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Different Curing Temperature Effects on Mechanical Properties of Jute/Glass Fiber Reinforced Hybrid Composites

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Abstract

In this study, the effect of different curing temperatures (60°C,80°C, and 100°C) on the mechanical characteristics of Jute and Glass fiber-based hybrid composites were analyzed mechanically, physically, and morphologically. Jute fiber fabric and glass fiber fabrics (49 gr/m² and 100 gr/m²) were used as reinforcement elements, while epoxy was utilized as matrix materials. A vacuum assisted resin transfer molding method (VARTM) was used as the production method. The mechanical test results were achieved by the Tensile test and Vickers hardness test, while morphologic images were obtained by Scanning Electron Microscopy (SEM). Physical data was also obtained by the ignition loss test. The effects of temperature and hybridization on mechanical properties of hybrid composite samples formed with jute fabric and glass fiber material with different weights per square meter at different curing temperatures are given in the results. Results show that increasing post cure temperature 60°C to 80°C 3.18%-3.41% rate augment in tensile strength. It was discovered that there was a decreasement in tensile strength with an increase in temperature from 80 °C to 100 °C after curing. In the hardness test results, increasing post curing temperature had an increasing effect on the hardness values. SEM analysis results also supported the tensile test results.

Keywords: Curing temperatures; Glass fiber; Hybrid composites; Jute fiber; Mechanical properties

Research Article

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1. Introduction

In recent years, the increasing pressure of environmental volunteers, the protection of natural sources, and the harshness of the laws enacted by the state lead to the discovery and improvement of natural materials. The composite production industry has started to use plant-based natural fiber supplements such as jute, kenaf, flax, banana, sisal, hemp as an alternative material more than synthetic-based fibers. Natural fiber composites have high modulus, specific strength, low cost, low density compared to synthetic fiber polymer composites, making them preferable. Natural fiber composites also have advantages such as less dependence on non-renewable energy sources as environmentally friendly materials, increased energy recovery, lower pollutant emissions and greenhouse gas emissions, and biodegradability of components at the end of their life cycle [1]–[3]. Nevertheless, the main disadvantages in natural fibers such as the tendency to moisture absorption causing loss of strength, differences in properties and quality as a result of cultivation terms, low impact strength, restricted maximum processing temperatures, and weak fire resistance limit their use in most applications [4]. Instead of using natural fibers as a reinforcement element alone, composite materials containing two or more fibers in a single matrix called hybrid composites are becoming the focus of new studies. Hybridization with more than one type of fiber in the same matrix material diversifies the properties of fiber reinforced composite materials [5]. With hybrid composites, a material can be created that has the combined advantages of the individual components and meanwhile reduces their fewer desirable qualities. Hybrid composites can increase the impact and fatigue resistance, the toughness of the material compared to individual reinforced material, and can provide the material with better strength, high stiffness, and also reduce the material weight and total cost [6], [7]. Composites that fiber reinforced are increasingly made use of in automotive and marine applications, coating industry, aviation applications, aircraft, and safety equipment due to their extraordinary properties [8]–[10].

Jute fabric is the most used natural fiber as a reinforcing element in natural fiber composites. Their superior environmental performance, good thermal and electrical insulation resistance, better acoustic insulation properties than some of the synthetic fibers provide a wide application area for jute fabrics in industries such as construction, textile, furniture industry, and automotive [11], [12]. Glass fibers are one of the widely preferred synthetic fibers due to their low cost and their ability to be used in various fields such as automotive, marine and aviation. High chemical resistance, high tensile strength, and high dimensional stability in glass fibers provide more orientation to E-glass fibers as reinforcement materiel in the composite sector. The presence of critical size defects determines the strength of any material. In this case, E-glass fibers are also elements that increase the material surface cubage rate by decreasing the counts of crucial defects as reinforcement material and thus increase the strength [13], [14]. When the previous studies are examined, it is revealed that the hybrid operation of jute fiber fabric and glass fiber fabric is commonly performed. Researches in one of this, Jha et al. [15] investigated the effectiveness of combined jute fabric with glass fabric on the abrasion strength and tensile features of jute/glass fiber hybrid composites. While making five different hybrid composite layers, the hand lay-up technique was used, and the compression technique was used to provide the appropriate thickness. In addition to that the elastic modulus and tensile strength values of the samples formed by the hybridization process were approximately 150% better than the homogeneous ones, it was understood that the tensile strength values of the composites with higher jute ingredients were better than e-glass. Braga and Magalhaes Jr. [16] studied mechanical features like impact, flexural, tensile, thermal features, and water absorption testing for glass/jute fiber reinforced composites. They produced composites by using epoxy resin in three different proportions (69%, 68%, 64%) by mass. According to the results, it was seen that the higher the glass fiber ratio, the higher the mechanical properties. However, while the tensile strength increased substantially (68% and 92%), the increase in bending strength (1.9% and 2.2%) was not significant. Bindal et al. [17] investigated the effect of using different weight percentages of jute and glass fiber on tensile strength, flexural strength, impact strength, and water absorption tests. The method of hand lay-up was applied to all composite specimens produced, and they were produced in different combinations with 20%, 30%, and 40% weight percent of the total reinforcement in the composite material. Their results show that the best percentage for the natural reinforcement content is between 25% and 33% in the material where the total reinforcement ratio is 30% to 40%. In another search, Reddy et al. [18] fabricated glass/jute fiber reinforced composites with the sandwich structure to examine the impact of water absorption on mechanical characteristics of produced hybrid composites. While epoxy is used as the matrix material, polyethylene foam is used in the center of the sandwich structure. From the results, they found the incorporation of natural, synthetic fibers and foam to the products produced greatly increased their mechanical properties. Nagaraj et al. [19] examined the mechanical features (tensile strength, hardness) of hybrid composites in the JGJ (Jute-Glass-Jute) and GJG order, which were manufactured by using the hand lay-up method. In terms of tensile strength results, hybrid fabric samples made in the GJG order gave 45% better results. Pandita et al. [20] fabricated composites in which jute and jute/glass fabrics were used as reinforcing elements and epoxy was used as resin, applied to samples on drop impact, flexural, and tensile testing to study the effect of hybridization on jute composites. When the results were evaluated, it was determined that placing thin glass fabric layers on the exterior decreased water absorption while increasing the bending, tensile, and impact features of jute reinforced composites. Sezgin and Berkalp [21] searched the impacts of diverse sorts of Multi-walled carbon nanotubes(MWCNT) on mechanical characteristics of Jute/glass fiber reinforced composites. They preferred polyester resin as the matrix materiel and the VARTM method as the production method. Considering the data obtained from the results, it was seen that adding MWCNT to the composite formation improved the mechanical characteristics of the composite materiels. Meanwhile, it was understood from the results that when high-strength fabrics were placed on the exteriors of the composites, high impact strength values were obtained, and the lowest values were obtained in tensile strength when using the same sequence. The influence of temperature has been found to be very important both during the manufacture and operation of the composites, as well as on the tensile, compression, bending, and shear strength features. Aktas and Karakuzu [22] studied the effect of diverse temperatures (20°C, 40°C, 60°C, 80°C, 100°C) on mechanical properties of glass/epoxy composites. They concluded that glass-epoxy composites lost their hardness and strength with the increase in temperature, and after 60°C and 80°C, their tensile strength and elastic modulus in the fiber direction decreased dramatically. Hiremath et al. [23] investigated how post-cure temperature would affect material properties such as bending and viscoelastic in epoxy/alumina polymers composites. According to the results of the work done to optimize the post-curing temperature, it was seen that the final curing temperature is a temperature below or above the glass transition temperature is a crucial factor for the mechanical properties of the material. Kumar et al. [24] searched the impact of optimum post curing temperature and post curing time on mechanical properties in glass fiber reinforced composites. Results show that glass transition temperature and interlaminar shear strength are considerably affected by post curing factors. While it was observed in the study that there is an increasing tendency in the mechanical properties of composite materials with the increase of temperature after curing, in addition, this elevated post-curing temperature rises the cross-link density and heat resistance [25], in another search, the effectiveness of post-cure temperature on the mechanical characteristics of composites and adhesives was investigated [26].Cao et al. [27] searched the tensile properties at high temperatures in carbon fiber reinforced composites. When they test their samples at temperatures ranging between 16 °C to 200 °C, the results obtained indicate that the tensile strength decreases substantially with augment in temperature. On the other hand, it has been found in the study that carbon fiber reinforced polymers show good mechanical properties at cryogenic temperatures(-150°C) [28]. In this study [29], composite specimens cured at room temperature and isothermal high temperature were compared, and mechanical properties gave better results in samples cured at high temperature. Balcıoglu et al. [30] investigated the impact of curing time and temperature on mechanical properties in woven glass-reinforced polyester composites. It was found that the optimum time and temperature for the samples produced were 40 minutes and 70°C, respectively, above which the temperature and time deteriorated the structure of the matrix material. After examining other literature studies, the main purpose of this study is to improve a new hybrid composite form by hybrid operation jute fabrics with glass fiber fabrics with different weights per square meter. In addition, different post-cure temperatures are applied to this hybrid structure and to investigate the impact of these different temperatures on the mechanical characteristics of the structures.

2. MATERIAL AND METHODS

2.1 Material

Two different glass fiber fabrics (49 gr/m² and 100 gr/m²) and 265 gr/m² jute fabric were used as reinforcement material supplied from companies in Istanbul. Table 1 shows the properties of these fabrics. The structure of these fabrics is plain weave. The fabric samples are indicated in Figure 1.

Table 1. Properties of fabrics

Fabric	Weight(gr/m²)	Thickness of Fabric(mm)	Warp	Weft
Jute	265	0.7	-	-
Glass Fiber	49	0.02	11x1	24x19
Glass Fiber	100	0.08	22x1	24x22.8

Fig. 1. Fabric samples: a) Jute b) Glass fiber (49 gr/m²) c) Glass fiber (100 gr/m²)

In the study, the matrix system was created using Epoxy resin (L160) and hardener (LH260S) supplied by Kompozitshop (Turkey). While determining the resin and hardener mixture ratio, 100:36±2 by weight was used, taking into account those given by the manufacturer. Table 2 indicates the properties of the resin system [31].

Table 2. Epoxy and Hardener Properties

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

In this study, twenty-one composite models were fabricated with distinct fabric stacking orders for three different curing temperatures (60°C, 80°C, 100°C). The fabric laminas reference codes in composite models are indicated in Table 3.

Table 3. Codes of produced samples

Composite Codes	Fabric types
J	Pure Jute fabric composite
JG49	Jute/Glass Fiber (49 gr/m²) fabric hybrid composite
JG100	Jute/Glass Fiber (100 gr/m²) fabric hybrid composite

After curing, the composite specimens were cut by water jet to the test dimensions specified in the standards, as shown in Figure 2.

Fig. 2. Water jet application to composites

2.2 Method

The vacuum assisted resin transfer molding system was used to fabricate the composite specimens. Composite production was carried out at room temperature (20°C±2°C). In this production technique, a vacuum pump is an important tool in removing air gaps and dispersing the resin into the fabric. Composite production was made on tempered glass. First, the designated area was cleaned and then a release agent was applied to the surface twice at fifteen minutes intervals. Then the fabrics were arranged in the determined order, the peel ply and the infusion mesh were placed on the fabric, respectively. The determined area was surrounded by a vacuum sealing band. After the vacuum sealing tape was attached around the specimen, a vacuum bag was enclosed to it. Small holes were made in the vacuum bag for the infusion hose and vacuum hose. While these processes were being carried out, the mixing rate of the resin and hardener was determined by taking into account the previous productions and the values given by the manufacturer, and the mixture was prepared accordingly. Finally, the vacuum pump was turned on (about 1 bar) to absorb the extra resin from the specimen and the pump was turned off when the resin was completely infused through the reinforcement (Figure 3). Figure 4 shows the resin infusion process in this method. Vacuum pipes and open areas were covered with a sealing band to avert air entry. The sample was quit in this position for 24 hours to cure. The test specimens were placed in an oven after production and kept at 60 °C, 80 °C, and 100 °C for 1 hour, with final curing.

Fig. 3. Vacuum assisted resin transfer method

Fig. 4. Resin infusion process in Vacuum assisted resin transfer method

2.3 Physical Testing

One of the main parameters in specifying the mechanical characteristics of composites is the fiber volume ratio. The fiber volume fraction can be determined experimentally by the loss-of-ignition method or the matrix burn test according to ASTM D2584 [32]. Matrix burn tests were performed according to ASTM D2584-02 Standard Test Method for Ignition Loss of Cured Reinforced Resins to determine the ignition loss of cured reinforced resins. In this method, a composite sample is heated in a porcelain crucible until the epoxy matrix ignites in an electric muffle furnace that reaches 330˚C (Figure 5). Although the standard method recommends a furnace temperature of 565 °C, this furnace temperature is sufficient for jute and glass fiber extraction. The reason for using this temperature is that the decomposition temperature of the epoxy in the results of the thermogravimetric analysis was 326 °C in the previous study [33]. In the hot oven environment in composite samples, the resin part is separated from the fiber parts. The remaining amount is filtered and weighed [34]. The position of the produced composite sample placed in an electric ash furnace in a porcelain crucible is shown in Figure 6. The ignition loss of the specimens is calculated according to the ASTM D2584 standard as in Eq (1):

$$IL = \left[\frac{W_1 - W_2}{(W_1)}\right] \mathrm{x}100 \qquad (1)$$

where W_1 is measured weight of the sample before the testing(gr), W_2 is measured weight of the sample after the testing, the weight residue(gr).

Fig. 5. An electric muffle furnaces

Fig. 6. Composite samples in a porcelain crucible in an electric ash furnace

2.4 Tensile Testing

The mechanical characteristics of the produced composite specimens produced were scrutinized by tensile strength. A minimum of five samples was tested for the produced J, JG49, JG100 composite. The outcomes are also provided as the mean value of the specimens tested. Tensile testing is done using ALŞA Hydraulic Test Machine (KOLUMAN Automotive Industry Laboratory) according to ASTM D 3039 standard and the crosshead speed was set as 2 mm/min using a capacity of 98000 kN load cell [35]. The tests were done at room temperature. The universal tensile testing machine is indicated in Figure 7. As a result of the tensile test; Tensile Strength, Elastic Modulus, Stress-Strain diagram, and Elongation rate of hybrid composites were calculated.

Fig. 7. Tensile Testing Machine

2.5 Hardness Test

Hardness is called the resistance of a material to local plastic deformation. In this study, Vickers hardness tests were performed to specify the hardness of the samples produced. Vickers hardness value was found by taking an average of fifteen readings in different places in each sample. AOB Lab product device was benefited to interpret the hardness test of samples according to the ASTM E92-17 standard [36]. The Vickers hardness test machine is shown in Figure 8. While the machine has a test force capacity of 0.1 kgf-1 kgf, the hardness measurement range is available between 8HV-2900HV.

Fig. 8. Hardness Testing Machine

2.6 Morphological Analysis

The interfacial morphologies of the composite samples, which were formed as a result of the test, were examined with the help of a Scanning Electron Microscope FEI Quanta 650 Field Emission device at 100V-30kV acceleration voltage. In order that increases the surface conductivity of the samples, gold plating was made by using the sputtering method. The device has the capacity to magnify 6-1.000.000 x times (Figure 9). This analysis would give the opportunity to scrutinize the fracture surface of composite specimens and to see the fiber-matrix interplays.

Fig. 9. SEM Analysis Machine

3. RESULT AND DISCUSSION

3.1 Physical Test Analysis Results

In this test, as stated in the standard method, at least three tests were performed for the samples and their average weights were found as in Table 4. According to Ignition loss test results, jute reinforced composite specimens have the highest ignition loss as a percent by weight of the specimen. JG49 and JG100 composite samples have close results as ignition loss. In this case, it is due to the close chemical and physical properties of the 49 gr/m² and 100 gr/m² glass fibers used. Moreover, hybridization of jute fiber with glass fiber, ignition loss by weight of specimen has decreased. One of the critical parameters in this analysis was temperature. It has been understood that when the temperature is exceeded 330 °C, the fiber materials are burned and no correct results can be obtained. The time required for this combustion is 3 minutes on average.

Table 4. Ignition loss results of produced samples

	J	JG49	JG100
Arithmetic Average of W_1 Weights (gr)	8.001	9.804	10.113
Arithmetic Average of W_2 Weights (gr)	7.724	9.566	9.901
Ignition loss, weight (%)	3.454	2.43	2.093

3.2 Mechanical Testing Analysis Results

Figure 10 shows the samples after the tensile test. Five samples were tested and average tensile strength results were indicated in Figure 11.

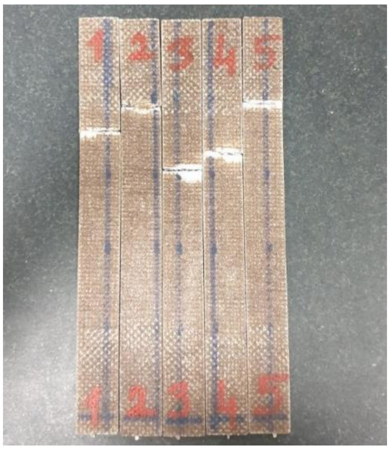

Fig. 10. Samples after the tensile test

According to tensile strength results as seen in Figure 11, increasing the curing temperature from 60 °C to 80 °C had a positive effect on the J and JG49 samples, while it had a negative effect on the JG100 sample. The curing temperature, which increased from 80 °C to 100 °C, decreased the tensile strength of all samples. Hybridization of jute fabric with 49 gr/m² glass fiber gave an increase in tensile strength of 3.39 times at 60 °C, 3.4 times at 80 °C, and 3.22 times at 100 °C. In the hybridization of jute fabric with 100 gr/m² glass fiber, the tensile strength increased by 4.19 times at 60 °C, 4.02 times at 80 °C, and 3.41 times at 100 °C.

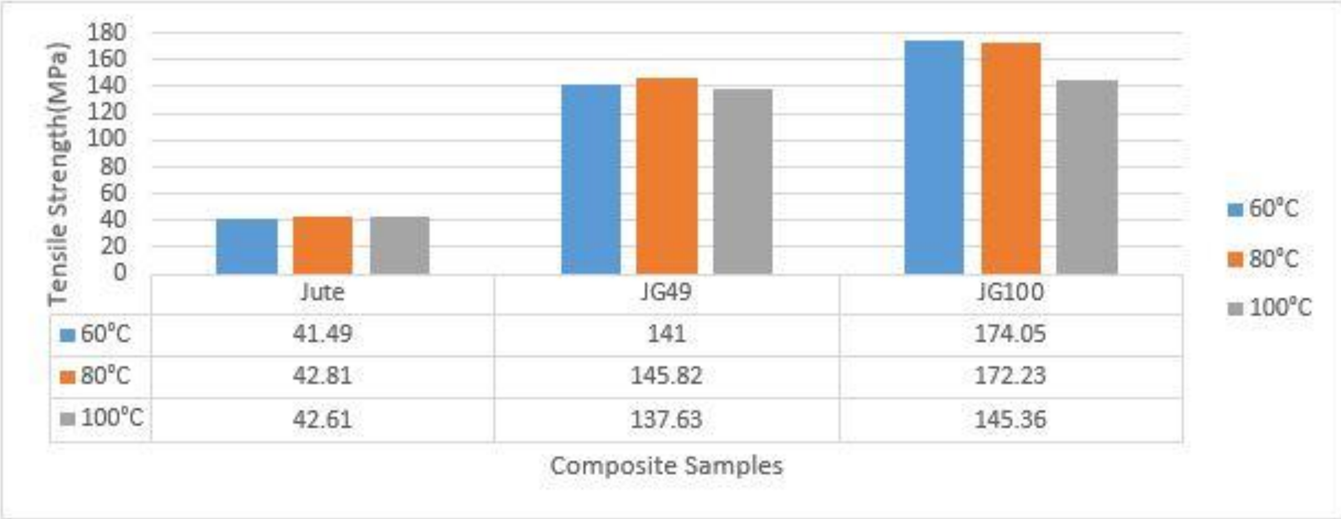

Fig. 11. Comparison of Tensile test results

Figure 12 shows the comparison of elastic modulus of produced samples. It can be seen that the elastic modulus results also tend to have a similar trend to the results in tensile strength. It was found that there was no sharp increase in elastic modulus as much as increases in strength of tensile. The augment in modulus of elasticity and tensile strength seen in hybrid composites is based on the fact that jute fibers are weaker and softer than glass fibers. When the samples were observed, it was understood that in jute laminates, breakage was sudden with little or no shrinkage of the jute fibers, whereas in hybrid laminates, breakage was determined by dense fiber shrinkage and breakage [37]. One reason for this is that glass fibers (7.64%-8.88%) can be shown to have greater extensibility than jute fibers (4.1%-4.5%), as seen in Figure 13.

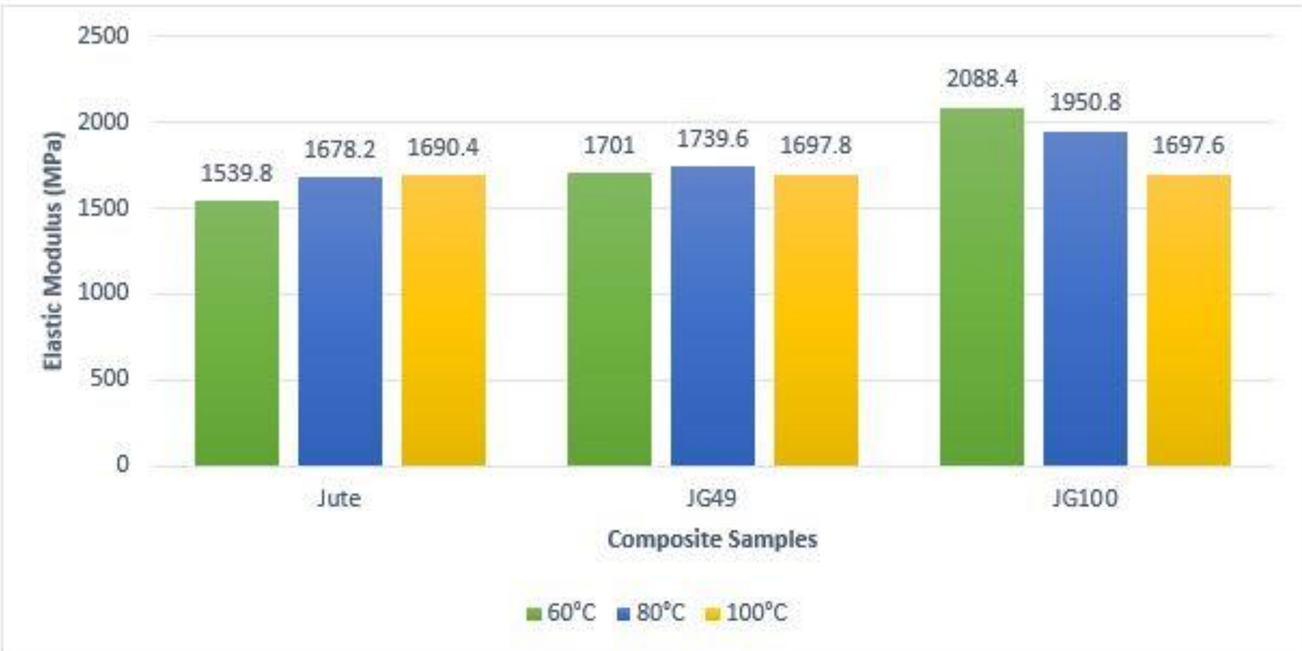

Fig. 12. Comparison of Elastic Modulus of samples

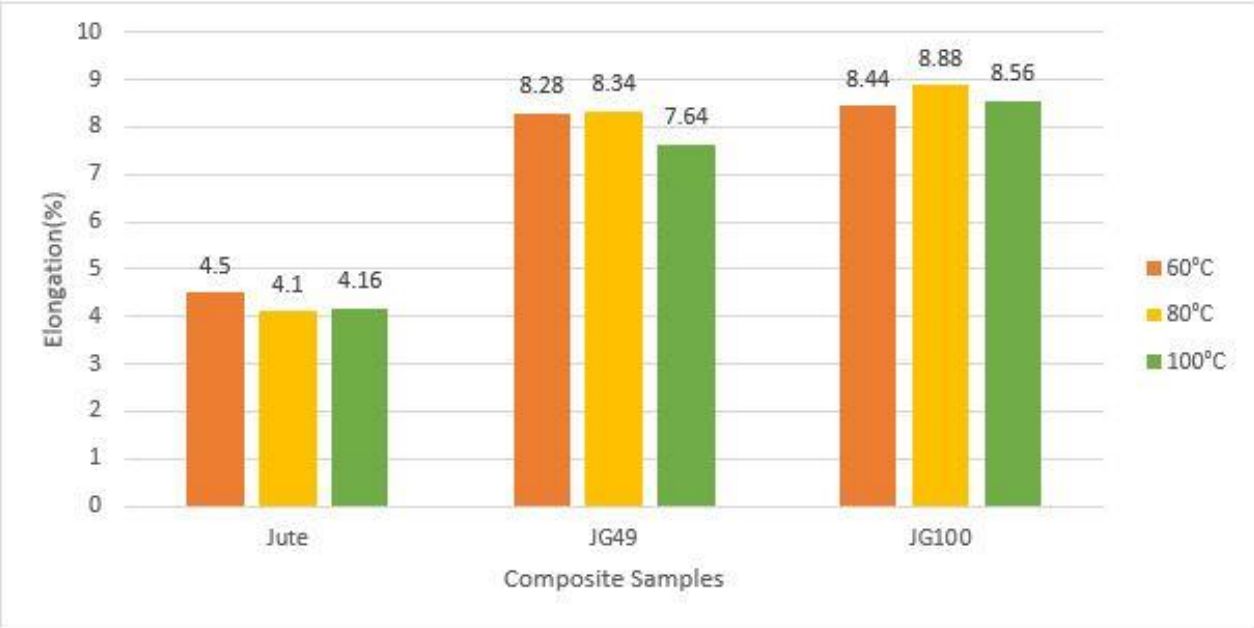

Fig. 13. Comparison of Elongation of samples

3.3 Hardness Test Analysis Results

Vickers mean hardness values of the produced samples were obtained for J, JG49, and JG100 configurations as seen in Figure 14. It was found that the hardness value of produced composites ascended as the curing temperature increased. It was understood that the rising in post curing temperature contributed positively to the hardness value of the produced samples. The hybrid operation of jute fabric with glass fiber increased the hardness of the produced material by 42.7% to 93% at three different post-cure temperatures. When the curing temperature of 60 °C is taken as an example, the hybrid process of jute fabric with glass fibers increased the hardness of the material produced between 1.6 and 1.9 times. This increased rate was 1.5 to 1.8 times at 80 °C curing temperature and 1.4 to 1.6 times at 100 °C curing temperature.

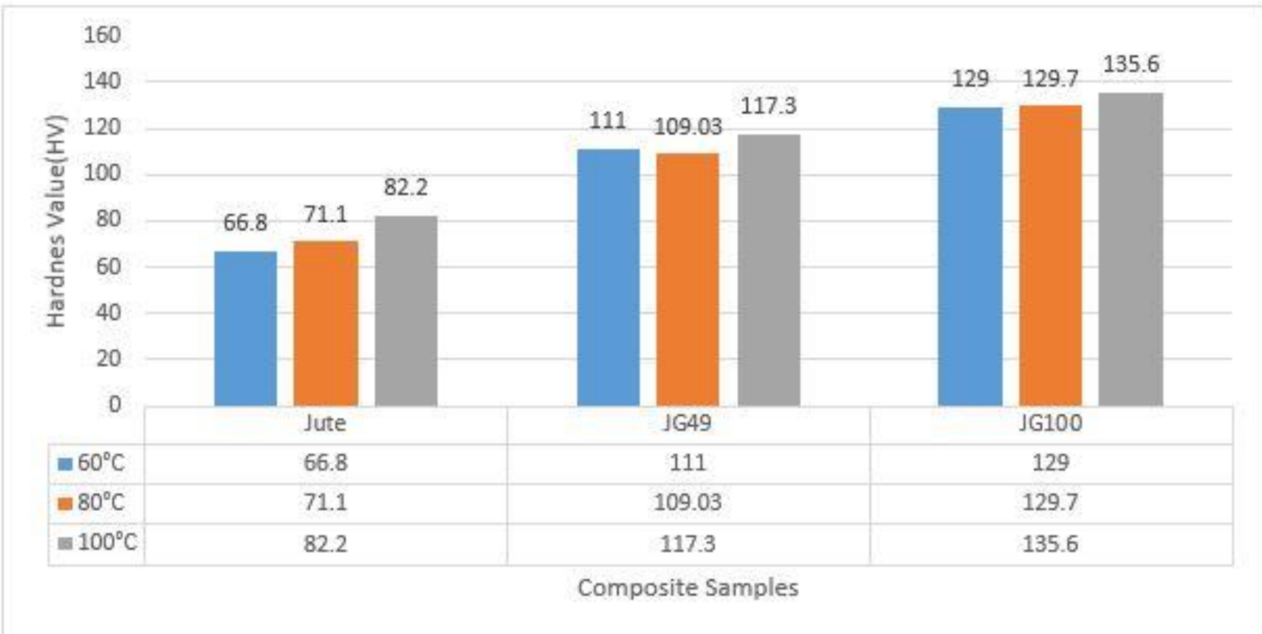

Fig. 14. Hardness test results

3.4 Morphological Analysis Results

Figure 15,16 and 17 indicates that SEM images of J samples after the tensile test at 60 °C, 80 °C, and 100 °C post cure temperature, respectively. When the tensile test results are also evaluated, the highest value in J samples was reached at 80 °C post curing temperature. Compared to Figure 15 and Figure 16, the structure of Figure 16 has almost no voids, while the fiber of Figure 15 has voids and cracks. In Figure 17, the image is almost similar to Figure 16, and there is a structure in which the epoxy and jute fibers are not separated from each other. The images in Figures 16 and 17 also confirm that the tensile strength results are close to 80 °C and 100 °C.

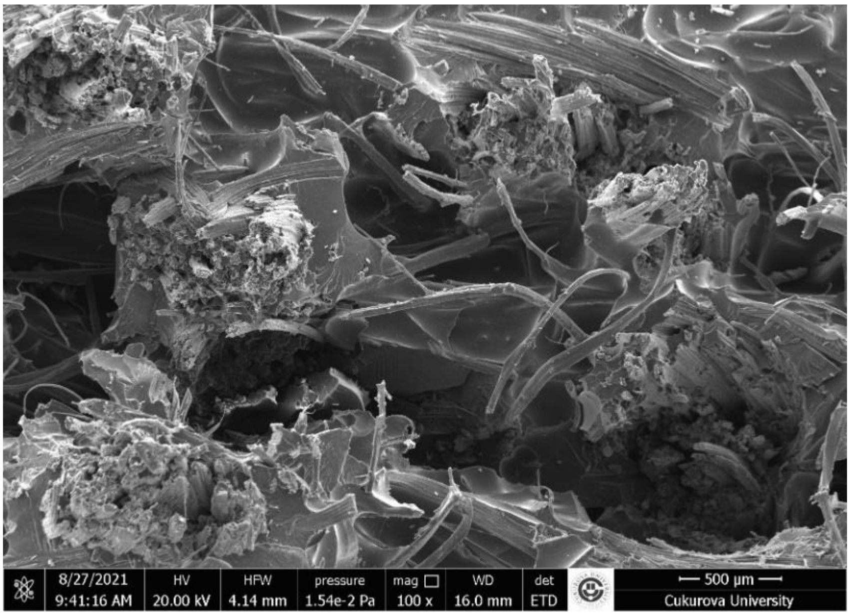

Fig. 15. Morphological images of J sample at 60 °C post-cure temperature

Fig. 16. Morphological images of J sample at 80 °C post-cure temperature

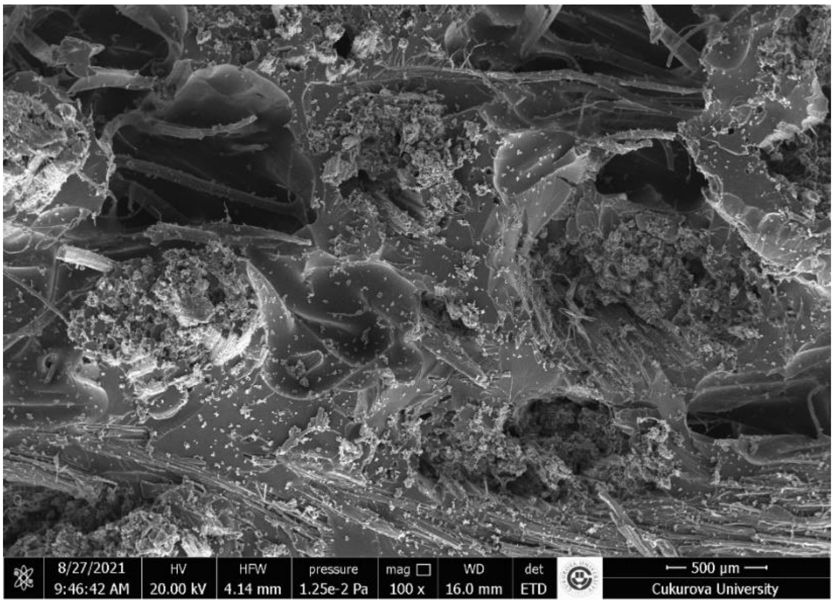

Fig. 17. Morphological images of J sample at 100 °C post-cure temperature

SEM images of JG49 samples at 60 °C, 80 °C, and 100 °C post cure temperature is indicated in Figure 18, Figure 19, and Figure 20, respectively. In Figure 18, it is the process of hybridization of jute fiber to glass fiber, which increases the bonding of fibers with epoxy compared to homogeneous jute fibers. In accordance with the tensile test results, it is understood that the fiber breaks in the images in Figure 19 are less than the images in Figures 18 and 20. In the image of Figure 20, in some parts of the structure, it is seen that the resin and fiber are in good harmony, while in some parts of the structure, voids and bubbles are encountered.

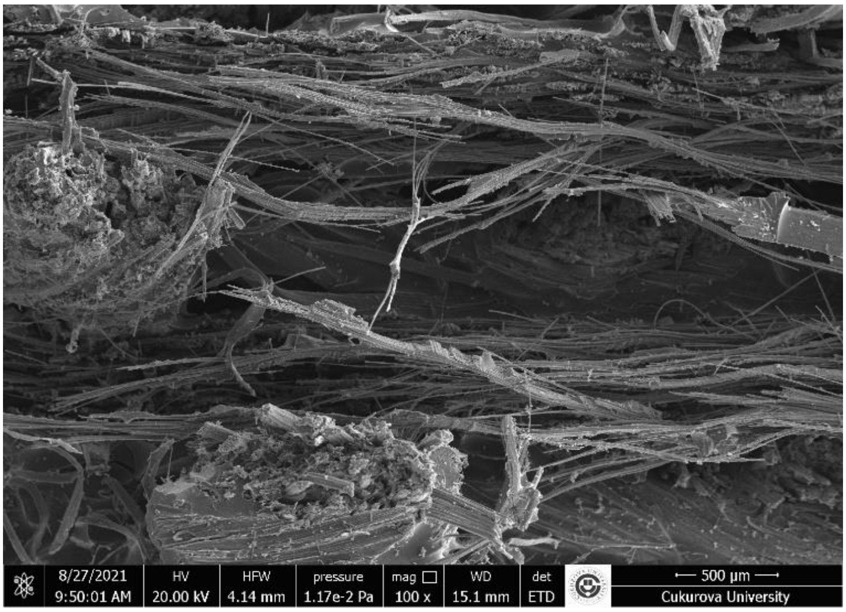

Fig. 18. Morphological images of JG49 sample at 60 °C post-cure temperature

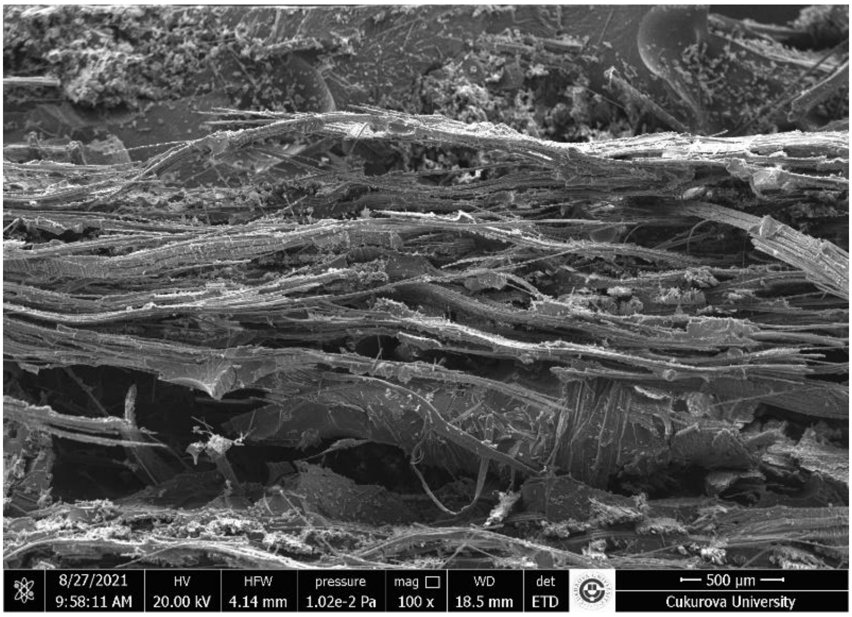

Fig. 19. Morphological images of JG49 sample at 80 °C post-cure temperature

Fig. 20. Morphological images of JG49 sample at 100 °C post-cure temperature

Figure 21, Figure 22, and Figure 23 indicate that SEM images of JG100 samples at 60 °C, 80 °C, and 100 °C post cure temperature, respectively. Unlike the SEM image of the other two samples (J and JG 49), it is observed in Figure 21 that the JG100 sample has less void structure at 60 °C post cure temperature and the fiber and resin compatibility is better. This image also supports better results from post-cure temperatures of 80 °C and 100 °C, as in the tensile strength results. The hollow structure in Figure 22 is slightly more visible than in Figure 21. It is seen that these differences also have a similar impact on the tensile strength results. In the image in Figure 23, it is seen that fiber breaks and ruptures are more common.

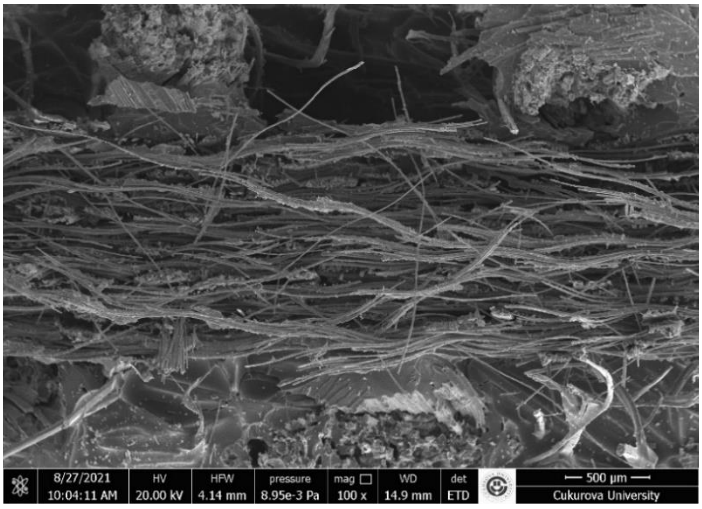

Fig. 21. Morphological images of JG100 sample at 60 °C post-cure temperature

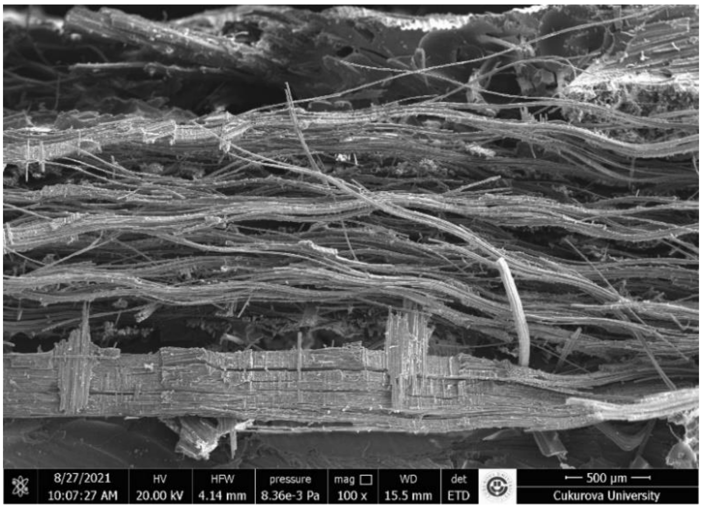

Fig. 22. Morphological images of JG100 sample at 80 °C post-cure temperature

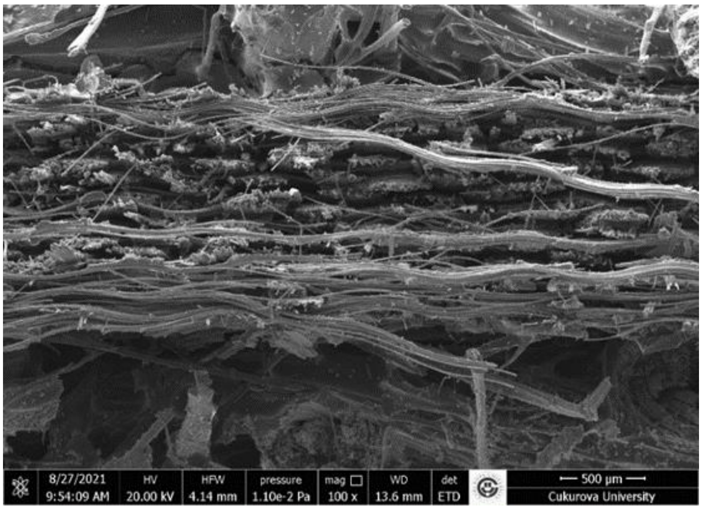

Fig. 23. Morphological images of JG100 sample at 100 °C post-cure temperature

4. Conclusions

In this search, the mechanical characteristics of composite samples produced with jute fabric, 49 gr/m² glass fiber fabric, 100 gr/m² glass fiber fabric, and epoxy resin was determined at three different post-curing temperatures (60, 80, and 100 °C). The following conclusions can be drawn from the experimental results:

- Increased temperature from 60 °C to 80 °C after curing, an enhancement in tensile strength of 3.18% for J composite samples and 3.41% for JG49 specimens was observed.
- The temperature rising from 60 °C to 100 °C in JG100 samples caused a 28.67% decrease in tensile strength.
- Increasing curing temperature from 80 °C to 100 °C had a decreasing effect on tensile strength in all samples.
- While the elastic modulus increases with increasing temperature for J and JG100, the elastic modulus decreases after 80 °C, similar to the tensile strength in the JG49 sample.
- There is a difference of 1.84 to 1.87 times between the amount of elongation in the composites made by hybridizing the jute fiber fabric with epoxy and the composites made by hybridizing with glass fibers, considering the temperature of 60 °C.
- Microhardness values of produced samples increase by increasing temperature.
- In terms of ignition loss, it was found that the greatest weight loss was in the J samples, and the least loss was in the JG100 samples.
- The results of the morphological analysis indicate low bonding between the sample layer when increased temperature from 80 °C to 100 °C after curing.

All in all, according to the physical tests, glass fiber fabrics were found to be highly resistant to high temperatures, while the mechanical test results showed that the ideal post-cure temperature in this study was 80 °C. For the automotive usability of these materials, different hybrid material combinations and post-cure temperatures will reveal the expected properties to be supported by further research.

Nomenclature

VARTM : Vacuum Assisted Resin Transfer Molding

JGJ : Jute-Glass-Jute

GJG : Glass Jute-Glass

MWCNT : Multi-walled carbon nanotubes

IL : Ignition Loss (%)

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Berkay Karaçor: Investigation, Writing-original draft, Resources
Mustafa Özcanlı: Conceptualization, Writing – review and editing

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