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RESEARCH ARTICLE

INVESTIGATION of MECHANICAL PROPERTIES of CARBON FIBRE REINFORCED POLYESTER MATRIX COMPOSITE

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ABSTRACT

This study aimed to administer hand lay-up method for designing composite materials in which unidirectional and biaxial carbon fiber reinforcements are placed in a polyester matrix to generate one, two and three layers at room temperature. The samples were laid up from composite plates with the help of a mold in accordance with the fiber direction angle in accordance with the standards. In order to determine the mechanical properties of the samples, tensile, bending and drop weight low velocity impact tests were performed. The tensile test results in composite materials with the same layer number, pointed out that 0^0 unidirectional fiber reinforced composite materials performed the highest tensile strength values. On the other hand, the biaxial carbon fiber reinforced composite materials had the highest elasticity values of $\pm 45^0$. The highest elasticity values have been found in the unidirectional carbon fiber reinforcements of composite materials with 0^0 fiber direction angle in terms of bending test results. The biaxial composite materials with a $\pm 45^0$ fiber direction angle showed the highest values of impact tensile strength in drop weight low velocity impact tests. 0^0 unidirectional fiber reinforced composite materials, which showed the highest elasticity values in tensile and bending tests, were found to be the composite materials with the highest deformation values in the falling weight low velocity impact tests. It appears that increasing the number of layers caused an increase in the impact strength. They can be an alternative to aluminum and glass fiber reinforced polyester matrix composite materials due to their lightness and strength at the same thickness, which is valuable in boats, caravans and design cars.

Keywords: *Carbon fiber, Composite, Mechanical properties, Polyester resin*

1. INTRODUCTION

Composite materials are used to reduce the energy consumption caused by weight, especially in vehicles. The use of composite materials increased this gain between 60-80% instead of iron and its alloys, while it was possible between 20-50% instead of aluminum and its alloys.[1] In addition, the polymer composite materials give strength, flexibility, lightness to any material.[2-5] In such, aramid reinforced polymer composites are used in the production of sports equipment, ropes, tires, vehicle brake systems, gaskets, armor and missile sheaths with high strength, temperature, and friction resistance.[3] Another polymer is epoxy resin which can form a good bond with many types of fibers and thus composite products can be produced with the desired properties. As a result of the reactions with amines at high temperatures during ripening, it can form very good cross-links and a product with high chemical resistance, strength and hardness can be obtained. Its shrinkage values are very low during freezing and hardening. Epoxies have a more fragile structure.6-9 During the reaction, the epoxy rings, also called ring cleavage, are opened, taking a hydrogen from the amine group or hydroxyl group and reacting with the oxygen atoms of the epoxide group to form a crosslink.[6,10-11]

The most used reinforcing elements in fiber reinforced polymer composites are glass fiber, carbon fiber and Kevlar type fibers.[12-15] Glass fibers are the oldest fiber type preferred to be used in many composite studies. Carbon, boron, silicon carbide and aramid fibers are types of fibers that have been gradually used increasingly later to obtain the desired properties.[16, 17] In addition, polyethylene fibers, which have a chemically stable structure, easily shaped, and produced in film and layer. On the other hand, chemical resistance might decrease, and it softens at high temperatures.[18, 19]

Carbon fibers are bundles consisting of 6-15 μm diameters and 500-2000 filaments obtained at the application stage.[20, 21] These bundles can be used on their own or as a fabric by weaving.[22] Beside the carbon fibers to adhere well with the resin, their surfaces are also treated. This process is to obtain a threadlike structure by opening a pit on its surface by gas and liquid oxidation process or by forming silicon nitride crystals on its surface.[23-26] Carbon fibers are also marketed as continuous fibers and chopped fibers. Chopped fibers are used in pressure vessels, injection molding, machine manufacturing and chemical environments. [17, 27] Polyester-carbon composite materials are still being in the center of research focus. [28-30]

This study is part of master thesis and designed as part I. [31] In this study, composite materials have been designed using Uni-Directional Carbon Fiber and Double Axis Carbon Fiber as reinforcement materials having different number of layers and fiber orientation angles into the polyester matrix. The mechanical properties of composite materials were compared by performing tensile, three-point bending and falling weight low speed impact tests of the composite materials. The mechanical, structural, and thermal properties of carbon fiber reinforced composite materials produced in the studies were examined.

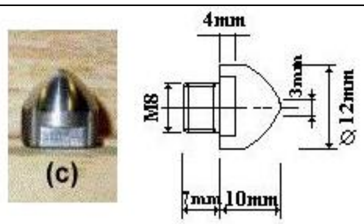
2. EXPERIMENTAL METHOD

The composite material was produced at room temperature using hand lay-up method at Bandırma Vocational School-Shipbuilding Program Workshop in Bandırma Onyedi Eylül University. In the experimental part, two different knitted carbon fiber fabrics were combined with polyester matrix, and then, the mechanical properties of composites consisting of one, two and three layers were compared. [32, 33]

In the samples, carbon fiber fabric with two different weaves, polyester as matrix material, freezer, and accelerator and solid (Polivaks SV-6) and liquid separators (Polivaks PVA) were used as additives. The carbon fiber fabrics were supplied from Telateks as unidirectional woven CW400 B-Carbon 12K Plain Weave Fabric and biaxial woven CX300 E05A-45/45 Biaxial carbon fabric. The matrix material was directly provided from the company of "Yücel Kompozit A.Ş". CAMELYAF brand CE 92 N8 general purpose polyester resin is used as matrix material. It is one of the most preferred polyester types in hand lay-up methods. Methyl ethyl ketone peroxide (MEK-P) and cobalt were used for fast freezing of the matrix material.

Tensile and three-point compression tests were carried out in the test training laboratory of Zwick Avrasya firm. The falling weight-low speed impact test was carried out in Dumlupınar University Mechanical Engineering Department Laboratory. For the tensile test, Zwick / Roell brand Allround Line Z250 SrR test device was used with the samples produced according to ISO 527-1 standard. Four samples were tested for each sample batch. For the three-point compression test, Zwick / Roell branded ProLine table-top testing machines Z005 up to Z100 test device was used with samples produced according to ISO 178 standard.
The low-speed impact test of the falling weight was achieved in Kütahya Dumlupınar University Engineering Faculty Mechanical Engineering Department Laboratory. The samples of 10x10 cm were prepared for the test and five samples were tested for each group. The speed of the falling weight and the energy at the time of impact were calculated after necessary assumptioms made, and the numbers were presented in Table 1.

Table 1. Falling weight low speed impact test data entry values.

Property	Unit	Value
Fallen weight	Kg	3.10
Falling Distance	m	1.00
Gravitational Acceleration (g)	m/s2	9.81
Velocity	m/s	4.43
Impact Energy	J	30.41
Friction force	N	0
Tip Used		

3.1. RESULTS AND DISCUSSION

The composite samples were prepared and named differently. The abbreviations of BCF for biaxial carbon fibers, angle 0- ± 45 values of the samples according to the fiber-fiber direction, B for tensile test, E for flexure test, K for drop test and 1,2,3 for layer numbers are given according to the test type.

3.1. Tensile Test
The grouped test samples were tested according to the number of layers from low to high (Table 2). The tensile test results of the Biaxial Carbon 0^0 single layer composite (BCF 0 B 1) group with an angle of fiber orientation showed that the values are close to each other except for the last sample. There is a difference of 44.06% between the highest and the lowest values in tensile test and a 17.63% difference in the breaking strength value. The tensile test results of the Biaxial Carbon 0^0 fiber orientation angle two-layer composite (BCF 0 B 2) group show a 13.16% difference between the highest and the lowest values in elasticity and a 5.95% difference in the breaking strength value.

JSR A
Journal of Scientific Reports

Urtekin et all., Journal of Scientific Reports-A, Number 47, 68-79, December 2021.

These results showed that two-layer samples had closer properties than single-layer samples. As a result of the breakings, the carbon fibers are separated from the sample in some cases. It was found that there was less dispersion in single-layer samples, and two-layer samples were more durable. On the other hand, the tensile test results of the Biaxial Carbon 0^0 three-layer composite (BCF 0 B 3) group with an angle of fiber orientation showed close values to each other. It is seen that there is a 19.24% difference between the highest and lowest values of tensile test results, and a 22.93% difference in the breaking strength value.

The tensile test results of the Biaxial Carbon ± 450 fiber orientation angle single layer composite (BCF 45 B 1) group pointed out that there is a difference of 30.04% between the highest and the lowest values in the elasticity value and an 11.68% difference in the tensile strength values. The reason for the low values was the capillary fractures on the surfaces. Those fractures might be caused by the hand lay-up method or during sample preparation. The tensile test values of the two-layer (BCF 45 B 2) group are quite similar. It is seen that there is a difference of 12.40% between the highest and lowest values and a difference of 34.27% in the breaking strength value. Comparison of them with single-layer samples points out that the values are closer to each other which makes them more durable but more flexible. There is a 26.68% difference between the highest and the lowest values and a 12.83% difference in the breaking strength value of the three-layer composite (BCF 45 B 3) group.

Table 2. Comparison of average tensile test results of the samples.

Sample	Elasticity (E_t) MPa	Tensile Strength (σ_m) MPa	Percent of Elongation at Break (ε_m) %
BCF 0 B 1	27000	417	1.6
BCF 45 B 1	2690	24.3	1.8
BCF 0 B 2	43300	601	1.5
BCF 45 B 2	4680	42.8	3.9
BCF 0 B 3	36900	468	1.6
BCF 45 B 3	4080	56.4	6.5

3.2. Three Point Bend Test

The sample values were different from each other in the three point bending test results of the composite (BCF 0 E 1) group consisting of Double Axis Carbon 00 fiber orientation angle and single layer. These changes might occur because the matrix material does not cover the carbon fiber reinforcement at the same rate everywhere during the sample preparations. There is a 52.72% difference between the highest and the lowest values and a 25.37% difference in the bending strength value.

The composite (BCF 0 E 2) group consisting of double axis carbon 0^0 fiber orientation angle and two layers have close values to each other except for the first sample. The two-layer sample values have reached better values as the number of layers increased. Besides, there is a difference of 57.67% between the highest and lowest values and a 58.88% difference in the bending strength value.

Considering the three-point bending test results of the Double Axis Carbon 0^0 fiber orientation angle composite (BCF 0 E 3) group consisting of three layers, the sample values were found closer to each

JSR A
Journal of Scientific Reports

other than the other layer numbers. There is a 21.84% difference between the highest and the lowest values in the elasticity value and a 21.30% difference in the bending strength value.

In the Biaxial Carbon ± 45^0 single layer composite (BCF 45 E 1) group with an angle of orientation, the first sample has higher values than the other samples, and the other sample values are close to each other. The reason is that the matrix material was more than the other samples. There is a 49.45% difference between the highest and the lowest values in the elasticity value and a 27.51% difference in the bending strength value.

The two-layer composite (BCF 45 E 2) group with double axis carbon ± 45^0 fiber orientation angle test values are close. It was observed that the samples were stronger than a single layer. There is a 23.11% difference between the highest and the lowest values in the elasticity value and a 30.68% difference in the bending strength value. While the elasticity values of the ratios between the samples decreased, the bending strength ratio increased.

Examining the bending test results of the Biaxial Carbon ± 45^0 fiber orientation three-layer composite (BCF 45 E 3) group showed close sample values to each other, but they were lower than the two-layer samples. There is a 21.02% difference between the highest and the lowest values in the elasticity value and an 11.76% difference in the bending strength value.

The average elasticity (Ef), bending strength (σfM) and bending elongation percentage values (εfM) of the samples were compared according to the layer numbers. The average values of the three-point bending test data belonging to the sample groups consisting of a single layer are presented in Table 3.

Table 3. Average three-point bending test results of the single layer samples**.**

Sample	Elasticity (E_f) MPa	Bending strength (σ_{fM}) MPa	Bending elongation percentage value (ε_{fM}) %
BCF 0 E 1	4480	174	4.0
BCF 45 E 1	1940	66	4.2
BCF 0 E 2	14000	218	1.3
BCF 45 E 2	4650	104	3.4
BCF 0 E 3	23400	293	1.4
BCF 45 E 3	4250	94.1	6.1

The biaxial carbon ± 450 fiber orientation angle single layer (BCF 45 E 1) composite group, which has the lowest elasticity and bending strength value, was the most ductile material. BCF 0 E 1 group have a higher elasticity value of 230.92%. Similarly, in terms of bending strength, BCF 0 E 1 group has higher values by 263.64% compared to BCF 45 E 1 group. Looking at the breaking elongation percentage values, the BCF 0 E 1 group was brittle at a rate of 95.24% compared to the BCF 45 E 1 group.

The best bending strength values of a single layer belonged to the two-layer composite group (BCF 0 E 2) with biaxial 0^0 fiber orientation angle. The most ductile material was a two-layer (BCF 45 E 2) composite group with a biaxial carbon ± 45^0 fiber orientation angle as in a single layer. When the values of BCF 45 E 2 group are accepted as 100%; BCF 0 E 2 group is seen to have 301.08% higher elasticity value. Similarly, it was seen that the bending strength of the BCF 0 E 2 group was 209.62%

higher than the BCF 45 E 2 group. The breaking elongation percentage values point out that the BCF 0 E 2 group was 38.24% brittle compared to the BCF 45 E 2 group.

In terms of bending strength values, the best average result belonged to the biaxial 0^0 fiber orientation angle three-layer (BCF 0 E 3) composite group, as in the two-layer samples. The most ductile material was the three-layer composite group (BCF 45 E 3) with a biaxial carbon ± 450 fiber orientation angle compared to the other groups. BCF 0 E 3 group has 550.59% higher elasticity value. Similarly, in terms of bending strength, BCF 0 E 3 group has 311.37% higher values than BCF 45 E 3 group. The breaking elongation percentage values show that the BCF 0 E 3 group was brittle at a rate of 22.95% compared to the BCF 45 E 3 group.

The most ductile material belonged to the single layer three (BCF 0 E 1-3) composite sample with biaxial carbon ± 45^0 fiber orientation angle as in the average value. The BCF 0 E 1-3 sample has a higher elasticity value of 230.99%. Likewise, in terms of flexural strength, BCF 0 E 1-3 sample has higher values by 254.03% compared to BCF 45 E 1-1 sample. The elongation at break percentage values presents that the BCF 0 E 1-3 sample was 103,125% brittle compared to the BCF 45 E 1-1 sample. It was determined that the highest values and average values showed similar properties.

The best bending strength values belonged to the two-layer composite sample (BCF 0 E 2-2) with biaxial carbon 00 fiber orientation angle. In the samples with the highest value of BCF 0 E 2 group, the most brittle material belonged to the two-layer composite sample (BCF 0 E 2-2) with biaxial carbon 00 fiber orientation angle. As with the average values, the most ductile material belongs to a two-layer (BCF 0 E 2-1) composite sample with biaxial carbon ± 450 fiber orientation angle. The BCF 0 E 2-2 sample has a higher elasticity value of 317.30%. Likewise, in the bending strength, the BCF 0 E 2-2 sample has 262.07% higher values than the BCF 45 E 2-1 sample. The breaking elongation percentage values show that the BCF 0 E 2-2 sample was 38.24% brittle compared to the BCF 45 E 2-1 sample. The comparison of the mean with maximum values of the samples showed a slight difference from each other.

The three-point bending test with the highest value of the samples consisting of three layers showed similar properties with the other layers. The best bending strength values were found to be the biaxial carbon 0^0 fiber orientation angle three-layer composite sample with four (BCF 0 E 3-4). The most ductile material was found to belong to the three-layer composite sample. The BCF 0 E 3-4 sample has a higher elasticity value of 512.77%. Similarly, in the bending strength, the BCF 0 E 3-4 sample has 317.65% higher values than the BCF 45 E 3-4 sample. The breaking elongation percentage values point out that the BCF 0 E 3-4 sample was brittle at a rate of 22.81% compared to the BCF 45 E 3-4 sample.

3.3. Dropped Weight Impact Test at Low Speed

Considering the biaxial Carbon 0^0 composite group samples with an angle of orientation, all samples are pierced because of the breakage of the fibers at the contact point due to the energy generated by the weight. All the samples showed same results that there is a deformation at the point where the weight falls on the sample surface and its close vicinity, but the deformation on the back of the sample is greater.

The two-layer (BCF 0 D 2) composite group samples with Biaxial Carbon 0^0 fiber orientation angle were drilled because of the breaking of all the fibers at the contact point of the samples with the energy generated due to the weight used. In the three-layer (BCF 0 D 3) composite group samples with Biaxial Carbon 00 fiber orientation angle, some of the samples were pierced because of the breaking of the fibers at the contact point due to the energy.

Table 4. The falling weight low speed impact test results of the two-layer composite group with biaxial carbon 0^0 fiber orientation angle (Fall height is 1.00 meter, and Velocity is accepted as 4.43 (m/s), and Impact energy 30.41 J)

Sample No	Average Thickness (mm)	Dimension (mm-mm)	Hole diameter (mm)	Hole depth (mm)	Rear surface deformation height (mm)
BCF 0 D 1-1	1.43	99.26x99.43	16.98	3.19	4.14
BCF 0 D 1-2	1.37	99.60x99.52	17.04	5.55	5.79
BCF 0 D 1-3	1.46	99.52x99.35	16.23	3.75	3.98
BCF 0 D 1-4	1.36	99.82x99.74	16.32	4.63	4.87
BCF 0 D 1-5	1.49	99.74x99.63	16.26	4.89	5.38
BCF 0 D 2-2	1.92	99.26x99.12	16.38	5.33	6.95
BCF 0 D 2-3	1.89	99.50x99.92	16.07	5.78	7.49
BCF 0 D 2-4	1.95	99.67x99.29	15.94	5.17	6.64
BCF 0 D 2-5	1.93	99.67x99.52	15.64	5.23	6.18
BCF 0 D 3-1	2.83	99.12x99.16	11.3	4.36	4.67
BCF 0 D 3-2	2.89	99.18x99.09	11.02	4.19	5.03
BCF 0 D 3-3	2.92	99.20x99.16	10.96	3.67	5.12
BCF 0 D 3-4	2.78	99.50x99.38	10.67	4.27	4.44
BCF 0 D 3-5	2.82	99.40x99.06	10.76	4.48	5.08

In the composite group samples with Biaxial Carbon ± 45^0 fiber orientation angle, all samples are pierced by the breakage of the fibers at the contact point due to the energy generated by the weight. At the two-layer (BCF 45 D 2) composite group samples with Biaxial Carbon ± 450 fiber orientation angle, we see that all samples are pierced by the breakage of the fibers at the contact point due to the energy generated by the weight. Some of the three-layered (BCF 45 D 3) composite group samples

JSR A
Journal of Scientific Reports

with biaxial carbon ± 45^0 fiber orientation angle were pierced because of the breakage of the fibers at the contact point.

Table 5. The falling weight low speed impact test results of the composite groups with biaxial carbon ± 45^0 fiber orientation angle. (Falling height is 1.00 meter, and Velocity is accepted as 4.43 (m/s), and Impact energy is 30.41 J).

Sample No	Average Thickness (mm)	Dimension (mm-mm)	Hole diameter (mm)	Hole depth (mm)	Rear surface deformation height (mm)
BCF 45 D 1-1	1.02	99.67x99.68	16.04	3.06	3.8
BCF 45 D 1-2	0.93	99.62x99.58	16.43	4.42	3.56
BCF 45 D 1-3	0.92	99.72x99.47	16.15	3.02	3.49
BCF 45 D 1-4	0.98	99.40x99.27	16.86	2.84	4.25
BCF 45 D 1-5	0.99	99.58x99.79	-	3.07	3.58
BCF 45 D 2-1	1.51	99.25x99.30	15.05	6.9	5.23
BCF 45 D 2-2	1.54	99.23x99.30	14.95	6.89	4.94
BCF 45 D 2-3	1.56	99.21x99.46	15.48	6.64	3.2
BCF 45 D 2-4	1.52	99.13x99.43	16.3	6.22	3.18
BCF 45 D 2-5	1.5	99.30x99.44	16.45	6.74	4.35
BCF 45 D 3-1	2.47	99.54x99.63	10.23	5.01	3.46
BCF 45 D 3-2	2.51	98.64x98.59	9.85	5.23	4.09
BCF 45 D 3-3	2.58	98.74x98.92	9.82	4.83	3.81
BCF 45 D 3-4	2.56	99.85x99.43	10.77	5.51	4.57
BCF 45 D 3-5	2.53	99.50x99.45	10.84	5.7	4.52

Examination of the falling weight low speed impact test results showed that all sample groups undergo deformation (Table 4 and 5). The best resistant group to impact energy of 30.41 J is the composite materials with biaxial ± 450 fiber orientation angle (BCF 45 D), followed by the composite material group with Biaxial ± 450 fiber orientation angle (BCF 0 D). Besides, the samples of BCF 45 D 3 group had the best tensile strength. The deformation on the surface of the samples in the BCF 45 D and BCF 0 D groups occurred in the direction of the fiber orientation angles or circularly. It was also found that the deformation on the sample lower surface was caused by the fiber orientation and separation of the fibers.

4. CONCLUSIONS

The mechanical test results have shown that the reinforcement element, the number of layers, the fiber orientation direction, angle, matrix material and the selected production method during production have great importance according to the place and purpose of use of composite materials. In the production of carbon fiber composites, the high cost of carbon fiber materials has led to the selection of matrices with higher mechanical values and the use of more technological methods.

In further studies, the composite production method can be changed and compared with the hand lay-up method. The falling weight can be compared with the work made in the low-velocity impact test that has been selected for the deformation that can occur by changing the weight and drop height. It is thought to be an alternative to composite materials with aluminum and glass fiber reinforced polyester matrix due to its lightness and strength at the same thickness values in boats, caravans, and design cars. Moreover, by using these unidirectional carbon fibers and different fiber orientation angles, lower-cost products can be obtained.

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This article is not relevant.

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