the vacuum sealing tape was attached to every side of the sample, a vacuum bag was enclosed to it. Small holes were made in the vacuum bag for the infusion hose and vacuum hose. During these processes, the resin and hardener were mixed and made ready according to the value given by the manufacturer. Finally, the vacuum pump was turned on (about 1 bar) to absorb the surplus resin from the specimen and the pump was turned off when the resin was completely infused through the reinforcement. Vacuum pipes and open areas were covered with a sealing band to disallow air entry. The specimen was left in this position for 24 hours to cure (Figure 2). The test specimens were placed in an oven and kept at 60 ° C for 1 hour, post curing process was applied (Figure 3).

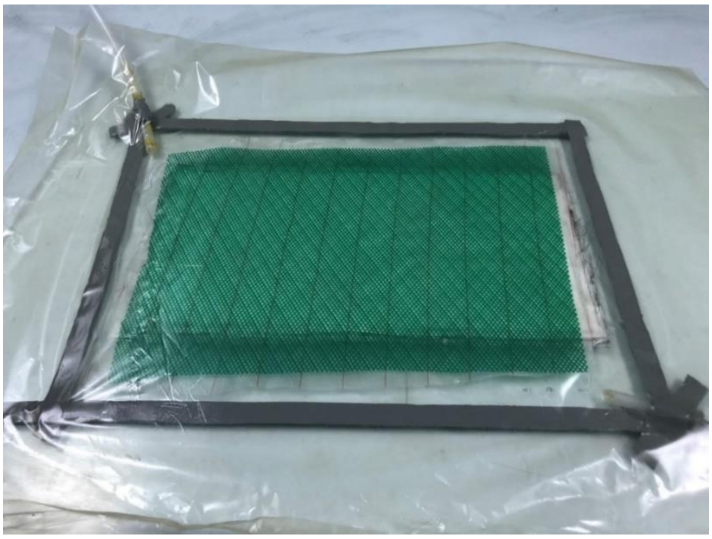

Figure 2. *Vacuum assisted resin transfer molding process*

Figure 3. *Produced samples after post curing*

2.3. Mechanical Testing

The mechanical characteristics of the produced composite specimens produced were analyzed by tensile strength and three-point bending tests. Five samples were tested in each of the five different combinations, giving the test results as the mean value of the five samples. Tensile testing is done using ALŞA Hydraulic Test Machine (KOLUMAN Automotive Industry Laboratory) according to ASTM D 3039 standard and the crosshead speed was set as 2 mm/min using a capacity of 98000 kN load cell [50]. The tests were done at room temperature. The universal tensile testing machine is shown in Figure 4. In the tensile test, the load is applied uniformly until the specimen breaks and the ultimate force and ultimate stress values are measured before failure. Load and deflection, stress and strain graphs are created. The elastic modulus was found by performing linear regression to the linear area on the experimental stress-strain curve. Also, flexural tests were applied using the Instron 5985 250 kN test machine in Figure 5 at Uluğ Bey High Technology Application and Research Center (ULUTEM) according to the ASTM D790 standards [51].

Figure 4. *Tensile testing machine*

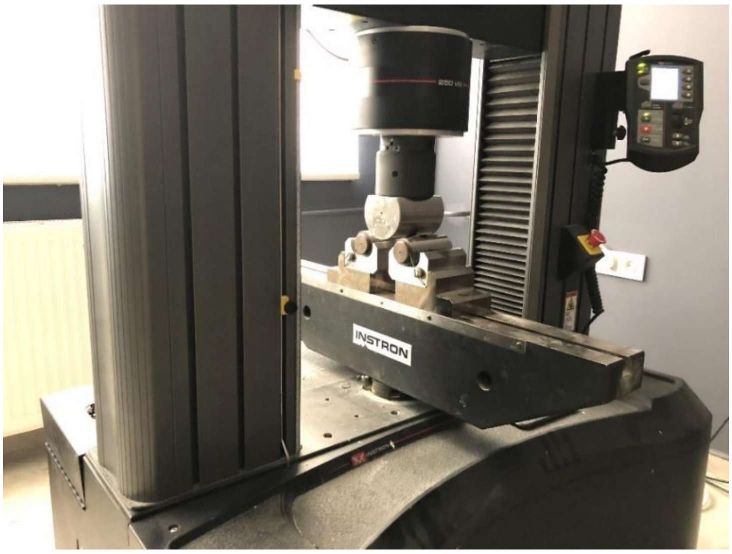

Figure 5. *Three-point bending testing machine*

The flexural test was applied on 5 samples 125 mm long and 20 mm wide depending on the proposed sizes for the flexural features of polymer matrix composite materiels from the ASTM standard. The tests were carried out at ULUTEM, with each specimen supported on a 112 mm span length fixture based on the specimen thickness (span to thickness ratio equal to 32: 1). The flexural stress of the samples produced was calculated according to the Equation (1):

$$\sigma_f = \frac{3PL}{2bd^2} \ . \tag{1}$$

In Equation (1), σ_f indicates the stress in the outer fibers at the midpoint (MPa), P indicates the load at a given point on the load-deflection curve (N). L is a support span (mm), and b, d shows the width of the beam tested (mm), depth of the beam tested (mm), respectively. Moreover, the flexural modulus of elastic values was calculated in the Equation (2):

$$E_B = \frac{L^3 m}{4bd^3}. \tag{2}$$

In Equation (2), The E_B shown in the equation indicate modulus of elasticy in bending (MPa), L indicates the support span (mm). The m variable indicates the slope of the tangent to the initial straight-line portion of the load deflection curve(N/mm). b and d are the width of the beam tested (mm), depth of the beam tested (mm), respectively.

2.4. Hardness Test

Rockwell hardness tests were done on the specimen from each combination based on the ASTM standard at Mechanical Engineering Department of Ceyhan Engineering Faculty. All test specimens were optically observed on parallel flat surfaces to remove deflection gave rise to poor contiguity between specimens and the anvil of the hardness device [52]. A large steel ball was used to spread the load equally, despite the fact that the fibers could affect the indentation penetration. Tests were conducted at ambient temperature using a Rockwell hardness tester that forces a 1/16-inch diameter steel sphere at a 100kg (HRE) load. While measuring, 15 values were obtained for the hardness of each sample in 5 combinations, and the average of these values was recorded as the hardness value of the composite product (Figure 6).

Figure 6. *Rockwell hardness test machine*

2.5. Morphological Analysis

SEM is utilized to analyze fiber-matrix interactions in materials and to examine the fracture surface. The produced samples were scanned utilized an FEI Quanta 650 Field Emission SEM instrument with 30 kV operation and 10,000x magnification in Cukurova University Center Research Laboratory (CUMERLAB). The sample is covered with a thin layer of gold for SEM monitoring. The fractured surfaces in the samples were characterized under a 2.0 nm high resolution Scanning Electron Microscope (Figure 7). Figure 8 also shows the samples placed on device.

Figure 7. *Scanning Electron Microscope machine*

Figure 8. *Samples placed on the device*

3. THE RESEARCH FINDINGS AND DISCUSSION

3.1. Mechanical Testing Analysis Findings

Table 5 gives the tensile test findings. According to the results, the single flax composite has the lowest tensile strength among the produced composites, while the single glass fiber composite has the highest tensile strength value. With the hybridization of flax and glass fiber, it is seen that the tensile strength value increased by 154% for FLG86 and 70% for FLG100 compared to the single flax composite value. The difference of these values not only supports the tensile strength results of the composite specimens produced but also indicates that the type of reinforcement material and the hybridization process have a significant effect on the tensile strength of the composite material. As Cihan et al. stated [36], hybridization of flax fibers with glass fibers increases the tensile strength from 1.92 times to 3.16 times. In another study also using glass/flax fiber hybrid composites improves the mechanical performance of mechanically fastened joints compared to single flax composites [41]. Similar results can be seen when comparing the modulus of elasticity. It is seen that hybrid composites have a 1.65 times higher elasticity modulus value for FLG86 and 1.32 times higher for FLG100 compared to single flax composites. On the other hand, no big differences were observed between the tested samples in the percentage elongation amounts. In addition, there is a significant difference between the tensile strength values of flax/glass fiber fabric reinforced samples with different stacking sequences. The tensile strength value of the hybrid composite made of linen fabric with 86 gr/m² glass fiber fabric has a value 49% higher than the composite sample made with 100 gr/m² glass fiber. It has been stated that low values in tensile strength occur when low strength fibers are placed inside the composite structure [3]. It is understood that the impact of different piling series affects the tensile strength to a certain extent.

Table 5. *Tensile Strength test results of composites*

Composite Fibers	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation (%)
FL	70.09	1170	10.18
FLG86	178.37	1936.6	9.54
FLG100	119.53	1545.66	7.8
G86	301.624	3638.2	9.46
G100	334.78	3903.83	9.35

Figure 9 shows that flexural stress of FL, FLG86, FLG100, G86, and G100 were 181.92 MPa,325.56 MPa,224.65 MPa,446.53 MPa, and 573.08 MPa, respectively. Among the produced composite samples, G100 has the highest flexural stress and FL has the lowest flexural stress value. Hybridization of glass fiber fabric to linen fabric resulted in a 78.9% increase in flexural strength for the FLG100 and a 23.4% increase for the FLG86.In the study of Kumar et al. [32], it was observed that the flexural strength of composites made with glass fiber was the highest among other composites, with the hybridization of flax to glass fiber, the flexural strength of single flax fiber composites increased between 1.56 times and 2.83 times. In another study using natural fiber/glass fiber composite materials in which the flexural strength was examined, an improvement in flexural strength from 43.66% to 95.64% was observed in hybrid composites compared to homogeneous natural fiber composites [1].

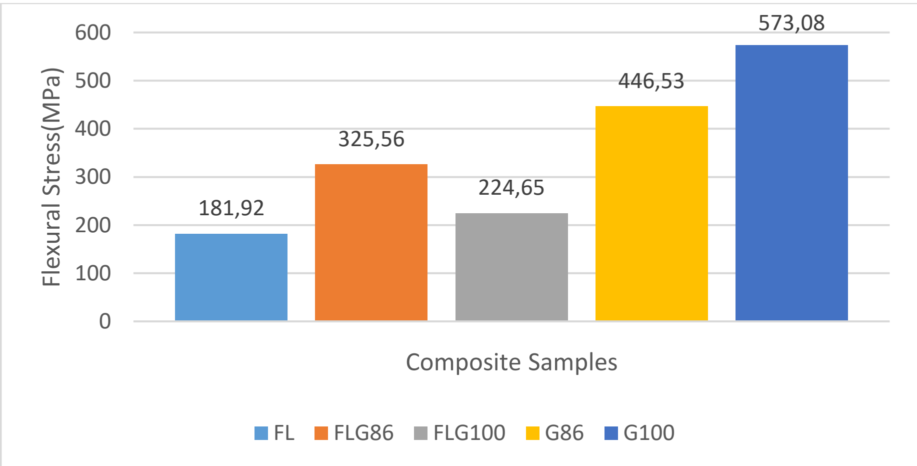

Figure 9. *Three-point bending test results*

The maximum force on the load for the samples is given in Figure 10. During testing, the G100 has the highest breaking force before the specimen breaks. Here, the difference between the FLG86 and FLG100 force values is due to the sequence difference in the fabric order. A higher force value was achieved by placing the E-glass plies to the outer layers.

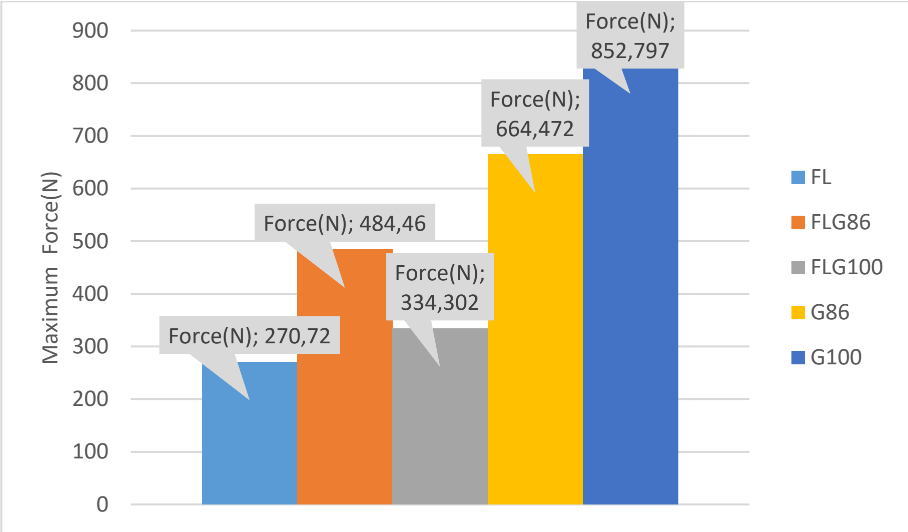

Figure 10. *Maximum force on the load-deflection curve*

3.2. Hardness Test Analysis Findings

In materials, hardness is known as the measure of the resistance to deformation caused by the compression force exerted by a keen object. Figure 11 gives the results of the Hardness test applied to the samples. The results indicate that FLG 86 hardness is slightly higher than FL and FLG100 has the highest hardness value among hybrid composite samples. This is because the penetration resistance depends on the order of the alternatively arranged fibers as in the studies of Agarwal et al. [4]. In their studies, the lowest values in glass-carbon fabric reinforced composites were observed in homogeneous composites, while hybrid composites arranged in an alternative order gave higher hardness values

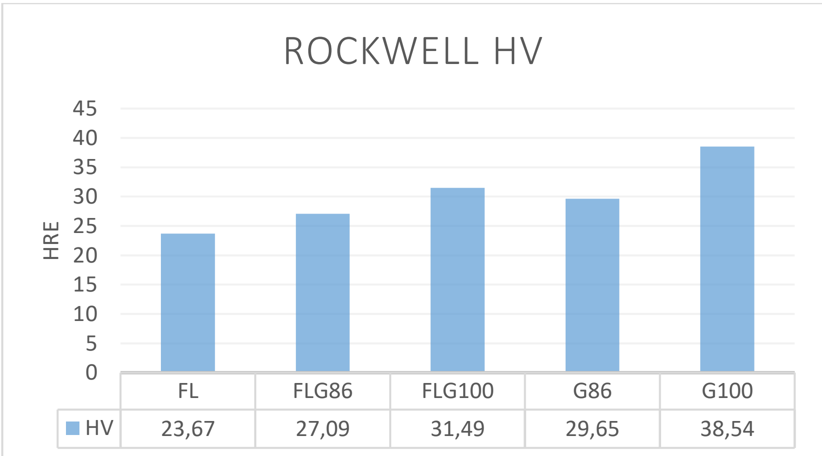

Figure 11. *Hardness values of composite*

3.3. SEM Analysis Findings

Figures 12-16 indicates the images of samples after the tensile test. G86 and G100 images state that there are fewer voids than FL images. Besides, FLG86 and FLG100 images show higher adhesion between resin and flax/glass fibers in comparison with the flax/resin interface. This brings about low tensile strength for flax/epoxy resin composites. Figure 12 clearly shows fiber failure, however, in Figure 13 and Figure 14, separation of glass fibers from the matrix material and sudden fiber breaks were not observed. In a study examining flax fiber [40], similar to the present study, separation of fiber/matrix bonds with fiber separation was detected. Less extensibility of flax fibers under tensile load caused fiber breakage with little or no shrinkage. Further, in the morphological analysis in this study [12], it is understood that the stress in the fibers indicates that the adhesion of glass fiber and epoxy resin increases the polymer strength, whereas in natural fiber composites, fiber stretching and fiber breakage are evident on the surface. It is seen that the fiber bundles have a stronger bond structure in Figure 15 and Figure 16 than the images of linen composites. These morphological analysis images explain why the tensile strength is highest in glass fibers. It has been observed that better stress transfer in hybrid interfaces has been achieved by the rough surface of the flax fiber and the structure of the twisted flax yarn, providing significant bonding tasks on adhesion between the plies [42]. As stated in other morphological analysis studies, the fact that natural fibers form hybrid composite materials strengthen their weak mechanical aspect and eliminates their disadvantage.

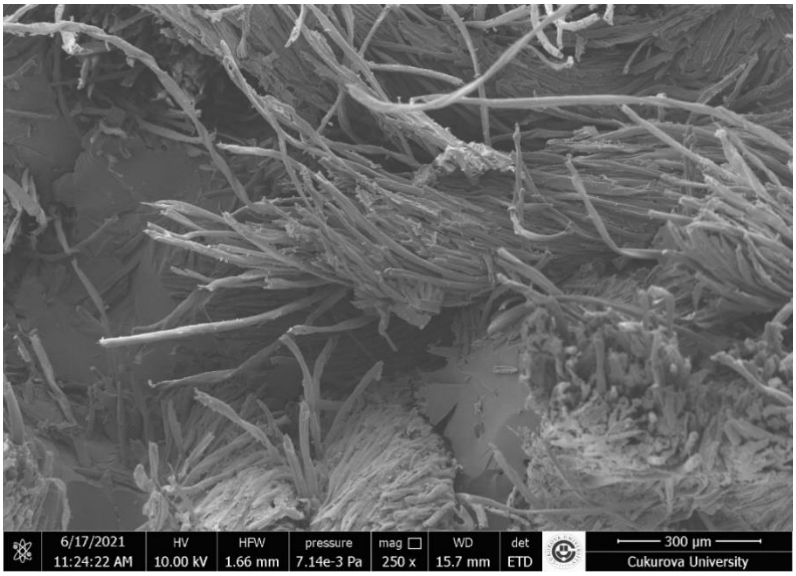

Figure 12. *After Tensile Test SEM images of FL*

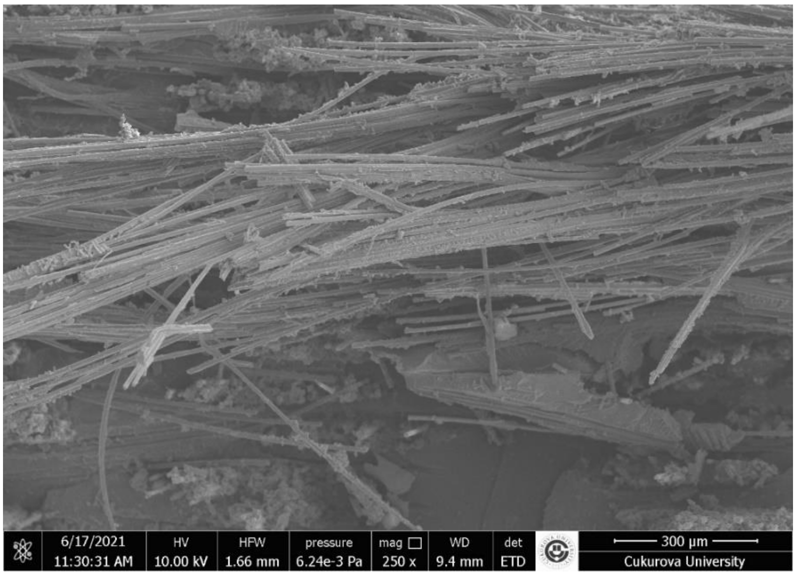

Figure 13. *After Tensile Test SEM images of G86*

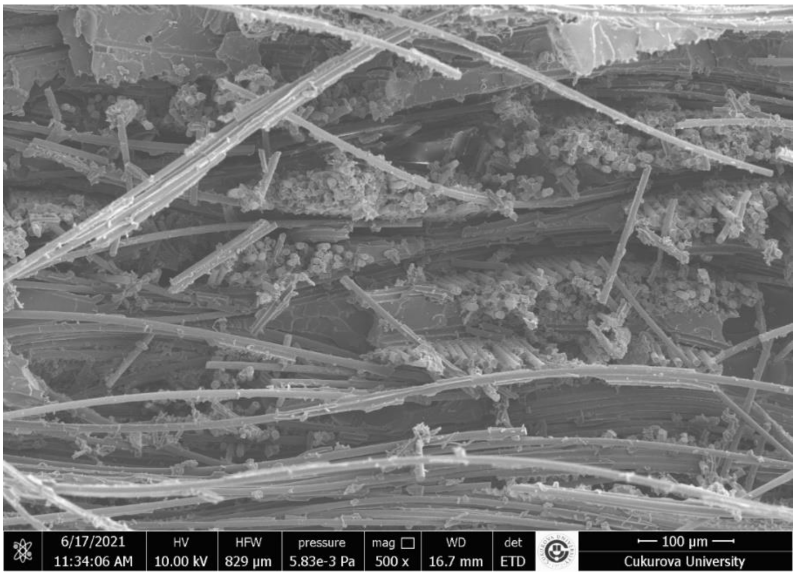

Figure 14. *After Tensile Test SEM images of G100*

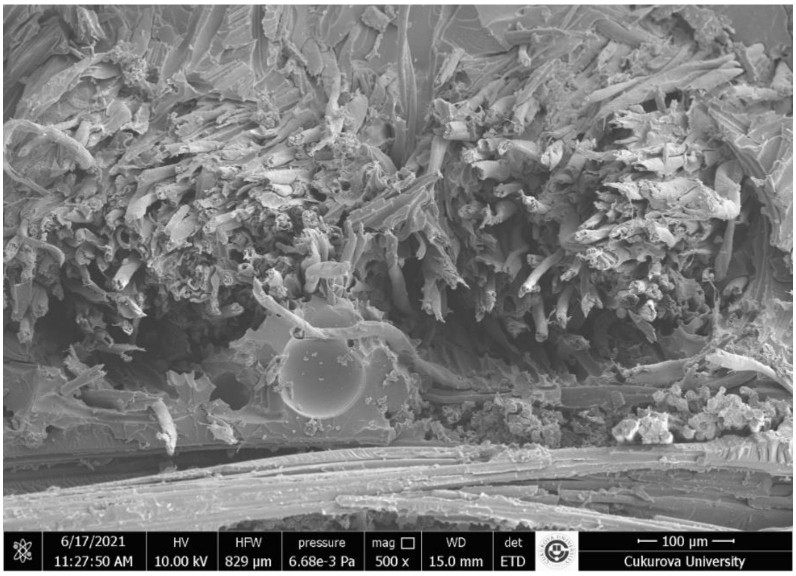

Figure 15. *After Tensile Test SEM images of FLG86*

Figure 16. *After Tensile Test SEM images of FLG100*

Figures 17-21 shows the images of samples after the flexural test. Figure 17 indicates the damaged surface of flax. Figures 18 and 19 states the unbeaten surfaces of glass fibers. While the fibre breakage was clearly visible in Figure 17, less damages were revealed in glass fibers as in Figures 18 and 19. Hybrid natural fiber/synthetic fiber composites exhibit fewer voids and strong adhesion compared to lamina flax composites. In another study of morphological analysis of flax/glass fiber composite, it was seen that the presence of glass fibers in hybrid composites led to the appearance of no delamination, which resulted in a decrease in the tension gap between natural fiber and glass fibers [31]. In the flax laminated composite in Figure 17, it is clear that the fibers have been stripped from the fracture surface. Glass fibers in Figure 18 and Figure 19 have a wide degree of fiber shrinkage. As in the tensile test morphological analysis results, the bending test analysis results indicate that the physical structure of hybrid composites formed by flax fibers with glass fibers is stronger than homogeneous flax fiber composite structures.

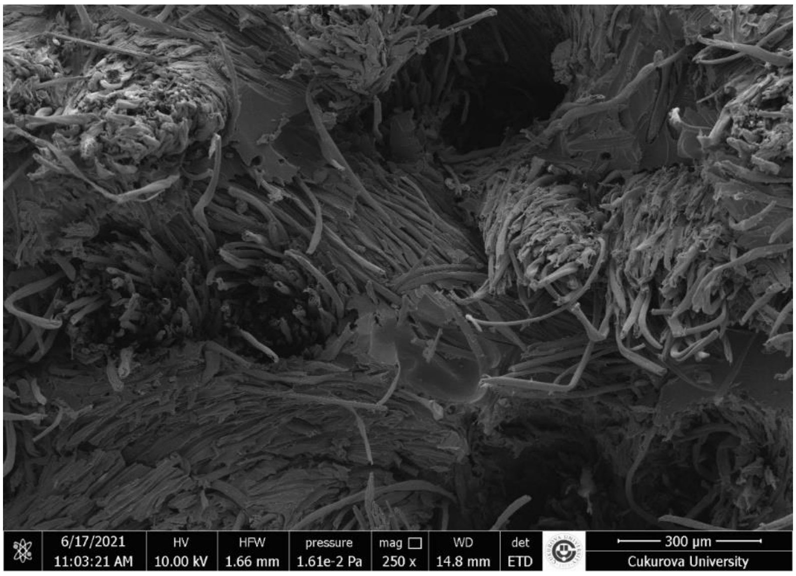

Figure 17. *After Flexural Test SEM images of FL*

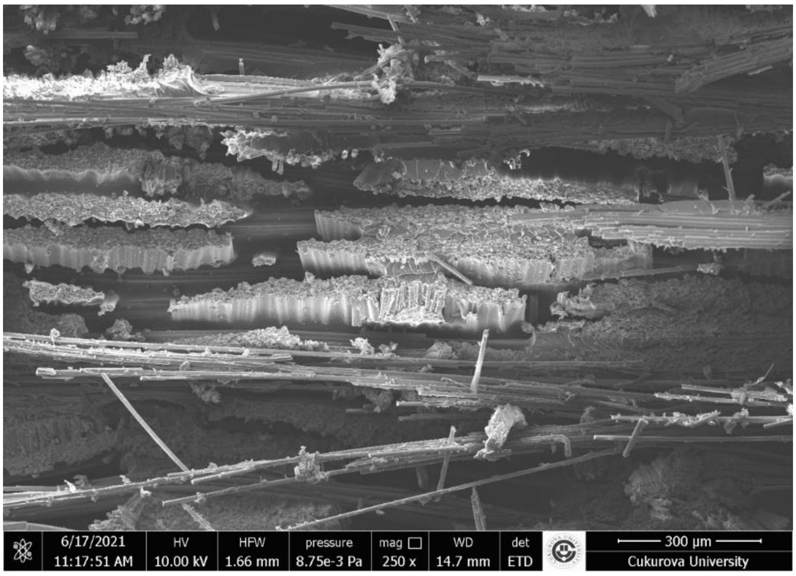

Figure 18. *After Flexural Test SEM images of G86*

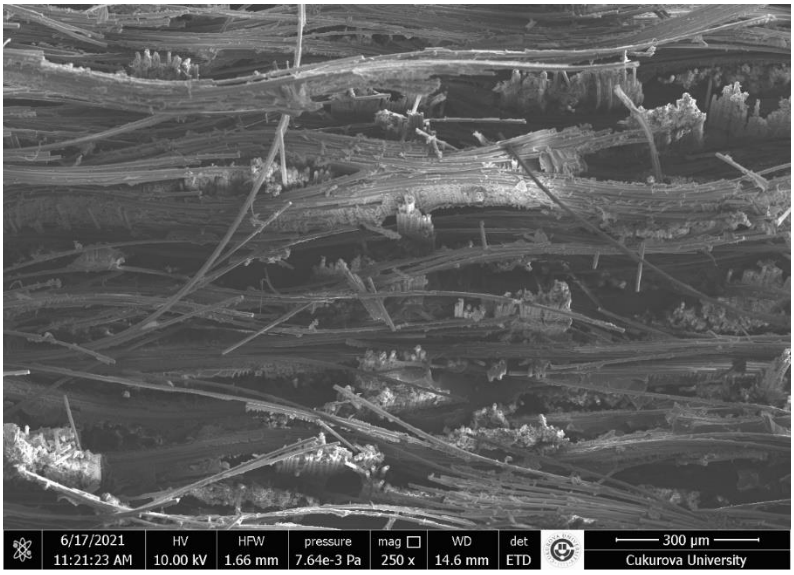

Figure 19. *After Flexural Test SEM images G100*

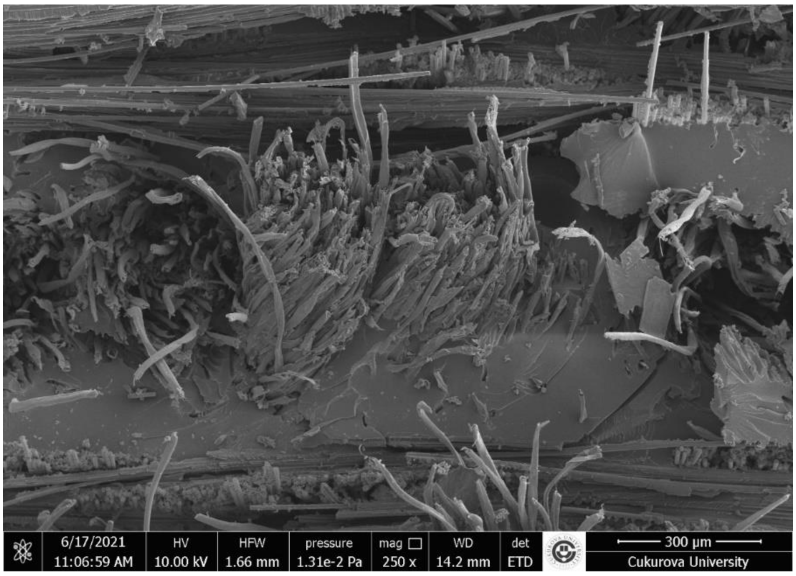

Figure 20. *After Flexural Test SEM images of FLG86*

Figure 21. *After Flexural Test SEM images of FLG100*

4. CONCLUSIONS

The hybridization process and different stacking orders are the parameters used in this study in terms of the developing of the mechanical characteristics of composites. Hybridization of synthetic fiber fabric with natural fiber fabric turns out remarkable increments in tensile strength, flexural strength, and stiffness values. Linen fabric/epoxy composite,86 gr/m² and 100 gr/m² glass fiber fabric/epoxy composites were produced, and experiments were carried out to analyze the effect of hybrid composites and glass fiber fabric at different weights per square meter on the mechanical properties of the produced samples. In both tensile strength and flexural stress analysis results, the value of G100 higher than any other composite specimen produced as expected. In addition, it was determined that the tensile strength value of the FLG100 sample was enhanced by 70% with the hybridization process compared to the FL sample, and this rate was 154% in the FLG86 sample. The hardness test of composites, FL has the lowest value. With the hybridization process, the microhardness value of the FLG86 sample increased by 14.4% compared to the FL sample, while the increase was 7.81% when the FLG100 sample was examined. The mechanical properties of FLG86 and FLG100 are higher than FL, which indicates that the hybridization process has a positive effect. In comparison with G86 and G100 samples, all of the mechanical test results show that G100 values have higher than G86 values. However, the FLG86 hybrid composite sample test results are higher than the FLG100 sample test results. The reason for this is the effect of positioning the glass fiber fabrics on the outer layer in the fabric array on the results. SEM results show that while fiber shrinkage and fiber breakage are commonly detected in samples after tensile tests, matrix cracking and delamination are prominent in samples under bending loads. As a result, in the light of the results obtained, it can be concluded that higher strength fabrics should be positioned on the outer layers in hybrid composite structures in order to obtain higher tensile and flexural strengths. It is seen by the hybridization process of glass fibers of different weights to flax that glass fibers improve the mechanical properties of natural fibers, making them usable in the automotive industry. Both cost and environmental concern the fabricated synthetic-natural fiber hybrid composites are emerging as important alternatives that can be used in the automotive industry.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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