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# Influence of Nano-Silica on the Mechanical Properties of Jute/Glass Fiber Reinforced Epoxy Hybrid Composites

**Ahmet ERKLİĞ*[1] ORCID** *0000-0003-3906-3415*
**Ömer Yavuz BOZKURT[1] ORCID** *0000-0003-0685-8748*
**Wassan Falah AL-TEKREETI[2] ORCID** *0000-0003-3436-4884*

*[1] Mechanical Engineering Department, University of Gaziantep, Gaziantep,*
*[2] Inspection Department, NRC Company, Baghdad, Iraq*

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## Abstract

Natural composites have gained importance recently due to increasing environmental factors and relatively low cost. Although their biodegradability, low density, and high processability, the use of natural fibers in composite materials as the only reinforcement phase faces with some challenges due to their disadvantages such as high moisture absorption and low mechanical properties. To overcome these issues, the natural fibers are generally utilized in composite materials by synthesizing with synthetic fibers. In this context, jute/epoxy composites have been hybridized with glass fiber layers and nano-silica particles to improve low mechanical properties, and the contributions of hybridization on mechanical properties are investigated through performing tensile, bending, and impact tests. Nano-silica particles in the ratio of 1%, 2%, and 3% by weight have been used in composite production. Three different hybrid configurations ($G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$) are tested as well as pure jute/epoxy and pure glass/epoxy composites. According to the experimental results, nano-silica additive has a significant effect on both non-hybrid and hybrid fiber reinforced composites. By using the glass fiber layer on the outer surface, the highest tensile strength, flexural strength, and impact behavior have been achieved in the G1J6G1 hybrid configuration.

**Keywords:** Jute/glass fiber, Nano-silica, Hybrid composite

*Corresponding author (Sorumlu yazar) : Ahmet ERKLİĞ, *erklig@gantep.edu.tr*

## Nano-Silikanın Jüt/Cam Elyaf Takviyeli Epoksi Hibrit Kompozitlerin Mekanik Özellikleri Üzerindeki Etkisi

**Öz**

Doğal kompozitler, artan çevresel faktörler ve nispeten düşük maliyet nedeniyle son zamanlarda önem kazanmıştır. Biyolojik bozunurlukları, düşük yoğunlukları ve yüksek işlenebilirliklerine rağmen, kompozit malzemelerde tek takviye aşaması olarak doğal liflerin kullanılması, yüksek nem emilimi ve düşük mekanik özellikler gibi dezavantajları nedeniyle bazı zorluklarla karşı karşıyadır. Bu nedenle doğal kompozitler genellikle sentetik liflerle sentezlenir. Bu çalışmada jüt/epoksi kompozitler, cam elyaf tabakaları ve nano-silika parçacıkları ile hibritlenmiş çekme, eğilme ve darbe davranışları incelenmiştir. Kompozit üretiminde ağırlıkça %1, %2 ve %3 oranlarında nano silika partikülleri kullanılmıştır. Üç farklı hibrit konfigürasyonun ($G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$) yanı sıra saf jüt/epoksi ve saf cam/epoksi kompozitlerin testleri gerçekleştirildi. Deneysel sonuçlar nano-silika katkısı hem saf hem de hibrit kompozitler üzerinde önemli etkiye sahip olduğunu göstermiştir. Dış yüzeyde cam elyaf tabakası kullanılarak oluşturulan G1J6G1 hibrit konfigürasyonu en iyi gerilme mukavemeti, eğilme mukavemeti ve darbe tokluğunu vermiştir.

**Anahtar Kelimeler:** Jüt/cam elyaf, Nano-silika, Hibrit kompozit

## 1. INTRODUCTION

Natural fiber reinforced polymer composites are hybrids with both natural fiber and polymer properties. Because of their inactive and heat-resistant properties, phenol or melamine-formaldehyde resins reinforced with wood or cotton fiber were developed at the beginning of the 20th century and used in insulating electrical applications. One of the recent developments in the automotive industry is the natural fiber plastic composites in which natural fibers are beneficially used due to their specific weight and increase of ecological regulations. Natural fiber reinforced composites, such as jute fiber are used on a daily basis in a variety of industries such as buildings, electronic devices, sport equipment's, interior parts of vehicles and elevators. A growing number of studies aiming to replace synthetic fibers with natural ones across a range of engineering applications is found in the literature [1-8]. Natural fibers such as hemp, sisal, jute, cotton, flax, and broom are commonly used to strengthen polymers such as polyolefins, polystyrene, and epoxy resins [9,10].

In comparison to other materials, it has a comparatively a low elongation at break and high tensile modulus, jute fiber has become one of the popular natural fiber for the reinforcement of thermoset resins [11]. Compared to synthetic fibers such as carbon, glass and aramid, jute fibers can also be provided benefits in terms of cost and process in the production of composites. However, their relatively low mechanical properties and high-water absorption characteristics limit the use of natural fibers as the only reinforcement phase in the composite materials. Hybridization of natural fibers with synthetic ones is a commonly used technique to overcome these drawbacks in composites. It is possible to take advantage of natural fibers in structural applications through the hybridization of natural fibers with synthetic fibers [12-16]. For example, the hybridization of carbon fiber or glass fiber with natural fibers reduces the drawbacks of composites that are reinforced with only a natural fiber by providing improvements on strength and stiffness as well as resistance to water absorption.

Ashworth et al. [13] investigated the mechanical and damping properties of carbon, jute and hybrid carbon/jute fiber-reinforced composites. It was showed that hybridization with carbon fiber provided considerable improvements on tensile strength, modulus, and damping properties of the jute fiber reinforced composites. Ali et al. [14] investigated the bending and impact behavior of carbon/jute epoxy hybrid composites according to different jute ratios. The increase in the amount of jute in the hybrid structure caused a decrease in the flexural strength and an increase in the damage surface after the impact. Braga and Magalhaes [15] hybridized jute fiber with glass fiber to improve the mechanical properties of jute/epoxy composite. Two different hybrid configurations were created: glass/jute epoxy and glass/jute/glass. The addition of the glass layer into the jute/epoxy composite increased the impact energy, tensile and bending strengths of the composite. Rosa et al. [16] assessed the post-impact deterioration characteristics of jute/glass hybrid fiber-reinforced composite laminates. According to the results, the sudden breakage of jute fibers in glass/jute hybrid configuration under impact limits their use on the surface. However, more controllable damage was observed when jute fiber was used in the hybrid configuration in the center. The bending and indentation properties of different pultruded jute fiber and kenaf fiber/polyester composites and their hybrid composites with E-glass fiber were compared by Akil et al. [17,18] and the damage modes were monitored using acoustic emission. Results showed that the addition of glass reinforcement to the pultruded hybrid composite appeared to be highly effective in jute fiber reinforced laminates, but not comparable results in kenaf fiber laminates. Ramesh et al. [19] investigated the mechanical properties of glass fiber epoxy hybrid composites reinforced with jute and sisal fibers. According to the results, sisal fiber reinforcement increased the tensile strength of the hybrid composite compared to the jute fiber reinforcement, but the jute reinforcement increased the flexural strength of the hybrid composite. The effect of glass hybridization and the layering sequence effect on the tensile, bending and interlaminar shear properties of jute-glass fiber hybrid composites were investigated by Ahmed and Vijayarangan [20]. According to the results, hybridization of jute fiber composites with glass fiber significantly increased the mechanical properties and adding an outermost layer of glass fiber layer to the jute fiber composite showed the best mechanical properties. Rafiquazzaman et al. [21] investigated the tensile, flexural, and Charpy impact properties of chopped glass fiber and woven jute fabric reinforced epoxy matrix composite material. Hybrid composite production was carried out by hand lay-up method and two different proportions of the chopped glass fiber layer were considered. Accordingly, it was stated that if the optimum amount of jute fabric reinforcement was settled into the cropped glass fiber, the cost could be reduced without loss of strength.

The mechanical properties of composites are influenced by the interfacial bond between the reinforcing fiber and the resin. To eliminate the disadvantages of natural composites such as jute fibers, hybrid structures are formed with synthetic fibers such as glass fiber. However, due to the differences between the mechanical properties of the fibers, separation between the layers and a decrease in the mechanical properties can be seen. Therefore, nano-sized particles can be added to the resin to increase the mechanical properties of composite materials. In this way, both the mechanical properties of the matrix are improved and the bond between the layers is strengthened. Nanoparticles such as nano-silica and nano-clay are widely used in polymer matrix composites due to their low cost [22]. Afrouzian et al. [23] sought the effects of nano-silica particles on flexural, tensile, and quasi-static penetration properties of glass/epoxy composites. They reported that nano-silica particles were affecting the tensile, flexural, and energy absorption capacity of the glass/epoxy composites. Kallagunta and Tate [24] modified epoxy resin with 10 wt.% nano-silica to investigate the low-velocity impact behaviour of glass/epoxy composites under different impact energies. They reported that compared to unmodified composites, the nanoparticle modification resulted with high peak forces, also with rising impact forces, the density of failure mechanisms from matrix failure to fiber failure increases. Uddin and Sun [25] reported that adding 15% by weight of silica nanoparticles into epoxy resin (Nanopox F 400) increased the elastic modulus of unidirectional e-glass fiber-reinforced composites in the compression test. Also, this ratio of nano-silica additive slightly increased the tensile strength in the direction of the fiber.

Jute fiber and glass fiber are the well-known fiber types in the literature due to their widespread uses in various hybrid composite materials and the reinforcement of these hybrid composite with different nanoparticle additives have been widely investigated in the literature. However, the studies related with jute/glass hybrid fiber composites reinforced with nano-silica has not been encountered in the literature. The main aim of this study is to examine the effects of nano-silica particles on jute fiber, glass fiber, and hybrid glass/jute epoxy composites. The epoxy matrix was modified with 1%, 2%, and 3% by weight of nano-silica particles. Furthermore, three different hybrid structures were investigated: jute/glass/jute ($J_3G_2J_3$), glass/jute/glass ($G_1J_6G_1$), jute/glass/jute/glass/jute ($J_2G_1J_2G_1J_2$). Tensile, three-point bending and Charpy impact tests were performed.

## 2. MATERIALS AND METHODS

### 2.1. Materials

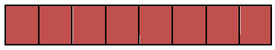
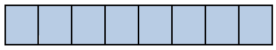
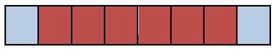
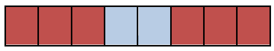
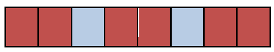
Nano-silica was supplied from Grafen Chemical Industries, Turkey with 99.5% high purity, 15 nm average particle size, 300 $m^2$/g specific surface area, and 0.05 g/$cm^3$ bulk density. The plain weave jute fabric having 311 g/$m^2$ areal density was supplied by the local market in Gaziantep, Turkey. Plain weave E-glass fabric with 200 g/$m^2$ areal density, Epikote MGS LR160 epoxy resin and Epikote MGS LH160 hardener were bought from DOST Kimya, Turkey. Jute fabrics were treated by NaOH solutions with concentrations of 1% at 25°C for 2 hours. The fabrics were further cleaned with water including acetic acid to eliminate the sodium hydroxide. Lastly, the fibers were cleaned again with fresh water and dried at 60°C for 24 hr. until completely dry.

### 2.2. Production of Composite Laminates

Eight-layer non-hybrid and their 1 wt.%, 2 wt.%, and 3 wt.% of nano-silica particle filled jute/epoxy ($J_8$), glass/epoxy ($G_8$) composites were prepared as the reference samples Hybrid fiber reinforced composites in three different stacking configurations ($G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$) containing 2 wt.% of nano-silica particles were also prepared as eight-layered.

Fabrics were cut in 300 mm × 250 mm dimensions. The mixing ratio of epoxy (EPIKOTE MGS LR160) and hardener (EPIKOTE MGS LH160) was used as 100:25±2 by weight following the instructions found on the boxes of epoxy and hardener. Epoxy resin and nano-silica particles were firstly mixed with a mechanical stirrer at 650 rpm constant speed for 20 minutes. After that, a hardener was added to the mixture and mixed with the same speed for 5 minutes to get a homogeneous mixture. Composite samples were laminated using a hand layup method and cured in a hot press under 0.4 MPa pressure at 80°C for 1 hour. Then composite laminates left for cooling under pressure. Table 1 shows the stacking configurations and thicknesses of the relevant composites. The test coupons were removed from the laminates using a CNC router according to the dimensions mentioned in ASTM standards. ASTM D790-10 [26], ISO 179/92 [27] and ASTM D638-10 [28] were used for flexural, impact and tensile tests, respectively.

**Table 1.** Composite configurations and thicknesses

| Laminate Codes | Configuration | Thickness |
|---|---|---|
| $J_8$ |  | 6.2 mm |
| $G_8$ |  | 1.6 mm |
| $G_1J_6G_1$ |  | 5.2 mm |
| $J_3G_2J_3$ |  | 6.4 mm |
| $J_2G_1J_2G_1J_2$ |  | 6.4 mm |

### 2.3. Determination of Mechanical Properties

The tensile and flexural strength characteristics of the composite samples were measured at room temperature using the AG-X series Shimadzu universal testing machine with a 300kN capacity (Kyoto, Japan). Tensile test specimens were prepared in a dog bone shape with a gauge length of 50 mm and flexural test specimens were in 200 mm × 12.7 mm with a span to thickness ratio of 32:1. The thickness of tensile, flexural, and impact specimens was changed depending on the type and number of layers (glass or jute) that were used to fabricate the laminates and variation of nano-silica content. The crosshead speed was 3 mm/min for a test of flexural and 2 mm/min for a test of tensile. Köger 3/70 Charpy impact test machine was used for the low-velocity impact tests in which specimens having 55 mm ×10 mm dimensions were employed. Five samples were tested for each composite configuration, and averages of them were presented.

## 3. RESULTS AND DISCUSSION

### 3.1. Tensile Test Results

The stress-strain curves for the tensile tests of non-hybrid (glass/epoxy and jute/epoxy) composites reinforced with varying weight ratios of nano-silica particles are presented in Figure 1. It is seen that the addition of nano-silica particles obviously affects the tensile strength and strain up to the failure of both glass/epoxy and jute/epoxy composites. An increase in tensile strength values is achieved with the incorporation of nano-silica particles to pure non-hybrid jute/epoxy composites. In contrast, except the incorporation of 1 wt.% nano-silica, decreases in tensile strength values is obtained with the inclusion of nano-silica to glass/epoxy composites. The inclusion of nano-silica particles has led to a reduction in tensile failure strain of glass/epoxy composites. Except the 2 wt.% nano-silica, the addition of nano-silica particles to jute/epoxy composites has also exhibited a similar decrement trend in tensile failure strain of jute/epoxy composites. Fig. 2 shows the average tensile strength values of non-hybrid (glass/epoxy and jute/epoxy) composites with different amounts of nano-silica particles. Compared to their pure mates, the highest enhancement in tensile strength is obtained as 76.6% for jute/epoxy composites and 16.3% for glass/epoxy composites with the incorporation of 2 wt.% and 1 wt.% nano-silica particles, respectively. The improvement in tensile strength with the inclusion of nano-silica particles were ascribed to good interfacial bonding between the epoxy and nano-silica particles [29, 30]. This interfacial bonding provides an extra load carrying capability with the transfer of load from lower strength epoxy to the much higher strength nano-silica particles. Cohesion between nano-silica particles could lead to agglomeration resulting in stress concentrations between epoxy and nano-silica particles. This is thought to be reason of the decrements in tensile strength of both glass/epoxy and jute/epoxy composites with the inclusion of nano-silica particles at higher amounts [31].

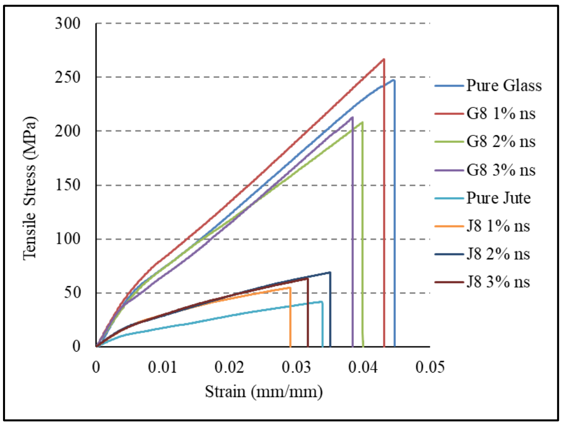



**Figure 1.** Tensile stress-strain curves of the jute/glass fiber epoxy composite.

### 3.2. Tensile Test Results of the Jute/Glass Hybrid Configurations

The jute/epoxy composites are exhibited very low tensile properties compared to glass/epoxy ones and the highest improvement has been achieved with the inclusion of 2 wt.% nano-silica particles. This jute/epoxy configuration is selected for the further improvement of mechanical properties through hybridization with glass fiber. In this context, symmetrical configurations have been prepared with the replacement of 2 jute fabric layers from the different places of stacking sequence by the glass fabrics. Tensile strength variations of the jute/glass epoxy hybrid configurations with 2 wt.% nano-silica content is shown in Figure 3. The tensile strength results showed that the best configuration is $G_1J_6G_1$ with a value of 92.00 MPa compared to that of jute/epoxy laminate 2 wt.% nano-silica ($J_8$ 2% ns). The significant increase in the tensile strength of the $G_1J_6G_1$ hybrid composite is ascribed to stiffer and stronger structure of glass fiber compared to jute fiber [6]. Hybrid structures in which glass fabrics are substituted in inner layers ($J_3G_2J_3$, $J_2G_1J_2G_1J_2$) exhibited a tensile strength of 74.02MPa and 76.85MPa, slightly increasing compared to the tensile strength of 2% nano-silica filled jute/epoxy laminate by weight.

All samples shown in Figure 4 have mostly displayed crack and fiber pull-out as the failure mechanism. When the applied tensile load increases, the specimens are separated into two parts where the break starts with matrix cracking, then fiber breakage and separation of jute/glass layers start from the interface surface.

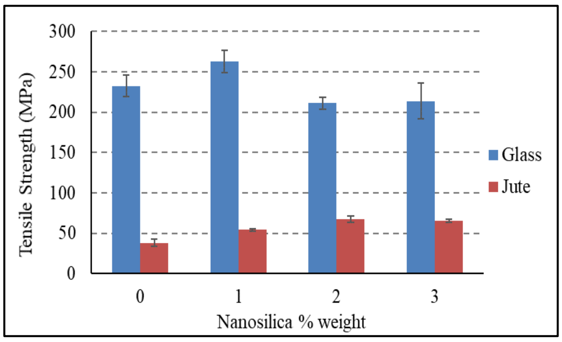



**Figure 2.** Variation of tensile strength according to nano-silica content

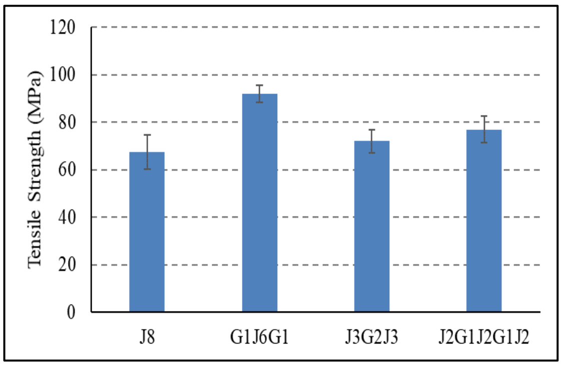



**Figure 3.** Variation of tensile strength of the jute/glass hybrid configurations with 2wt.%.

### 3.3. Flexural Result of Jute/epoxy and Glass/epoxy Composite Plates

The force-displacement curves for the flexural tests of non-hybrid (glass/epoxy and jute/epoxy) composites reinforced with varying weight ratios of nano-silica particles are presented in Figure 5. It is seen that the addition of nano-silica particles negatively affects the deflections of both glass/epoxy and jute/epoxy composites. Flexural strength and flexural modulus values were calculated according to ASTM D-790-10 standard. Figure 5 shows the flexural strength and modulus of jute/epoxy and glass/epoxy composites with respect to nano-silica loadings. The increase in nano-silica ratio has a significant effect on jute/epoxy composites. However, the addition of nano-silica particles has a negative effect on the glass/epoxy composites. The flexural strength of pure glass/epoxy is exhibited a decrease from 238.01 MPa to 202.08 MPa at 1 wt.% nano-silica content. It is thought that agglomeration of nano-silica particles, which may cause the weak interaction between nano-silica and epoxy matrix, the formation of stress condensation zones and thus the initiation of cracks, leads to a reduction in the flexural strength of the composite [24]. The highest flexural strength is 110.38 MPa with jute/epoxy at 2 wt.% particle content. There is an increasing trend in flexural strength of jute/epoxy composites up to 2 wt.% nano-silica loading, and the maximum improvement has been obtained as 96.42% compared to neat jute/epoxy composites. A decline in flexural strength is viewed with the further nano-silica substitution. This showed that the chemical compatibility and adhesion strength between the nano-silica particles and the jute/epoxy are optimal in this content. The inclusion of nano-silica particles has also provided a similar trend for the flexural modulus and the maximum flexural modulus for jute/epoxy composites is obtained with 2 wt.% nano-silica amount which presents an increase of 53.3%. On the other hand, the flexural strength and modulus of glass/epoxy composites show a different trend that decreasing with the inclusion of 1 and 2 wt.% nano-silica. The improvement in flexural modulus and flexural strength is only seen for the 3 wt.% nano-silica additive.

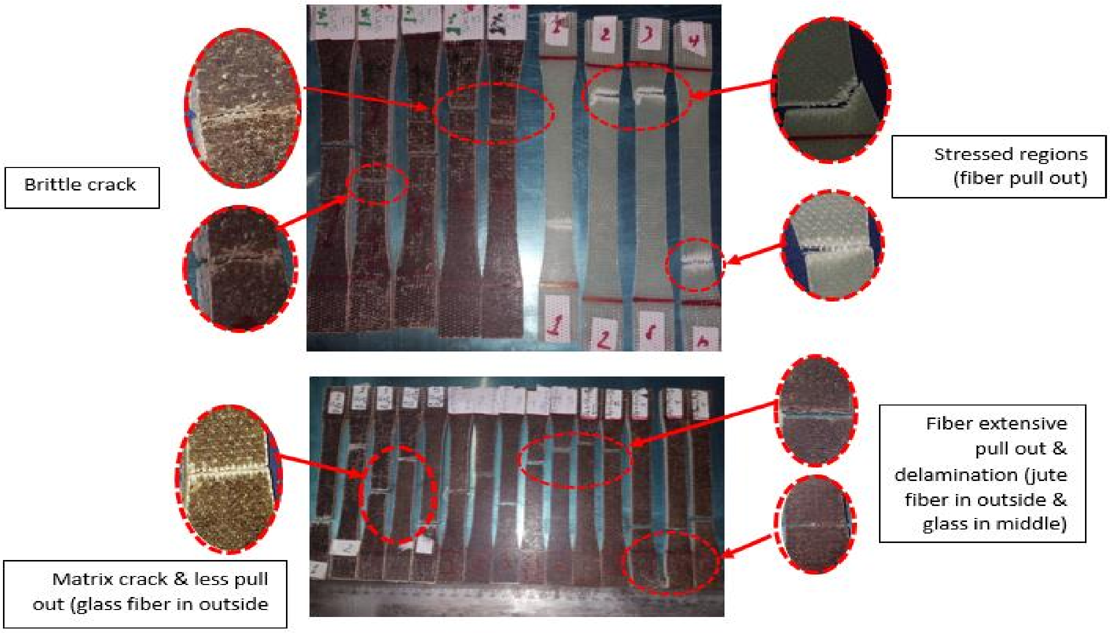



**Figure 4.** Failure of specimens after tensile test

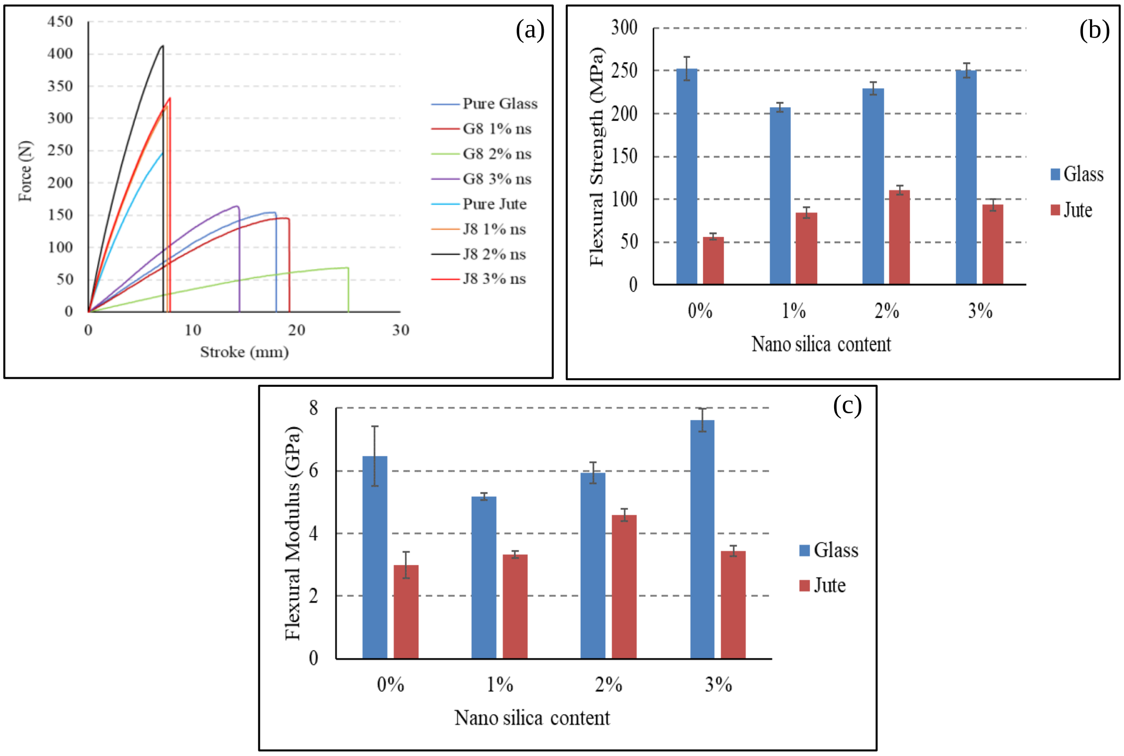



**Figure 5.** (a) Load-displacement (b) Flexural strength (c) Flexural modulus of glass/epoxy and jute/epoxy with various nano-silica addition

### 3.4. Flexural Test Results of the Jute/Glass Hybrid Configurations

A flexural test result of jute/epoxy composite is lower than glass/epoxy composite. Glass layers have been used to improve the strength of jute/epoxy composites. Symmetric configurations have been prepared by replacing 2 jute fabric layers from the different places of stacking sequence with glass fabrics. $G_1J_6G_1$, $J_3G_2J_3$, and $J_2G_1J_2G_1J_2$ hybrid configurations having 2 wt.% nano-silica content are taken into consideration.

Flexural strength and modulus variation of the jute/glass hybrid configurations specimens with 2 wt.% nano-silica content is shown in Figure 6. A substantial improvement in the strength of the material has been achieved by adding glass layers to the jute/epoxy composite. The $G_1J_6G_1$ hybrid configuration has provided the maximum improvement with 176.67 MPa and 8.56 GPa flexural strength and modulus, respectively. In this configuration, the glass layers are outermost and jute is in the middle. The increase in flexural strength of the $G_1J_6G_1$ hybrid composite can be attributed to the stiffer structure of glass fiber which becomes more effective at outer layers [6]. The use of glass fabrics at inner layers ($J_3G_2J_3$, $J_2G_1J_2G_1J_2$ configurations) has provided lower flexural properties than the jute/epoxy composites ($J_8$ 2 wt.% nano-silica).

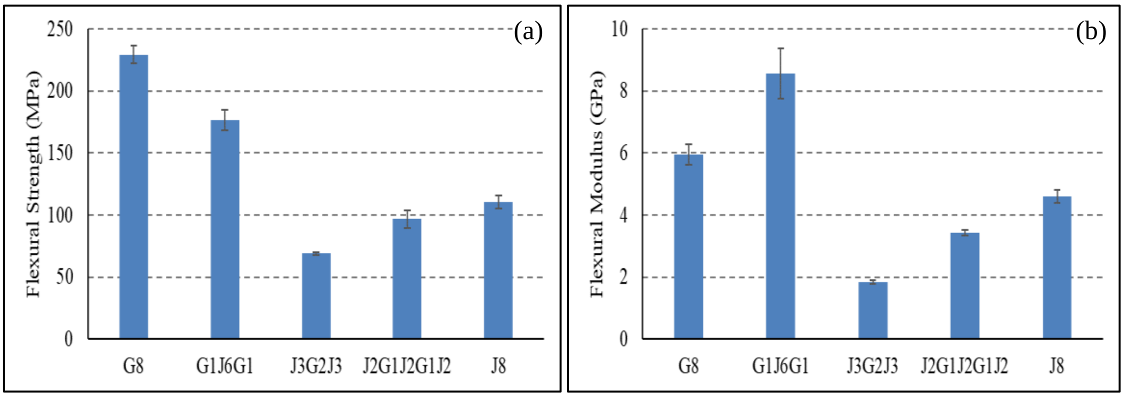



**Figure 6**. (a) Flexural strength and (b) Flexural modulus variation of the jute/glass hybrid configurations specimens with 2 wt.% nano-silica content

Fracture surfaces of the jute/epoxy and glass/epoxy composites after the three-point bending test are seen in Figure 7. A brittle crack due to jute fiber properties is observed in samples that only jute fibers are used as the fiber reinforcement. Fiber shrinkage has not observed in samples consisting only of glass fiber layers, due to the strength and rigidity of glass fibers [2]. No delamination has been observed between the jute fiber and glass fiber layers in hybrid configurations, and the fracture mode is with little or no fiber stripping. This may be because glass fibers have greater extensibility than jute fibers [20]. However, failure mode indicates breakage and less pulling of the fibers.

### 3.5. Impact Result

The Charpy impact test has been performed to measure the absorbed impact energy for jute/glass/epoxy composites. The impact toughness values for the impacted specimens are presented in Figure 8. The impact toughness of jute/epoxy and glass/epoxy composites has gradually increased by the addition of nano-silica particles and the highest impact toughness is obtained at 2 wt.% nano-silica content. Further addition of nano-silica has led to reduction in impact toughness of the composite test samples.

Impact toughness variation of the jute/glass hybrid configurations specimens with 2 wt.% nano-silica content is shown in Figure 9. The best laminate is $J_3G_2J_3$ with impact toughness 43 kJ/m$^2$ when compared to that of jute/epoxy laminate J8 2 wt.% ns that glass layer location in middle and jute in the outer layer.

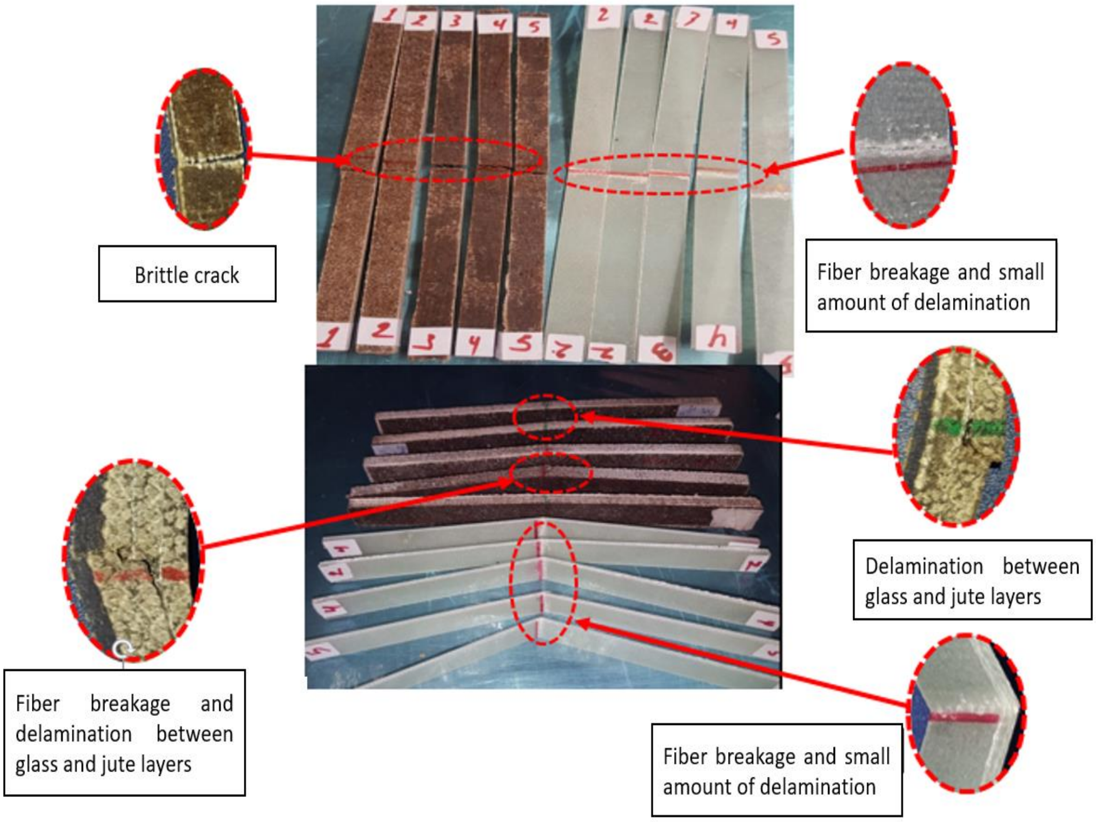



**Figure 7.** Flexural specimens after the three-point bending test

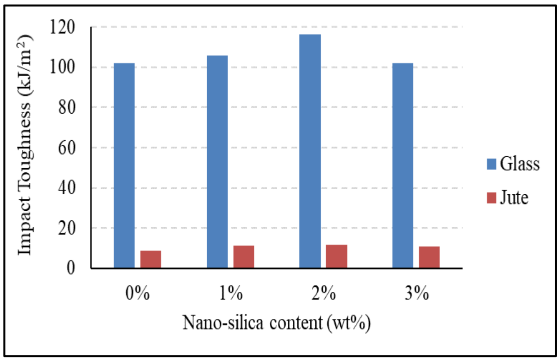



**Figure 8.** Variation of impact toughness of composites

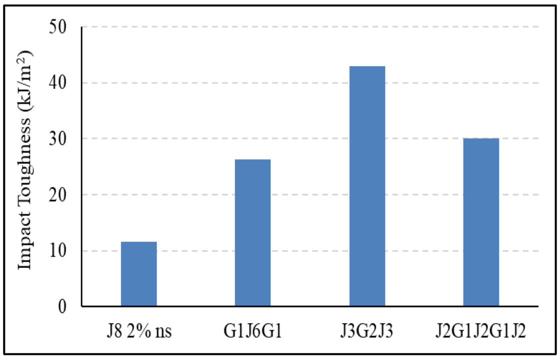



**Figure 9.** Variation of Impact Toughness of the Jute/Glass Hybrid Configurations with 2wt.% nano-silica

## 4. CONCLUSION

In the present work, mechanical properties of glass/epoxy, jute/epoxy, and glass/jute/epoxy hybrid composite laminates were investigated with different weight ratios of nano-silica particles. The main conclusions from this study can be explained as:

- When hybrid configurations were inspected, the highest tensile strength was obtained from the $G_1J_6G_1$ hybrid configuration where glass layers are in out and jute layers in middle with a value of 92.01 MPa. 37.31% increase was obtained when compared with jute/epoxy having 2 wt.% nano-silica content.

- The maximum improvement in flexural strength was obtained as 96.42% for jute/epoxy composite at 2 wt.% by weight particle content.

- When hybrid configurations were inspected, the highest flexural strength was obtained from the $G_1J_6G_1$ configuration where glass layers are in outer and jute layers are at middle with a 37% increase was obtained when it's compared with jute/epoxy having 2 wt.% nano-silica content.

- When hybrid configurations were inspected, the highest impact energy was obtained from the $J_3G_2J_3$ hybrid composite configuration where glass layers are in the middle and jute layers are in the outer. A 270% increase was obtained when compared with jute/epoxy having 2 wt.% nano-silica content.

- Placing glass fiber as a layer on the outer surface will be sufficient to increase the mechanical properties of jute/epoxy composites.

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