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The effect of use of different types of matrix material on mechanical characteristics in jute/carbon fiber reinforced hybrid composites

Jüt/karbon elyaf takviyeli hibrit kompozitlerde farklı tip matris malzeme kullanımının mekanik karakteristiklere etkisi

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Abstract

The use of natural fibers in the automotive industry as potentially renewable and environmentally friendly materials is increasing day by day. Natural fiber reinforced polymer composites are also replacing traditional materials in the vehicle interior and exterior of the current automobile industry. This study focuses on the fabrication of hybrid composite materials reinforced with jute fibers and carbon fibers using two different thermoset resins such as epoxy and polyester. During this production, vacuum assisted resin transfer molding production technique was utilized. The hybrid composites were evaluated for tensile strength and hardness characterization. The surface morphology of the specimens broken after the mechanical tests were scrutinized using scanning electron microscopy. Results reveal that in the use of polyester resin in tensile strength, there is 3.29 times increase in hybrid structures compared to pure jute composites, and in the case of using epoxy resin there is 3.66 times increase in tensile strength. In the comparison of microhardness values, hybrid composites formed with jute/carbon fabric and polyester resin have a hardness value 1.6 times higher than structures with pure jute fabric and polyester resin. Hybrid composites formed with jute/carbon fabric and epoxy resin have 1.64 times higher hardness than the structure made with pure jute fabric and polyester resin. In the analysis of the surface morphology of the produced composite structures, it has been revealed that the mechanical features and physical characteristics give compatible results.

Keywords: Hybrid composites, Matrix material, Jute fiber, Carbon fiber, Mechanical properties

Öz

Doğal liflerin otomotiv endüstrisinde potansiyel olarak yenilenebilir ve çevre dostu malzemeler olarak kullanımı her geçen gün artmaktadır. Doğal elyaf takviyeli polimer kompozitler, mevcut otomobil endüstrisinin araç içi ve dışındaki geleneksel malzemelerin yerini alıyor. Bu çalışma, epoksi ve polyester gibi iki farklı termoset reçine kullanılarak jüt lifleri ve karbon lifleri ile güçlendirilmiş hibrit kompozit malzemelerin üretimine odaklanmaktadır. Bu üretim sırasında vakum destekli reçine transfer kalıplama üretim tekniği kullanılmıştır. Hibrit kompozitler, çekme mukavemeti ve sertlik karakterizasyonu için değerlendirildi. Mekanik testler sonrasında kırılan numunelerin yüzey morfolojisi taramalı elektron mikroskobu kullanılarak incelenmiştir. Sonuçlar, çekme mukavemetinde polyester reçine kullanımında hibrit yapılarda saf jüt kompozitlere göre 3.29 kat, epoksi reçine kullanılması durumunda ise çekme mukavemetinde 3.66 kat artış olduğunu ortaya koymaktadır. Mikrosertlik değerleri karşılaştırıldığında, jüt/karbon kumaş ve polyester reçine ile oluşturulan hibrit kompozitler, saf jüt kumaş ve polyester reçineli yapılara göre 1.6 kat daha yüksek sertlik değerine sahiptir. Jüt/karbon kumaş ve epoksi reçine ile oluşturulan hibrit kompozitler, saf jüt kumaş ve polyester reçine ile yapılan yapıya göre 1.64 kat daha yüksek sertliğe sahiptir. Üretilen kompozit yapıların yüzey morfolojisinin analizinde mekanik özelliklerin ve fiziksel özelliklerin uyumlu sonuçlar verdiği ortaya çıkmıştır.

Anahtar kelimeler: Hibrit kompozitler, Matris malzemesi, Jüt elyaf, Karbon elyaf, Mekanik özellikler

1 Introduction

Today, natural fibers are widely used as a replacement for synthetic fibers, combining a high strength-to-weight ratio with low density, easy availability, biodegradability, cost reduction, and low weight. Along with their many advantages, natural fibers are disadvantaged in some areas compared to synthetic fibers due to low moisture resistance, poor adhesion with the matrix, low strength, low modulus, and low thermal stability. This disadvantageous situation can be improved with various combinations [1, 2]. Hybridizing these materials with higher strength fibers instead of using them alone as reinforcement is the most common method in these combinations, thus providing a better balance between mechanical properties and cost [3]. Hybrid composites are superior to homogeneous material components with their features such as high elasticity, high impact strength, low density, and high hardness. In many areas such as the automobile, defense, structural engineering, aerospace, transportation, and construction applications, hybrid composites are not only the main field of study for researchers, but their usage rates are increasing and they are becoming more popular [4, 5]. The main reasons for the increase in these rates are the resistance to corrosion, high strength, relatively reasonable production cost, good thermal

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features, and availability, especially in composites where natural fiber is used as reinforcement. However, natural fiber reinforced materials have porous structures, acoustic and damping properties, and their recyclability reveals their benefits to the ecosystem [6]. In hybrid composites, the physical and mechanical characteristics are determined by the properties of the fiber forming the hybrid composite, the length of the fiber, the fiber aspect ratio, the fiber orientation, the fiber stacking order, and the adhesion between the fiber and the matrix [7]. However, in the application of natural fibers to composites, the hydrophobic property of the fibers is poorly matched to the hydrophobic character of the polymer matrix, resulting in poor mechanical features with poorly bonded interfaces in the composites [8]. Although the majority of the mechanical characteristics in composites are determined by both the reinforcement element and the matrix, the determining factor in corrosion, temperature, and chemical resistance parameters is the matrix material. In the production of composite materials, thermoset polymers are mostly used as matrix material [9,10]. Among the thermosets preferred in our current study, polyesters are more cost-effective resins than epoxy resins, which are synthetic or natural, are also grouped as aromatic or aliphatic according to their main chain groups. It has become a critical matrix material in studies where the mechanical strength, glass transition temperatures, chemical stability, and heat stability of polyesters are developed for use in high technology and advanced engineering fields. The characteristics of polyesters can be changed directly depending on the possible curing process at room temperature and high temperatures [11,12]. Epoxy, which is the other resin we use in our comparison with polyester, is the most common thermoset known for its higher thermal resistance, good moisture resistance, and low shrinkage value, although its cost is higher than other thermoset resins [13]. Natural fibers that are widely preferred in composite production are shown as jute, flax, banana, hemp, kenaf, and ramie. Jute takes more attention than other fibers because it is the second most produced natural fiber after cotton fiber and is at least 50% cheaper than linen and other natural fibers. While jute fibers consist of approximately 65-70% cellulose, 13.6%-20.4% hemicellulose, and 8% microfibril, the mechanical properties in fibers generally vary depending on the amount of cellulose and microfiber angles. Although jute fibers are very brittle, the high lignin content causes low elongation in the fibers and also has low resistance to moisture, acid, and UV light. However, with their fine textures, their resistance to heat and fire is at the forefront of being preferred in sectors like automotive, construction, and textile. Panels and other automotive components in vehicles in use are known to be made of jute fibers or other bio-thermoplastic and hybrid composites [14–17]. Carbon fibers, which are the most widely used synthetic fibers, are accepted for their, high electrical, thermal conductivity, high strength, and toughness features. Carbon fiber plays an important role in many composite products, as well as enabling new applications in the aerospace and automotive industries [18]. There are many studies in which carbon fiber and jute fiber are used as reinforcement elements, but the number of studies comparing the use of resin using both polyester and epoxy resin is few. Ravikumar et al. [19] created hybrid materiel using bidirectional woven jute fiber and carbon fiber polyester resin and investigated the tribological properties of the formed materiel. According to the experimental and statistical data they obtained, they showed that the increase in sliding speed and load increased the wear loss, while the coefficient of friction decreased with increasing load and sliding speed. In another research using polyester resin, hybrid cardboard was produced using chopped carbon fibers and jute fibers. While the materials show anisotropic characteristics, carbon hybrid materials have obvious superiority in the impact test from mechanical tests, while cardboard fiber reinforced plastics have been found to give better results than raw carbon fiber and raw jute fiber reinforced plastics in tensile and bending tests [20]. In the studies where jute and polyester were used [21, 22], diverse thicknesses and different volume fractions were taken into account while determining the mechanical features. The determination of the optimum thickness and volume fractions by comparing the simulation results with the experimental results provides convenience in the design for the engineers regarding the possible range of mechanical properties. In spite of the mechanical characteristics of jute/polyester composites do not have as high strength and modules as traditional composites, they have better strengths than wood composites and plastics, making them a good alternative to wood in drainage pipes, automobile components, electrical installations, roof coatings, interior partitions of houses. Albuquerque et al. researched the physical and mechanical features of the materials produced using two different polyester resins with and out of wetter agent ingredients as matrix material in uniaxially oriented jute reinforced composites. Their test results revealed that polyester type with wetting agents showed superior mechanical characteristics with better wetting on the fiber surface than polyester resin without wetting agents [23]. Saiteja et al. [24] contemplated a material alternative to conventional materiel in the automobile industry by applying carbon nanotubes at 5 different percentages to epoxy resin composites reinforced with jute fiber. In the results of the tensile and impact strength tests, they stated that 6% by volume carbon nano tube additive gave the best mechanical results, and in the flexural strength results, the strength increased up to 8% and decreased after 8%. In his study [25], Abd El-Baky investigated how hybridization, diverse fiber content, and stacking sequence affect the mechanical characteristics by producing jute, carbon, glass fiber with hand lay-up process. He found that the mechanical features of jute fibers increased with hybridization with synthetic fibers, the fabric ordering had no effect on the tensile strength, but the outer high-strength fiber gave better results in bending strength, and the highest void content was obtained in pure jute fiber and epoxy hybrid composites. Ali et al. [26] observed both numerically and experimentally the flexural strength of jute and carbon fiber and the falling impact test. They concluded that as the percentage of carbon fiber decreased from 80% to 40% in the bending tests, the strength value decreased by approximately 53%, and the decrease in the carbon fiber percentage in the falling impact test caused the damaged area to enlarge. While they state that the experimental and numerical results differ by 10%, they say that the two analyzes are compatible. Ramana and Ramprasad [27] compared the combination of jute fiber and carbon fiber hybrid composite with pure carbon fiber and pure jute fiber composites. Whilst the results were in favor of homogeneous carbon composites with 1.73 times higher in tensile test and 1.18 times higher flexural test, jute/carbon hybrid composites exhibited a 46.15% rate higher energy absorption in the impact test. Velu et al. [28] created hybrid composite material combinations using carbon, jute, and glass fiber in 6 different arrays. When the tensile test results were examined, the use of carbon fiber instead of glass fiber in the JJGG array increased the strength by 16.34%, by 20.41% in the bending test, and by 54.22% in the impact test. Ashworth et al. [29] searched the mechanical and damping characteristics of the materials by producing jute, carbon, and hybrid composite specimens using the resin transfer molding method at pressures ranging from 4 bar to 8 bar. Mold pressure rising from 4 bar to 8 bar caused a 38% decrease in tensile strength in pure jute fiber composites, while a 6% decrease was detected in hybrid composites. Vibration test results also showed that the good bending performance of jute/carbon composites can replace pure carbon fiber composites in structural applications where cost is important. The aim of this research is to produce hybrid composites using two different resins such as epoxy and polyester, which are not frequently encountered in previous studies, and to explore the effect of using various resins on mechanical characteristics in these hybrid composites formed by jute fiber and carbon fiber reinforcement. According to the results obtained from these hybrid composites, the potential of using the composites produced in the automotive interior or exterior of the vehicle will be revealed.

2 Material and methods

2.1 Material

Jute plain woven texture and carbon plain woven texture were supplied by companies located in Istanbul. These textures were utilized as reinforcement materials. Table 1 gives these texture characteristics used in this research. Figure 1 indicates the fabric specimens.

Figure 1. Fabric specimens: a) Jute fabric b) Carbon fabric

Table 1. Fabric characteristics[30, 31]

Fabric	Weight (g/m²)	Fabric Thickness (mm)	Warp (tex)	Weft (tex)
Jute fabric	250	0.4	-	-
Carbon fabric	200	0.25	200	200

In this work, the related hardener LH160 and L160 epoxy resin, polyester, and its accelerator and hardener were utilized as matrix material. The epoxy resin and hardener were supplied by the Kompozitshop company and the Polyester material was purchased from the Poliya company. The specific features of the matrix arrangement are demonstrated in Table 2 and Table 3. When mixing epoxy resin and hardener, a weight ratio of 100:25±2 is chosen, which is given by the manufacturer and from previous studies, while the mixing ratio for vinyl ester resin is Resin: cobalt nephthalate (as an accelerator): methyl ethyl ketone peroxide (MEKP) of 1:0.002:0.02 by weight.

Table 2. Hardener and epoxy characteristics [32]

	LH160 Hardener	L160 Epoxy
Density (g / cm³)	0.96-1.0	1.13-1.17
Process temperature (° C)	-	+10 / +50
Actuation temperature (° C)	-	-60/+50 except heat treatment -60/+80 by performing heat treatment
Viscosity (mPas)	10-50	700-900
Amine value (mg KOH /g)	550-650	-
Refractor index	1.520-1.521	1.548-1.553
Mensuration circumstances	25°C	25°C

Table 3. Polyester characteristics [33]

Maximum temperature (°C)	170
Flexural strength (MPa)	134
Elongation at break (%)	2.6
Viscosity (cps)	500-600
Tensile strength (MPa)	71
Barcol hardness	40

In this search, twelve composite specimens were prepared using two different resins and with various fabric stacking arrays. The pattern names given to the composite specimens for the fabric laminas are as indicated in Table 4.

Table 4. Naming of prepared specimens

Pattern Name	Textile versions
J	Jute fabric
C	Carbon fabric
JC	Jute/Carbon fiber hybrid composite
JE	Jute fiber reinforced epoxy hybrid composite
CE	Carbon fiber reinforced epoxy hybrid composite
JCE	Jute/ Carbon fiber reinforced epoxy hybrid composite
JP	Jute fiber reinforced polyester hybrid composite
CP	Carbon fiber reinforced polyester hybrid composite
JCP	Jute/ Carbon fiber reinforced polyester hybrid composite

After curing the specimens for 1 hour in the oven at 60 °C, they were cut off with a water jet device in the test sizes designated in the norms.

2.2 Method

The vacuum- assisted resin transfer molding (VARTM) method has been used for hybrid composites formed using jute and carbon fiber reinforced epoxy and polyester resin. In this technique, removing the air that may occur in the reinforcement materiel and entering the resin into the mold is provided by the vacuum force. The most important point to consider during fabrication is to ensure impermeability. All samples were produced at 20°C ± 2°C using 1 bar pressure, as indicated in Figure 2. Firstly, the production area was determined based on the fabric dimensions. After the fabrics were lined up on the area in the predetermined order, the peel fabric, infusion net, and vacuum nylon were laid on top. Then the outlet and inlet hoses were connected to the system and the resin prepared in the determined mixing ratios was infused into the system. The vacuum pump was actuated at one bar for approximately two hours until surplus resin movement ceased. The specimens were cured as such for 24 hours. The specimens taken after 24 hours were post-cured in the oven at 60 °C for 1 hour and prepared for cutting with the waterjet.

Figure 2. VARTM technique

2.3 Tensile testing

The tensile test was used to determine the mechanical features of the produced composites. For the tensile test, the specimens were prepared with respect to the ASTM D3039 standard with a length of 250 mm, a width of 25 mm, and a thickness of 2.5 mm. The tests were carried out with the ALSA Hydraulic test device (KOLUMAN Automotive Industry Laboratory). The tensile test of the materials was carried out with regards to the ASTM D 3039 rule [34]. The test was accomplished by adjusting the cross-head speed to 2 mm/min in the device with a 98000 kN load cell. The tensile testing device is displayed in Figure 3. The tests were implemented at room temperature, and the specimen sizes were entered into the computer program at the beginning of the test. After this test, the tensile strength, modulus of elasticity, and percent strain rate of the materials produced were obtained, and the stress-strain graph was automatically drawn by the program. When the results of the 5 tested specimens were averaged, the characteristics related to the tensile strength of the produced composites were found.

Figure 3. Tensile testing machine

2.4 Hardness testing

Microhardness tests of the manufactured composite products were carried out using the Vickers hardness method. The measured Vickers hardness values are directly dependent on the applied load as well as the area created by the impression on the test surface of the material. In this method of measurement, the Vickers hardness measurement of the materiel is specified by the instrument forming a square alcove with measured diagonals in the indentation on the material. The shape of the indentation used in Vickers hardness testing is the geometric configuration of a square pyramid of diamond with an angle of 136° between the opposing faces. Hardness testing of the specimens was carried out using an AOB Lab product machine with reference to ASTM E92-17 standard [35]. Figure 4 demonstrates the Vickers hardness testing device. Fifteen hardness measurements were made on the prepared specimen and the average of the 15 values was reported as the Vickers hardness value of the composite product.

Figure 4. Hardness testing machine

2.5 Morphological analysis

Scanning Electron Microscopy (SEM) FEI Quanta 650 Field Emission instrument was used to analyze interfacial surface morphologies of the composite samples. In order to increase the surface conductivity of the samples, the surface coating was done with gold with the instrument in Figure 5. The aggrandizement capacity of the instrument is in the range of 6-1,000,000 x times and can be operated at 30 kV. SEM analyzes were carried out in CUMERLAB (CUKUROVA UNIVERSITY RESEARCH CENTER LABORATORY) using the instrument shown in Figure 6. With this analysis, it is possible to observe the fracture surface of the composite samples and observe the fiber-matrix interactions, interfacial characteristics of the material such as matrix cracking, fiber shrinkage, fiber breakage, and separation of fiber-matrix bonds.

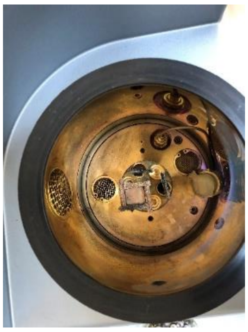


Figure 5. Gold plating process machine

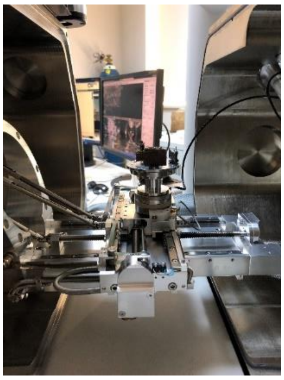


Figure 6. SEM analysis device

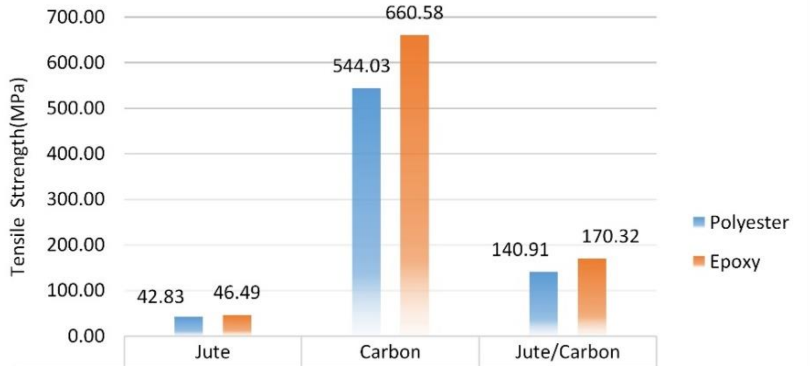
3 Result and discussions

3.1 Tensile test results

According to tensile test outcomes, hybrid composites that were used epoxy resin as a matrix, they have higher tensile strength than using polyester resin as a matrix as seen in Figure 7. When comparing JCE and JCP hybrid composites, the JCE structure has a 20.87% superiority in tensile strength. The difference between these tensile strength values is 8.54% between JE and JP composite structures and 21.42% between CE and CP composite structures. These differences are in favor of composite structures using epoxy resin in both homogeneous composite structures. In similar studies [36], it was figured out the tensile strength values of hybrid Jute/Carbon epoxy composites were higher by 7.35% to 19.94% compared to hybrid Jute/Carbon polyester composites. Considering these ratios, the close difference in tensile strength values between JE and JP may have arisen due to the inability of resins and natural fiber to bond well. The difference of 21.42% between CE and CP values indicates that the bonding of carbon fiber and epoxy is stronger than the adhesion between carbon fiber and polyester resin. In addition, the fact that carbon fiber fabric is structurally stronger and harder than jute fiber fabric, and the brittleness of jute fibers due to their natural structure has led to higher strength values of structures using carbon fiber [37]. The tensile strength value of hybrid composites formed by jute fabric using polyester resin and carbon fabric is 229% higher than homogeneous jute polyester composite products. It is seen that the tensile strength value of hybrid Jute/Carbon structures in which epoxy resin is used is 266.35% higher than the tensile strength value of homogeneous jute epoxy structures.

When the elastic modulus values in Figure 8 were examined, it was found that CE and CP homogeneous composites had the highest values (7420.8 MPa and 6446.4 MPa) in samples produced with epoxy and polyester resins. The lowest elastic modulus values were obtained in JE and JP homogeneous composites, with 1866.4 MPa and 1738.2 MPa values, respectively, in products prepared with epoxy and polyester resin. It was observed that the hybridization of jute fabrics with carbon fabrics increased the modulus of elasticy value of hybrid composites by 1.42 times with the use of polyester resin, and 1.35 times the modulus of elasticy value of hybrid composites with the use of epoxy resin. Similar results were also observed in previous studies [38] when hybrid composites were obtained by adding jute fibers to homogeneous carbon fiber composites. It has been stated that the weak mechanical features of jute fiber are eliminated from the covalent bonds along the longitudinal direction of carbon fibers, and improved mechanical properties are achieved in hybrid structures compared to homogeneous jute composites.

A comparison of the percent elongation rates of the manufactured products is given in Figure 9. The results of percent elongation rates showed that similar to the results of tensile strength and elastic modulus values, structures formed with epoxy resin have superior rates than structures formed with polyester resin. The percent elongation ratio difference between JCE and JCP structures is 1.08 times, and this difference is in favor of the JCE structure prepared with epoxy resin. The low tensile strength in polyester resin, as well as the adhesion between carbon fibers and resin, significantly affect the tensile strength of the hybrid composites produced [36]. When comparing homogeneous jute composites in which polyester resin is used as matrix element and hybrid carbon/jute composites, it was understood that homogeneous composites had 1.78 times less elongation rate. In the comparison of the JE homogeneous structure using epoxy resin and the hybrid JCE structure, the hybrid composite structure has a 1.58 times higher elongation rate. These elongation rates also indicate that the hybridization process of carbon fibers with high tensile strength features with jute fibers with low mechanical features provides a remarkable improvement in the mechanical characteristics of hybrid jute/carbon structures compared to non-hybrid jute composite structures.



	Jute	Carbon	Jute/Carbon
Polyester	42.83	544.03	140.91
Epoxy	46.49	660.58	170.32

Figure 7. Comparison of tensile strength results

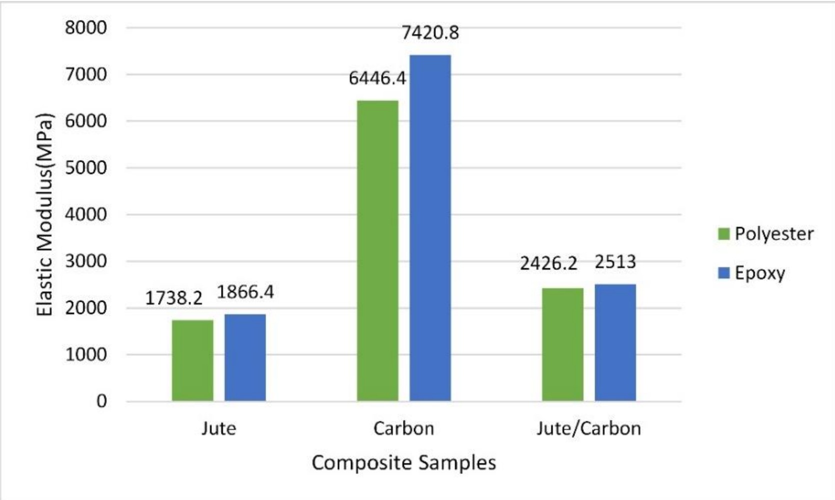


Figure 8. Comparison of elastic modulus results

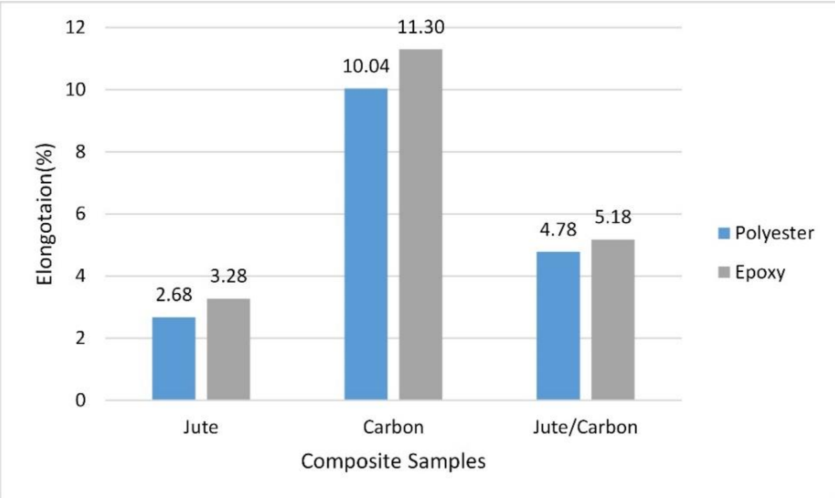


Figure 9. Comparison of elongation rate results

3.2 Hardness test results

The microhardness results of the produced products are presented in Figure 10. While the JP composite structure prepared with pure jute fabric polyester resin had the lowest Vickers hardness value, the highest hardness value was found in the CE structure prepared with pure carbon fabric epoxy resin. In hybrid structures, on the other hand, hybrid JCE composites obtained 64.47% higher Vickers hardness values compared to pure JE composite structures, and 60.04% higher Vickers hardness values for hybrid JCP structures than pure JP structures. It can be seen from the results in the graph, hybridization of jute fibers with low mechanical features with high strength carbon fibers caused a significant increase in the hardness value. In addition, it has been found in previous studies that conditions that cause weak bonds between the matrix and the reinforcement, such as the addition of filler, lead to a decrease in the hardness value in carbon fiber composites [39,40]. In terms of the use of resins, the JCE composite structure has a 6.36% higher microhardness value than the JCP composite structure in hybrid composites. In both pure jute composites and pure carbon composites, the samples prepared with epoxy resin had superior Vickers hardness values compared to the specimens prepared with polyester resin at the rate of 3.91% and 21.95%, respectively. Both tensile strength and hardness values indicate parallel trends in terms of resin usage.

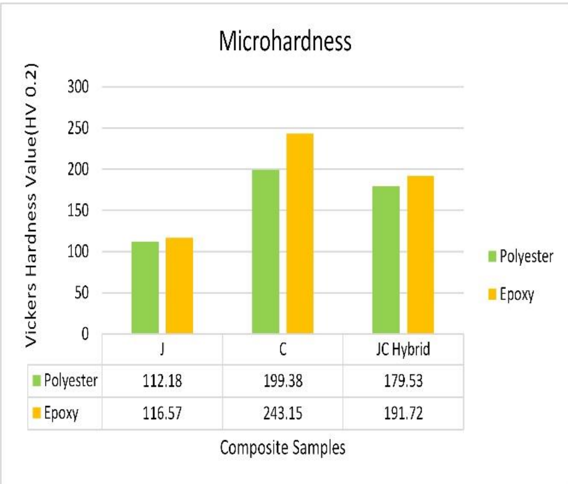


Figure 10. Micro hardness test results

3.3 SEM analysis results

Figures 11,12, and 13 demonstrate the SEM micrograph of fractured surfaces of JP, CP, and JCP structures after the tensile test. While fracture and rupture are seen in jute fibers in Figure 11, it is observed that carbon fibers break in bundles in Figure 12. It is expressed that the appearance of jute fiber breakage indicates the weak interfacial structure and the poor compatibility of the jute fiber and the matrix may be due to the bonding problem of the hydrophilic jute fiber and the hydrophobic polyester matrix [41]. In Figure 13, it is seen that in jute/carbon hybrid composites, there is less hollow structure compared to pure jute composites, and carbon fibers break in bundles and strengthen the structure even more. In addition, damages such as fiber breakage, fiber shrinkage, and matrix and fiber separation have been observed in hybrid composite structures formed by using jute fiber and polyester resin in previous studies [42].

Figures 14,15, and 16 depict the SEM image of JE, CE, and JCE composites. In comparison to SEM images of JP, CP, and JCP, fiber and matrix bonding is stronger and less fiber pull out, breakage was been observed. This good interfacial bonding reflects how the tensile strength of structures using epoxy resin is increased compared to those using polyester resin [41]. In the structure formed by jute fiber with epoxy resin, as shown in Figure 14, hollow structures were observed, but fiber shrinkage and breakage are less common than the JP structure in Figure 11. It is also a situation stated in previous studies that damages occur more in areas with dense matrix [43]. In the SEM image in Figure 15, the matrix and fiber form strong bonds in CE structures, and homogeneous breaks were detected. It has been determined that the matrix and fiber form strong bonds in the JCE hybrid structures in Figure 15 and homogeneous breaks occur in the structure. The occurrence of less fiber breakage and shrinkage in Figure 16 compared to Figure 13 explains why the JCE structure has higher tensile strength than the JCP structure.

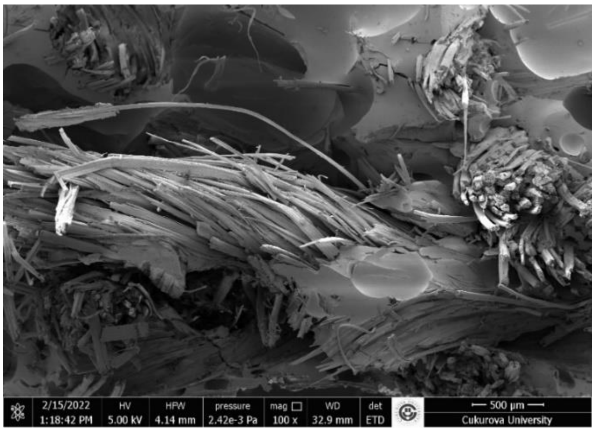


Figure 11. JP composites SEM micrograph

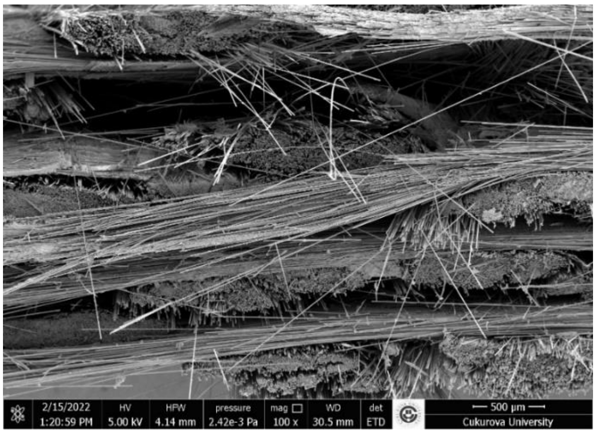


Figure 12. CP composites SEM micrograph

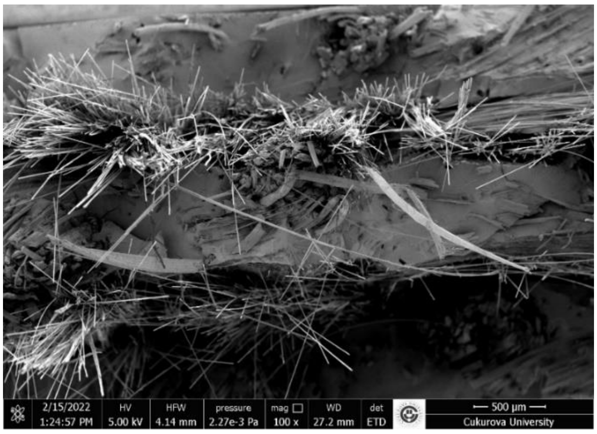


Figure 13. JCP composites SEM micrograph

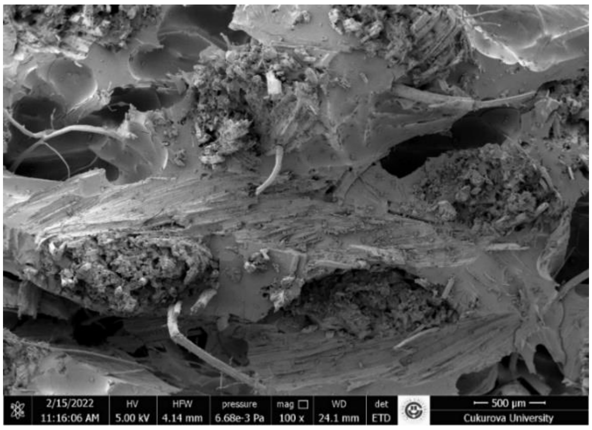


Figure 14. JE composites SEM micrograph

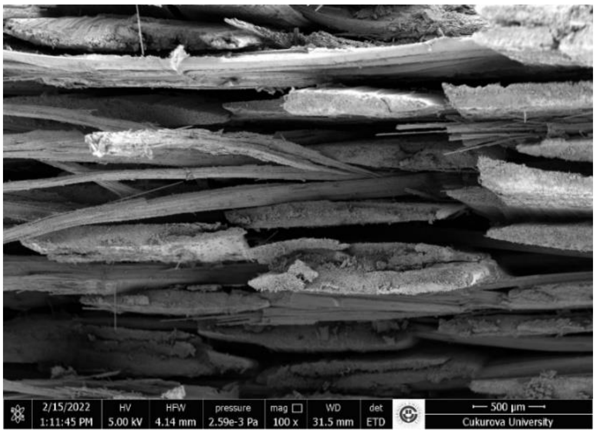


Figure 15. CE composites SEM micrograph

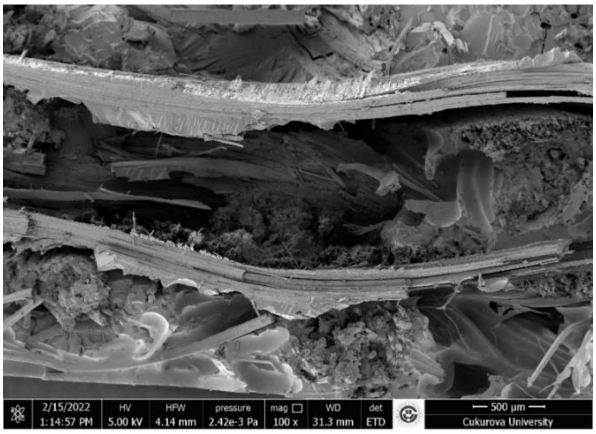


Figure 16. JCE composites SEM micrograph

4 Conclusions

In this experimental study, pure jute composites, pure carbon composites, and jute/carbon hybrid composites were prepared with two different resins. The effects of polyester and epoxy resins on the mechanical characteristics (tensile strength and hardness) of the fabricated products were determined. Predicated on the information in the paper, the ensuing outcomes were derived:

- The hybrid composites prepared with epoxy resin provided the highest tensile strength, tensile modulus, and hardness compared to the hybrid composites fabricated with polyester resin.
- For the hybrid composites fabricated, a tensile strength value for the JCE sample was found to be 170.32 MPa, while the value of 140.91 MPa was found for the JCP sample, in the meanwhile the tensile modulus value of the JCE sample was 3.57% higher than that of the JCP sample.
- Hybridization of jute and carbon fabric resulted in an increment in tensile strength increase of 3.28 times for JCP structures compared to JP products and 3.66 times for JCE structures compared to JE structures.
- Hybridization of jute fabric with carbon fiber fabric increased the hardness value of JCP hybrid structures by 1.6 times compared to homogeneous JP structures, while the hardness value of JCE hybrid structures increased by 1.64 times compared to homogeneous JE structures.
- The usage of epoxy resin increased the hardness of the J, C, and JC hybrid specimens by 1.03 times, 1.22 times, and 1.07 times, respectively, compared to the usage of polyester resin.
- In SEM micrographs, less fiber shrinkage can be seen in the jute fiber composites made with epoxy resin than in the jute fiber composite structures produced with polyester resin. The fact that the polyester-resin interfacial bond of the jute fibers is not very strong causes more elongation.
- The SEM analysis depicts that the carbon fibers are broken into irregular bundles in the JCP structure, while there are more homogeneous fractures in the JCE type.

Conflicts of interest

No conflict of interest was declared by the authors.

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