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M.Sc. in Mechanical Engineering

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REPUBLIC OF TURKEY
UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

INVESTIGATION OF THE MECHANICAL PROPERTIES OF NANO-SILICA PARTICULATE JUTE/GLASS FIBER HYBRID COMPOSITES

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Investigation of The Mechanical Properties of Nano-silica Particulate Jute/Glass Fiber Hybrid Composites

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Assoc. Prof. Dr. Ahmet ERKLİĞ

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Wassan Falah Hassan

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This is to certify that we have read this thesis and that in our concerns opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Wassan Falah HASSAN

ABSTRACT

INVESTIGATION OF THE MECHANICAL PROPERTIES OF NANO-SILICA PARTICULATE JUTE/GLASS FIBER HYBRID COMPOSITES

WASSAN FALAH HASSAN

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The increasing demand for environmental friendly materials and the desire to reduce the cost of traditional fiber lead to the development of natural fiber composites. Natural fibers presented in the composite have some important advantages such as low density, appropriate stiffness. Mechanical properties of natural fibre composites are much lower than those of synthetic fiber composites in an effort to develop a superior, but economical composite, a natural fiber can be combined with a synthetic fiber in the same matrix material so as to take the best advantage of the properties of both the fibers. In this study, tensile, flexural and impact properties of jute, glass and hybrid jute/glass fiber nano-silica particle filled epoxy matrix laminated composites were investigated. Nano-silica content ratios were 1wt %, 2wt% and 3wt % in the epoxy. Hybrid configurations were produced as G_8, $G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$ and J_8. The composite laminates were fabricated by hand lay-up process. The charpy impact tests were conducted according to ISO 179/92 standard, tensile tests were conducted according to ASTM D638-10 standard and flexural tests were conducted according to ASTM D790-10 standard. The results of the tensile, flexural and impact tests showed that 2wt.% ratio of nano-silica content gives the best values for all hybrid and non-hybrid configurations.

Key Words: Jute/Glass fibre, nano-silica, hybrid composite.

ÖZET

NANO-SİLİKA PARÇACIKLI JÜT/ CAM ELYAF HİBRİT KOMPOZİTLERİN MEKANİK ÖZELLİKLERİNİN ARAŞTIRILMASI

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67 sayfa

Çevre dostu malzemeler için artan talep ve geleneksel elyafın maliyetinin azaltılma isteği doğal elyaf kompozitlerinin popülaritesinin artmasına yol açmaktadır. Kompozit malzemelerde kullanılan doğal lifler, düşük yoğunluk, uygun mukavemet gibi bazı önemli avantajlara sahiptir. Doğal elyaf kompozitlerin mekanik özellikleri sentetik elyaf kompozitlerden çok daha düşüktür, ancak üstün ve ekonomik bir kompozit geliştirmek için doğal bir elyaf ile bir sentetik elyaf aynı matriks malzemesinde kombine edilebilir ve böylece her iki lifin en iyi özellikleri birleştirilebilir. Bu çalışmada jüt, cam ve hibrit jüt / cam elyaf nano-silis parçacık dolgulu epoksi matriks lamine kompozitlerin gerilme, eğilme ve çarpma özellikleri incelenmiştir. Nano-silika içeriği oranları epoksi'de %1, %2 ve %3'tür. Hibrit konfigürasyonlar G_8, $G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$ ve J_8 olarak üretildi. Kompozit laminatlar elle yatırma yöntemi üretildi. Charpy darbe testleri ISO 179/92 standardına göre yapıldı, ASTM D638-10 standardına göre çekme testleri yapıldı ve ASTM D790-10 standardına göre bükme testleri yapıldı. Çekme, eğilme ve darbe testlerinin sonuçları, nano-silika içeriğinin %2'lik oranının tüm hibrit ve hibrit olmayan konfigürasyonlar için en iyi değerleri verdiğini göstermiştir.

Anahtar Kelimeler: Jüt/cam elyaf, nano-silika, hibrit kompozit

To my husband, I am grateful to God for having husband like you. Your unconditional love and support made my every achievement possible.

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LIST OF SYMBOLS/ABBREVIATIONS

FRP	Fiber Reinforced Polymer
CFRP	Carbon Fiber Reinforced Polymer
GRC	Glass Reinforced Cement
GRP	Glass Reinforced Polymer
SEM	Scanning Electron Microscope
PP	Polypropylene
ILSS	Inter-Laminar Shear Strength
USP	Unsaturated Polyester
PBS	Butylene Succinate
PJF	Phthalic Anhydride Treatment of Jute Fibers
SJF	Succinic Anhydride Treatment of Jute Fibers
HDPE	High Density Polyethylene
MAPE	Maleic Anhydride Grafted Polyethylene
EDTA	Ethylenediaminetetraacetic acid
EFB	Empty Fruit Bunch
SLS	Sodium Lauryl Sulphate
SJGFRP	Sisal/Jute and Glass Fiber Reinforced Polymer

CNC	Computer Numerical Control
σt	Tensile Strength
σf	Flexural Strength
Ef	Flexural Modulus
wt. %	Weight Percentage
EC	Electric Cutter
ASTM	American Society for Testing and Materials
MWCNT	Multi-Wall Carbon Nano Tubes
PNCs	polymeric Nano-composites
EPC	Epoxy Reinforced Polymer composite
G	Glass fiber
J	Jute fiber
NS	Nano-silica

CHAPTER 1

INTRODUCTION

1.1 introduction

The polymer composite material has been used for its unique properties such as ease of manufacture, light weight, low cost and high resistance comparison with monolithic metal alloy [1]. Due to the rare characteristic possessed led to being the appropriate choice in many applications such as, the blades of helicopter rotor, pipe lines, holding sand slurries in oil refineries, aircraft operating and vehicle of high-speed in wilderness environments, water turbines, and blades of aircrafts engines. [2, 3].

Natural fibers such sisal, linen, silk, jute, banana, and cotton fiber are utilized from downward time as a source of cellulose-base fiber. The characteristics of natural fibers are biodegradable in nature, resources natural fibers are a reinforcing material that is used as an alternative to conventional fibers in the work where the composite needs a low weight [4]. Unlike synthetic fibers such as glass fiber, it is easier to break when intensely mixed with polymer resin. However, a number of different natural fiber hybrid composites have superior mechanical strength, due to the compatibility fiber of a polymer matrix required by the natural hydrophobic nature, flammability at various temperature grades, and increased working characteristics of natural fibers. Meanwhile, researchers are interested in natural fibers as lightweight and low cost reinforced materials. Natural fibers provide many benefits in low density conditions such as cost of total weight, specific module, cost per length, biodegradability, and renewability naturally required for composite production with green composite and bio-resin [5, 6]. More or less of the natural fiber is used as reinforcement in the production of the hybrid polymer composite. Fiber reinforced polymer composites also have better damping properties, good fatigue resistance and high corrosion resistance [7]. Natural fiber classification is shown in Figure 1.1.

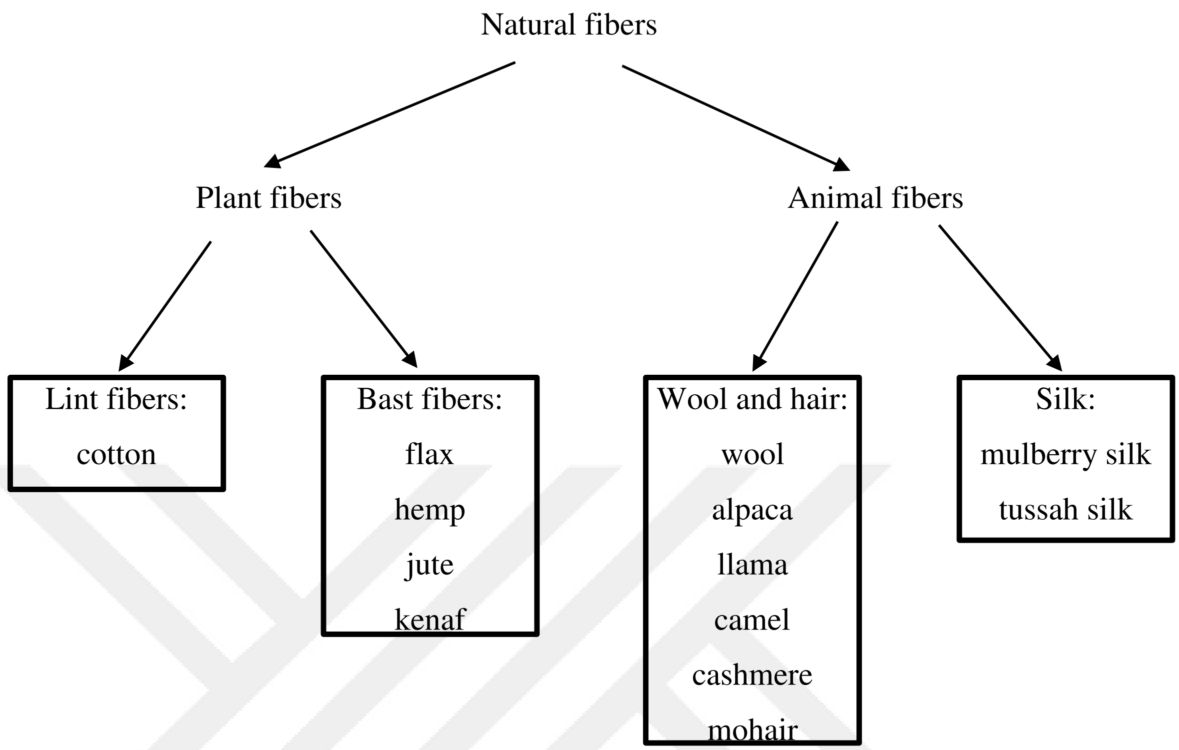


Figure 1.1 Natural Fiber Classification

1.2 Composites

A composite material is a material made from two or more component materials having substantially different physical or chemical properties, when combined, produce a material having different properties. Generally, it has got two phases as reinforcement and matrix. A matrix can be metal, ceramic, or polymer. Composites are ordinarily having a fiber or particle phase in solid and vigorous than continuous matrix phase. There are many examples of utilized it starting from the shield used at wars and ending with a modern application in tires and luxury parts such as fishing boats, plastic pipes and human parts such as the industrial heart and the manufacture of bricks and armor and ships. Composite classification is important in any analysis and discussion of how the composite characteristics are influence by the inner reinforcement of the geometries. There are two types of composites, the first is based on matrix and the second is based on reinforcement. Everyone has unique characteristics divided into specific classes as shown in Figure 1.2 [8].

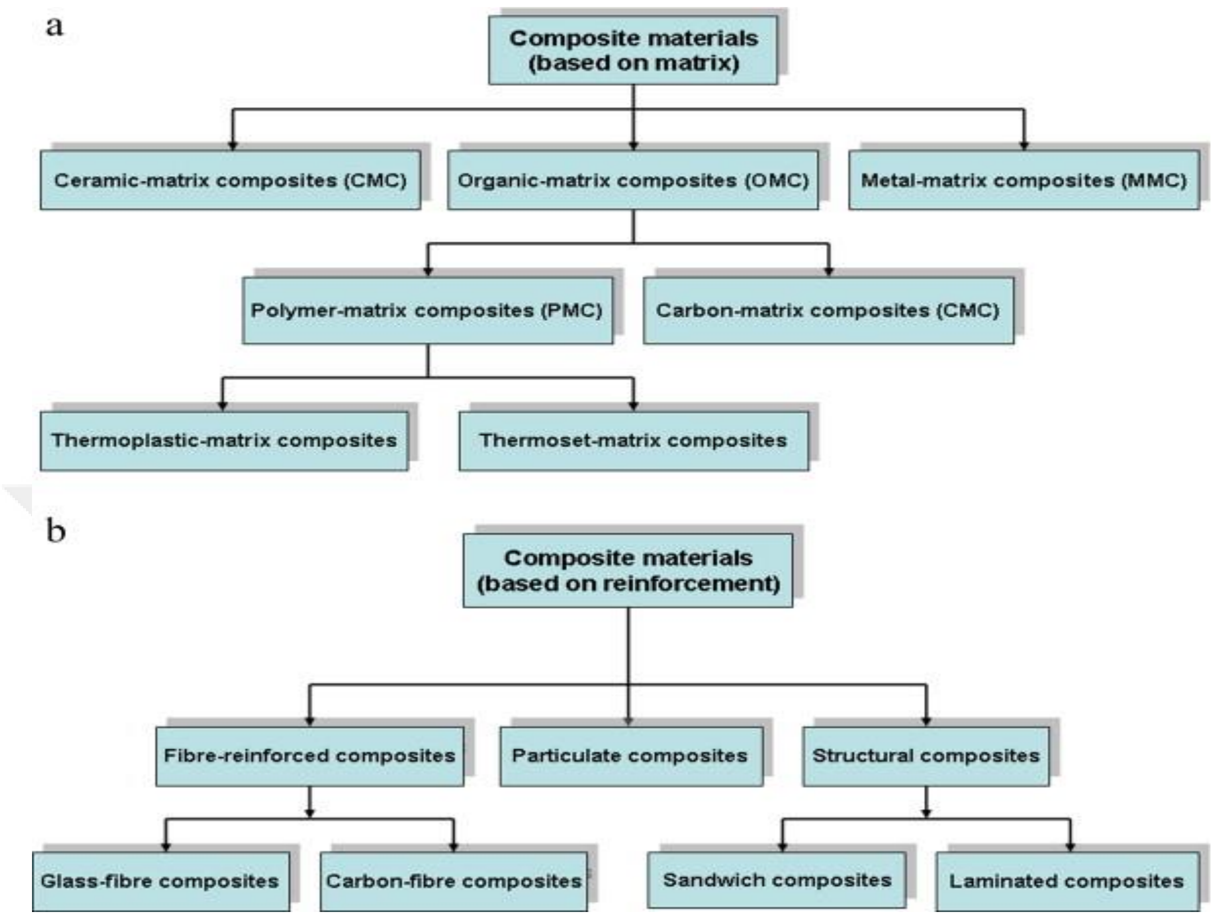


Figure 1.2 Classification of Composites [8]

1.3 Benefits and Disadvantages of Composites

Composites are creating a significant advantage by aggregate the original characteristics of the contained material. Today, composite materials are produced in order to ensure adaptation with outstanding features include the difficult working conditions. A superior feature expected from a material generally are as below;

• High strength,

• High rigidity,

• High fatigue resistance,

• Superior wear resistance,

• High temperature capability,

• High corrosion resistance,

• High thermal conductivity,

• Formability,

• Low density,

• They reduced the number of complex parts because of the part produced as a single.

All the above features can be obtained in composite material if it is considered to suitable matrix/reinforcement element pairs, manufacturing techniques, Strength advantage of components and other factors. The selection of appropriate matrix / reinforcing elements is important in mechanically and physically properties of system. For composite materials, the bond among the matrix and the reinforcement elements must be strong in order to transfer the load from the matrix to the reinforcing element [9, 10]. This depends on the harmony of pair. Besides the above-mentioned excellent properties, some disadvantages are also available for composite materials. These are as follows;

• Production difficulties,

• It is expensive,

• There is no recycling for composite material,

• Operating problems,

• High operating costs,

• It is difficult to achieve the required surface roughness,

• The air particles in the polymer based composite materials adversely affects the fatigue properties of material [10, 11, 12].

1.4 Hybrid Composite

Hybrid composites are materials produce by merging more or two different kind of fillers in a common matrix. Through hybridization is likely to balance performance characteristics and cost of composite, which cannot be obtained through one set of reinforcement. And then through choice of processing and reinforcements techniques, it is likely to engineer the hybrid material to Improvement commensurate with various practical requirements with economic gains. [13, 14] Hybrid composites has more than one reinforcement or one matrix phase in a composite laminate. Basically, there are four types of hybrid laminates as:

- Interply hybrid composites have more than one different reinforcement in composite laminates. For example, car bumpers have two laminate materials (glass/epoxy and graphite/epoxy). Glass/epoxy layers supply torsional rigidity and graphite/epoxy layers provide toughness.
- Intraply hybrid composites have more than one reinforcement in laminate. Golf clubs are produced using aramid and graphite fibers in same layer. Aramid fibers supply tensile strength and toughness and the graphite fibers provide the torsional rigidity.
- Interply–intraply hybrid composites are combination of interply and intraply hybrid composites. Such that it has more than one fiber in same ply and also different fiber in layers.
- Resin hybrid composites are produced by the use of more than one resin for each layer. One resin may give rigidity and other one may give flexibility.

1.5 Fiber

Fiber or fibre is a natural or artificial material that is notably longer than its width. Fibers are frequently utilized in manufacture of another substance. The most powerful engineering materials frequently incorporate fibers such as, glass fiber, carbon fiber, aramid fiber, ultra-high-molecular-weight polyethylene fiber etc. There are two types of fiber as natural fibers (hemp, cotton, flax, jute, ramie, sisal, banana, and bagasse ...etc) and synthetic fibers (polymer fibers, mineral fibers, fiberglass, carbon fiber, etc.) [13].

1.6 Jute Fiber

Jute is a plant of corchorus species grown every year. It has different types; white jute and tossa jute are the most common [14]. It is mainly grown in India and Bangladesh. It takes 2-3 months to grow recording 3-5 meters tall. It has a thick covering named as jute cane and burst fibers sprung surrounding the pulp. To separate the jute burst fiber, the following process is carried out; by putting jute stalks in tanks for many weeks, during this process the microbial action helps in softening the jute and weakening the bonds between the parts. The fiber filaments are then stripped off manually from the jute plate and hung on the shelves to dry. Long fiber strands can be produced in this way [15]. The employ of jute fiber for a composite had numerous benefits [16]. Jute was renewable multilateral which does not cause scratchin , pored, visco elastic, decomposes , crusty , computable and interacting. Jute fiber was a rising aspect proportion, elevated intensity to weight rate and was good insulation property. Jute being expensive effective materials especially in the construction industry. Figure 1.4 shows jute fiber.

Figure 1.3 Jute fiber

1.7 Glass Fiber

Glass fiber is a material consisting of a large number of highly fine glass fibers. Although it is not as strong as carbon fiber, it is cheaper and less fragile when used in composites. Familiar glass fibers are silica based (50-60% SiO_2) and comprises of a steward of another oxides of calcium boron, sodium, aluminum, and iron. E-glass is a useful electrically insulator in addition to possessing perfect strength and a sensible Young's Modulus. C-glass possesses a best resistance to chemically corrosion S-glass withstand higher temperature than other glasses. Most of the continuous glass fiber produced is of the E-glass type but, notwithstanding the designation E, electrically employ of E-glass fiber are only teeny fraction of the total market [17, 18].

Glass fiber reinforced polymer composites have three important limitations:

1. Relatively low elastic modulus
2. Low interlaminar shear strength, if associated with tensile strength.
3. Compressive properties are lower than tensile properties.

The low modulus of glass reinforced composites limits its usefulness in applications where buckling stability or high natural frequency is an important criterion. Both compressive and shear failure limit the bending performance. Figure 1.5 shows typical glass fabric.

Figure 1.4 Glass Fiber

1.8 Matrix

The goal of the matrix in a composite material is to transfer and redistribute loads towards and between fibers. It also maintains the right direction of fibers, protects the fibers from the environment and provides resistance to interlaminar shear, compressive strength and transverse resistance. Matrix is also the responsible of determining the process ability and the maximum service temperature of the composite material. There are three main types of matrix as polymer, metal and ceramic. Polymeric matrix can be divided as thermoset and thermoplastic. Thermoset polymers are presented without polymerization, doing it during the manufacturing process of the final piece while thermoplastics are presented in solid state polymerized. [19].

1.9 Nano-Particle

"Nano" denotes nanometer (10^{-9} m). A nanoparticle is a microscopic molecule with at the minimum one dimension little than 100 nm. Nano molecule research is currently a region of intense scientific research, due to a broad kind of potential enforcement in optical, biomedical, and electronic scope. Nano molecules are of large scientific benefit as they are influentially an embankment between size materials and atomic or molecular structures [20]. A size material should have fixed physical props regardless of its magnitude, but at the nano-scale this is frequently not the case. Nano technology has advanced into a multi-disciplinary scope of technology and practical sciences. The ability work on the level about 1–100 nm was nanotechnology by a view to create, comprehend, depict and utilize physical structures, apparatus and systems to new characteristics derived from their nanostructures [Roco, 2003]. On account of their magnitude, Nano molecules possess proportionately massive surface and thus more surface atoms than their microscopic counterparts [21]. Figure 1.6 shows some nano-particles.

Figure 1.5 Nano-Particles [22]

1.10 Nano- Silica

It is an inorganic chemical material commonly known as silica, since the ultrafine nanometer size rang 1-100nm, and therefore has many unique properties to the other inorganic material. NS was supplied from Grafen Chemical Industries, Turkey with a high lucidity 99.5%, 15 nm average particle size, 300 m2/gr specific surface area and 0.05 gr/cm^3 bulk density. Derivatives of nano-silica have been rated as an effective filler in enhancing composite's mechanical characteristic; however, there are a little research that report enhancements in parameters of mechanical like as elongation, elastic modulus, tensile strength, and toughness. It is showed that the filler additive may be useful for the enhancements of a certain characteristics but may reason the decline of other characteristics.

1.11 The Objectives of Research and Tasks

In this study, the aim is to inspect the effects of nano-silica in tensile, flexural and Charpy impact behavior of Jute/glass/epoxy composite laminates. The research tasks can be summarized as follows;

Production of jute/epoxy composite laminates filled with nano-silica.

Production of Jute/glass/epoxy composite laminates filled with nano-silica using different stacking sequence.

Production of glass /epoxy composite laminates filled nano-silica.

Conduction of the tensile, flexural and Charpy impact tests for all of prepared laminates.

Discussion of nano-silica using the results of experiments on the effects of composites on mechanical properties.

1.12 Layout of Thesis

The study has been divided into five chapters.

A general introduction, research objectives and tasks of the study are given in Chapter 1.

A comprehensive literature survey is presented in Chapter 2. Literature review be classified to four parts; introduction and literature survey conclusion.

In Chapter 3, information about the materials (fibers, epoxy, and nanoparticle) and fabrication method used in this study are provided.

The results and discussions of tensile, flexural and Charpy impact experiments are offered in Chapter 4.

General conclusions about the results are offered at Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the literature review, researches on natural fiber reinforced composite materials and hybrid fiber reinforced composite materials and the effects of various factors on the performance of the composites examined by various researchers have been investigated. Several investigations have been conducted on the effectiveness of different fillers on mechanical, thermal and some other properties of composite materials. This study deals with particles in the mechanical properties of composite materials, and similar studies in the literature have been investigated.

Literature review has been arranged in five sections as:

- Studies on jute/glass and natural fiber/glass hybrid fiber reinforced composite laminates
- Studies hybrid fiber reinforced composite laminates
- Studies on particle filled composites
- Studies about treatment for jute fiber reinforced composite laminates
- Studies about untreated jute fiber reinforced composite laminates

2.2 Studies on Jute/Glass and Natural Fiber/Glass Hybrid Fiber Reinforced Composite Laminates

Aquino et al. [23] examined absorbed moisture influence in mechanical characteristics of glass/jute hybrid composite created by ortho-phthalic polyester resin. The results showed the maximum moisture absorption after eleven months from water immersion for the hybrid composite was 7.64%. Also display that the absorbed moisture caused reduced in mechanical characteristics for both loading kinds, bending and tensile of hybrid composite.Braga [24] investigated thermal and mechanical characteristic of glass/jute fiber epoxy hybrid composites. Jute, glass fibers and epoxy resin were laminated in three weight ratios (31/0/69, 25/7/8 and 18/19/64) respectively to create composites. The flexural, tensile, density, impact, water absorption and thermal tests were done utilizing hybrid composite laminated. This study display that added glass fiber and jute fiber in epoxy, increases the impact energy, the density, the flexural strength and the tensile strength, in other side reduced the water absorption and the loss mass in function of temperature. Morphological analysis was done to show fiber a retreat & breaking attitude of the samples by employ scanning electron microscopic (SEM).

Rosa et al. [25] investigated the post-impact deterioration characteristics of jute/glass hybrid fiber reinforced composite laminates. The resulted suggested that the sudden fail of jute fiber core in the sandwich arrangement may represent a restrictive parameter for using, while in the intercalated arrengament impact damage can be more easy controlled. This outcome may lead in the future to a specific layup design of these hybrid laminates for best post-impact accomplishment.

Akil et.al. [26] investigated environmental influence in mechanical conduct of pultruded glass and jute fiber with polyester matrix hybrid composites. The outcome exhibit hybrid composites have best strength and modulus retention with high temperature (50 and 80^{o}C) compared to jute composites because of the declination experienced fibers of jute. This study offered evidence that strength of natural fiber composites being tailored to a suitable hybridization with man-made fibers in order to get a proper cost-performance balance, meantime decrease the environmental impact of the material.

Akil et.al. [27] examined the behavior of flexural for pultruded kenaf/glass and glass/jute hybrid composites supervised utilizing acoustic emission. The outcome shows that the introduction of this large quantity of reinforcement lead to quite efficient on jute fiber reinforced laminates, while with an important influence of fiber architecture, while it did not yield compared outcome in kenaf fiber laminates. This was due to the insufficient fiber saturation and to the need for enhancing the orientation of fiber in the laminate, Rames et.al. [28] studied flexural and tensile characteristics of hybrid fiber glass/jute and glass/sisal reinforced epoxy hybrid composites. The results showed that the sisal/glass reinforced epoxy composite tensile results were better than jute/glass composites, but flexural properties of jute/glass reinforced epoxy composites were better than other.

Ahmed & Vijayarangan [29] looked into the influence of stacking and hybridization of glass fiber composite with jute fiber on tensile, flexural and interlaminar shear properties. It was shown that improvement in the mechanical characteristic of hybrid composites and stacking arrangement influence on the interlaminar shear strength and flexural, but for the similar relative weight fraction of glass and jute fibers, layering arrangement has little influence on tensile characteristics.

Kushwaha and Kumar [30] studied on water absorption and mechanical behavior of glass mat /bamboo (woven and strand) reinforced polyester and epoxy laminate composites. Hybridization with glass mat improved water absorption and mechanical characteristics of woven glass mat and hybrid composites reinforced hybrid composites give best characteristics liken to the strand mat. It also indicated influence of glass fiber loading and layering pattern for both the polyester and epoxy matrix composites.

Panthapulakkal and Sain [31] investigated the thermal and mechanical characteristics of glass/hemp fiber reinforced polypropylene matrix composite materials. The results showed that strengthening hemp fiber with glass fiber hybrid composite material improved bending, impact properties and water resistance. In addition, it has been observed that the addition of glass fiber to hemp polypropylene composites results in thermal imperfections as well as thermal properties of the composites.

Haneefa et al. [32] examined the effect of fiber content, fiber loading, hybrid influence and influence of interface modification on the mechanical characteristics like elongation at break, young modulus, flexural and tensile strength characteristics of the glass/banana hybrid fiber reinforced polystyrene composite. The chemical modified like benzoyl chloride, polystyrene maleic anhydrites, and alkali treatment enhanced the tensile characteristics of the composites. Modification showed in improved fiber inclusion in the composite, decrease hydrophilicity fiber of banana and enhanced fiber/matrix compatibility thru chemical bonding, mechanical anchoring and physical.

Anuar et al. [33] examined the influence of fiber (oil palm EFB and glass) handling by coupling agent on the impact and tensile strength. It was shown that composite containing 10% oil palm and 10% glass EFB fiber led to an optimum impact and tensile strength for unhandled and handled hybrid composites.

Wan et al. [34] evaluated hybrid composites of natural rubber for glass/kenaf fibers reinforced were prepared by melt blending technique. Content of fiber (5, 10, 15, and 20 vol% of fiber) was used to prepared hybrid composite. The obtained result that the hybrid composite glass/kenaf (1:3) give better properties.

Mandal et al. [35] studied influence of length and weight fraction of short glass/bamboo fibers on inter-laminar shear strength and flexural strength of unsaturated polyester resin and vinyl ester resins-based composites. It was noticed that bending characteristics of bamboo/glass hybrid composites were higher than those supported on unsaturated polyester resins. Changed of 25 wt% of glass fibers did not influence on marginal increment and flexural modulus a in inter-laminar shear strength was displayed. However, changed of 75% fiber of glass by fiber of bamboo showed an important decrement in modulus, inter-laminar shear strength and flexural strength.

Samanta et al. [36] investigated the mechanical properteis of bamboo/glass fiber and jute/glass fiber hybrid composites. It was showed that the properties of tensile modulus and tensile strength are increased with increment in glass fibers in jute and bamboo fiber-based laminates. The flexure strength of jute hybrid and bamboo hybrid composites were high when the jute and bamboo reinforcement placed on top (under compression) and glass reinforcement at bottom (under tension). The compressive modulus increment from full jute to full glass composite with the increment in glass reinforcement. In state of strength, it increments with hybridization and exceeds the glass composite strength.

Abdul Khalil et al. [37] studied on the physical and mechanical characteristics of oil palm of empty fruit bunch fibers (EFB) reinforced with vinyl ester laminated composites at various layer sequences. The flexural, impact and tensile of glass/EFB fiber with vinyl ester hybrid composites were result higher than that of chemical and mechanical board. Various layers sequence of fibers (glass fibers and oil palm EFB) displayed various characteristics of composites. Thickness swelling and water absorption characteristics of the hybrid composites at different layer sequence were decrement by the merge of fiber of glass liken to chemical and mechanical board.

Shahzad [38] investigated fatigue and impact characteristics of glass-hemp hybrid fiber reinforced biocomposites. The results showed that changing of approximately ten percent of the hemp with glass fibers in produced hybrid composites has significantly increased the damage tolerance. Incorporation of hemp fiber with glass fiber showed increase in fatigue strength of hybrid composites.

Bhoopathi et al. [39] studied the mechanical properties (tensile strength, flexural strength and flexural strength) of hemp-banana-glass fiber reinforced epoxy hybrid composites. Hemp/glass/epoxy, banana/glass/epoxy and hemp/banana/glass epoxy hybrid composites were produced and tested. Experimental results showed that, It was noted that the hemp/banana/glass epoxy hybrid composite gave superior results than other hybrid types.

2.3 Studies on Hybrid Fiber Reinforced Composite Laminates

Amico et al. [40] investigated tensile and flexural properties of glass/sisal hybrid composites produced with compression molding. Different stacking sequences were taken into account as pure glass, pure sisal and sisal/glass. Experimental results showed that location of glass fiber is important in flexural properties such that when glass layers were placed in outer layer, flexural strength is getting better than other locations.

Thiruchitrambalam et al. [41] studied the influence of sodium lauryl sulphate (SLS) and alkali treatment on mechanical characteristics of banana/ kenaf woven hybrid composites. The result showed SLS treatment observed better enhancement in impact, tensile and flexural strength of hybrid composites compared to alkali treated composites.

Venkateshwaran et al. [42] investigated the mechanical characteristics like impact strength, flexural strength, water absorption rate and tensile strength of banana and sisal fibers reinforced epoxy composite materials. The result showed that there was reduction in water absorption rate and significant enhancement in mechanical strength whilst hybridizing the sisal fiber more than 50% by weight with fiber of banana reinforced epoxy composites. The GFRP and banana composites have best tensile properties with smallest deflection when liken to the GFRP and flax composites. As well as the flax and banana fiber reinforced composites gives more impact and flexural strengths when liken to the glass and flax fiber reinforced polymer composites.

Boopalan et al. [43] observed the effects of hybridization of jute fiber with banana fiber on thermal and mechanical properties. Pure jute/epoxy, pure banana/epoxy and jute/banana hybrid composite having different weigth fractions were produced and tested. It is shown that addition of banana fiber to jute-epoxy composites increased mechanical properties with lower moisture absorption of hybrid composite.

Pandya et al. [44] examined hybrid composites made of 8H satin weave T300 carbon and plain weave E-glass fabrics under in-plane quasi-static tensile and compressive loading. It’s reported that putting glass layers in the outside and carbon layers in the inside give highest tensile strength.

Hosur et al. [45] researched impact response of hybrid composites using impact testing machine Hybrid composites were produced with plain weave S-glass and twill weave carbon fibers. Square plates having dimensions 100 mm × 100 mm and thickness 3 mm were exposed to low velocity impact loads at 4 energy levels of 10, 20, 30 and 40 J. Experimental studies showed that there is an important increase in load carrying capability of hybrid composited with small decrease in stiffness compared with carbon/epoxy composite.

Jawaid et al. [46] studied the influence of jute fiber loading on dynamic mechanical characteristics and tensile of epoxy/oil palm composites. The result showed that the additive fibers of jute to oil palm composite increment the storage modulus whilst damping factor shifts towards height temperature zone. As well as the hybrid composite with jute:oil palm (4:1) showed highest tensile properties and maximum damping behavior.

2.4 Studies on Particle Filled Composites

Particulate Polymer composite materials are used for many engineering applications in addition to the production of electrical products, computer housing, etc. In order to provide unique physical and mechanical properties of low specific weight, the molecules used in composites are borax, perlite, silicon, Carbide, fly ash, sewage sludge ash, silica, etc. Morphology filler, volume, particle quantity and homogenization dispersion effect of large-scale composite performance

Shao [47] studied the wear properties of epoxy composite having TiO_2 and SiO_2 particles. The addition of nanofiller TiO2 and SiO2 significantly increases the impact and tensile strength, which was almost 2-3 times that of pure epoxy resins. The addition of TiO_2 and SiO_2 nano particles improved the wear and friction performance of composites.

Yang et al. [48] studied the particles of the nano SiO2 have been to modify epoxy emulsion sizing of carbon fibers for improving the epoxy composites that is reinforced . To investigate the strength that is mechanical interfacial between matrix fiber, To modify sizing with nano-SiO2 1.0 wt%, it has maximum Interfacial shear strength as well as interlinear shear strength values, these are found in the results, nano-SiO2 modified epoxy emulsion sizing for carbon fibers improved more than the properties of the fiber surface that are chemical and physical, giving in the increase of the mechanical interfacial properties of the composites.

Chen et al. [49] studied the thermal and mechanical properties of nano composites with SiO_2 as nano filler. With increasing SiO_2 loading, curing and glass transition temperature is reduced occurred. The 25% increase in tensile modulus and 30% in fracture toughness was obtained by 10 % wt. SiO2 addition into epoxy resin. Further addition of SiO_2 increased in modulus occurred but it decreased the strength and fracture toughness.

Zeng et al. [50] studied the interlaminar fracture toughness of carbon/epoxy composites with addition of rubber and silica nano particles. Double-cantilever-beam test was applied to investigate the interlaminar fracture toughness. From the result it was shown that the toughness was improved by the presence of these nano-particles. Nano rubber was more effective than nano- silica. Jointly addition of rubber and silica particles improve toughness but not more than single rubber if added or single silica.

Asi [51] studied the bearing strength behavior of pinned joints of glass fiber reinforced composite which was filled with different percentage of Al_2O_3 (7.7, 10, 15%). Single-hole pin loaded specimens of each percentage composite was tested in tension. From the result it was shown that with increase in percentage of Al_2O_3 bearing strength of composite increased and further increase in percentage of Al_2O_3 bearing strength decreased. 10 wt.% Al_2O_3 particle content composites had the best bearing strength and bearing strength is 20% higher than pure glass/epoxy composite.

Asi [52] examined properties of glass-fiber that are mechanically strengthened epoxy matrix and different ratios of Al_2O_3 particles. As a correlation, the properties of unfilled glass-fiber that are mechanical strengthen the epoxy composite that can be assessed under the conditions of indistinguishable test. When it compares with the properties that are flexural of the unfilled glass-fiber strengthened epoxy composite, by the addition of 10 wt% of Al_2O_3 particles in the flexural modulus and matrix flexural strength will be individually up by 33 and 78 %.

Setsuda et al. [53] considered the effects of fly ash in composites created by injection molding. The outcomes showed that the substance of fly ash debris is profoundly huge and contributive to the shrinkage proportion and bowing strength. The shrinkage proportion, bending strength and flexural modulus of LDPE composites containing crude fly ash powder were found to progress. The shrinkage proportion and flexural modulus of PP composites containing ground fly slag were additionally found to move forward.

Gu et al. [54] investigated damping properties of particle filled composites. Fly ash was used as a particle with different volume fractions (30, 40, 50 and 70 vol%). The maximum damping value was obtained with 30 vol % fly ash addition. All volume fractions of fly ash gave higher damping ratio than unfilled epoxy composite. According to the experimental results, fly ash increased damping property of epoxy.

Poly ether ether ketone (PEEK) composites reinforced with nano-sized silica (30 nm in size) particulates were produced by Lai et al. [55]. Thermal expansion coefficients and dynamic modulus of PEEK composites were measured with an elevated temperature. 40% increase of dynamic modulus were obtained with addition of nanosilica to the PEEK.

Ruse et al. [56] examined the effects of zinc powders on high density polyethylene (HDPE) composites in terms of mechanical and thermal properties. Volume fractions of used zinc powders were increased from 0 to 20 %. They found that, addition of zinc powder reduced mechanical properties, but density and hardness of HDPE/zinc composites increased as compared to unfilled HDPE composite. Also, thermal stability of HDPE/zinc composites is better than unfilled composite.

Patnaik et al [57] investigated effects of different ceramic particles on mechanical properties of glass fiber reinforced polyester composites. Fly ash, Al2O3 and SiC ceramic particles were used as filler materials. It has been found that type and ratio of particles affected tensile strength, flexural properties, interlaminar shear strength, density and hardness of the composites. Addition of these fillers drastically reduced the tensile strength of composites, but 10 wt% addition of fly ash increased flexural strength compared to all other fillers.

2.5 Studies of Treatment For Natural Fiber Reinforced Composite Laminates

Paridah et al. [58] investigated the influence of chemical handling on the tensile strength and morphological of the (Empty Fruit Bunch) EFB fiber. The handled were by the kind of handled, 2% concentrations of sodium hydroxide (NaOH) and combination of both boiling water and NaOH. The chemical handling by NaOH led to improving the topography of fiber surface, thermal stability and tensile strength of the fiber, whilst the chemical handling with water boiling and NaOH led to height thermal characteristics of the EFB fibers comparison with unhandled fibers.

Perumal et al. [59] investigated the influence of alkali (NaOH) handling of different concentrations (20%, 15%, 10%, 5%, 2%, 1%, and 0.5%) on the mechanical characteristics of banana/epoxy composite. The outcome appeared that as liken to other handled and unhandled fiber composites, 1% concentrations of NaOH handled fiber reinforced composites have a best characteristic. The 1% concentration of alkali on the fiber surfaces showed best mechanical characteristics.

Cordeiroa et al. [60] examined the impact of Iranian cultivated natural fibers with alkaline treatment on surface properties. The study revealed that treatment with alkaline gets rid of several chemical components fibers surfaces, aromatic moieties (extractives), nonpolar molecules and comprising uranic acid (hemicellulose) from the partial lignin depolymerisation. There is a firmer influence on chemical components in fibers of nonwood. Crystallinity of fibers of nonwood was enhancing, but the outcome in the soft wood fibers was only a minor increment. Hence, handling with alkaline can effect in a remarkable enhancement in the specific react of the fibers also enhancing the wettability of fibers.

Sedan et al. [61] investigated the influence of several chemical handlings, NaOH, polyethylene imine (PEI), CaCl2, comprising ethylenediaminetetraacetic acid (EDTA), and Ca $(OH)_2$. The influences were on the mechanical characteristics of the composite materials from mixtures of lime and hemp fiber by difference thermal valuation and tests. The notice was that each handling had a direct influence on the surface of fiber. The handling was by 6% concentration of NaOH and it causes modifying fibers by eliminating the amorphous compounds, and the increment of the crystallinity index of fiber bundles, although the ethylenediaminetetraacetic acid handlings it causes separates complex calcium ions and fibers related to pectins. In summary, polyethylene imine handling displayed all studied characteristics intermediate lime water and character handling depicts calcium ions' fixation at fibers surface of compared to a calcium chloride handling which does not.

Arbelaiz et al. [62] investigated the effect of matrix modification and fiber surface treatments on flax fiber polypropylene matrix composites. They checked mechanical properties of composites and found that matrix modification gave better results than fiber surface treatment.

John et al. [63] examined the effects of treatment with sodium hydroxide solution and different silane coupling agents on sisal and oil palm hybrid composites. It was shown that with chemical treatment increased the crosslinking of fiber with matrix. Composites treated with 4% concentrations of sodium hydroxide solution gave highest tensile strength than other ratios and untreated composites.

B.F. Yousif [64] studied flexural characteristics of untreated and treated epoxy/kenaf composites with 6% NaOH. It was shown that reinforcement of epoxy with handled kenaf fibers increment the flexural strength of the composite approximately 36%, whilst, unhandled fibers gave 20% enhancement.

2.6 Studies of Untreatment for Jute Fiber Reinforced Composite Laminates

Andersen et al. [65] investigated the tensile behavior for fiber of jute reinforced L-polylactide composites. The outcome showed that the stiffness and tensile strength of the composites was nearly multiple when fibers of jute reinforcement was utilize on 40 wt. % base.

Khan et al. [66] investigated the influence of jute fiber amount on the tensile behavior from fabrics of jute -polyester amide composites. Jute amount was different ratio from 20 wt. % to 53 wt. % to find its influence on tensile characteristics. The results showed that the tensile strength of composite increment from 20 wt.% to 32 wt.% fiber amount and afterward with far increment of jute fiber amount characteristics tend towards less quantity.

Gowda et al. [67] investigated the tensile behavior for fabric of jute reinforced polyester composites in transverse and longitudinal orientation. The result showed that the tensile strength and modulus of composites found out in longitudinal orientation were about five times the modulus and strength of polyester resin and twice that for the transverse orientation laminate. The variations in supreme stress between the same specimens of laminate are because of inconsistent nature and the majorly non-uniform fibers of jute.

Mohanty et al. [68] examined the effects surface treatment and amount of jute fiber on the mechanical performance of biodegradable polymer (Biopol) composites. The tensile strength, bending strength and impact strength were increased with addition of jute fiber to the Biopol when compared with neat Biopol.

Mohanty et al. [69] examined the influence of fiber content on the tensile strength of unhandled fiber of jute reinforced high density polyethylene (HDPE) composite. The result showed that the tensile strength of the composite increment with raise in fiber content from 0 to 30 wt.%, higher up which there was a big drop in the strength. An increment in tensile strength of the composite was displayed with the increment in values of maleic anhydride grafted polyethylene up to 1 %.

Mohanty et al. [70] studied the tensile behavior of jute-polycarbonate composites with 13%,23%,26%,32%,35% and 42 % jute amount. The results showed that as the fiber amount increased the tensile strength of the composites raised up to 32% jute fiber amount, but further increment in the jute fiber amount cause decrement in the strength quantity.

Bisaria et al. [71] studied the influence length and ratio of fiber on mechanical characteristics of jute fiber reinforced epoxy composite. Jute fibers having 5, 10, 15, and 20 mm long were randomly distributed to the epoxy matrix with 30 % weight. 15 mm fiber length gave better tensile and flexural strength, while 20 mm fiber length gave highest impact strength.

Dwivedi and Chand [72] exam the influence of fiber orientation on impact of the sliding wear and friction performance of fiber of jute reinforced polyester composites. Various direction in fiber on the composite called TT, LT and LL with respect to sliding orientation were taken for wear research. It was shown that the supreme wear resistance was showed in state of TT specimen and lower limit in state of LL specimen. The coefficient of friction was largest for TT specimen and smallest for LT specimen. Mmicro-pitting, debonding and micro-cracking were responsible wear mechanisms under slipping wear mode in jute-polyester composites.

2.7 Conclusion of Literature Review

The resulting conclusions can be taken from the earlier literature survey

- Natural fiber reinforced composite materials are becoming essential structural materials in numerous engineering applications due to their biodegradable properties.
- Some of studies are concentrated on the surface modification of natural fiber to improve crosslinking of fiber with matrix.
- It is seen from the literature another procedure to promote mechanical characteristics of natural fiber reinforced polymer composites that is treatment it by some chemical solution like sodium hydroxide (NaOH) with different concentration, sodium lauryl sulphate, maleic anhydride grafted polypropylene, alkali and siloxane. From the literature, 1% NaOH solution give is the highest surface treatment ratio for the jute fiber to mechanical properties of composites.
- Some of studies are concentrated on to improve mechanical properties of natural fiber composites by means of hybridization with inorganic fibers such as glass, carbon etc. or addition of some particles in micro or nano level to the matrix. Studies have shown that the addition of nano particles on matrix positively effecting the mechanical properties of natural fiber composites.
- Some researchers proved that 1.5 wt% -2wt % of nano-silica particle content is the perfect percentage for mechanical properties. More increase in particle content leads to agglomeration of particles and that could weaken the bond between fibers and epoxy. As for the effect of nano-silica particles on failure mechanism, it changes it from intra laminar to mix failure mode.
- There are a little literature on hybridization influence of jute/glass with treatment by 1% NaOH on the mechanical properties of composite materials that let to investigate it.

CHAPTER 3

EXPERIMENTAL STUDIES

3.1 PRODUCTION OF COMPOSITE LAMINATES AND DETERMINATION OF MECHANICAL PROPERTIES

In this section the production of a composite laminate, the preparation of the test piece, the tensile test, the flexural test and the experimental procedure of the impact test are explained. General information on the components of prepared composites such as jute fibers, glass fibers, epoxy resin systems, nano silica particles are explained and manufacturing technique is described.

3.2 Materials

3.2.1 Nano-Silica

Nano-silica (NS) particles sufficiently uniform dispersed in polymer material–which can be overall improved in performance comprising. NS is an inorganic chemical material commonly known as silica, since the ultrafine nanometer size rang 1-100nm, and therefore has many unique properties to the other inorganic material. NS was supplied from Grafen Chemical Industries, Turkey with 99.5% high purity, 15 nm average particle size, 300 m^2/gr specific surface area and 0.05 gr/cm^3 bulk density. SEM image of NS particles is shown in Figure 3.1.

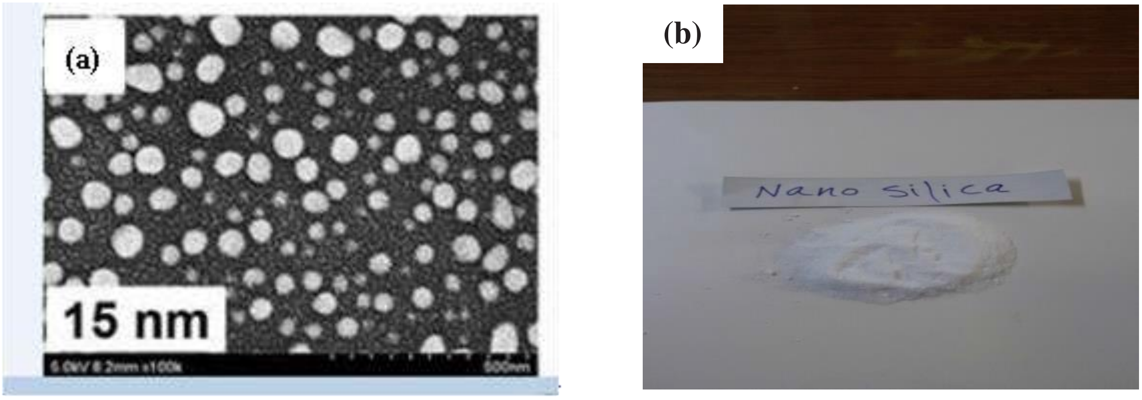


Figure 3.1 (a) image of NS particles, (b) NS particle

3.2.2 Jute Fiber

Jute is multi-celled in construction. Cell wall of a fiber created of a many of layers: the initial wall and the minor wall, which again was content three layers. As in all lignocellulosic fibers, these layers at most include cellulose, lignin hemicellulose at differing quantities [73]. The jute fiber was supplied by local market, Turkey. Figure 3.2 shows jute tiber that used in this study. The physical characteristics and constituents of jute fiber are given in the Table 3.1 [74].

Figure 3.2 Jute Fiber

Table 3.1 Physical characteristics and constituents of jute fiber [74]

Physical properties		Constituents (%)	
Density (g/cm3)	1.3	Cellulose	60 – 62
Young’s modulus (GPa)	26.5	Hemi Cellulose	22 – 24
Strength (MPa)	393-773	Lignin	12 – 14
Elongation at break (%)	1.5-1.8	Others	1 – 2

3.2.3 Glass Fiber

Fiber glass can be changed to a textile layer or can be used as reinforcement due to the excellent properties made up of thin fibers of glass. It is strong, durable and lightweight material. It is used in various industries. Glass fiber has low rigidity compared to carbon fiber-based composite, it is strong, but it is cheap and not brittle [75, 76]. Plain weave E-glass fabric with 200 g/m^2 areal density was supplied was supplied from DOST Chemical Industrial Raw Materials Industry (Turkey). Glass fiber fabric is shown in Figure 3.3.

Figure 3.3 Glass Fiber

3.2.4 Epoxy Resin

The fibers are arranged in a specific direction in the fiber reinforced structure to concentrate the reinforcement as necessary and the epoxy helps to keep the fiber position in the required location. The purpose of the epoxy matrix is to surround the fibers and transfer loads to the fibers despite their strong material. It helps protect the fibers from damage and provides impact resistance [77]. Figure 3.4 shows epoxy resin and hardener. Physical properties of epoxy and hardener are given in Tables 3.2. Epikote MGS LR160 epoxy resin and Epikote MGS LH160 hardener were supplied from DOST Chemical Industrial Raw Materials Industry, Turkey.

Epoxy Hardener

Figure 3.4 Epoxy Resin and Hardener

Table 3.3 Physical characteristic of the epoxy resin and hardener [77]

Properties	Epoxy (EPIKOTE MGS LR160) specification	Hardener (EPIKOTE MGS LH160) specification
Density [g/cm³]	1.13 – 1.17	0.96 – 1.00
Viscosity [mPas]	700 – 900	10 – 50
Refractory index	1.548 – 1.553	1.517 – 1.520

3.2.5 Fiber Surface Treatments

The treatment on jute fibers were about 2 hr. under ambient situation with NaOH solutions of concentrations of 1% at 25ºC. The fibers were further cleaned with water including acetic acid to eliminate the sodium hydroxide. Lastly, the fibers were cleaned again with new water and dried at 60ºC for 24 hr until completely dry.

3.3 Hybrid Fiber Reinforced Composite

The hybrid fiber reinforced composites were prepared by combination of jute fiber and glass fiber with different stacking sequences. Five configurations were produced as J_8, G_8, $G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$ with 0 wt.% , 1 wt.%, 2wt.% and 3wt.% of Nano particle-silica contents.

3.3.1 Production Of Hybrid Composite Laminates

Fibers were cut with a desired dimension 300 mm × 250 mm that enough to prepare specimens for mechanical test using electric cutter (Figure3.5). The ratio of epoxy (EPIKOTE MGS LR160) to hardener (EPIKOTE MGS LH160) was 100:25±2 by weight and prepared with suitable and enough amount.

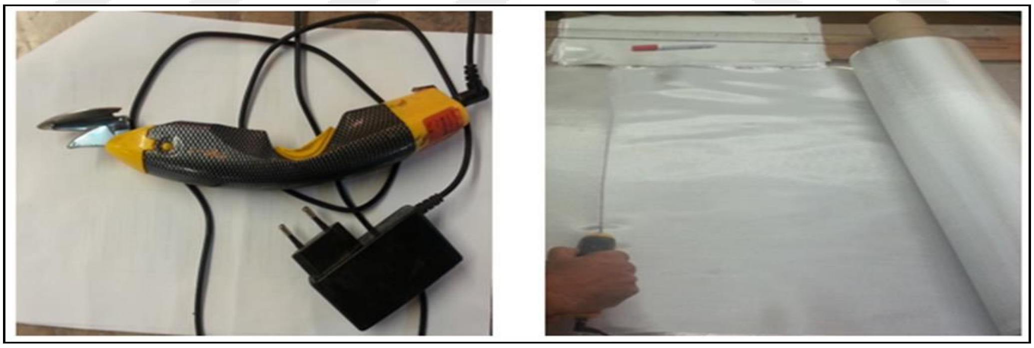


Figure 3.5 Electric Cuter

Epoxy resin and Nano silica particles were firstly mixed with a 650 rpm constant speed with a driller for a 20 minutes (Figure 3.6). Then hardener was added to the mixture and mixed with constant speed for a 2 `minutes to get homogeneous mixture.

Figure 3.6 Mixer

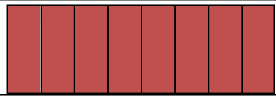
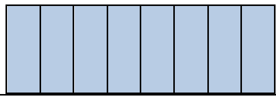
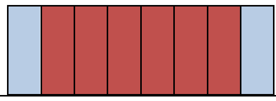
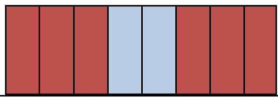
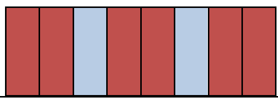
Composite laminates were produced using hand layup method. In the production epoxy resin and Nano silica mixture were poured layer by layer. After that wetted then laminated fabrics were into the hot press (Figure 3.7) 0.4 MPa pressure was applied to the composite plates for 1h curing time with 80°C curing temperature.

Figure 3.7 Production Unit

The composite laminate was cooled to room temperature under constant pressure for 3 hours. Finally, the composite laminate was removed from the hot press, completing the composite laminate as shown in Figure 3.8. Table 3.5 shows the produced composite configurations and their thicknesses.

Figure 3.8 Composite Laminates

Table 3.5 Hybrid Configurations

Laminates	**Configuration**	**Thickness (mm)**
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

The laminate size was 300 x 250 mm. It was cut to the specimens size using small CNC machine as shown in Figure 3.9 according to the ASTM standards. ASTM D 790 [78] used for flexural test, ISO 179/92 for impact test and ASTM D-638 [79] used for tensile test.

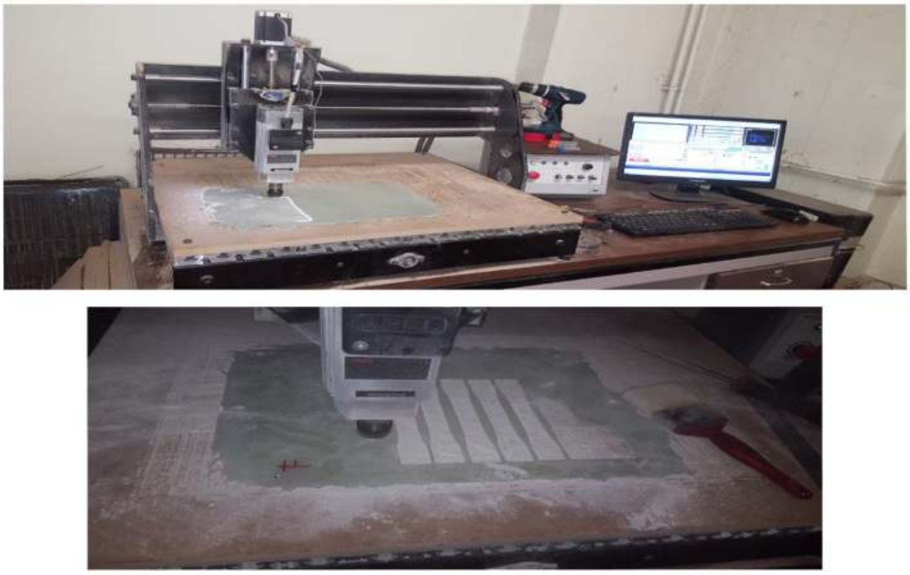
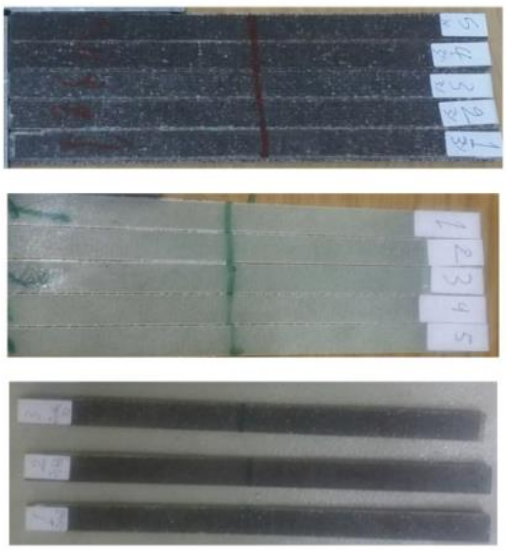


Figure 3.9 Cutting the Specimen Using CNC Machine

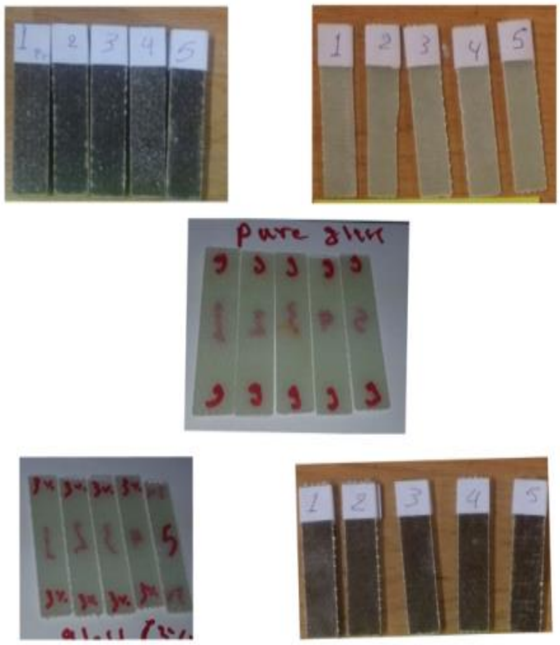
3.3.2 Preparation of Test Specimens

Specimens for tensile test, flexural test and impact test and have been prepared for testing are shown in Figure 3.10.

(a)



(b)



(c)

Figure 3.10 Specimens of (a) Tensile test (b) Flexural test (c) Impact test

3.4 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 testing machine (Kyoto, Japan) Figure 3.11. Appropriate samples were prepared with a size of 165 mm × 13 mm for a gauge length of 50 mm for test of tensile and 200 mm × 12.7 mm with span to thickness ratio of 32:1 for test of flexural. The thickness of tensile, flexural and impact specimens was changed depended on type and number of layers (glass or jute) that used to fabricated the laminates and variation of Nano-silica content. The crosshead speed was 3 mm/min for test of flexural and 2 mm/min for test of tensile. And for impact test the Köger 3/70 Charpy impact test machine, as shown in Figure 3.15 was used in the tests with 55 mm ×10 mm dimension of test specimen. Five samples were examined at least for each compound, and the average value was calculated.

3.4.1 Determination of Tensile Properties

Testing of tensile, also known as testing of tension is a fundamental materials science test in which a specimen is subjected to a controlled tension until failure. The outcome results from the exam are commonly utilized to select a material for an application, for quality control, and to predict how a material will respond under other kinds of forces. Characteristics that are directly determined via a tensile test are ultimate tensile strength, reduction in area and maximum elongation. From these measurements the following characteristics can also be measured: Poisson's ratio, Young's modulus, strain-hardening and yield strength characteristics. Uniaxial testing of tensile is the most commonly utilized for obtaining the mechanical qualities of isotropic materials. For anisotropic materials, like as textiles and composite materials, biaxial tensile examining is required. Figure 3.11 show tensile test.

Figure 3.11 Tensile Test

3.4.1.1 Tensile specimen

Tensile characteristics of samples were determined according to the ASTM standards (D638-00) standard test method, a suitable specimen cutting to make test with L= 165 mm, w =13 mm. Figure 3.12 show the tensile test specimen with dimensions.

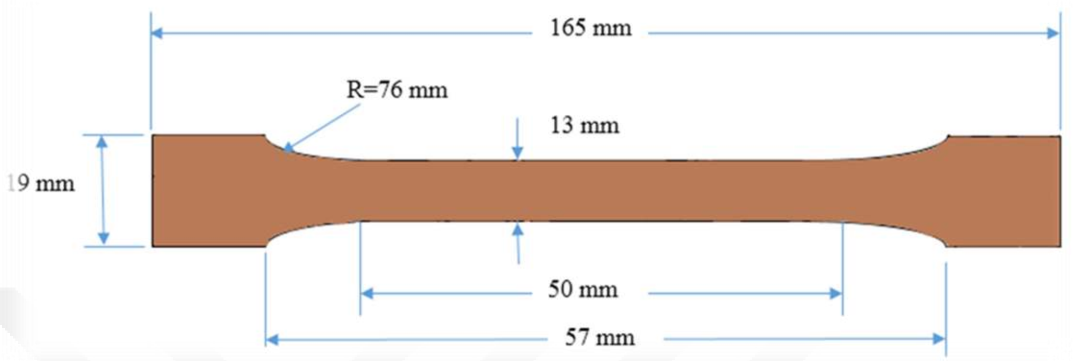


Figure 3.12 The dimensions of the tensile samples according to ASTM 638-00

Through this method, the recording section elongation measured against the applied force. Engineering strain is calculated using the equation:

$$\varepsilon = \frac{\Delta L}{Lo} = \frac{L - Lo}{Lo} \qquad (3.1)$$

Where ΔL is the amount of change in length, (Lo) is the length of the initial measurement, and (L) it is the ultimate length.

The force measurement is utilized to calculate the engineering stress, σ, utilize the next equation:

$$\sigma = \frac{Fn}{A} \qquad (3.2)$$

Where Fn is the tensile force and A is a cross-section nominal sample.

Mechanical characteristics of sample were acquired utilize Shimadzu AG-X series testing machine. To calculate tension characteristics, sample was loaded in tension direction with the 2 mm/min velocity up to failure. Then tensile strength (σ_t) was determined to utilize the stress and strain data's obtained from the testing machine.

3.4.2 Determination of Flexural Properties

Flexural strength, as well known as modulus of rupture, fracture strength or bend strength, is a material property, defined as the stress in a material only before it yields in test of flexure. The transverse test of bending is most frequently employed, in which a sample having either a rectangular or circular cross-section is bent until yielding or fracture using a three-point bending test method. The flexural strength symbolizes the highest stress experienced within the material at its moment of failure. It is measured in terms of stress. Figure 3.13 shows flexural test.

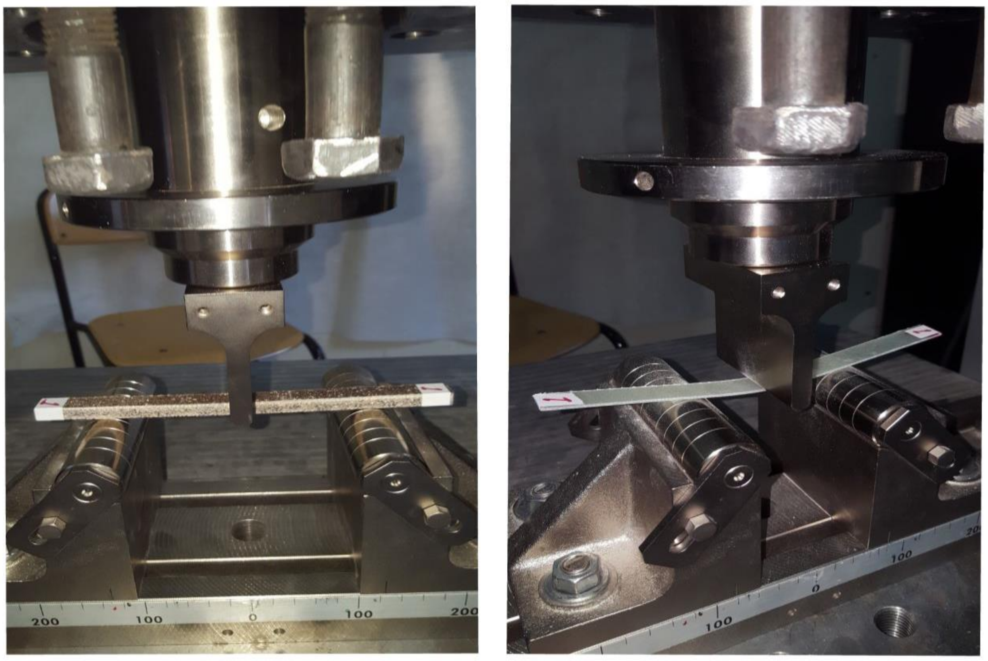
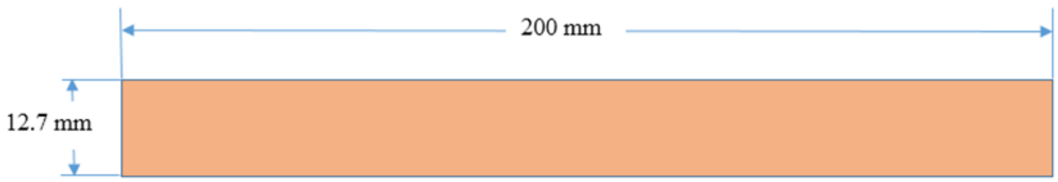


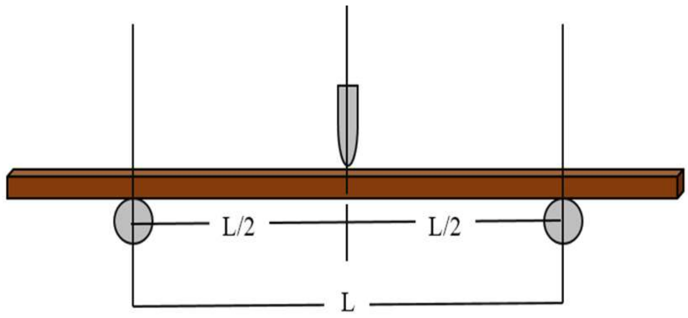
Figure 3.13 Flexural test

3.4.2.1 Flexural Specimen

Flexural characteristics of samples were determined according to the ASTM D790- 00 standard test method as shown in Figure 3.14 a, a suitable specimens of rectangular cross section with L= 200 mm, w =12.7 mm rests on two supports and was loaded midway between the supports. As shown in Figure 3.14 b.



(a)



(b)

Figure 3.14 (a) Flexural specimens according to ASTM D 790 – 00 (b) loaded specimens.

Flexural strength, flexural modulus & strain were determined from the test machine data's through the over the use of the formulas [3-1008].

$$\sigma_F = \frac{3P_{max}L}{2bh^2}\left[1 + 6\left(\frac{D}{L}\right)^2 - 4\left(\frac{h}{L}\right)\left(\frac{D}{L}\right)\right] \quad \text{..} \quad (3.3)$$

$$E_F = \frac{mL^3}{4bh^3} \quad \text{..} \quad (3.4)$$

$$\varepsilon_F = \frac{6Dh}{L^2} \quad \text{..} \quad (3.5)$$

Where L, b and h square measure the span, width and depth of the sample respectively, m is that the slope of the tangent to the initial line a part of the load deflection curve, D is that the maximum deflection before failure and P is that the load at a given point on the load-deflection curve.

3.4.3 Impact Test

The most important of those limitations is a reaction against regional impact which they are exposed to the foreign material under operating situation. To know the impact react of composite materials, several researches were accomplished. Test apparatuses used to measure the response to the impact load of a composite are Izod and Charpy pendulum impact test, drop weight test and gas gun test.

3.4.3.1 Charpy Impact Test

Charpy impact test was conducted according ISO 179/92 standard. A Köger 3/70 Charpy impact test device, as shown in Figure 3.16 was used in the tests. Before starting test, the device was calibrated and scaled by putting the device on a smooth and flat surface to obtain more reliable results during testing. Flatwise specimens are illustrated in Figure 3.16.

Figure 3.15 Charpy impact test (flatwise impact loadings)

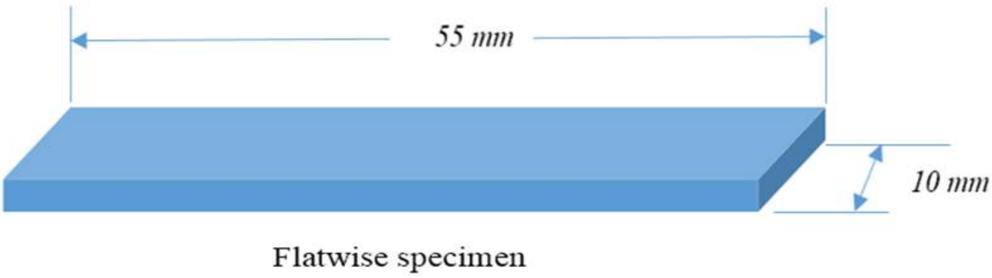


Figure 3.16 Flatwise specimen

The impact absorption energy and impact toughness of specimens were determined according to the coming equations:

$$E = E_a - E_b \tag{3.6}$$

$$a_{cu} = \frac{E}{b \times h} \tag{3.7}$$

where, E, E_a, E_b, in Equation (3.6) represent the absorbed impact energy, potential energy of the weighted pendulum before and after impact respectively, and a_{cu} , h and b in Equation (3.7) represent impact toughness, thickness of test sample and width of the test sample, respectively.

Average values and standard deviations for the absorbed impact energy and impact toughness were used to assess the effect of nano-silica particles.

CHAPTER 4

EXPERIMENT RESULTS AND DISCUSSION

4.1 Introduction

Mechanical tests have significant role in the detection of appropriate materials in mechanical use to perform high efficiency at work. Many tests have been made upon the Jute/glass /epoxy and hybrid composite with Nano-silica addition. Test results are explained in terms of figures and tables.

4.2 Tensile Test Results

4.2.1 Tensile Results of Jute/Epoxy and Glass /Epoxy Composite Plates

Jute/epoxy and glass/epoxy composite plates were tested with different nano-silica content ratios 1wt %, 2wt% and 3wt % Nano-silica contents were used in production. Tensile test results are listed in Table 4.1 for the jute fibre reinforced epoxy composite filled with nano-silica content. Five specimens were tested and averages tensile strength were determined.

Table 4.1 Tensile test results for the jute fibre reinforced epoxy composite filled with nano-silica content

Particle ratio (wt.%)	Specimen	Max. Tensile Strength (MPa)	Average Tensile Strength (MPa)	Max. Tensile Strain	Average Tensile Strain
	1	55.89		0.0330	
0%	3	38.18	**43.49**	0.0112	**0.0250**
	3	48.74		0.0317	
	4	32.79		0.0239	
	5	41.85		0.0337	
	1	58.07		0.0267	
1 %	2	56.56	**56.14**	0.0290	**0.0277**
	3	54.31		0.0250	
	4	57.11		0.0305	
	5	54.68		0.0273	
	1	69.99		0.0350	
2 %	2	63.91	**67.51**	0.0299	**0.0339**
	3	72.52		0.0392	
	4	65.52		0.0311	
	5	70.62		0.0343	
	1	65.79		0.0229	
3 %	2	66.37	**65.11**	0.0335	**0.0327**
	3	68.54		0.0419	
	4	64.92		0.0336	
	5	63.35		0.0317	

Table 4.2 Tensile test results for the glass fibre reinforced epoxy composite filled with nano-silica content.

Particle ratio (wt. %)	Specimen	Max. Tensile Strength (MPa)	Average Tensile Strength (MPa)	Max. Tensile Strain	Average Tensile Strain
	1	218.24		0.0380	
0%	3	226.04	**232.68**	0.0450	**0.0450**
	3	246.99		0.0445	
	4	246.77		0.0527	
	5	225.35		0.0543	
	1	253.03		0.0441	
1 %	2	233.14	**312.02**	0.0385	**0.0442**
	3	277.77		0.0459	
	4	346.93		0.0430	
	5	370.33		0.0492	
	1	304.13		0.0472	
2 %	2	325.25	**320.02**	0.0467	**0.0432**
	3	312.50		0.0398	
	4	311.89		0.0404	
	5	330.42		0.0420	
	1	289.70		0.0398	
3 %	2	303.38	**295.43**	0.0448	**0.0414**
	3	341.88		0.0442	
	4	314.82		0.0401	
	5	273.80		0.0380	

Tensile stress-strain curves of production composite are given in Figure 4.1. Figure 4.2 shows effect of nano silica content on tensile strength of jute/epoxy and glass/epoxy composites, unfilled nano silica (pure) was gradually increased with adding nano silica particle. The tensile strength reached the maximum improvement which is 55.8 % for jute/epoxy and 37.9 % for glass/epoxy with particles content of 2wt % as compared with pure jute/epoxy and glass/epoxy composites. After this ratio the tensile strength tends to decrease as a result of agglomeration or bad dispersion due to poor bending between epoxy and nano-silica. According to Figure 4.1 tensile stress and strain increased with the increase of nano-silica content this agrees with [80] and [81]. In addition, whether it was filled or unfilled with nano-silica particles, the tensile samples were failed at higher stress. The jute/epoxy and glass/epoxy composites of 2wt % nano silica content produced the highest tensile strength value of 67.51 MPa with maximum strain 0.0339 for jute/epoxy and 320.02 MPa with maximum strain 0.0432 for glass/epoxy, whilst the minimum value of tensile stress a for jute/epoxy is 43.94 MPa with minimum strain 0.0250 and for glass/epoxy is 232.68 MPa with minimum strain 0.0450.

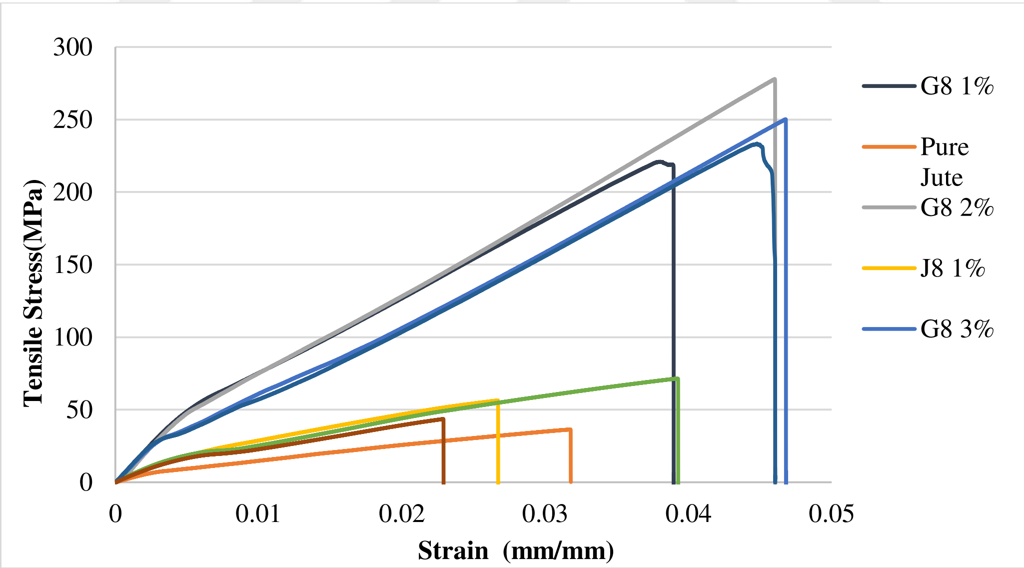


Figure 4.1 Tensile Stress –Strain Curves of the Jute/Glass Fiber Epoxy Composite.

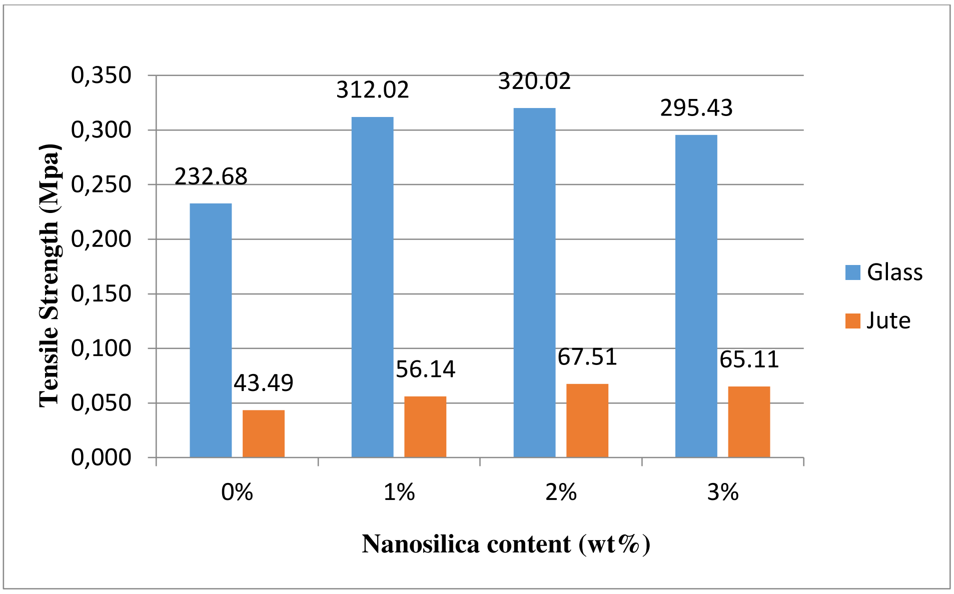


Figure 4.2 Variation of Tensile Strength According to Nano-silica Content

4.2.2 Tensile Test Results of the Jute/Glass Hybrid Configurations

Tensile test result of jute/epoxy composite is very low than glass/epoxy composite. Glass layers were used to improve the strength of jute composites. Symmetric configurations were arranged with 2 layers of glass and its placements were investigated. G1J6G1 , J3G2J3 and J2G1J2G1J2 hybrid configurations having 2 wt% nano silica content were taken into consideration.

Table 4.3 Tensile test results of the Jute/Glass hybrid configurations

Configurations	Specimen	Max. Tensile Strength (MPa)	Average Tensile Strength (MPa)	Max.Tensile Strain	Average Tensile Strain
	1	68.97		0.0350	
J8	3	62.95	**67.51**	0.0299	**0.0338**
	3	71.47		0.0392	
	4	64.57		0.0311	
	5	69.59		0.0343	
	1	92.00			
$G_1 J_6 G_1$	2	90.62	**92.01**	0.0358	**0.0365**
	3	99.22		0.0357	
	4	87.99		0.0363	
	5	90.25		0.0383	
	1	73.28		0.0313	
J3 G2 J3	2	69.13	**74.02**	0.0318	**0.0302**
	3	77.72		0.0303	
	4	75.95		0.0295	

	5	64.15		0.0282	
	1	75.26		0.0402	
J2G1J2G1J2	2	76.67	**76.85**	0.0232	**0.0333**
	3	77.22		0.0326	
	4	79.97		0.0392	
	5	75.14		0.0312	
	1	304.13		0.0472	
G8	2	325.25	**320.02**	0.0467	**0.0432**
	3	341.88		0.0398	
	4	314.82		0.0404	
	5	273.80		0.0420	

Tensile test results are given in Table 4.3, tensile strength variation values of the jute/glass hybrid configurations specimens with (2wt%) nano-silica content are shown in figures 4.3 and 4.4, The best laminate was glass (G_8) with stress value 320.02 MPa and strain 0.0432, the less value was in jute (J_8) laminate with stress 67.51 MPa and strain 0.0338. For hybrid composite laminate with arrangements of jute/glass ($G_1J_6G_1$, $J_3G_2J_3$ and $J_2G_1J_2G_1J_2$). The result of tensile strength showed the best configuration is $G_1J_6G_1$ with value 92.01 MPa and strain 0.0365 when compared to that of jute fiber laminate J8 it was 67.51 MPa. That glass layer location in out and jute in middle. A significant augmentation in the tensile strength of $G_1J_6G_1$ hybrid composite is ascribed to the reason that, glass fibers are stiffer and stronger than jute fibers [82]. As well as it is observed that there is small increase in the tensile strength with the merging of glass fiber as middle glass layers ($J_3G_2J_3$, $J_2G_1J_2G_1J_2$) the tensile strength with value 74.02Mpa and 76.85Mpa it is increasing when compared to jute laminate J8 at 2wt % nano silica content it was 67.51 MPa .

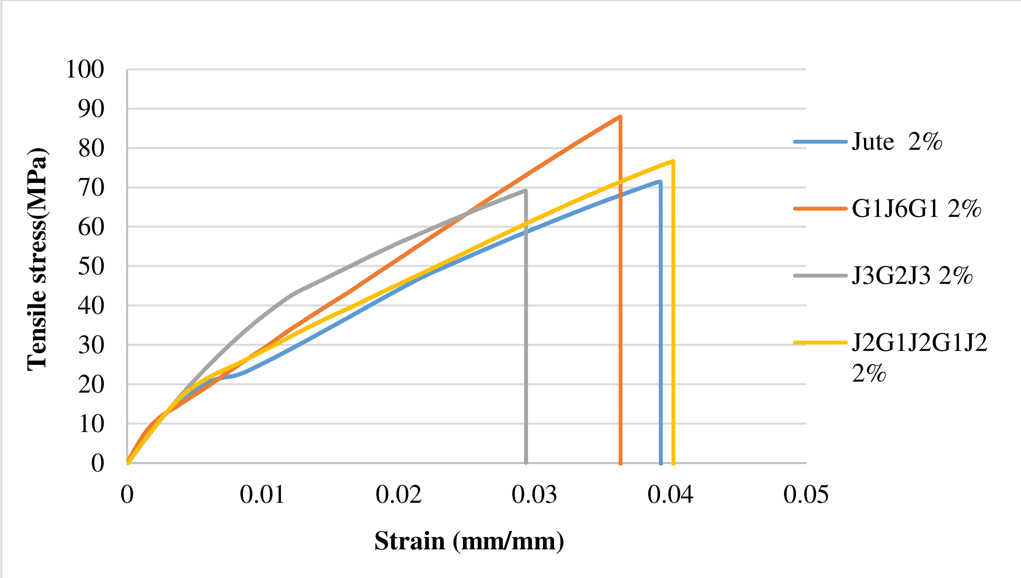


Figure 4.3 Tensile Stress-Strain Curves for The Jute/Glass Hybrid Configurations with 2wt%NS.

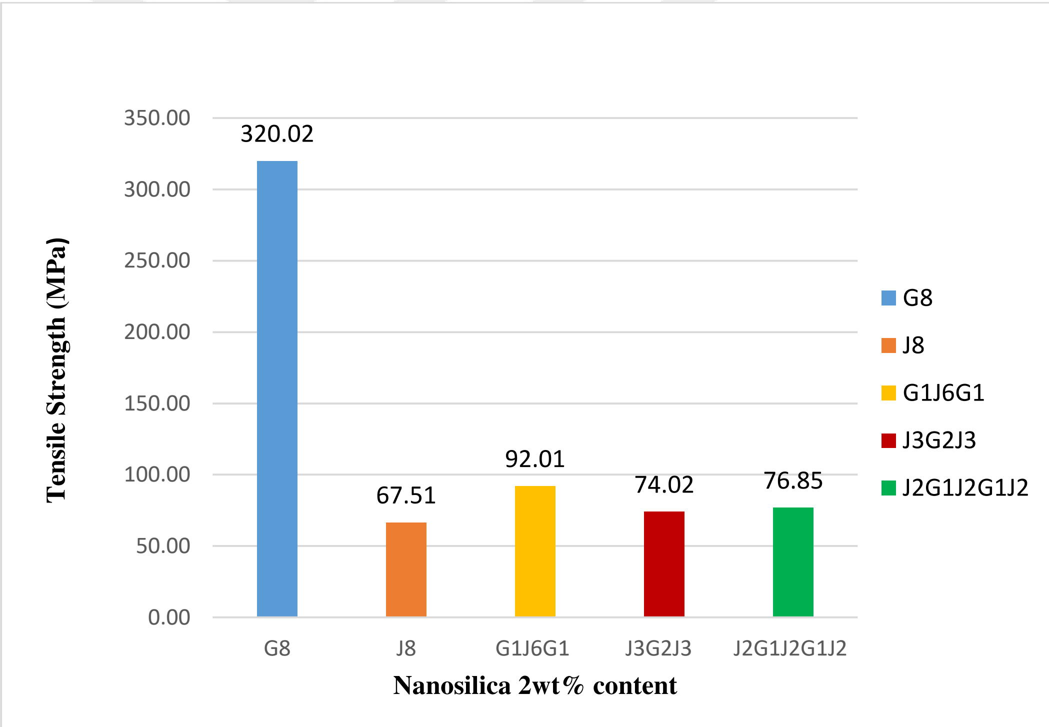


Figure 4.4 Variation of Tensile Strength of the Jute/Glass Hybrid Configurations with 2wt %.

Figure 4.5 Failure Specimens of Different Composite Laminates After Tensile Test.

All samples as showed in picture 4.5 failed when tension load applied is increased were mostly the crack type are fiber pull out and the samples separated two part that failure was started with matrix cracking then fibers breakage and jute/glass layers delamination start from the surface.

4.3 Flexural Result

4.3.1 Flexural result of jute/epoxy and glass/epoxy composite plates

Jute/epoxy and glass/epoxy composite plates were tested with different nano-silica content ratios 1wt %, 2wt% and 3wt % nano-silica contents were used in production. Flexural strength results are listed in Table 4.4 for the jute fibre reinforced epoxy composite filled with nano-silica content. Five specimens were tested and averages flexural strength were determined.

Table 4.4 Flexural strength values of jute /glass fibre epoxy composite filled with nano-silica content.

	Flexural Strength (MPa)							
	Jute/Epoxy				Glass/Epoxy			
	Nano-silica content				Nano-silica content			
	0%	1%	2%	3%	0%	1%	2%	3%
	60.21	90.45	110.145	97.67	194.08	211.48	191.32	118.39
	56.52	77.97	114.91	94.49	225.03	206.55	239.62	108.95
	58.09	79.06	103.19	84.81	238.02	210.43	260.08	110.7
	53.55	87.69	113.27	91.06	268.74	155.61	257.85	100.78
	54.21	87.48	0	100.99	264.16	179.86	248.69	105.31
Average	56.52	83.05	110.38	96.06	202.01	202.08	251.63	108.83

Flexural load-displacement curves of production composite are given in Figure 4.6. Figure 4.7 shows effect of nano silica content on flexural strength of jute/epoxy and glass/epoxy composites and table 4.4. It can be observed significant effect of addition nano-silica content at 2wt% with maximum flexural load and displacement. The variation of flexural strength values with nano-silica content were presented in figure 4.7. It is noticed that flexural strength of pure glass decreased from 238.01 MPa to 202.08 MPa at 1% nano-silica content, may be occurred due to the agglomeration of nano-silica particles, the weak interaction between nano-silica and epoxy matrix and formation of stress concentration sites and thus crack initiation led to the weakness in the composite strength [83]. Highest flexural strength was 110.38 MPa with jute/epoxy and 251.62 MPa with glass/epoxy at particle content of 2wt. %, the flexural strength reached the maximum improvement which is 96.42% with jute and 5.46% with glass at 2 wt.% particle content, then the flexural strength decreasing to reach 96.05 MPa with jute/epoxy and 108.82 MPa with glass/epoxy at content of 3wt%. This indicated that the chemical compatibility and adhesion strength between nano-silica particles and epoxy/jute/glass fiber was optimum at this content.

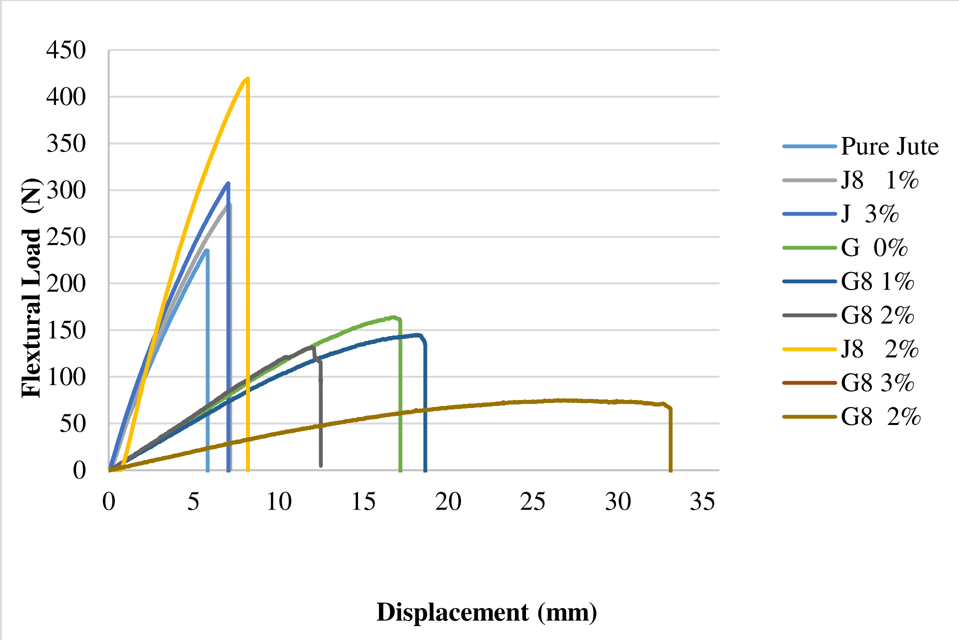


Figure 4.6 Flexural Load-Displacement curves for Jute/Glass epoxy -NS Composites

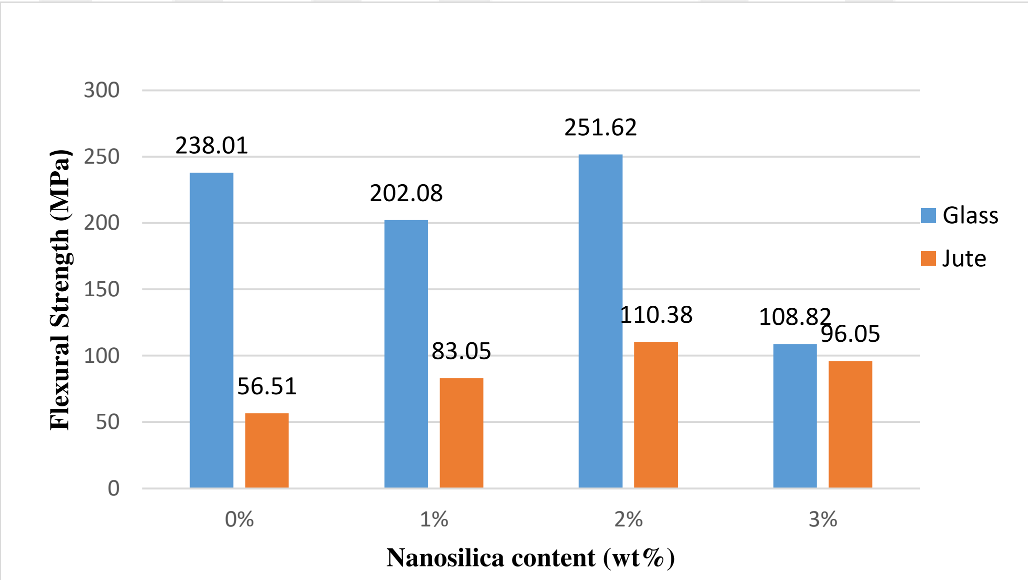


Figure 4.7 Variation of Flexural Strength According to Nano-silica Content

Table 4.5. Flexural modulus values of jute/glass fibre epoxy composite filled with nano-silica.

	Flexural Modulus (GPa)							
	Jute/epoxy				Glass/epoxy			
	Nano-silica content				Nano-silica content			
	0%	1%	2%	3%	0%	1%	2%	3%
	2.53	3.38	4.58	3.48	5.31	5.24	7.19	0.17
	2.77	3.29	4.58	3.32	5.93	5.15	7.73	1.11
	3.25	3.17	4.58	3.52	6.57	5.32	8.12	1.41
	3.29	3.38	4.58	3.39	7.84	0.096	7.7	1.30
	3.11	3.40	4.58	3.43	6.66	3.87	7.32	1.12
Average	2.99	3.33	4.58	3.43	6.46	3.94	7.61	103

Flexural modulus of nano-silica filled Jute/Glass and unfilled composite laminates Jute/Glass were plotted in figure 4.8. And table 4.5. As seen in the figure, the flexural modulus of all nanocomposites, except 3wt% content nano silica, showed an increase in the values of the flexural modulus compared to Jute/Glass(pure).The obtained improvement in the flexural modulus specimens were 53.2% with jute and 17.6% with glass for 2wt% nano-silica content.

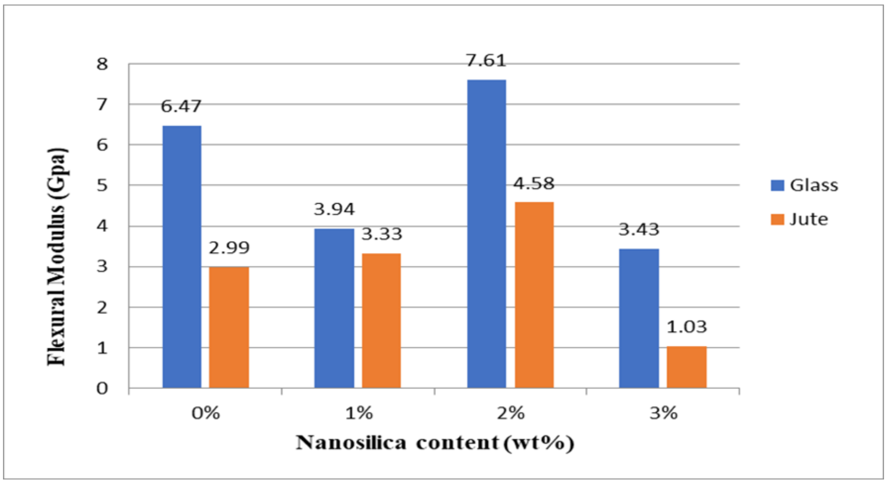


Figure 4.8 Variation of Flexural Modulus According to Nano-silica Content

4.3.2 Flexural Test Results of the Jute/Glass Hybrid Configurations

Flexural test result of jute/epoxy composite is very low than glass/epoxy composite. Glass layers were used to improve the strength of jute composites. Symmetric configurations were arranged with 2 layers of glass and its placements were investigated. $G_1J_6G_1$, $J_3G_2J_3$ and $J_2G_1J_2G_1J_2$ hybrid configurations having 2wt.% nano-silica content were taken into consideration.

Flexural test results are given in Tables 4.6 and 4.7, flexural strength and modulus variation the jute/glass hybrid configurations specimens with (2wt%) nano-silica content are shown in figures 4.10 and 4.11, The best laminate was glass (G_8) with flexural strength 251.62 MPa and modulus 7.61 GPa. The result of flexural strength showed the best configuration is $G_1J_6G_1$ with value 176.67 MPa and flexural modulus with 8.56 GPa when compared to that of jute fiber laminate J8 it was 4.54 GPa . That glass layer location in out and jute in middle. A significant increase the flexural strength of $G_1J_6G_1$ hybrid composite is ascribed the reason that, glass fibers are stiffer and stronger than jute fibers [82]. The flexural strength by the merging of glass fiber as middle glass layers ($J_3G_2J_3$, $J_2G_1J_2G_1J_2$) with value 69.01 MPa and 96.66 MPa it is decreasing when compared to jute laminate J8 at 2wt % .

Table 4.6 Flexural strength values of jute/glass hybrid configurations filled with nano-silica.

	Flexural Strength(MPa)				
	Configurations				
	J8	G1J6G1	J3G2J3	J2G1J2G1J2	G8
	111.79	181.23	69.35	85.58	191.32
	114.91	164.18	69.55	99.79	239.62
	103.19	173.50	71.73	99.49	260.08
	113.28	189.38	70.49	89.16	257.85
	0.00	175.05	63.94	109.31	248.69
average	110.38	176.67	69.01	96.66	251.62

Table 4.7 Flexural modulus values of jute/glass hybrid configurations filled with (2wt%) nano-silica content.

	Flexural modulus(GPa)				
	Configurations				
	J8	G1J6G1	J3G2J3	J2G1J2G1J2	G8
	4.59	7.48	2.07	3.41	7.19
	4.65	9.04	0.66	3.47	7.73

	4.23	9.08	1.98	3.49	8.12
	4.71	8.21	2.09	3.31	7.7
	0	9	2.36	3.43	7.73
Average	3.64	8.56	1.83	3.42	7.61

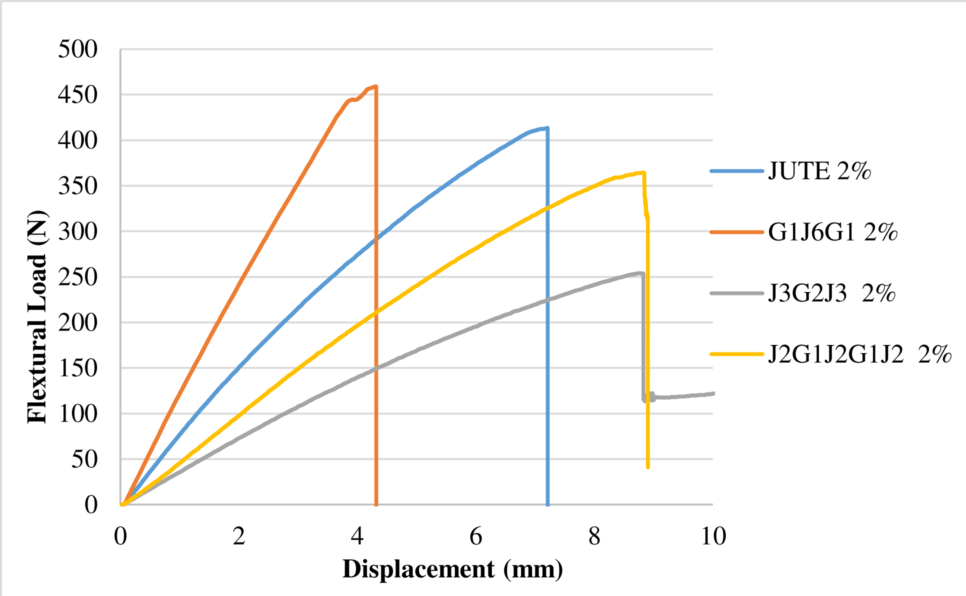


Figure 4.9 Flexural Load-Displacement Curves for the Jute/Glass Hybrid Configurations with 2wt% NS.

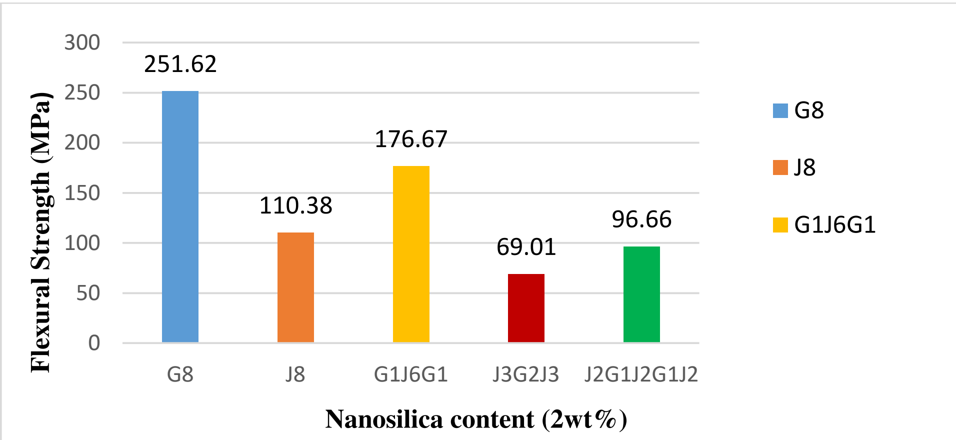


Figure 4.10 Variation of Flexural Strength of the Jute/Glass Hybrid Configurations with 2wt %NS

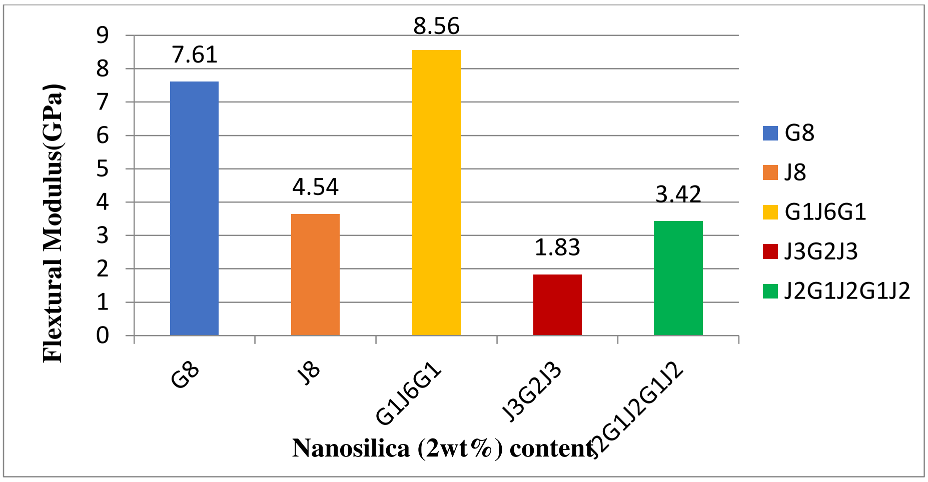
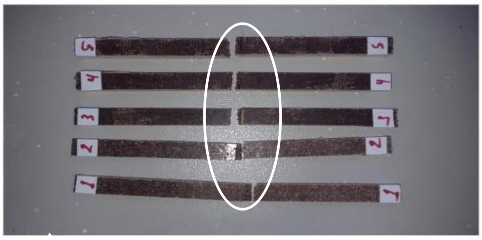


Figure 4.11 Variation of Flexural Modulus of the Jute/Glass Hybrid Configurations with 2wt %NS .

As shown in figure 4.12 the specimen in picture 1 that laminate consists of only jute fiber showed brittle crack that is due to jute fiber properties. The specimen in picture 2 that laminate consist of only glass fiber layers is show no fiber pull-out that is because of glass fibers were strong and stiffen [90]. The specimen in picture (3, 4 and 5) that content glass fiber has no delamination between the jute fiber and glass fiber layers is observed for flexural samples and the failure mode shows small or no fiber pull-out that is because One reason for this may be because of greater extensibility of glass fibers (2.5–3.0) than jute fibers (1.5–1.8) [84]. However, the failure mode displays breakage and less pull-out of fibers.



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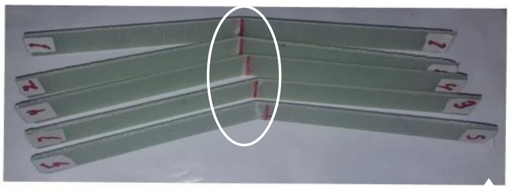

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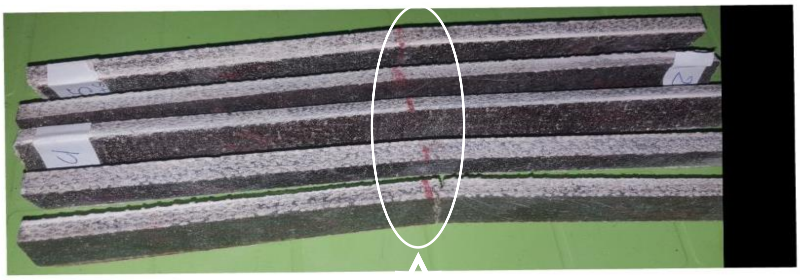

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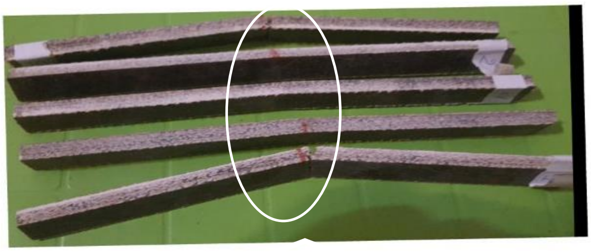

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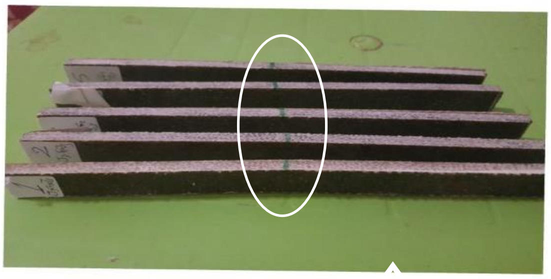

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Figure 4.12 Flexural Specimens after Test

4.4 Impact Result

The Charpy impact test was performed to measure the absorbed impact energy for jute/glass/epoxy composites. The impact energy values for flatwise impacted specimens are plotted in Figure 4.13. From the values of absorbed impact energy in figure 4.13. The absorbed energy of jute/glass /epoxy composites unfilled nano-silica (pure) was gradually increased by addition of nano-silica particles and highest improving impact energy was determined at 2wt% nano-silica content. After that more addition of nano-silica to 3wt% had reduced the absorbed energy values of the composite test samples and most probable reason for this is particle agglomeration. Homogeneous dispersion is difficult because the large surface area of the particles stimulates attractive forces between them, leading to excessive aggregation Zaldivar et al.[85].

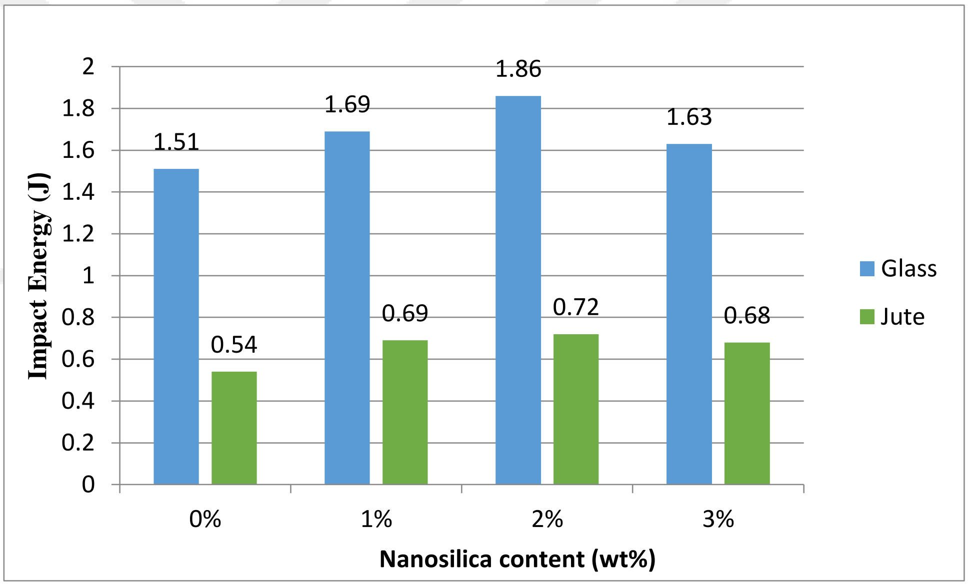

Figure 4.13 Variation of Absorbed Impact Energy Values According to Nano-silica Content

Impact toughness of nano-silica filled jute/glass/epoxy composites was plotted against nano-silica content as appeared in figure 4.14. Nano-silica modified composites showed higher impact toughness compared to composites without nano-silica content. The addition of 2wt% of nano-silica content into jute/glass/epoxy composites resulted in increasing the impact toughness from 79.5 kJ/m^2 to 95.5 kj/$m^{2\ for}$ glass, and from 8.71 kJ/m^2 to 11.4 kJ/m^2 for jute.

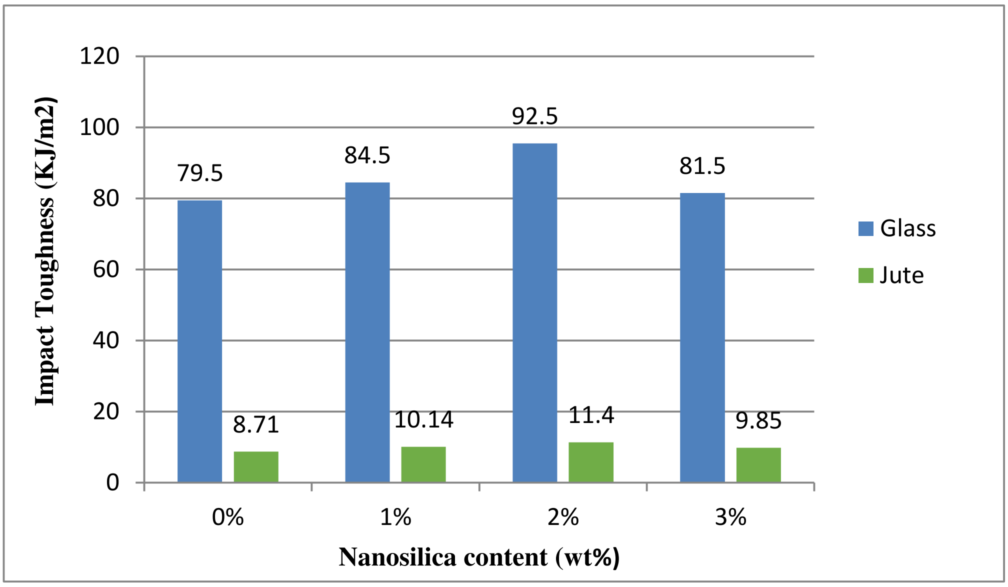

Figure 4.14 Variation of Impact Toughness Values According to Nano-silica Content.

Absorbed impact energy and toughness variation of the jute/glass hybrid configurations specimens with (2wt%) nano-silica content are shown in figures 4.15 and 4.16, The best laminate was ($G_1J_6G_1$) with impact energy 2.78 J and toughness 51.48 kJ/m^2 when compared to that of jute fiber laminate J8 it was 10.4 kj/m^2. that glass layer location in out and jute in middle. The considerable increase in the impact energy of $G_1J_6G_1$ hybrid composite is ascribed to the reason that, glass fibers are stiffer and stronger than jute fibers [82]. The impact energy with the merging of glass fiber as middle glass layers ($J_3G_2J_3$, $J_2G_1J_2G_1J_2$) with value 1.43 J and 1.96 J it is increasing when compared to jute laminate J8 at 2wt %. All tests were carried out at room temperature with a constant impact load of 15 J.

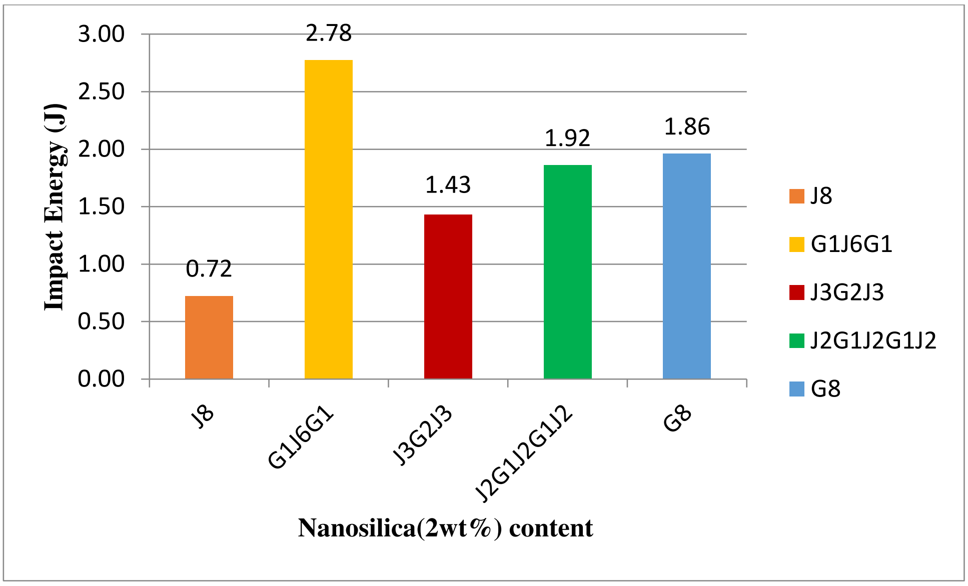

Figure 4.15 Variation of Impact Energy of the Jute/Glass Hybrid Configurations with 2wt %NS .

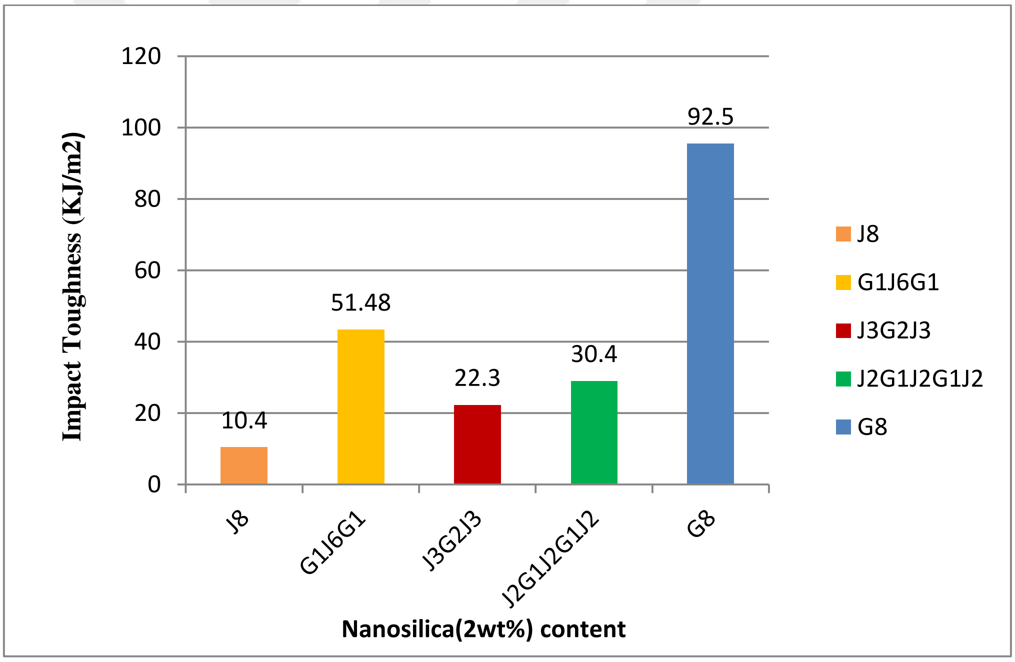

Figure 4.16 Variation of Impact Toughness of the Jute/Glass Hybrid Configurations with 2wt %NS .

From the picture of specimens of impact after test as shown in Figure 4.17 the picture number 1 that laminate consist of only jute fiber showed specimens were separated to two parts that was because of jute fiber make specimen more brittle. For picture 2 that laminate consist of only glass fiber layer the impact side was glass show stressed region and the color of specimen was changed, no fiber breakage and a small amount of delamination compared with other specimens. The picture number 3 and 4 display a brittle fracture for all laminate that content the fiber of jute in outside location from laminate, also the fracture surface laminates were larger than other laminate that content glass fiber in outside location, and the samples separated two part. As well as in picture number 5 that content glass fiber in outside location from laminate and jute fiber in the middle of specimen show there are matrix cracking and fiber pullout at the affected surface near the impact point, samples were separated into two parts.

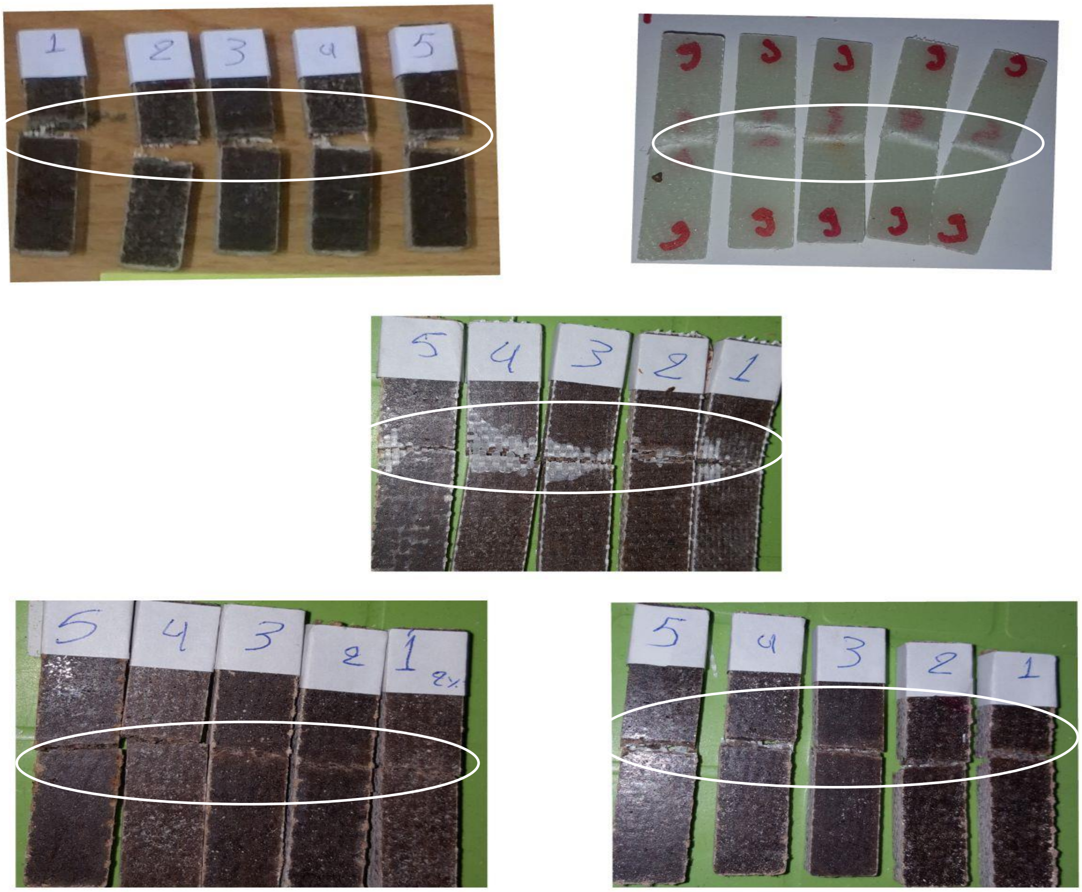

Figure 4.17 Samples of Flatwise Specimen after Test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this study, tensile, flexural and charpy impact behaviors of Jute/Glass composite laminate consisting of an epoxy matrix with nano-silica addition were investigated. The tensile and flexural tests are determined by using a 300 kN Shimadzu AG-X series universal testing machine. The impact behaviors each specimen was determined by performing Charpy impact test. The hybrid composite ($G_1J_6G_1$, $J_3G_2J_3$, $J_2G_1J_2G_1J_2$) laminates were prepared with different stacking configurations.

5.2 Conclusion

Main Conclusions From This Study Can Be Explained As:

- Best result of tensile strength for J_8, G8 are 67.51 and 320.02 MPa with improvement 55.8% and 37.9% respectively compared with pure laminate with 2% wt. nano-silica content.
- The best result of flexural strength for J_8 and G8 are 110.38 and 251.62 MPa with improvement 5.71 % and 95.32 % compared with pure laminate for each configuration respectively that occurred with 2% wt. nano-silica content.
- When hybrid configurations were inspected, highest tensile strength were obtained from G1J6G1 configuration where glass layers are in out and jute in middle with value of 92.01 MPa. 37.31% increase were obtained when its compared with pure jute/epoxy having 2% nano-silica content.
- The best result of flexural modulus for J8 and G8 are 7.51 and 6.47 GPa with improvement 17.61 % and 53.17 % compared with pure laminate for each configuration respectively that occurred with 2 % wt. nano-silica content.
- When hybrid configurations were inspected, highest flexural strength were obtained from G1J6G1 configuration where glass layers are in out and jute in

middle with value of 176.67 MPa. 60 % increase were obtained when it's compared with pure jute/epoxy having 2% nano-silica content.

- The best result of impact energy of flatwise samples for J_8 , G8 are 0.72 and 1.86 J with improvement 23.17 % and 33.3 % compared with pure laminate with 2% wt. nano-silica content .
- The best result of impact toughness of flatwise samples for J_8, G8 are 51.48 and 92.5 kj/m^2 with improvement 16.35 % and 30.9 % compared with pure laminate for each configuration respectively that occurred with 2% wt. nano-silica content.
- When hybrid configurations were inspected, highest impact energy were obtained from G1J6G1 configuration where glass layers are in out and jute in middle with value of 2.78 J .28.6 % increase were obtained when its compared with pure jute/epoxy having 2% nano-silica content.

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