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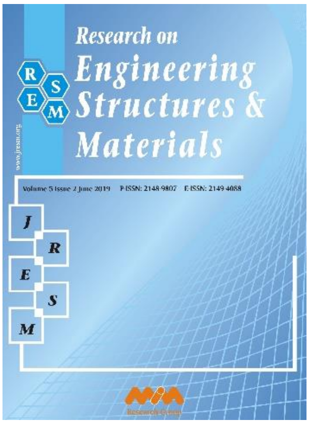

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H Ersen Balcıoğlu

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Research Article

An investigation on the mechanical strength, impact resistance and hardness of SiC filled natural jute fiber reinforced composites

H Ersen Balcıoğlu[*,a]

Department of Mechanical Engineering, Faculty of Engineering, Usak University, Usak, Turkey

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Abstract

Natural fibers are a good alternative as economically since they are readily available in fibrous form and can be extracted from plant leaves at very low costs. However, they have lower strength values than synthetic fibers due to their deficiencies in material structure. In this respect, many studies have been carried out by researchers to increase the strength of natural fibers. In this study, mechanical properties, Izod impact toughness, and Shore D hardness behavior of silicon carbide (SiC) filled natural fiber reinforced laminated composites were investigated. In this context, natural jute/epoxy laminated composites were reinforced in different ratios (3%, 6%, and 9%) with SiC powders having different grain size (4.5μ, 9.3μ and 53μ). The test results were compared with the results of unfilled jute/epoxy composites in order to better understand the effects of the fill percentage and grain size on mechanical strength. The produced laminated composites were tested under tensile, compression and impact loads. Scanning Electron Microscopy (SEM) was also performed to analyze the mechanisms of damage of the specimens. The test results showed that the SiC particle size and the percentage of reinforcement were effective on the mechanical behavior of the composite material.

1. Introduction

Composite materials are produced by combining two or more materials at the macro level in order to create new material with superior properties which have better properties than its conventional materials. Composite materials are used as the alternative materials to the conventional materials in many engineering applications due to their superior properties such as lightness, high impact strength, high corrosion resistance, and appropriate thermal properties [1,2]. Fiber reinforced composite materials are the most used composite material type in the structures. Glass, carbon, aramid, and boron fibers are the major reinforcement materials which are used in the fiber-reinforced composite materials. But, either the manufacturing cost of such unnatural fiber is expensive or waste emission into the environment during their manufacturing encourage researchers to find eco-friendlier solutions. Due to low energy cost for the manufacturing of natural fibers without carbon emissions during their manufacturing, this type of fibers is preferred. From an economic point of view, natural fibers exhibit decent price stability, being less dependent on the price of oil than other materials. Natural fibers exhibit lower mechanical properties than their synthetic counterparts as well as have a high degree of fiber to fiber mechanical variability based on growing conditions and plant varieties which lowers their mechanical performance predictability. Natural fibers; such as jute, sisal, and kenaf are the most used as reinforcing the material in polymer composites. Recently, the interest of scientists in

*Corresponding author: ersen.balcioglu@usak.edu.tr
[a] orcid.org/0000-0002-8579-5142
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natural fibers has been increasing thanks to the use of these fibers as a reinforcement constituent in composites, being eco-friendly and their sustainability. Such that, they have presented a number of studies to investigate and improve the mechanical strength of natural fiber reinforced composites.

Sarikaya et al. [3] have studied the production of epoxy resin composites reinforced by birch, palm, and eucalyptus fibers with resin transfer molding technique and molded fiber production technique combination. The results of studies showed that molded fiber production method had a very promising future for the development of natural fiber reinforced composites. Chegdani et al. [4] investigated the tribomechanical behavior of flax fiber reinforced plastic composites with consideration of the multiscale complex structure of natural fibers. Test results showed that confirm the significant effect of the geometric contact scale on the flax fibers stiffness. Shahinur and Hasan [5] have presented a review article on the comparison of natural and synthetic fiber composite, where matrix materials are polymer particularly, thermoplastic, thermosetting and bio-degradable. Test results showed that although natural composites are cheap and environmentally friendly, they lagging behind synthetic fibers in terms of mechanical strength. So, some studies in the literature aim to improve the weak mechanical strength of natural fiber reinforced composites.

The mechanical properties of natural fiber reinforced polymer composite are the result of the chemical properties of the materials that form the composite and the interface properties at the fiber surface. Structures such as cellulose and lignin on the natural fiber surface create a negative surface environment for the fiber matrix combination. The chemical treatment that applied to the fibers is one of the methods to increase the strength of natural composites. Narin et al. [6] have studied surface modification effects on the mechanical properties of woven jute fabric reinforced laminated composite plates, experimentally. Test results showed that the surface modification process and type of matrix material have dramatically affected the mechanical properties of woven jute fabric reinforced laminated composites. Yan et al. [7] have improved the mechanical properties of flax, linen and bamboo fabric reinforced epoxy composites by alkali treatment. Lui and Dai [8] have done an experimental study to enhance the performance of jute/polypropylene (PP) laminated composites by using treated jute mat with Sodium Hydroxide (NaOH) and Maleic anhydride-grafted polypropylene (MPP) emulsion. The experimental results showed that the treatment process was increased the interfacial shear stress and flexural stress of PP based composites.

Hybridization is another method that increases the strength of natural fiber reinforced composites. Rajesh and Pitchaimani [9] have aims to improve the poor mechanical strength that is associated with the natural fiber composites by reinforcing them in fabric form. Jawaid et al. [10] have improved tensile and flexural performance of natural fiber polymer composite researchers proposed hybridization of two different natural fibers such as oil palm empty fruit bunches and jute fiber. Zivkovic et al. [11] have investigated the influence of moisture absorption on the impact properties of flax, basalt, and hybrid flax/basalt fiber reinforced natural composites. Sanjay and Yogesha [12] have investigated hybridization of natural/glass fiber reinforced polymer composites to develop their applications in the field of engineering and technology. Flynn et al [13] investigated the hybridization effect of on the tensile, flexural and impact performance of carbon/flax hybrid composites. Test results suggest that hybridizing synthetic fibers with natural fibers is an effective method of improving the mechanical properties and controlling vibration damping.

Many studies aimed to improve the properties of composite materials by incorporating different micro or nanoparticles in combination with various forms of powders. The modulus and strength of filled polymers increase with increasing filler content [14]. Matykiewicz et al. [15] have studied the influence of basalt powder addition on thermomechanical properties of natural basalt fiber reinforced epoxy composites. Prasob and Sasikumar [16] have investigated the viscoelastic and mechanical behavior of reduced graphene oxide and zirconium dioxide (ZrO_2) filled jute/epoxy composites at different temperature conditions. Dhanola et al. [17] have studied mechanical, wear and water absorption behavior of luffa-fiber reinforced polyester composites with and without the addition of natural fillers of a ground nutshell, rice husk, and wood powder. Patel and Dhanola [18] have investigated the effect of addition micro filler such as Calcium carbonate ($CaCO_3$), Alumina (Al_2O_3), and Titanium dioxide (TiO_2) on the physico-mechanical properties of Luffa-fiber based polyester composites. Song et al. [19] have performed a study on the effect of carbon black morphology to the thermal conductivity of natural rubber composites. Kumar et al. [20] have investigated mechanical and tribological behavior of Polyamide 66/Polypropylene composites, which filled with nanoclay and short carbon fiber. The results indicate that addition of nanoclay/short carbon fiber in PA66/PP have significant influence on wear under varied abrading distance/loads. Suresha et al. [21] have studied mechanical, tribological and dielectric properties of glass fabric reinforced epoxy composites with and without graphite particulate filler.

The improvement in the mechanical strength of natural composite materials has had a positive effect on their use in various industrial areas. Several studies have been conducted over natural fiber composites in a variety of application areas. Verma and Goh [22] have discussed seawater effect and moisture absorption on the natural fiber reinforced composites, which are used in the marine industries. Luzi et al. [23] have investigated employability of the natural fiber biodegradable composites and nano-cellulose based materials for biomedical applications. Huda et al. [24] have searched the using of natural fiber composites in the automotive industry. Lau et al. [25] have investigated mechanical properties and the manufacturing process of natural fiber composites for structural engineering applications.

Ceramic fillers have been widely used to manufacture composite parts, they often have a low resolution and poor mechanical strength. In this study, mechanical properties, impact toughness, and hardness of jute/epoxy laminated composites, which were filled with ceramic particles, were determined under tensile, compressive, and impact loading condition. For this aim, jute/epoxy composite plates with six layers, which were filled with SiC having 4,5μ, 9,3μ, and 53μ particle size and 0%, 3%, 6%, and 9% reinforcement ratio, were manufactured. In order to better understand the effects of fill percentage and grain size on mechanical strength, the test results were compared with the results of unfilled jute/epoxy laminated composites.

2. Material and Method

2.1. Materials

The natural fiber jute plant is produced from a plant family called Corchorus, which has nearly one hundred varieties. Jute Fiber, which is an annual fiber plant that can extend up to 2-4 m in height, grows mostly in tropical regions. Its homeland is East India and China and Malaysia are the other countries that produce the most. Jute fiber used in the trade is obtained from two types of plants. One of them is Corchorus capsularis and the other is Corchorus olitorius. The capsularis jute is whitish in nature and the olitorious comes in yellow, grey, brown varieties. The jute used for this research is olitorious jute and it was grey in color. As with other cellulosic fibers, the moisture absorbency of the jute fiber is high. Its strength is lower than flax and hemp. The structure of jute fiber contains 60 - 64% cellulose, 20% lignin and 5% pectin. A large part of the jute fibers produced in the world is used for making sacks, fabrics, rope and string (Fig. 1a) [26–28]. In this study, jute woven fabrics with a weight of 300g/m^2, which were weaved by using Jute fibers of Corchorus capsularis type were used (Fig. 1b).

(a) (b)

Fig. 1. (a) Harvested jute bundles [28] and (b) woven jute fabric

The matrix material was procured from Duratek Epoxy and Polyurethane System in Turkey. It has two components as DTE 1100 epoxy and DST 1105 hardener (Fig. 2a). They were prepared by mixing 74/26 in weight, respectively.

(a) (b)

Fig. 2. (a) Epoxy matrix material and (b) SiC particles with three different grain sizes

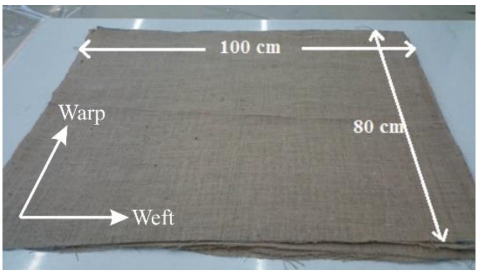
Silicon carbide (SiC) is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. It was originally produced by a high-temperature electrochemical reaction of sand and carbon. This produces a very hard and strong material. Silicon carbide is not attacked by any acids or alkalis or molten salts up to 800°C. In the air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up to 1600°C. Table 1 shows the physical and mechanical strength values of silicon carbide. Laminated composite having natural fiber and epoxy components were reinforced with green silicon carbide (SiC) particles from the ceramic oxide group. SiC micro-fillers were procured from Akyol Stone Industry and Trade Inc. in Turkey. SiC ceramic powders having three different grain size such as 4.5µ, 9.3µ and 53µ were used to reinforce the jute/epoxy laminated composites. (Fig. 2b). Each silicon carbide particle was added to the epoxy resin at 3%, 6%, and 9%, respectively, based on the weight of the matrix material.

Table 1. The physical and mechanical strength values of silicon carbide

Density (g/mm^3)	Bulk Modulus (GPa)	Compressive Strength (MPa)	Yield Strength (MPa)	Poisson's Ratio	Shear Modulus (GPa)	Tensile Strength (MPa)	Young's Modulus (GPa)	Melting Point (K)
4.36-4.84	100-176	1395	1245	0.35-0.37	51	240	137	1955

2.2. Manufacturing of Laminated Composite

Fabrication of composite was done by a conventional method called hand lay-up method. Hand lay-up method has been a widely explored technique of fabricating natural fiber based composites owing to its simplicity, cost-effectiveness, and flexibility. In order to manufacture natural laminated composite material, firstly woven jute fabrics were cut to 100x80cm (Fig. 3a). Secondary reinforcement material SiC ceramic powders were prepared by weighing according to the weight of the matrix material. Then, two-component matrix material and SiC powders were mixed in the same vessel along 2 minutes at 1500rpm (Fig. 3b). At this stage, the mixture of resin should not be mixed at high speed and for a long time. The heat, which generated by the friction of the molecules during the mixing, reacts the epoxy and the hardener. In this case, the pot life of the epoxy matrix is shortened. After the mixture was prepared, SiC reinforced epoxy resin was impregnated with jute woven fabric by means of a roller brush (Fig. 3c).

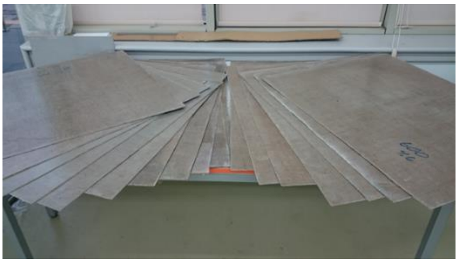


(a)

(b)

(c)

(d)



(e)

Fig. 3. Manufacturing stages of SiC powders filled jute/epoxy laminated composites

The hand lay-up process was carried out on a Teflon film which can withstand temperatures up to 250oC. This film acts as a mold release agent between the hydraulic press and the composite plate. After the impregnation process, the semi-finished composite plates were allowed to cure for 60 min at 100oC under pressure of 4MPa in the time-temperature-pressure controlled hydraulic press (Fig. 3d). After the curing process was completed, the composite plates were cooled along 24 h under the same pressure in order to avoid the warping effect. After cooling, the composite plates were separated from the mold separator Teflon film. The edges of the composite plate were cut with a circular saw and then ready for mechanical testing (Fig 3e).

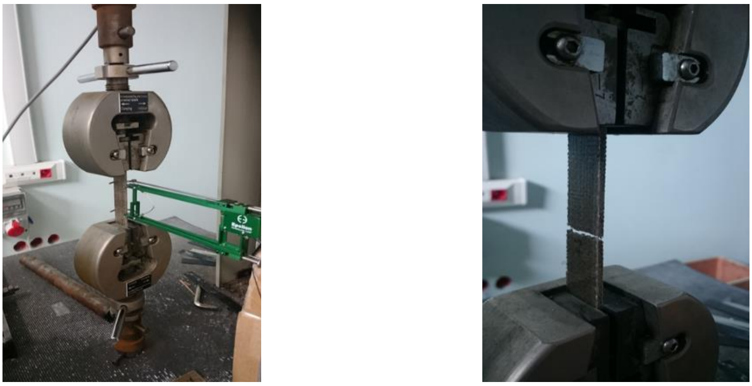
2.3. Determination of Mechanical Properties

Tensile properties were determined according to the ASTM D3039-76 test standard. This test method determines the in-plane tensile properties of polymer matrix composite materials reinforced by high-modulus fibers [30]. Longitudinal Young modulus E_1 and longitudinal tensile strength T_1 were obtained by using the wrap direction of jute/epoxy laminated composite specimens. Transverse Young modulus E_2 and transverse tensile strength T_2 were also obtained by using the weft direction of composite specimens. The tensile strengths in the warp and weft directions (T_1 and T_2) were determined by dividing the failure load by the cross-sectional area of the wrap and weft specimens, respectively.

Shear properties were determined according to the ASTM D3518M-13 standard test method. This test method determines the in-plane shear response of polymer matrix composite materials. The composite material form is limited to a continuous-fiber-reinforced composite ±45° laminate capable of being tension tested in the laminate roving direction [31]. In order to define the in-plane shear modulus, G_{12}, a specimen which fiber direction is 45^o according to the woven direction was used. The in-plane shear modulus, G_{12}, was defined by using Eq. 1, where E_{45} is elasticity modulus in 45^o woven direction and ϑ_{12} is major Poisson's ratio[32]. Poisson's ratio ϑ_{12} was accepted as 0.25 according to studies in the literature [33,34].

$$G_{12} = \frac{1}{\frac{4}{E_{45}} - \frac{1}{E_1} - \frac{1}{E_2} + \frac{2\vartheta_{12}}{E_1}} \quad (1)$$

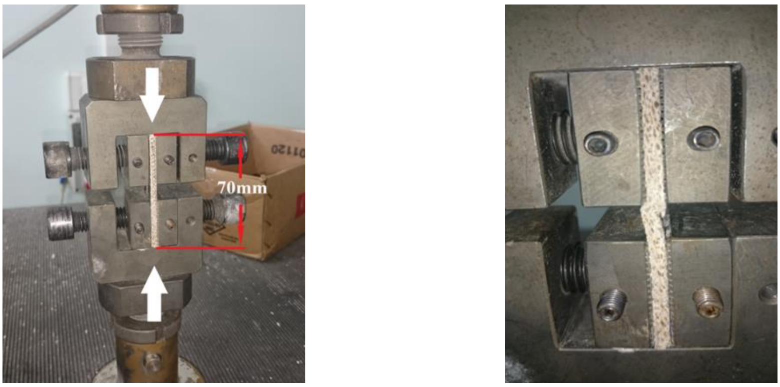
The elasticity modulus of the polymer matrix composite materials was calculated with the help of Hooke's Law, which formulated the stress-strain relationship of the material. Epsilon brand extensometer with a 50-mm gauge length was used for the unit deformation value of the material that needed in the calculation (Fig.4).



(a) (b)

Fig. 4. (a) Tensile test configuration and (b) tension damage

Compressive properties were determined according to the ASTM D3410-87 standard test method. This test method determines the in-plane compressive properties of polymer matrix composite materials reinforced by high-modulus fibers [35]. The wrap and weft compressive strength of laminated composite specimens (C_1 and C_2) were calculated by dividing the failure load to the cross-sectional area of the specimens in the longitudinal and transverse direction, respectively. The compressive test setup and the test specimen damaged by compression was shown in Fig. 5.



(a) (b)

Fig. 5. (a) Compression test configuration and (b) compression damage

The produced laminated composites were cut with a diamond saw and the tensile, compression and impact test samples were obtained. All mechanical strength tests were carried out in U-Test brand universal tensile-compressive test machine under room conditions. For each test parameter, five samples were tested at a crosshead deformation velocity of 1mm/min. The average of the results of these five tests was accepted as a significant strength value.

2.4. Determination of Izod Impact Strength

Impact strength is one of the properties usually included in the materials characterization programs of the composite materials manufacturers. The different methods used to determine impact strength try to simulate service conditions associated with high strain rates. Izod test is high strain rate tests that measure the energy absorbed by a material during high-speed impact. This test allows the elastic capability of reinforced and unreinforced plastics for energy absorption prior to any permanent damage (yield or microcrack) to be demonstrated. The Izod pendulum is one of the most widely used tests by the plastic industry. The results from these tests are highly dependent on specimen size, notch geometry, the amount and rate of loading, and the method of support of the specimen. Thus, they do not provide intrinsic material behavior properties, but the results can be used for relative comparisons if all test conditions are held constant.

The specimens were tested following ASTM D-256 standard for impact strength. This test estimates the energy to break standard test specimens under the influence of specimen mounting, notching and pendulum velocity at impact [36]. The geometry of the rectangular test specimen (80x10x3 mm) corresponds to the ASTM D-256 specification and the dumbbell-shaped specimen is according to the ISO 527 type 1A standard. A single edge 45^o V-shaped notch (tip radius 0.25 mm, depth 2 mm) was milled in the middle of the test specimens (Fig. 6a). Izod impact test was performed with a pendulum apparatus (OTS model XB-OTS-C500) with 5J capacity using conventional V-notched specimens (Fig. 6b). Five replicate tests were conducted for each material parameters.

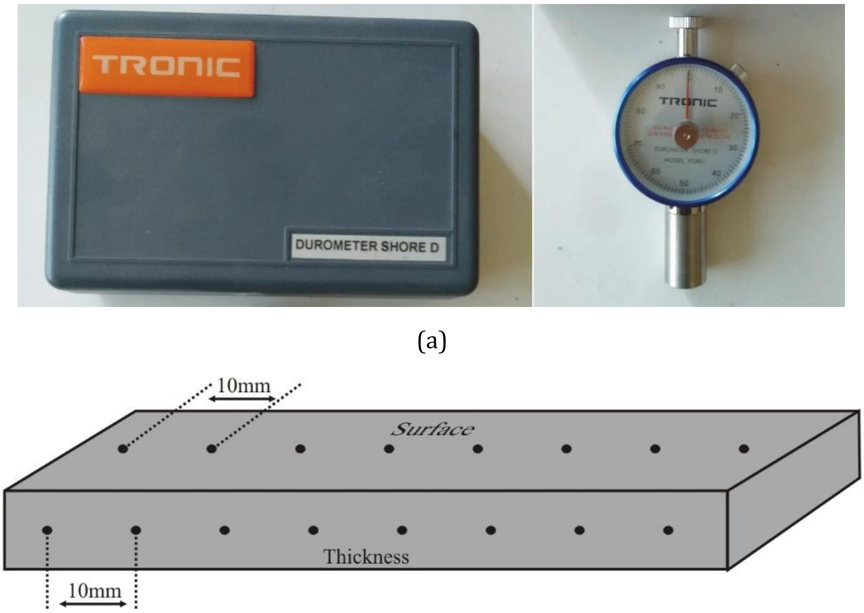
(a) (b)

Fig. 6. (a) Impact test sample and (b) Izod impact test machine

2.5. Shore Hardness Test

Shore hardness meter is one of the most widely used devices to determine hardness characterization of materials. The hardness is measured by the depth of indentation caused by a rigid ball under a spring load or dead load, the indentation being converted to hardness degrees on a scale ranging from 0 to 100. The hardness scale from 0 to 100 is chosen such that '0' represents a rubber having an elastic modulus of zero and '100' represents a rubber having infinite elastic modulus.

Hardness tests were performed by adhering to ASTM D2240 testing procedures. This test procedure describes determining of indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials, and some plastics [37]. Tronic trend mark Shore D Durometer Hardness Tester was used to measure the depth of penetration of the loaded indenter into unfilled and filled jute/epoxy laminated composites respectively (Fig. 7 (a)). The hardness measurements were made in two different directions as the surface and thickness of the sample. Hardness values were obtained from eight different points at a 10 mm interval along the length of each sample (Fig 7(b).



(a)

(b)

Fig. 7. (a) Shore D durometer hardness tester and (b)specimens measure points

2.6. Morphological Characterization

Studies on the morphology of the composites were carried out using scanning electron microscopy (SEM). Micrographs of the surfaces of tensile fractured specimens were taken using Phillips XL30CP. An accelerating voltage of 15 kV was used to collect the SEM images.

3. Result and Discussion

In this study, tensile, compressive and impact behaviors of jute/epoxy composites, which were filled with different percentages of silicon carbide powders, were investigated. In order to investigate the enhancement in mechanical strength, the test results were compared with the results of unfilled jute/epoxy laminated composites. The obtained results were summarized below.

3.1. Results of Tensile Tests

Tensile strengths (T) and elasticity modules (E) of the material in two different weaving directions (warp and weft) were determined. The load-displacement curves of the jute/epoxy laminated composites were obtained for each SiC filling ratio and grain size during the tests. The load-displacement behaviors of filled and unfilled jute/epoxy composites are given in Fig. 8. In order to make Fig. 8 more clear, the only result of the 6% filled composite tests were compared with the results of unfilled composites. As shown in Fig. 7, jute/epoxy composites were damaged as brittle under tensile loading.

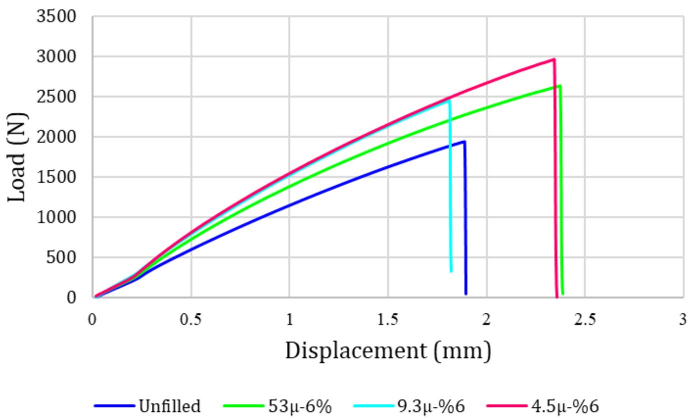


Fig. 8. The load-displacement curve of jute/epoxy with filled and unfilled composite under tensile load

The elasticity modulus of the filled and unfilled jute/epoxy laminated composites were given in Table 2 presents according to the direction of warp and weft. When Table 2 is examined, it was seen that the percentage of filling and powder grain size were effective on the modulus of elasticity of the laminated composite plates. The maximum elasticity modulus in the wrap direction (E1) was obtained as 6332.63 MPa from the samples that filled silicon carbide with 4.μ in the ratio of 6%. The minimum elasticity modulus was obtained as 5083.41MPa in the unfilled sample in the same weaving direction. The maximum and minimum elastic modulus values of Weft direction were 6378.45 MPa and 4969.66 MPa, respectively. In terms of weaving direction, it is seen that the results are close to each other. This result shows that yarns with similar physical properties in the direction of warp and weft are used in woven jute/fabric.

Table 2. Elasticity modulus values of jute/epoxy with filled and unfilled in warp and weft weaving direction

Filling Percentage	E1 (MPa)				E2 (MPa)			
	Unfilled	53μ	9.3μ	4.5μ	Unfilled	53μ	9.3μ	4.5μ
0	5083.41	-	-	-	4969.66	-	-	-
3	-	5633.56	5789.33	5847.99	-	5646.64	5799.30	6007.82
6	-	5721.57	6025.65	6332.63	-	5731.82	6168.49	6378.45
9	-	5367.16	5520.86	5768.64	-	5423.16	5434.66	5516.26

Considering the grain size and filling percentage, it was seen that the elasticity modulus of jute/epoxy composites improved up to 24% and 28%in the direction of warp and weft, respectively.

Table 3 showed the maximum tensile strength of jute/epoxy with filled and unfilled in the wrap (T1) and weft (T2) weaving directions. The maximum and minimum tensile strength in the wrap direction were 65.88 MPa and 52.12 MPa, respectively. In the weft direction, the maximum and minimum of tensile strength values were obtained 64.39 MPa and 54.55 MPa, respectively. Test results showed that the tensile strengths obtained from different weaving directions were similar. When considering the tensile strengths of unfilled jute/epoxy laminated composites, the tensile strength of filled jute/epoxy composites enhanced up to 24% in the warp direction and 18% in the direction of weft. This may be due to good particle dispersion and strong polymer/filler interface adhesion for effective stress transfer.

Table 3. Tensile strength values of jute/epoxy with filled and unfilled in warp and weft weaving direction

Filled Percentage	T1 (MPa)				T2 (MPa)			
	Unfilled	120	600	1000	Unfilled	120	600	1000
0	52.12	-	-	-	54.55	-	-	-
3	-	57.09	59.28	62.06	-	57.63	58.19	61.46
6	-	61.86	64.19	65.88	-	61.82	63.22	64.39
9	-	56.27	57.10	58.80	-	55.76	56.59	57.51

Table 4 presents the shear modules of filled and unfilled jute/epoxy laminated composites. As shown in Table 3, the maximum shear modulus (G12) is 1236.93 MPa and the minimum shear modulus is 1022.30 MPa. It has seen that powder filling process increased the shear modulus of the jute/epoxy laminated composite up to 21% depending on the granule size and the filling percentage.

Table 4. Shear modulus of jute/epoxy with filled and unfilled in warp and weft weaving direction

Filled Percentage	G12			
	Unfilled	120	600	1000
0	1022.30	-	-	-
3	-	1051.34	1073.24	1148.46
6	-	1176.70	1201.68	1236.93
9	-	1044.22	1117.01	1202.53

3.2. Results of Compression Tests

Compression tests were carried out in two different loading directions depending on the warp and weft directions of the jute fabric. Fig. 9 shows representative load-displacement curves for unfilled and %6 SiC filled jute/epoxy test specimens under a compression load in wrap direction. The load-displacement curves of all samples were not given because the compression behavior was similar for other samples and the graph was more understandable. All specimens showed an initial linear increase in the measured load, and after a bend of the curve, the compression load increased at a lower rate, indicating the first appearance of irreversible damage within the laminates. When the maximum compression load was reached, the sample slowly deformed and damaged. Unlike from tensile damage, filled and unfilled jute/epoxy composites were damaged in a ductile manner under compression load.

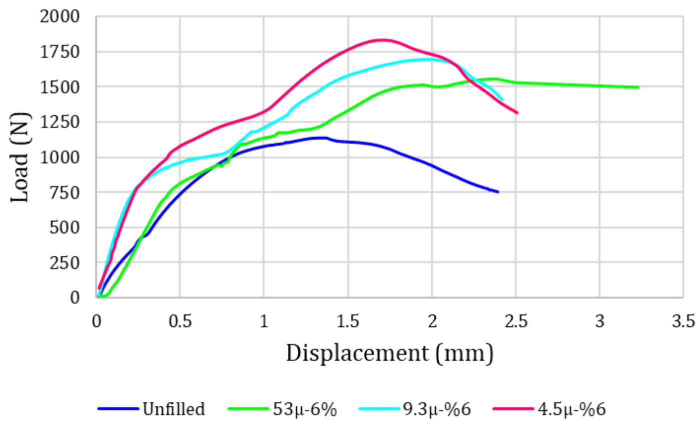


Fig. 9. The load-displacement curve of jute/epoxy with filled and unfilled composite under compression load

Table 5. Compression strength values of jute/epoxy with filled and unfilled in warp and weft weaving direction

Filling Percentage	C1 (MPa)				C2 (MPa)			
	Unfilled	53μ	9.3μ	4.5μ	Unfilled	53μ	9.3μ	4.5μ
0	45.10	-	-	-	45.19	-	-	-
3	-	51.73	54.33	55.58	-	49.60	52.26	54.13
6	-	55.37	56.88	59.02	-	53.27	56.77	58.04
9	-	47.02	48.82	51.00	-	48.03	49.09	52.29

Table 5 showed the average compressive strengths of filled and unfilled jute/epoxy laminated composites, which obtained from the wrap (C1) and weft (C2) direction. The maximum tensile strength values of C1 and C2 were 59.02 MPa and 58.04 MPa, respectively. Similarly, minimum compressive strengths for C1 and C2 were obtained as 45.10MPa and 49.19 MPa. When the compressive strengths obtained from the warp and weft weaving directions were compared, the values were close to each other. It has been seen that the powder filling process increased the compressive strength of the jute/epoxy laminated composites up to 31% in the warp direction and up to 28% in the weft direction, depending on the powder size and filling percentage. In addition, it was observed that the powder filling process increased the deformation ability of jute/epoxy composites under compression load.

3.3. Results of Izod Impact Tests

The complete set of ten different combinations of jute/epoxy composites were adopted for understanding filling percentage and granule size effect on the impact strength of the composites by the Izod impact test. The absorbed energy, i.e. the energy needed to break the specimen, provides an interesting trend of the impact strength in the considered ranges of the fillers weight contents. The impact toughness (strength) is determined by the loss of energy of the pendulum or determined by precisely measuring the loss of height in the pendulum's swing. Table 6 shows the absorbed energy and impact toughness of filled and unfilled jute/epoxy laminated composites. Test results showed that the powder filling process increased the energy absorption capacity and impact toughness of the jute/epoxy laminated composites up to 37% and 15%, respectively.

Table 6. Izod impact test results of filled and unfilled jute/epoxy composites

Filling Percentage	Absorbed Energy (J)				Impact Toughness (kJ/m²)			
	Unfilled	120	600	1000	Unfilled	120	600	1000
0	0.176	-	-	-	6.285	-	-	-
3	-	0.193	0.210	0.239	-	6.395	6.938	6.973
6	-	0.217	0.222	0.242	-	7.083	7.108	7.230
9	-	0.203	0.218	0.225	-	6.620	6.821	6.922

The changes in absorbed energy and impact toughness for jute/epoxy laminated composites according to the filling percentage were showed in Fig. 10. The percentage of filling is effective on the impact behavior of jute/epoxy composite material. Among various filling percentage and granule size, jute/epoxy composite, which was reinforced with %6 filling percentage and 4.5µ granule size, had the highest improvement in absorbed energy and impact toughness. SiC filling into jute epoxy up to 6% increased the absorbed energy and impact toughness of the material. After 6% filled percentage, these values decreased.

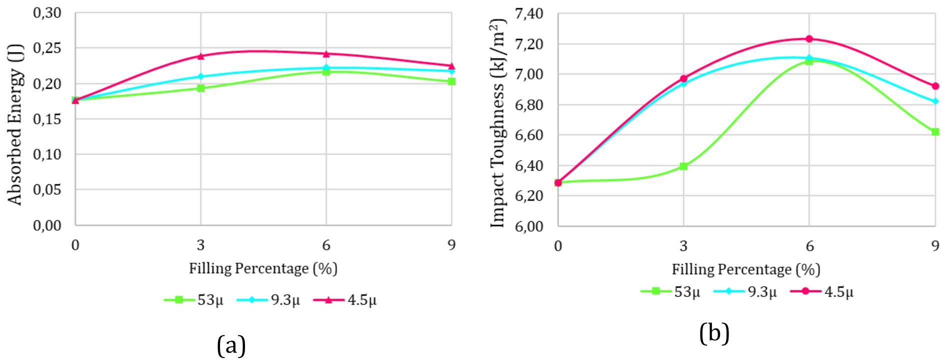


Fig. 10. Change in absorbed energy and impact toughness according to filling percentage

3.4. Results of Shore Hardness Tests

Shore-D Hardness test was applied to filled and unfilled jute/epoxy composites that measured 80x15x3 mm. The average of these measured eight hardness values was accepted as the hardness of the sample. Table 7 showed the hardness values of filled and unfilled jute/epoxy composites, which were measured in the direction of surface and thickness. The maximum surface and the maximum thickness hardness values were measured as 81.88 and 81.33 respectively. The minimum hardness values were measured as 65.38 and 66.33 in surface and thickness directions, respectively. While, the maximum hardness values were measured in the specimen, which was filled SiC with 9.3µ in 6% filling ratio. On the other hand, the minimum hardness values were measured in the unfilled specimen.

Table 7. Shore D hardness test results of filled and unfilled jute/epoxy composites

Filling Percentage	Surface Hardness				Thickness Hardness			
	Unfilled	53µ	9.3µ	4.5µ	Unfilled	53µ	9.3µ	4.5µ
0	65.38	-	-	-	66.33	-	-	-
3	-	68.50	70.13	74.75	-	71.67	72.33	73.00
6	-	71.75	81.88	70.50	-	77.67	81.33	67.33
9	-	67.13	79.00	73.13	-	68.33	73.33	69.00

When the hardness values of the samples, which have different granule size and different filling percentage, were compared with the hardness values of the unfilled samples, it was seen that the hardness value in the direction of surface and thickness increased up to 24% and 22%, respectively. In order to understand the effects of the filling percentage and the granule size on the hardness, the changes in the hardness values obtained from the surface and thickness direction were illustrated in Fig. 11.

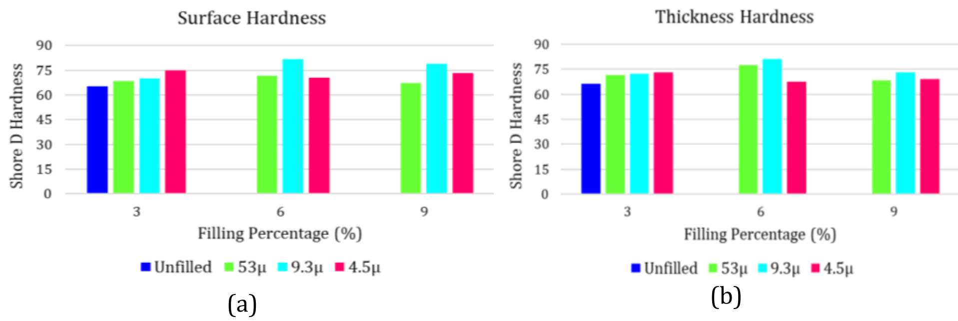
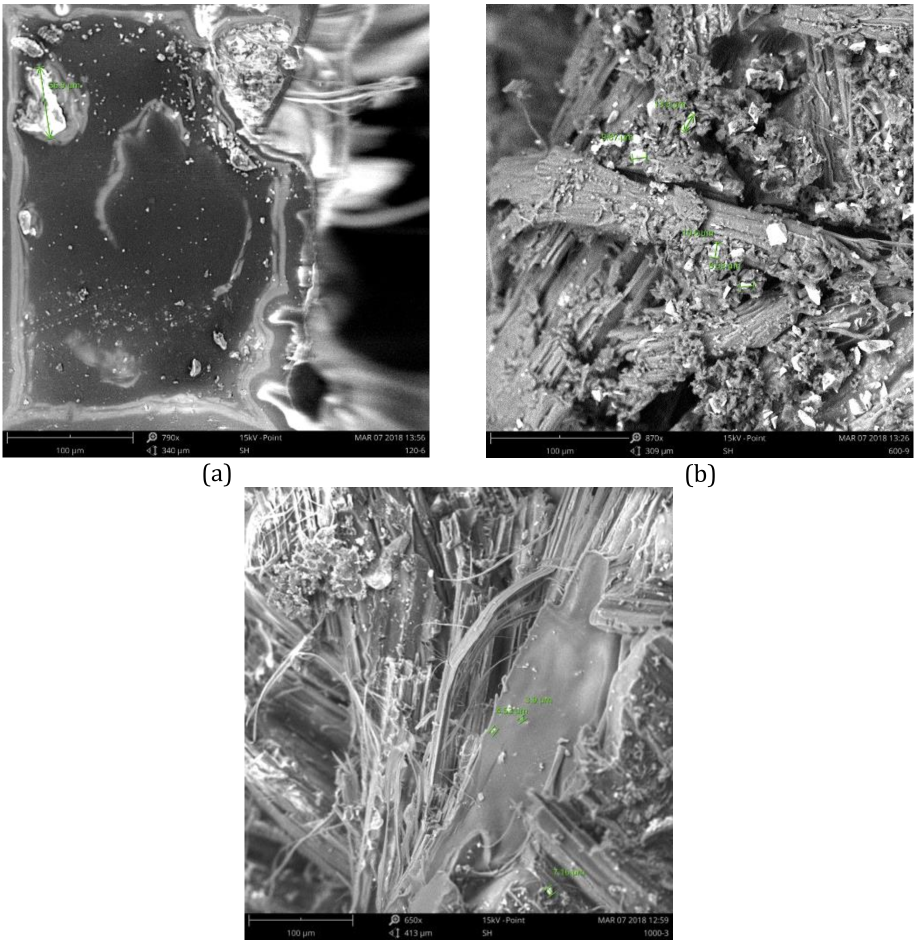


Fig. 11. Changes of Shore D hardness values according to filling percentage

The hardness value increases when the granule size decreases in samples having a filling ratio of 3%. There is no linear relationship between granule size and hardness in samples with a filling ratio of 6% and 9%. In samples with a filling ratio of 6% and 9%, hardness value of specimens with 4.5µ granule is less than specimens with 9.3µ granule size. This indicates that the powder filling process should not be applied at high filling percentages for small grain sizes in order to avoid agglomeration of the powders.

3.5. Results of Morphological Characterization

The distributions of SiC ceramic powder particles in jute/epoxy were visualized by scanning electron microscopy (SEM) and they were presented in Fig. 12. The voids, which can be seen between SiC Particle and matrix, clearly indicate the poor interaction between them. Further, different sizes and irregular shapes of the SiC fillers were evident in figures. Fibers, which prevented plastic deformation of the matrix, can be seen in Fig. 12. As the adhesion of the matrix and SiC particles is poor, the matrix can deform independently until the filler particles restrict the deformation. However, as filler percentage reaches %6, the observed plastic deformation characteristic seems to have decreased as the deformability of the matrix is limited earlier. Therefore, SEM observation of jute/epoxy laminated composites provides visual evidence for the poor mechanical properties and their trends against filler percentage.



(a) (b) (c)

Fig. 12. SEM photos of jute/epoxy laminated composites filled with (a) 53µ, (b) 9.3µ, and (c) 4.5µ SiC powders

A good dispersion was observed for jute/epoxy composite samples containing 3-6% SiC particles by weight. As the filler percentage for %9, significant filler agglomeration was indicated. This agglomeration factor contributes to the poor stress transfer from matrix to filler resulting in poor properties. Figure 13 also illustrates a state where agglomeration is observed visually. The results obtained from mechanical tests confirm this image.

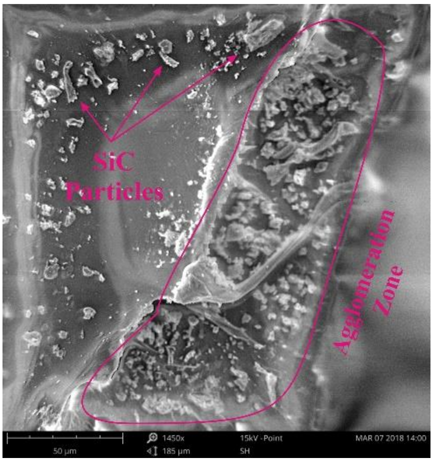


Fig. 13. Agglomeration of SiC particles with a size of 4.5μ

4. Conclusion

In this study, the effects of SiC filling process with different amounts and granule size on the mechanical, impact and hardness behaviors of natural jute fabric reinforcement laminated composites were investigated. Test results were compared with the results of unfilled jute/epoxy composite material to understand the effect of powder size and filling amount on the strength of jute/epoxy composite. Experimental findings were summarized as substances.

- The results obtained from the tensile and compression tests showed that the mechanical properties improved with the reduction of grain size. Accordingly, strength values of filled jute/epoxy laminated composites, such as elasticity modulus, shear modulus, and tensile strength, increased up to 18-28% by reduction of granule size, when compared to the unfilled jute/epoxy composite. Similarly, considering the compression values of unfilled jute epoxy composites, SiC filling provided up to 30% improvement in the compression strength of the jute/epoxy composites. It has also been seen from SEM photos where the SiC particles having small granule size were better positioned to the fiber-matrix interface voids. On the other hand, there is no linear relationship due to aggregation phenomenon between the filling percentage increasing and the mechanical strength.

- Although the tensile and compression tests were performed at the same deformation rate, the failure time of the sample in the compression test is much shorter than the tensile test. The main reason for this is that the fibers are vulnerable to compression load and that the delamination damage of the layers occurs at lower loads under compression loading.

- The jute fabric weaving direction (warp and weft) did not have a significant effect on the mechanical strength of the natural composite material. When the tensile strengths of the warp and weft directions of the samples having the same granule size and filling percentage were compared, it was seen that the tensile strengths were higher in the warp direction up to 2%. If a similar comparison was made for compressive strengths, it is seen that the strength difference due to weaving direction was around 9%.

- Izod impact tests have shown that SiC particles contribute to the impact resistance by delaying the plastic deformation of the epoxy matrix.
- Hardness strength behavior depends on the percentage of filling and SiC particle size. For a filling percentage of 3%, there is a linear relationship between grain size and fill percentage increase. For fill percentages of more than 3%, the hardness increase is affected by the grain size. This situation was due to the agglomeration, which occurred the excess amount of filling.
- According to the results obtained from tensile, compression, impact and hardness measurement tests, it can be said that SiC filling into natural jute fiber reinforced polymer composites has a positive effect on their mechanical performance. Two important parameters to be considered during the filling process are the granule size and filling percentage of the SiC granules. Test results show that small size granules are better dispersed than large size ones. In addition, SiC particles may have agglomeration or homogeneous dispersion problems if fill with more than 6% by weight of the matrix.
- Although SiC filling of a certain ratio and granule size enhance the mechanical strength of natural jute / epoxy composites, it increases the production costs too. In this context, the producer should consider the required strength / cost ratio.

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