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Research Article

Mechanical Structure Investigations of Woven and Knitted Carbon Fiber-Reinforced Polymer Composites

Ceyda Okta[1,] and Sidem Kaner [2,*]

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[1]Pamukkale University, Faculty of Technology, Department of Metallurgical and Materials Engineering; Denizli, Türkiye; cydokta@gmail.com

[2,*] Pamukkale University, Faculty of Technology, Department of Metallurgical and Materials Engineering; Denizli, Türkiye, skaner@pau.edu.tr

* Corresponding author

Abstract: In this study, polymer matrices were reinforced with carbon fabric obtained by weaving and knitting carbon filaments. Different industries reported that filament unwinding occurred in woven carbon fiber composites. In composite manufacturing where woven fabric is required, the laying and manufacturing processes are challenging due to the dispersion of the fabric. With the knotted chain structure of the knit, it is easier to apply epoxy to the fabric as desired and to convert it into a composite. Especially when it is possible to produce the knit-ted chains tightly and as a whole during the knitting process, it is possible for the product converted into a composite to exhibit higher strength. In this study, the effects of weaving and knitting methods on the mechanical properties of carbon fiber reinforced composites were investigated. Mechanical properties were examined in woven and knitted structures for carbon fiber composite materials with different densities and thicknesses. Single-layer composite was produced using 3-layer 200 g/m2 plain woven fabric, 200 g/m2 and 245 g/m2 twill carbon fiber woven fabric as woven fabric. Carbon fabric with 1x1, 2x1, and 3x1 interlock knit structures were knitted so that it could be compared with weaving. The carbon fabrics obtained from woven and knitted filaments were turned into car-bon fiber-reinforced composites produced by vacuum infusion. Tensile and three-point bending tests of carbon fiber-reinforced composites were carried out within the scope of experimental studies. The fracture surfaces of the composite plates obtained were investigated via FESEM and EDS analyses. The highest ten-sile strength values were achieved in 245 g/ m2 twill weave and 3x1 interlock knitted carbon composite samples. In the knitted samples used, no dissolution problem was observed in the knitted structure.

Keywords: fiber reinforced; carbon fiber; composite; mechanical strength.

Araştırma Makalesi

Dokuma ve Örme Karbon Fiber Takviyeli Polimer Kompozitlerin Mekanik Yapı Araştırmaları

Özet: Bu çalışmada, polimer matrisler, karbon filamentlerin dokunması ve örülmesiyle elde edilen karbon kumaş ile takviye edilmiştir. Farklı endüstriler, dokunmuş karbon fiber kompozitlerde filament açılmasının meydana geldiğini bildirmiştir. Dokuma kumaş kullanılması gereken kompozit imalatında serim ve imalat süreçleri kumaşın dağılmasından dolayı zorlayıcı olmaktadır. Örgünün sa-hip olduğu düğüm zincirli yapısı ile kumaşa istenilen şekilde epoksi uygulanması ve kompozite dönüştürülme süreci daha kolaydır. Özellikle örgü sürecinde örgü zincirlerinin sık ve bir bütün şekilde üretilmesi mümkün olduğunda kompozite dönüşen ürünün daha yüksek dayanım sergilemesi mümkün olabilir. Bu çalışma ile dokuma ve örme yöntemlerinin karbon fiber takviyeli kompozitlerin mekanik özellikleri üzerindeki etkisi araştırılmıştır. Yoğunluk ve kalınlıkları farklı olan karbon fiber kompozit malzemeler için dokuma ve örme yapılarda mekanik özellikler incelenmiştir. Dokuma kumaş olarak 3 katlı 200 g/m2 düz dokuma kumaş, 200 g/m2 ve 245 g/m2 dimi karbon fiber dokuma kumaş kullanılarak tek katlı kompozit üretilmiştir. Dokuma ile karşılaştırılabilmesi için 1x1, 2x1 ve 3x1 interlok örgü yapılarına sahip kar-bon kumaş örülmüştür. Dokuma ve örme filamentlerden elde edilen karbon ku-maşlar, vakum infüzyonla üretilen karbon fiber takviyeli kompozitlere dö-nüştürülmüştür. Deneysel çalışmalar kapsamında karbon fiber takviyeli kompozitlerin çekme ve üç noktalı eğme testleri gerçekleştirilmiştir. Kompozit plakaların kırılma yüzeyleri FESEM ve EDS analizleri ile incelenmiştir. En yüksek çekme mukavemeti değerleri 245 g/m2 dimi örgü ve 3x1 interlok örgülü karbon kompozit numunelerinde elde edilmiştir. Kullanılan örme numunelerde, örme yapısında çözülme problemi gözlenmemiştir.

Anahtar Kelimeler: fiber takviye; karbon fiber; kompozit; mekanik dayanım.

1. Introduction

An important class of textile composites is woven fabric composites. Carbon fabrics produced by weaving carbon filaments are generally used to manufacture these composites. The layers created in the manufacture of woven fabrics are made in piles by giving a certain direction to the warp and weft threads, respectively, along the existing length and width of the fabric [1]. Although the dense texture of the woven fabric and its quick-dissolving structure facilitate the process of obtaining it as a fabric, it complicates the process of getting composites by combining the material with a polymer-based system. Fabrics obtained by weaving have been used in technical textiles for many years [9]. The transformation of the fabric obtained after the production of knitted fabrics by loop formation into a composite may show significant mechanical differences compared to a compo-site obtained with woven fabric [24].

Different numbers of filaments can be used in carbon fiber manufacturing such as 3K, 6K, and 12K. Carbon fiber is a rigid and light material with high mechanical strength compared to metals. Correctly determining both the mechanical and physical properties of the product obtained in the production of composite materials is an important process [6]. It has high tensile strength, chemical resistance, and thermal resistance. Thanks to its thin filament structure, its ability to bend during weaving and knitting processes creates an advantage in fabric production [18].

In most of the carbon composite-based studies reported in the literature, the effects of filament (fiber structure, types, fiber-to-volume ratio, fiber orientation and number) and weaving (shape, yarn bundle density, bundle spacing, direction of weaving) on the physical, mechanical, and thermal properties of carbon composites were examined [5]. Tugan examined the mechanical proper-ties of woven-type composites obtained from glass, carbon, and basalt fibers in textile-based composites. Basalt, 3K, 12K carbon and E type 300 tex glass yarns in 1200 tex yarns obtained composite structures from the plain weave. According to the data obtained from the tensile and three-point bending test results; the highest tensile and bending strengths in the warp direction were observed in the glass fiber hybrid composite sample, the highest tensile strength in the weft direction was observed in the hybrid composite sample made with 12K carbon, and the highest bending strength was observed in the composite samples made with basalt [15]. Zhou et al. They produced epoxy-based carbon woven fabric with three different geometries consisting of single plain and double twill weave with different densities. They investigated the mechanical behavior of these composites under tensile loading. Different me-chanical values were determined for all three composites. Accordingly, the crimp ratios in the weave types affect the mechanical properties, and as a result of the damage, mechanical properties affecting tests and microstructure examinations of the woven fabric composites, it was determined that the weave pattern and geometry play a critical role [22].

Tursun carried out an experimental study by performing elastic analysis for two-dimensional orthogonal woven twill fabric and composite laminate material. Epoxy with glass fiber cloth and epoxy resin with carbon fiber cloth 12-layer composites were produced by vacuum infusion method as reinforcement and matrix material, respectively. According to the data obtained by the tensile test, the average tensile stress of the fabric and epoxy samples obtained with glass fiber was lower than that of the fabric and epoxy samples obtained with carbon fiber [17].

Gülcan, used carbon woven fabric of 200g/m2 (3K) and 600 g/m2 (12K) of different weights of carbon fibers with single and double-layer composite plate structures. Composite samples were produced as twill/twill, plain/plain, and twill/plain type hybrid structures by vacuum-assisted resin transfer molding method. According to the tensile test results, a higher elastic modulus value was achieved in the 200 g/m2 weighted plain fabric type composite plate than the twill fabric type composite plate. The same is true for 600 g/m2 fabrics. Among all the samples, the 200 g/m2 weighted plain fabric-type composite plate showed the highest elastic modulus due to the weight effects [8].

One of the most important industrial areas for carbon composites is the defense industry. High mechanical strength and lightness are very important for the equipment and defense vehicles used in this field [23]. Yanen and Solmaz examined the products obtained in terms of ballistic performance by manufacturing hybrid composite materials from armor materials used in the defense industry. [20]. Carbon composite materials have begun to take their place among the sought-after materials in dif-ferent areas of importance in the industry. Especially in vehicle brake pads, solid rocket engine parts and silicon crystallization furnaces. Korkmaz produced carbon composite materials by hand laying method in carbon fiber reinforced woven fabric type and examined their mechanical properties [12]. Turhan used 200 tex carbon fiber and 1x1 rib knitted fabrics in two different densities to manufacture composite plates by hand lay-up method. It has been observed that the material, the production method, and the density affected the mechanical properties significantly [16].

Durgun et al. compared the effect of vacuum bagging and vacuum infusion production methods on tensile strength. Samples produced by vacuum infusion showed higher tensile strength [7].

Considering the cost effect of carbon fiber materials, Shimokawa et al. produced carbon compo-site materials with epoxy resin cured under vacuum at low temperatures. It provided tensile and compressive strength at room temperatures and different elevated temperatures [14].

Depending on the weaving and knitting process, loss of strength in fiber structures is possible [25]. In the study, it was thought that in order to prevent the loss of strength that may occur during the composite manufacturing process, knitted fabric will provide a higher strength composite with epoxy compared to the transition of traditional woven fabric to rigid form. When the previous studies were examined, it was seen that the carbon fabrics were generally produced by weaving carbon fibers in the literature. Therefore, woven and knitted carbon fabrics were compared in terms of mechanically and metallogaphically in this study as a contribution to the literature. When the literature is examined, it is seen that while there are many studies on weaving, the study on carbon composite obtained by producing knitted fabric is incomplete. The main reason for this is that weaving production is easier. However, in terms of the process of converting the fabric into composite, both manufacturing and the strength that can be obtained are higher.

2. Materials and Methods

Within the scope of the study, carbon fabrics with 3K (3000 filaments) linear density-wire number as reinforcements and epoxy resin as matrix material were used in the production of the composite samples.

200 g/m2 plain, 200 g/m2 twill, and 245 g/m2 twill were woven-type carbon fiber fabrics. 1x1, 2x1, and 3x1 interlock carbon fiber fabrics were obtained by hand knitting in a knitting machine. The carbon

fibers were supplied by DowAksa Turkey (DowAksa Advanced Composite Materials Industry Limited Company, Istanbul, Turkey). Technical information on carbon fibers used in fabric produc-tion was given in Table 1.

Table 1. Technical information of 3K carbon fiber used in the study.

	3K	Standard Test Method (ISO)
Tensile strength (MPa)	3800	10618
The elasticity of modulus (GPa)	240	10618
Breaking length (%)	1.6	10618
Intensity(g/cm^3)	1.78	10119
Linear bulk density (Tex)	197 g/1000 m	1889

Knitted fabrics were manufactured in the laboratories of Pamukkale University Faculty of Enginee-ring. Carbon knitted fabrics were produced on the Passap Duomatic 80 knitting machine with a 6-gauge machine fineness located in the Yarn and Knitting Laboratory. The knitted fabric is knitted with 3K (3000 filament) carbon yarn. The density for 1X1, 2X1 and 3X1 interlock knits is 210g/m2, 420g/m2 and 720g/m2 respectively.

Woven fabrics were supplied by the Spinteks Textile Industry and Trade Joint Stock Company, Denizli, Türkiye. Technical information on woven carbon fiber fabrics is given in Table 2.

Table 2. Technical information on the woven fabrics used in the study

	200P	200T	245 T
Fabric construction	Plain	2/2 Twill	2/2 Twill
Gam (± %10) (g/m^2)	200	200	245
Yarn linear bulk density (Tex)	200	200	200

2.1. Production of Composite Plates

In the production of composite materials, epoxy resin was preferred as a matrix material. Epoxy resins adhere well to a variety of fillers, reinforcements, and surfaces [2]. Vacuum infusion was used as the production method. The Epakem EPX 200 Resin and 385 H Hardener were produced by Epakem Chemistry and Construction and Industry Trade Limited Company, Istanbul, Türkiye. The proper-ties of Epakem EPX 200 Resin were given in Table 3.

Table 3. EPX 200 epoxy resin properties

Properties	Chemical Appearance and Values
Hardness	90 Shore D
Appearance	Transparan
Viscosity	11000 cm.s.g^{-1}
Flash Point	>200 °C
EEW	180-192
Color Alpha	<200 Gms
Density	115 g/cm^3

Usage rates of epoxy resin and hardener during operation are given in Table 4.

Table 4. Fabric and resin properties used in the experimental study

Test Samples	Sample Structure	Fabric Weight (g)	Number of Layers of Fabric	Amount of Epoxy Resin Used (g)	Fabric thicness (mm)
200 plain	Woven Carbon Fiber Fabric	73	3 layers	77	0,22
200 twill		73		52	0,26
245 twill		85		63	0,32
1x1 interlock	Knit Carbon Fiber Fabric	48	1 layer	50	0,55
2x1 interlock		44		51	0,83
3x1 interlock		44		52	1,2

For the vacuum infusion method, first of all, the surface to be treated was cleaned with a mold surface cleaner. After the fabrics were cut, woven carbon fiber fabrics were laid in 3 layers, and knitted carbon fiber fabrics were applied in one layer. The average weight of the 3 layers of woven fabric and the single-layer knitted fabrics are arranged to be the same. The mixture of epoxy resin and hardener was applied to the fabrics, which were laid, in the ratio of 2:1 as specified in the instructions to ensure impregnation with resin. The process was repeated for each fabric layer. The epoxy mixture was applied with a roller so that there was no dry place on the fabric surfaces. Air bubbles may form during the vacuum process. At this stage, to prevent this situation, the edges of the vacuumed samples are compressed with yellow paste tape. A vacuum blanket is used to preserve the heat on the top cover. The curing process for the composite was completed by applying pressure with the vacuum process.

In order to evaluate the samples mechanically at the same standard, composite manufacturing was carried out in a way that both plain and twill fabrics would be strained 90° degees in the tensile test. The spreading was carried out in the same direction and the maximum strength values created by the mechanical strengths in one direction were taken into account.

The produced composite plates were cut with a water jet in the dimensions of 25 mm x 250 mm x 0.2 mm per ASTM D3039 standard (Figure 3) [3]. Examples of tensile test specimens taken from the composite plate obtained are shown in Figures 1 and 2.

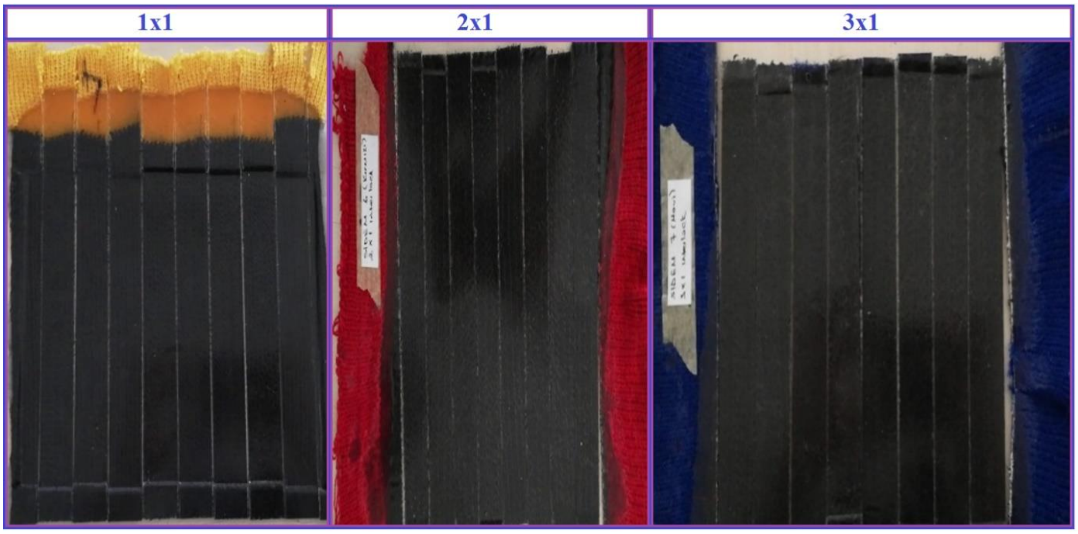

Figure 1. Knitted carbon fiber fabrics a) 1x1 interlock knitting, b) 2x1 interlock knitting, c) 3x1 interlock knitting.

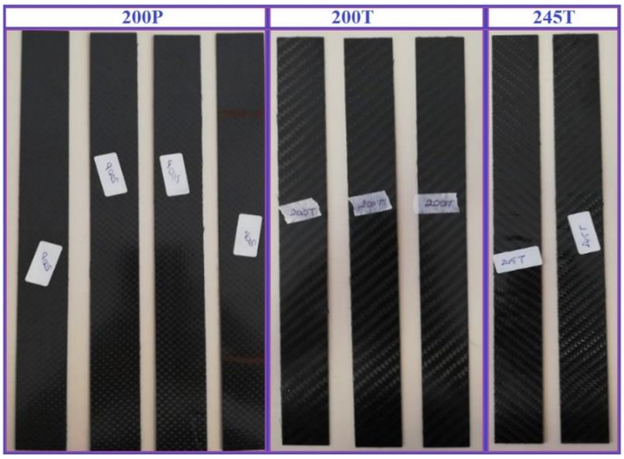

Figure 2. Woven carbon composite plates a) 200 plain weave, b) 200 twill weave, c) 245 twill weave.

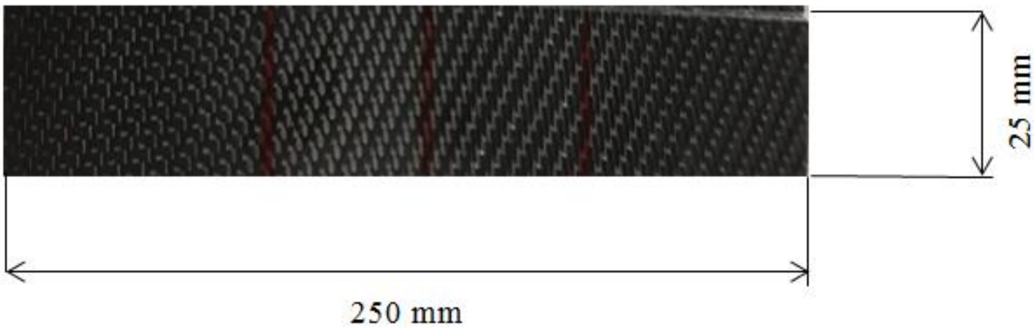

Figure 3. Tensile specimen size per ASTM D3039 standard.

To prevent slipping in the jaw area of the tensile machine, small composite plates were glued to the edges of the samples via Araldite 2015-1 chemical adhesive (see Figure 4). Thus, the problem of slipping in the jaws was eliminated.

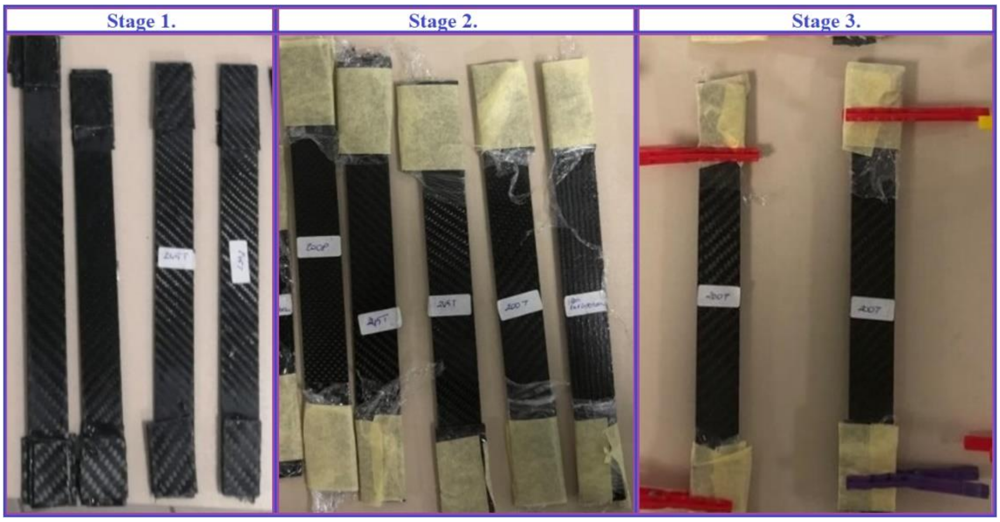

Figure 4. The preparation stage of samples Stage 1) The process of sticking the cut samples to the plate surface, Stage 2) The bonding process of samples wrapped with stretch film, Stage 3) Fastening with latch.

The sample plates in Figure 4 were adhered and kept for 6 hours and cured for 24 hours. Experimental studies were conducted on the HARDWAY universal tensile test device at Pamukkale University Faculty of Technology, Department of Metallurgical and Materials Science Engineering, Materials Analysis Laboratory. Behaviors of the prepared 25 mm x 250 mm specimens under tensile load were performed at 23°C room temperature, with a preload of 4 N at a jaw speed of 2 mm/min at a distance of 100 mm between the jaws. The tensile test was applied along the y-axis, depending on the weft and warp directions of the woven and knitted fabrics. In the content of the study, 4 test samples of each material type were prepared. Fracture surfaces of high-strength woven specimens obtained in the tensile test are given in Figure 5.

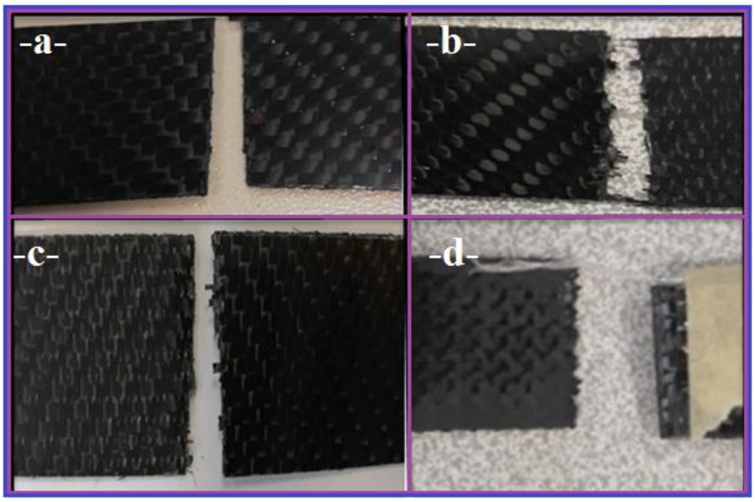

Figure 5. Fracture surfaces of woven composite plates a) Breaking surface in 245 twill weave type, b) Fiber separation on 245 twill weave type, c) Breaking surface on 200 plain weave type, d) Fiber separation in 200 plain weave type.

The three-point bending test was performed on the woven and knitted composites to determine bending strength and deformation properties on the SHIMADZU HARDWAY device at Pamukkale University Technology Faculty Material Inspection Laboratory. In accordance with the ASTM D790 standard, the samples were cut with a precision cutting device in the dimensions of 25 mm x 90 mm x 0.8 mm [2].

The images of the surfaces after bending tests are displayed in Figure 6.

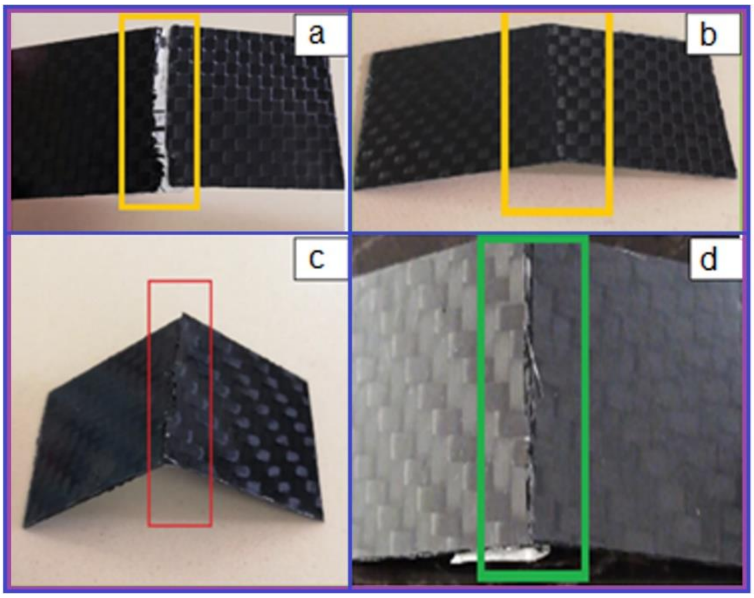

Figure 6. Bending test surfaces a) 200 plain weave type sample #1, b) 200 plain weave type sample #3, c) 200 twill weave type sample #1 d) 245 twill weave type sample #2.

FESEM images of the fracture surfaces were obtained on the ZEISS SUPRA 40VP model Field Emission Scanning Electron Microscopy (FESEM) device in Pamukkale University PAUILTAM (Advanced Technology and Research Center). Samples need to be made conductive in order to take FESEM images. At this stage, all samples were made conductive by coating them with Gold and Palladium before imaging.

3. Results

According to tensile test application on composite plates, the data in Table 5 were obtained.

Table 5. Tensile test results of 200 plain, 200 twill and 245 twill woven and 1x1, 2x1, and 3x1 interlock knit carbon composite samples

Woven	σ_T**(MPa)**	F (kN)	ε %	E (GPa)
200 plain	5720	11.44	14.98	44
200 twill	5280	10.56	15.20	39
245 twill	6210	12.42	14	51
Knit				
1x1 interlock	413	2.065	5.50	26
2x1 interlock	429	2.145	8.90	17
3x1 interlock	1315	2.63	8.00	43

The stress-strain curves obtained for the composite formed with 200 plain, 200 twill, and 245 twill woven carbon are given in Figure 7. When the twill woven fabrics, which are different in weight but have the same structure, are compared with the plain woven fabrics, the highest strength value of 6210 MPa was reached in the 245 twill woven structure with 3 layers of carbon fiber composite production.

In their study, Nicoletto and Riva investigated the mechanical properties of carbon woven twill weave type gaphite epoxy laminate under tensile loading. The resulting sample woven laminates become an advantageous product as they have a balanced structure in terms of mechanical properties, high impact resistance and are easier and more practical to shape. In the tensile test, the samples were cut in 8 layers. Homogenization was achieved at different levels by modeling the mechanical behavior of woven laminates. It was observed that the yarn structure and the fiber bundle in the polymeric matrix affected the mechanical properties [13].

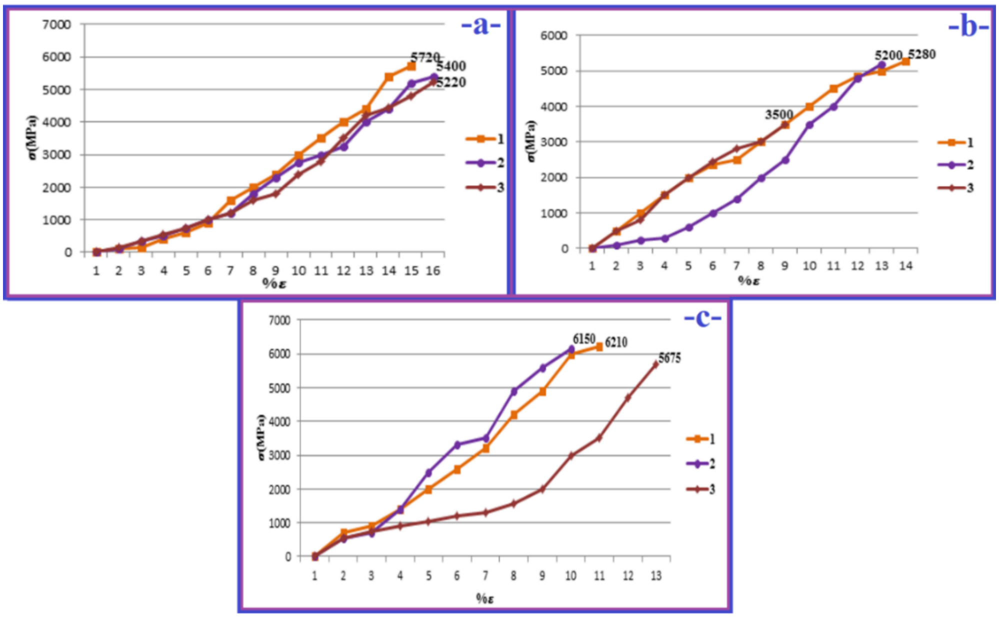

Figure 7. Stress-strain curves of a) 200 plain, b) 200 twill, c) 245 twill woven carbon composite samples.

The stress-strain curves of 1x1 interlock, 2x1 interlock, and 3x1 interlock knitted carbon composite samples are given in Figure 8. It was observed that there is an increase in strength value for the composite obtained with the 3- layer interlock knit compared to 1 and 2-layer samples.

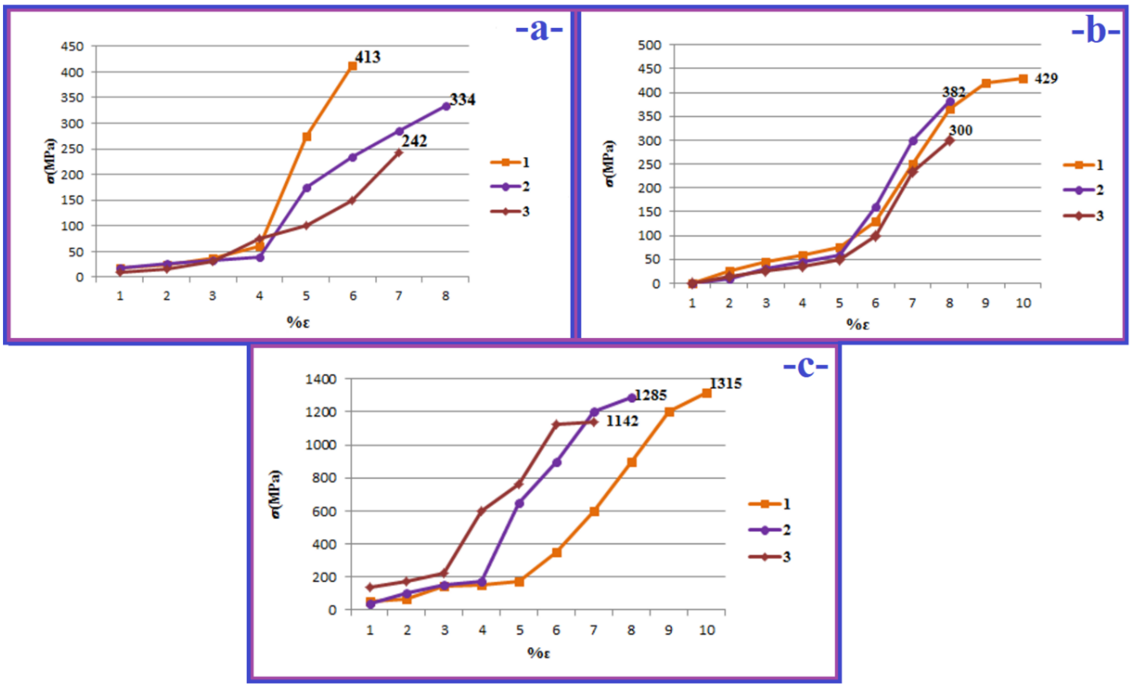

Figure 8. Stress-strain curves of a) 1x1 interlock, b) 2x1 interlock, c) 3x1 interlock knit knitted carbon composite samples.

FESEM images of the fracture surface formed after the tensile test for 245 twill-woven composite plates is given in Figure 9.

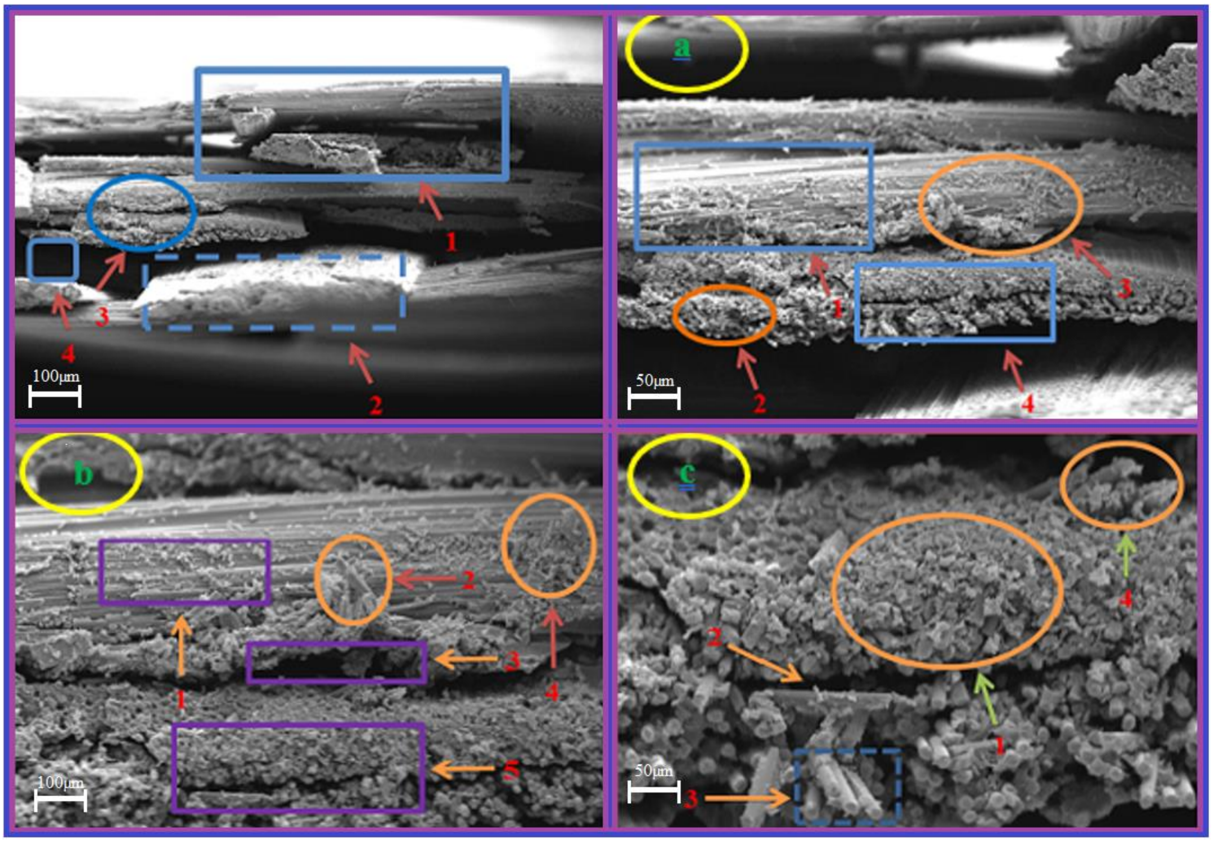

Figure 9. FESEM analysis images of 245 twill woven composite samples, 100X magnification, a) 250X magnification, b) 500X magnification, c) 1000X magnification.

In the 100X magnified sample, separations occurred between the layers in the direction of arrow number 1 in Figure 1. The fiber orientation within the layers is seen in arrow directions 2 and 3. There are breaks between the fibers. The gaps between the fibers are shown with the number 4 arrow. At 250X magnification, breaks were observed in the transverse layer region of the threads. In section 2, the fibers are in a tight structure. The effect of reinforcement-matrix material increases the strength. In 4, delamination is seen. At 500X magnification, it is seen that the fibers in the 1 and 2 directions are degaded. Inter-fiber spacing and separation of threads from the matrix material were observed in sections 3 and 5. Fiber separations in the twill structure were less in both the samples that broke in the tensile test and in the samples at the end of the bending test. The reason for this is that the woven structure of the twill form comes in an angular form. In addition, it is thought that the interface bond strengths formed with epoxy are better thanks to this. There is no known bond system in composites. Here, the bonding is achieved by the effect of the cohesive forces formed between the epoxy and the fiber. Therefore, as the cohesive bond formed becomes stronger, the strength that the composite can provide also increases.

FESEM analysis images of fabrics with 200 twill weave structures are given in Figure 10.

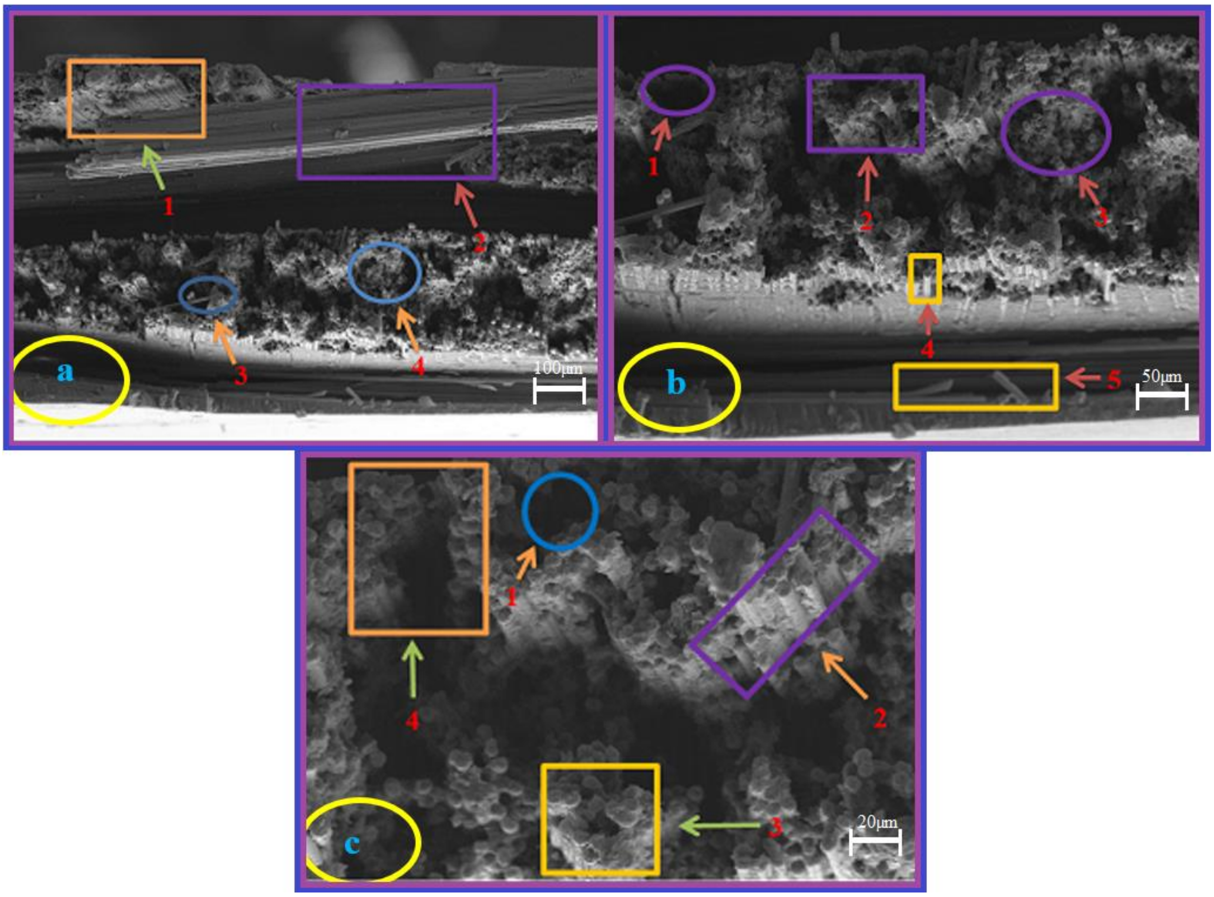

Figure 10. FESEM analysis images of 200 twill woven fabric samples a) 250X magnification, b) 500X magnification, and c) 1000X magnification.

When the 200 twill carbon composite was examined, it was observed that the fibers in the composite structure were pulled out, and interfacial debonding was observed. At 200X magnification, distortions occurred between the fibers along the cross-section of the layered structure due to the effect of tensile force on the 1 surface. Since the interface bond between the fiber and the matrix material in the 2nd region is strong, it increases strength properties. The fibers in the cross-section in area 3 are separated from the matrix structure. In area 4, gaps were observed between the fiber matrix. At 500X magnification, the situation at 250X is seen more clearly. At 1000X magnification, gaps between the fibers were observed by separating the carbon fibers from the matrix material in arrow directions 1 and 4. In regions 2 and 3, the interface bond between fiber and matrix material is vital. It was observed that there were gaps in the number 4 area.

The gap between the fibers was observed due to the separation of the carbon fibers from the matrix material. There were also separations in layers. This situation is called the deflection of crack error. Structural deterioration occurred in the fibers in the cross-section. The unidirectional nature of the plain structure of the weaving causes these deteriorations. This causes the interconnection forces to be unidire tional and reduces the ability to resist forces coming from horizontal or different angular directions.

Zhang et al. investigated the tensile, compressive and bending properties of three types of 3D carbon composites in different directions. It was observed that the 3D woven type samples with the same fiber volume had better mechanical properties in the warp direction.

The bending strength of the samples was approximately the same in the weft direction. The tensile strength properties varied depending on the thickness and yarn count. The same findings were obtained in the direction of the examinations in different axial directions [21].

FESEM analysis images of carbon composites with 3x1 knitted fabric structure are given in Figure 11.

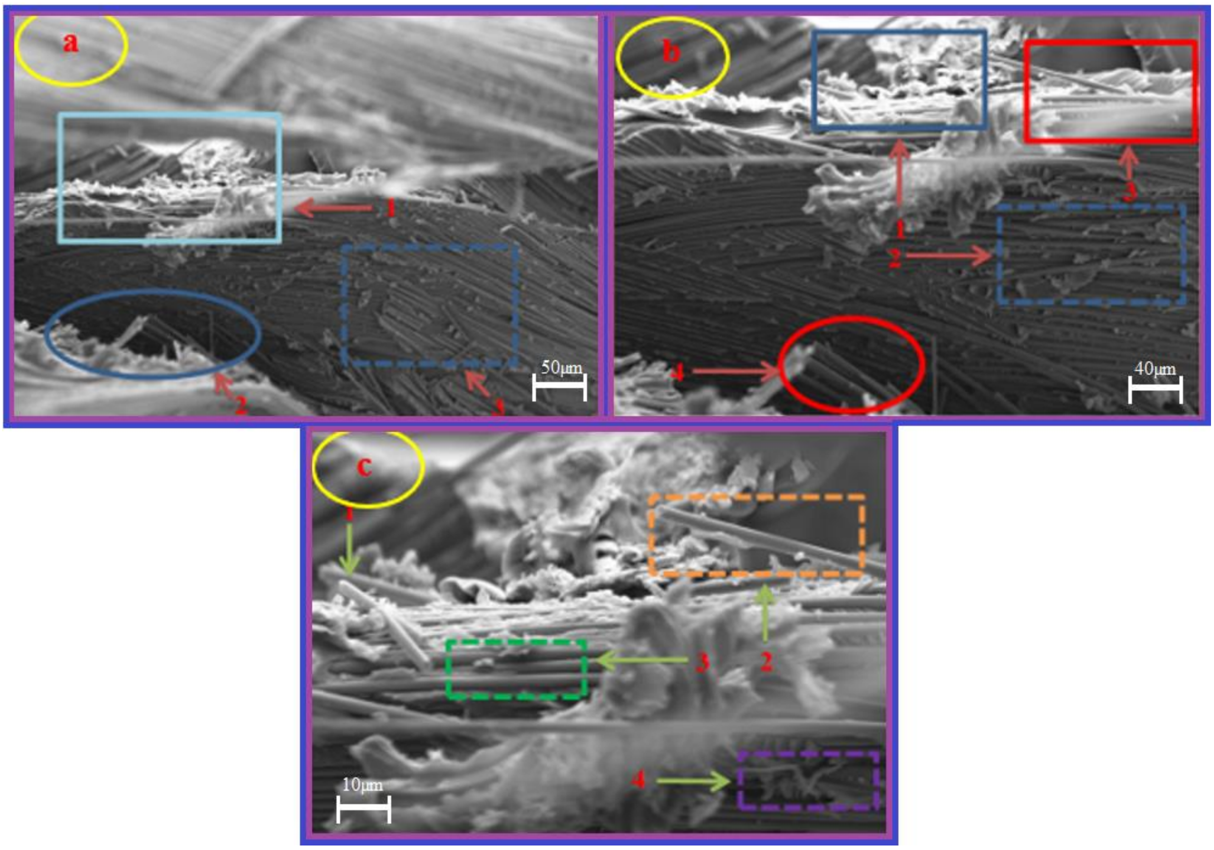

Figure 11. FESEM analysis images of the sample with 3x1 knitted fabric structure a) 250X magnification, b) 500X magnification, c) 1000X magnification.

At 250X and 500X magnifications, it was observed that the fibers were stripped from the matrix and there were gaps between the fiber and the matrix. The interfacial bonding between fiber-matrix in the co posite structure seems weak. For this reason, breaks and separations occur in the fibers. The formation of air bubbles and voids that occur during production and the entry of foreign matter is also important to process errors. It causes delamination in fibers in irregular or bent structures. Threfore, it is necessary to place the fibers regularly in the composite structure and to eliminate the bending. Since carbon fibers break due to friction in the machine during the knitting process, the structural integrity obtained in the knitte fabric is negatively affected by fiber breakage caused by friction. During the process of joining the knitted fabric with epoxy, good interface bonds may not be formed in these breakage areas.

At 1000X magnification, lateral cross-sections of the fibers are seen in the samples viewed from the cross-section. At this place, interfacial shear fields due to fiber separation at fiber interfaces under the force and separation between the layers occurs. Figure 11 shows the FESEM image and the EDS analysis over the FESEM image. With the EDS detector, the atomic concentrations of the samples to be analy-zed are determined. C, which is the main ingedient of the samples used, is seen in the EDS images. It is also proven that the selected fiber fabric structures for all samples used by EDS analysis are of pure C structure. EDS analysis outputs of 245 twill woven fabric, 200 twill woven fabric and composite samples with 3x1 interlock knit structure are given in Figure 12.

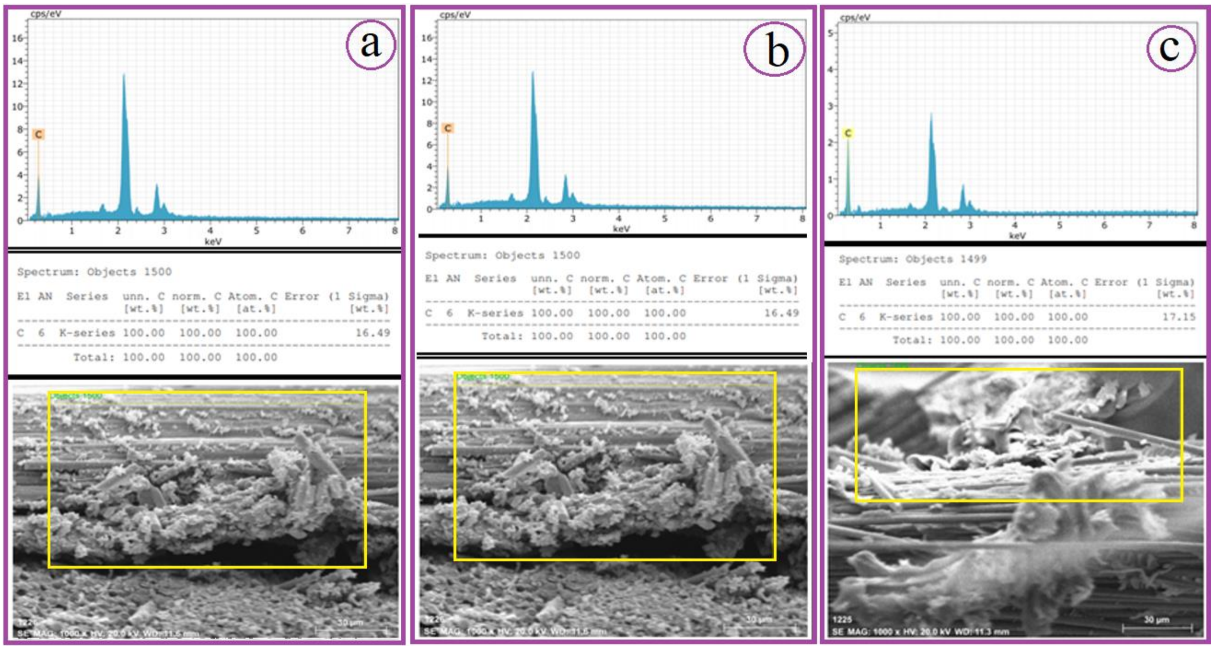

Figure 12. a) 245 twill woven fabric, b) 200 twill woven fabric, and c) 3x1 interlock knit EDS analysis.

4. Results and Discussion

For the samples within the scope of the study, the best strength was obtained in the composites produced with woven carbon fibers. Woven fabrics are more dense and more durable in terms of their properties. Knitted fabrics are generally known for having a more flexible structure. Therefore, the production methods have affected the mechanical behavior of the composite. The breakage of fibers in the knitting process adversely affects mechanical strength. A higher strength could be obtained by using a chain-like knit. It can be realized by making mechanical arrangements to the knitting machine. It is known that isotropic behavior and tensile strength for woven fabrics are dependent on the test direction when tested in the weft and filling directions. In the tests performed with the effect of weft and warp regions, the tensile strengths of the composites have very similar values [4].

According to the data obtained in this experimental study, the highest tensile strength was obtained in woven carbon fiber type carbon composite samples with 245 twill weave structures. The 3x1 interlock structure gave the best strength values in the composites obtained with knitted fabric. Strength values for composites formed with 1x1 and 2x1 interlock structures are close to each other.

In the woven samples, the percent elongation values were changing from 10 to 15%. Fracture occurs when the plates reach their highest tensile strength value. However, the fact that the broken fibers in the knitted composites adversely affect the percentage elongation rate. In the tensile test, a small amount of elongation was detected in the composite samples. Although the knitted fabric provides much better integity, the main reason why its strength values are lower is that carbon fibers break due to friction. In the study conducted to improve the friction and wear properties of carbon fibers, polydimethylsiloxane (PDMS) coaing was applied to the fiber. Increases in strength were observed in the carbon knitted and woven fabrics obtained with these fibers. In the tensile and bending tests conducted after this coating method, it was determined that there was a strength increase of 16.7% and 23.64%, respectively [26].

In this study, the fracture behavior still continues in the microstructure and it was observed that the percent elongation level increased. The fibers' separation in layers allowed the material to resist elongation for a while without breaking. During this period, the strength value exhibited by the material increases. The bond structure is strong at the fiber-matrix interfaces. Tight and coexisting reinforcement materials adhered to the matrix material increasing the strength values. In this process, as the resistance in the intermediate bonds increases with the increase of the force, the slip between the fibers has started. It is stated that this situation occurs due to the slippage of weak and non-linear loose fiber yarns in the first stage of the test process [19].

In the interlock knitting structure, it was observed that there were breaks in the loop areas of the carbon fabrics due to the mechanism of the machine. This situation was seen in carbon composite in the form of fabric. In the tensile tests applied after the material has turned into composite, fiber separations from these breaks have been observed. To prevent the strength loss caused by fiber breakage, increasing the filament thickness may also be an alternative. Kiasat and Sangtabi experimentally investigated the mechanical behavior of twill woven carbon fabric laminates under tensile loads and evaluated the effects of fiber bundle, bundle size and fabric weave density. Twill woven carbon fabrics were made of carbon fibers with densities of 200 and 600 g/m^2 from 3K and 12K fiber bundles, respectively. Composite laminates were produced by vacuum infusion method. In the study conducted with the aim of obtaining lightweight design, high weaving densities such as 50K filament were preferred. In this way, fiber bundles, size and structure can provide an improvement effect on mechanical behavior [10].

In the three-point bending test, fibers were separated starting from the outer part to the inner part. Fractures were also observed in some samples. The gap between the loops and the broken fibers reduce the mechanical strength of the knitted composites. In the composite samples obtained by weaving, it was observed that the matrix-reinforcing material showed a homogeneous distribution, strengthening the bond structure between the fibers and reaching higher strength values. On the other hand, since the epoxy resin filled the empty areas formed due to knitting, the strength is negatively affected.

5. Conclusions

Within the scope of the study, the highest tensile strength was obtained in composite samples obtained from knitted fabric and 3x1 interlock knitted carbon composite samples. It is possible to obtain composites with much higher strengths by providing more frequent knitting loops in the samples obtained with knitted fabric. In order to achieve this, knitting machines are needed that will prevent fiber breakage due to friction, especially during the loop formation process.

By applying polymer-containing coatings to carbon filaments against breakage and abrasion, it is possible to prevent fiber breakage due to gaps in knitting and weaving processes. Thus, fabric production without filament breakage can be achieved. This can also enable the production of composites that provide the same strength in every region.

Methods such as weft and warp details in the weaving and knitting process and production at different angles can increase the strength of the composite. In microstructure examinations, it was observed that especially in carbon fibers, peeling, breaking and interfacial bonds formed between the fiber and the matrix material created weak connections. This situation creates the result that the breakage in the fibers during knitting reduces the strength of the fabric and, therefore, the composite. The transverse and longitudinal fracture ease of the fabric obtained with woven fabric is higher in fiber-structured carbon composites. Having a higher filament density in woven fabric increases the strength. Within the scope of the study, the highest strength was determined in carbon composite samples obtained with 245 gr/m^2 twill fabric having a denser weave.

Studies on different woven and knitted structures have shown that there are significant mechanical strength reductions, especially due to friction and wear. Different applications should be developed to make the manufacturing process of carbon composite, which is an alternative to high-strength steels in the industry, practical and to reduce its cost. In particular, in order to provide long-term mechanical strength, it is necessary to obtain fabrics with reduced loss rates through technical changes to be made in weaving and knitting machines. In addition, mechanical losses should be prevented during the weaving and knitting process of the fiber with secondary processes that can be applied (fiber coatings, applications that will reduce friction loss, etc.).

Considering the data obtained in the study, the effect of friction loses its effect in fabrics with high density. In order to eliminate the negative effect that friction may create, composite manufacturing should be done by preferring more tightly woven fabrics such as twill. We can state this result within the scope of the study because the highest tensile strength values were obtained in 245 gr/m^2 twill weave and 3x1 in-interlock knitted carbon composite samples. As the carbon density and fiber density increased, the friction effect decreased.

During the transformation of the fabric into a composite, a bond structure is not formed. It is important to use epoxy that will ensure the correct formation of cohesion and adhesion forces between the fiber and epoxy.

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Conflict of Interest

The authors declare that they have no conflict of interest. The study was written with the contributions of all authors.

Research and Publication Ethics Statement

The authors declared that they complied with the scientific, ethical and citation rules of the *International Journal of Pure and Applied Sciences* throughout the entire process of the study.

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