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MECHANICAL PROPERTIES OF JUTE/GLASS FIBER REINFORCED EPOXY BASE COMPOSITE

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Abdullah Hameed Khalaf KHALAF

ABSTRACT

MECHANICAL PROPERTIES OF JUTE/GLASS FIBER REINFORCED EPOXY BASE COMPOSITE

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In this study, the impact, tensile and flexural properties filled epoxy matrix based hybrid laminate of jute/glass fiber reinforced composite laminates. Multi configurations were fabricated as (G_8, $G_3J_2G_3$, $G_2J_4G_2$, G_4J_4/G, J4G4/J, $J_2GJ_2GJ_2$, $J_3G_2J_3$, JGJ_4GJ, GJ_6G and J8) were investigated by Charpy impact, tensile and flexural test. The composite laminates were fabricated by hand lay-up process. The Charpy impact test of fabricated composite laminates was conducted following ISO 179/92 standard by Köger 3/70 Charpy impact test machine. The tensile and flexural tests were conducted by following ASTM D638-10 for uniaxial tensile and ASTM D790-10 for three-point bending. The results showed an increase in absorbing impact energy of the edgewise specimens of jute/glass hybrid configuration were 147.11 % and 424.52% for JG6J configuration compared with G8 and J8 respectively. And from flatwise the increase were 36.98% and 233.33% for G3J2G3 configuration compared with G8 and J8 respectively. The maximum flexural strength and flexural modulus of hybrid composites was obtained for the configuration G3J2G3 it was 411.25 MPa and 7.51 GPa respectively. The maximum tensile strength and tensile modulus of hybrid composites was obtained for the configuration G3J2G3 it was 160.42 MPa and 5.73 GPa respectively.

Key Words: Charpy, Tensile, Flexural, Hybrid fiber composite, Glass fiber, jute fiber

ÖZET

JUTE / CAM ELYAF TEDAVİ EDİLEN EPOKSİ BAZI KOMPOZİTİNİN MEKANİK ÖZELLİKLERİ

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82 sayfa

Bu çalışmada, jüt / cam elyaf takviyeli kompozit laminatların epoksi matris esaslı hibrid laminatını dolduran darbe, çekme ve eğilme özellikleri. Çok konfigürasyonları (G8 G3J2G3, G2J4G2, G4J4 / G, J4G4 / J J2GJ2GJ2, J3G2J3, JGJ4GJ, GJ6G ve J8) Charpy darbe, çekme ve eğilme testi ile araştırılmıştır olarak imal edilmiştir. Kompozit laminatlar el koyma işlemi ile imal edilmiştir. İşlenmiş kompozit laminatların Charpy darbe testi, Köger 3/70 Charpy darbe test makinesi ile ISO 179/92 standardı uyarınca gerçekleştirildi. gerilme ve bükülme testi üç noktalı eğilme için tek eksenli çekme ve ASTM D790-10 ASTM D638-10 izlenerek yürütülmüştür. Sonuçlar elyaf / cam melez bir yapılandırma yanlamasına örneklerin 147,11% sırasıyla G8 ve J8 kıyasla JG6J yapılandırma için 424,52% darbe enerjisini edildi emici bir artış gösterdi. Ve artış düzlemesine dan 36.98 ve% G8 ve J8 kıyasla G3J2G3 yapılandırma için 233,33% idi. Hibrid kompozitlerin maksimum bükülme mukavemeti ve esneme modülü sırasıyla MPa 7.51 GPa 411,25 olan yapılandırma G3J2G3 elde edildi. Hibrid kompozitlerin maksimum çekme mukavemeti ve gerilme modülü sırasıyla MPa 5.73 GPa 160.42 olduğu konfigürasyon G3J2G3 elde edildi.

Anahtar Kelimeler: Charpy, Çekme, Eğilme, Hibrid fiber kompozit, Cam elyafı, jüt lifi

Dedication

This Thesis Is Dedicated To ….

My family, my brothers and their families, my sisters and their families, my wife, my sons, my daughters, and My Friends, For Their Support and Encouragement….

With Great Love

ABDULLAH HAMEED

2017

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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

CHAPTER 1

INTRODUCTION

1.1 General Introduction

From the few years ago, the fibers of the natural have attracted much care from investigator from all countries for its alone characteristics. Common fibers of natural utilized in composite contain bagasse, empty fruit bunch, flax, kenaf, jute, bamboo, pineapple, animal fibers, hemp and wood fibers. The pretty characteristics fibers of natural are green in nature that is biodegradable, Can be produce as the origin comes through can be renew resources, eco-friendly, processing benefits at minimum cost. Fibers of natural are alternate materials utilized to exchange traditional fibers as reinforcing material in polymer composite specially in making the composite was low weight. Treating of composite with fiber of natural give some advantage like as fewer machine wear and the same fiber will bend rather than cracking during working. That different from man-made fiber like as fiber of glass, it breaks easy when intensively mingled with polymer resin. Nevertheless, because of poor compatibility fiber of the natural with hydrophobic kind of polymer matrix, temperature variation of flammability and compounding process properties of natural fibers, limit the utilize of biocomposite in certain applications specially for automotive areas and aerospace [1].

Fiber reinforced polymer composites also exhibit better damping characteristics, good fatigue resistance and high resistance to corrosion [2].

Fibers of natural can be utilized an replacement material to traditional synthetic fibers like as carbon, boron, Kevlar and glass fibers. Natural fibers like as sisal, jute, hemp and banana have benefits like as less weight, low cost, easily to process and bio-degradable liken to the men-made fibers [3, 4].

This led towards better environmental continuity suggested that as well mediated approaches, like as the manufacture of hybrids, containing both glass fibers and fibers of vegetable, like as hemp jute, flax, etc, would be of some interesting for the aim, allowing to take best control of the variables, which are important for the successful of the product and semi-structural utilize of PFCs, such as performance of impact [5].

Various investigators have researched mechanical characteristics of demonstrated that hybrid composites and various natural fiber hybrid composites have good mechanical strength. [1]

1.2 Natural Fibers

In this time investigators are relating much for the fibers of natural as light weight and cost effectual reinforced materials. A large different of variety type fibers of natural including wool, fibers of animal and cellulosic are abundantly available each throughout the world [6, 7]. Natural fibers can be divided into variety kinds relying on their source like as animal and fibers of plant [8, 9]. Natural fibers are of variety kinds depended on their origin source from the plant like as bast (kenaf, jute, hemp etc.), leaf (sisal, PALF and banana etc.), seed (cotton, kapok) and fruit (OPEFB, coir). The mechanical characteristics of natural fibers (jute, kenaf) are observed to be comparable with the commercial man-made fibers, making the fibers of natural very desirable to man-made fibers in automotive and another height end applications where stiffness and weight are of essential concerns [10, 11]. Natural fibers display a many of benefits in conditions of lower density, cost per weight, specific modulus, cost per unit length as well their biodegradable and renewable nature needed for manufacturing green composite and composite with bio-resin [12, 13]. More or less of the most public natural fiber that are utilized as reinforcement in polymer for manufacturing hybrid polymer composite are displayed in Fig. 1.1. Natural fiber can be classified as shown in Fig.1.2

Fig. 1.1 Several kinds of natural fiber that used in composite [1]

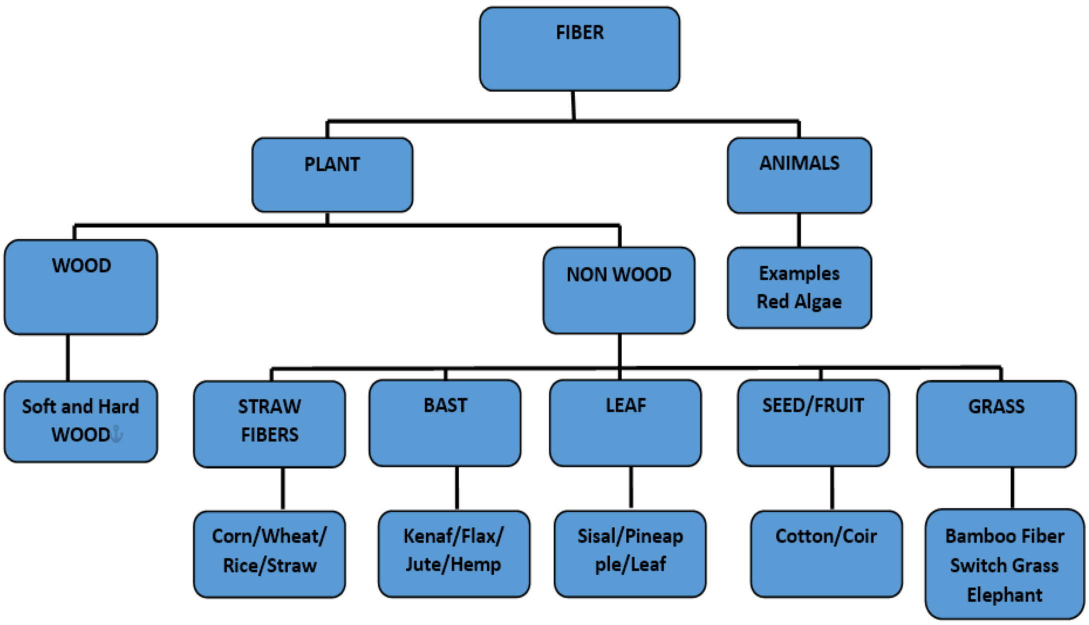


Fig. 1.2 Classification of natural fibers (courtesy of Mohanty et al [14]

1.3 Composites

A composite material is make by merging two or much material to give an unparalleled combination of properties. The above definition is much general and can contain metals alloys, minerals, plastic co-polymers, and wood. Fiber-strengthened composite materials vary from the above materials in that the constituent materials are various at the molecular scale and are mechanically separable. In bulk shape, the constituent materials work jointly, but remain in their original forms. The definitive properties of composite materials are best than constituent material properties and more application of it like aircraft as shown in Figure 1.3. [15,16].

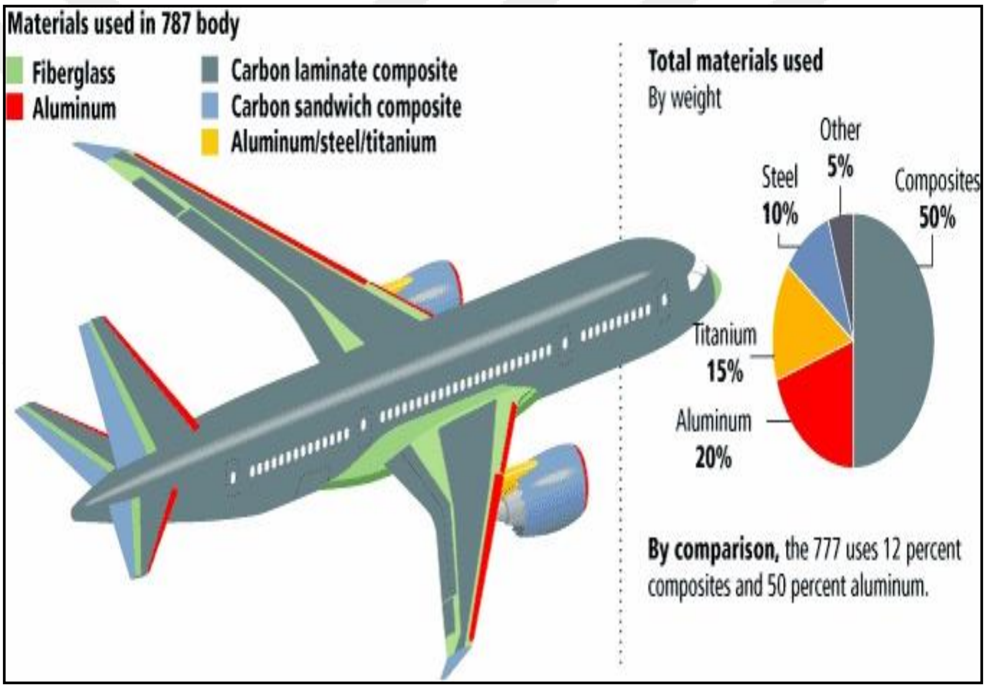


Figure 1.3 application of composite [17]

1.4 Classification of Composites

Composite classification was 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 one was fibrous and the second was particulate. Everyone has unique characteristics, and able to be divided into specific classes, figure 1.4 shows that [18].

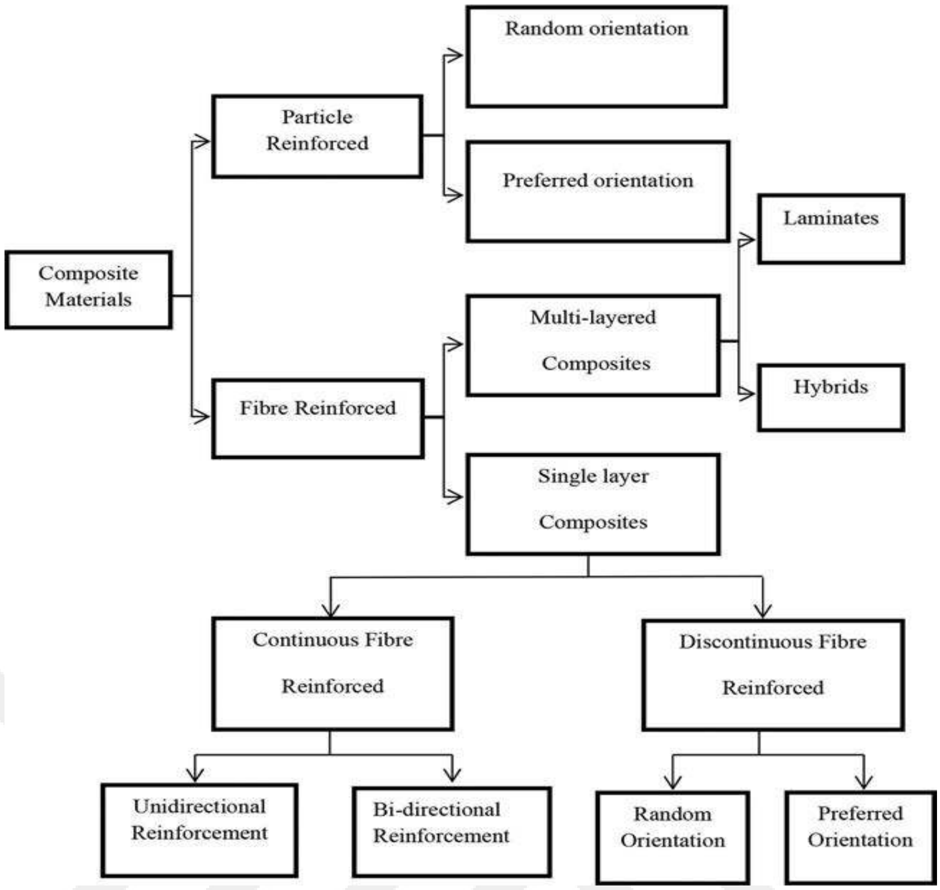


Figure 1.4 Classification of Composites [19]

1.5 Hybrid composite

The term "hybrid" is of Greek-Latin origin. Hybridization is an operation of incorporating of two strengtheners (either natural fibers/ metallic / nano fillers /or artificial fibers) in one polymeric matrix stage or the amalgamation of single reinforcements of polymer mixed by the arrangement to yield best characteristics like (thermal stability, compressive strength, high mechanical strength, stiffness and lowered absorbed water characteristics) which cannot be realized in traditional composite materials [20, 21]. Hybrid materials are very in progress composites materials including of more or two various constituents at the nanometer or molecular scale. Characteristics of crossbred composites are a weighted amount of the individual elements, thus it supply combination of characteristics like impact strength, tensile modulus and compressive strength [22]. Hybrid composite materials have expanded engineering, enforcement where weight to strength proportion, easy of manufacture and little price are necessary. The Hybrid composite characteristics on two various fibers are solely ruled by the fiber orientation, individual fibers content and fiber length, fibers configuration, fiber-matrix bonding and extent of intermixing of fibers. [1]

1.6 Jute Fiber

Structure of jute is multi-celled [23]. Jute is in general derivable from the steam of plant of jute. It grows from 2.5 to 4.5 m flourishes in monsoon climes and it is an annual plant [24]. Jute is a lingo-cellulosic fiber that is from major chemical constituents are cellulose and lignin. The electrical and thermal conductivity, proneness to mildew and moths, biological degradation, cold and radiation, reaction to light and sun, ability to protect from heat, etc. are observed by morphology and cellular structure [25]. The jute fiber chemical composition has been reported by many investigators [26, 27, 28, 29]. Among several natural fibers, fibers of jute are easy available in fabric and fiber shapes with better mechanical and thermal characteristics [30]. The inborn characteristics fiber of jute like as high tensile modulus, low elongation and low density at its specific stiffness, strength and break liken to those fiber of glass draws the care of the world [31-33]. About 100 years jute has been utilized in many uses such as bags, ropes, beds etc. it has besides became used in many things like the packing materials and automobile manufactures. Different most of the food crops and cotton, Jute fiber is largely grown in the state of Bangladesh, China, Thailand, Nepal and India. Approximated 95% of the world product fibers of jute is made by this country [34].

1.6.1 Jute in Different Forms

First one raw Jute that is a soft, shiny and long fiber got from the cover of leaf jute plant. Commercially the littlest part of raw jute is called as reed. Relying on the grade, the long of the reed differs about 1 to 4.5 m. The diameter of reed is normally from 6 to 20 microns [35]. Fig. 1.5 presented the raw jute fiber. It is can be prepared to various shape such as mats or yarn. It is mainly utilized in the fabricating of ropes, sacking cloths, hessian, cords, handicrafts, miscellaneous fabrics and bags [36]. The second type is short Fiber of Jute: fiber Jute in the shape of short fiber is presented in Fig. 1.6. Composites got from short fiber are utilized wide in bearing without load uses to get difficult geometry in automobile and aerospace manufacture [37, 38].

Figure 1.5 Fiber of Jute - Raw

Figure 1.6 Fiber of Jute - Short

1.7 Glass fiber

Fiber glass refers to a lightweight and strong material that consists of thin glass fibers that can be changed to a woven layer or utilized as reinforcement. Glass fiber is less stiffer and strong than carbon fiber-based composites, but less cheaper and brittle. It has display bendability, excellent strength, low weight and dimensional stability. Fiber glass is commonly used in boats, aircraft, swimming pools, automobiles, storage tanks, pipes, roofing, casts and cladding. Glass fiber is a type of fiber reinforced plastic and this reinforcement fiber is manufacture from glass fiber. These features make it very suitable to utilize in doors and windows for industrial applications. Fiber glass is non-conductive electrically, is utilize as an insulator, and remove chances of galvanic corrosion in coastal environments. This property makes it profits to utilize in the underground mining manufacture. [39, 40]

The next glass kinds account for the wide most of fiber glass fabricated commercially for utilize as strengtheners:

Advantex®. Calcium alumino-silicate glass utilized as a boron free substitute for E-glass, supplying E-CR Glass acid impedance with the reinforcing properties of E-glass. Introduce in 1997.

AR Glass. Alkali impedance glasses composed of silicates alkali zirconium, improved for use in utilize in concrete and cement. Chiefly utilized for GRC (Glass reinforced Cement) sheeting panels and roofing.

C glass. Calcium borosilicate glasses utilized for their exceptional stability in acidic surrounds. The poor impedance of water, and so C glass is scarcely utilized as a strengtheners in North America or Europe, but finds many uses in surface mats, glass flakes for acid impedance and coatings surface cloth.

D glass. Borosilicate glasses with little insulation constant utilized for radomes and other specialty enforcement needing permeability to electromagnetic waves.

E glass. Borosilicate-Alumina-calcium- glasses with a maximal alkali content about 2% w/w utilized as a general aim strengtheners where strength and higher electrical resistant are necessary. Together with Advantex, accounts for about 90% of all GRP strengtheners manufacturing today. Introduce in 1939.

E-CR Glass. Calcium alumino-silicate glasses with a high alkali content about 2% w/w utilized where acid corrosion resistant is necessary in additive to electrical resistivity and strength. Introduce in 1980.

R-glass. Calcium alumino-silicate glasses with upper temperature impedance and strength than Advantex or E-CR Glass.

S-glass. Magnesium alumino-silicate glasses utilized for textile substrates or strengtheners in composite structural enforcement, which need higher strength, durability and modulus under terms of extreme temperature of erosive environments [39].

1.8 The Objectives of Research and Tasks

In this study, the main aim is to study the effects of hybridization on Charpy impact behavior, tensile and flexural of jute/glass fiber reinforced hybrid fiber composite laminates. The research tasks can be summarized as follows;

I. Production of jute fiber reinforced composite laminates.

II. Production of jute/glass hybrid fiber reinforced composite laminates using different stacking sequence.

III. Production of glass fiber reinforced composite laminates.

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

V. Discussion about the influence of hybridization on the mechanical characteristics of composite using the obtained results from the tests.

1.9 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 review is presented in Chapter 2. Literature survey has been classified in four parts; introduction, and results on literature review.
- In Chapter 3, data about the materials (fibers, epoxy) and fabrication method used in this study are provided.
- The results and discussions of tensile, flexural and Charpy impact experiments are presented in Chapter 4.
- General conclusions about the results are given at Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the literature, there are many researches on composite materials. A brief literature review related to the jute fiber reinforced composite materials and hybrid fiber reinforced composite materials are presented in this chapter. A literature review has been classified into seven parts; studies on jute/glass and natural fiber/glass hybrid fiber reinforced composite laminates are reviewed in Section 2.2 and Section 2.3, respectively. The studies of tretment and untretment for jute fiber reinforced composite laminates are given in Section 2.4 and sevtion 2.5 respectively, studies of treatment for natural fiber reinforced composite laminates given in 2.6, studies hybrid fiber reinforced composite laminates given in 2.7. The conclusions of the literature review are presented in Section 2.8.

2.2 Studies on Jute/Glass Hybrid Fiber Reinforced Composite Laminates

Rames [41] studied flexural and tensile characteristics of hybrid fiber glass- jute/sisal reinforced epoxy composites. The results appeared that the merging of sisal fiber with fiber of glass reinforced polymer (GFRP) displayed superior characteristic than jute fiber reinforced GFRP composites in tensile characteristics and jute fiber reinforced GFRP composites performed best in flexural characteristic.

Ahmed and Vijayarangan, [42] looked into the influence of stacking and hybridization of glass fiber composite with jute fiber. It was shown 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.

Aquino et al. [43] examined absorbed moisture influence on the mechanical characteristics of glass/jute hybrid composite created by ortho-phthalic polyester resin. The results showed the maximum moisture absorption after eleven months of 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.

Tang [44] evaluated two class of glass-jute hybrid composite by bending test and tensile test in three plies and one ply. Stress displacement curve, load-displacement curve and strength bar chart were cited in this study to get best analysis. The follow points were resulted from this study, According to tensile test results of [0] and [0/90/0] specimens, it points that can be replacement glass fiber by jute fiber with only a low effect on tensile strength in type B structure. According to bending test results of [0/90/0] specimens, it points that can be replacement glass fiber by jute fiber with only a low effect on bending strength in type A structure.

Braga [45] investigated thermal and mechanical characteristic of glass and jute fiber as reinforcement epoxy hybrid composites. In this work 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 pull-out and fracture behavior of the samples by using scanning electron microscope (SEM).

Hazizan [46] investigated environmental influence on the mechanical behavior of pultruded glass/jute fiber reinforced polyester hybrid composites. The outcome showed 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 can be tailored by a suitable hybridization with man-made fibers in order to get a proper cost-performance balance, meantime decrease the environmental impact of the material.

Rosa et al. [47] investagated the post-impact damage 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.

Hazizan [48] 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 a 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,

Sanjay [49] inspected the influence of glass-Jute fiber reinforced polyester on mechanical property. It was noted that tensile strength and impact Strength of 50% glass - 50% Jute fiber composition is found to be best than the other two compositions and the flexural strength of 60% glass-40% Jute fiber composition is found to be best than the remaining two compositions.

2.3 Studies on Natural Fiber/Glass Hybrid Fiber Reinforced Composite Laminates

Haneefa et al. [50] examined the influence of fiber amount, 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 [51] 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.

Kushwaha and Kumar, [52] studied done 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.

Wan [53] 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.

Sain and Panthapulakkal [54] investigated the thermal and mechanical characteristics of glass/hemp fiber-polypropylene (PP) composite materials. The results demonstrated that the reinforcement of glass fiber with hemp fiber hybrid composite material improve the impact, flexural properties and water resistance. Also they have showed that the additive fiber of glass into hemp-PP composites showed in enhanced the water resistance as well as thermal characteristics of the composites.

Mandal [55] studied influence of length and weight fraction of short glass/bamboo fibers on inter-laminar shear strength (ILSS) and flexural strength of unsaturated polyester (USP) resin and vinyl ester resins based composites. It was noticed that flexural characteristics of glass/bamboo fiber reinforced vinyl ester resins were height 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.

Abdul Khalil et al. [56]. looked into the physical and mechanical characteristics of the oil palm reinforced with vinyl ester EFB laminated at various layer sequence with fiber of glass composites. 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.

Sutanu [57] researched characterization of mechanical properties for hybrid GFRP/bamboo and GFRP/jute 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 will be more when the jute and bamboo reinforcement will be on top (under compression) and glass reinforcement will be at bottom (under tension). The compressive modulus increment from JJ to GG with the increment in glass reinforcement. In state of strength, it increment with hybridization and exceeds the glass composite strength

Bhoopathi [58] studied the mechanical properties like tensile strength, impact strength and flexural strength of Hemp-Banana-Glass fiber reinforced composites. It was noted that the glass-banana fiber hybrid composites have much tensile strength from other composites can resist the tensile strength of 39.5MPa followed by the glass-hemp fiber reinforced composites which conclude the amount of 37.5MP. The supreme flexural strength of 0.51 kN conclude by fiber of hemp-banana-glass reinforced composites followed by glass-banana fiber reinforced composites which is having the amount of 0.50 kN. The changes in impact strength of the hybrid composites was 5.33 Joules to 8.66 Joules.

Shahzad [59] evaluate fatigue and impact characteristics of glass-hemp hybrid fiber reinforced biocomposites. The results showed that changed of 11% of hemp fibers with fiber of glass in hybrid composites gave rise to with a considerable increased in tolerance of impact damage. Following impact at 4 J energy, hybrid composites wasted only about 30% of their intrinsic stiffness and strength, compared to 70% loss in characteristics for hemp fiber composites at similar impact energy level. Nevertheless, at that hybridization ratio, the enhancement in impact damage tolerance was fixed to 15 J impact at which the hybrid composites lost about 90% of their actual strength and stiffness.

2.4 Studies of Treatment for Jute Fiber Reinforced Composite Laminates

Albuquerque et al. [32] analysis the influence surface wettability of fiber, various ageing conditions and alkali treatment on the tensile characteristics of longitudinally directed roving of jute fiber reinforced polyester composites as a function of fiber amount. The result showed that the characteristics of tensile for longitudinal composites increment with fiber amount.

Doan et al. [60] investigated the influence of coupling agent (maleic anhydride grafted polypropylene) on behavior of tensile for short fiber of jute reinforced polypropylene composites. The results appeared that the tensile strength of jute/PP composites enhanced in wet ageing terms, which was ascribed to both interfacial adhesion strength and enhanced polymer-matrix.

Gopinath [61] examined the mechanical characteristics fiber of jute reinforced composites with epoxy and polyester resin matrices. It was shown that the flexural strength of polyester-jute and epoxy-jute composites was evaluated to be 38.68 N/mm2 and 44.71 N/mm2 respectively. The 5% concentration from NaOH treatment of fiber reinforced polyester composites lead to 15.6 % enhance in the flexural strength but the 10 % concentration from NaOH treatment fiber of jute reinforced polyester composites while it was 20 % for epoxy-jute composites. Also the polyester-jute composite appeared to have best energy of impact than epoxy-jute composites. As well as the 5% concentration from NaOH treatment fiber of jute reinforced composites appeared to display significant outcomes than the 10 % concentration from NaOH treatment of jute composites.

Liu et al. [62] studied the influence of surface alteration on the tensile characteristics of jute fiber poly (butylene succinate) (PBS) bio-composites. The result shown the modulus and tensile strength increment gradually with fiber content from 0 wt. % to 20 wt.% and at 30 wt. % there is a reduce in tensile characteristics. The decrement of tensile strength at 30 wt.% fiber content might be because of the presence of several ends of fiber in the composites that led to initial slit and hence potential composite unsuccessful also inhomogeneous stress transfer because of aggregation of the fibers within the matrix.

Seki [63] investigated the influence of treatment by siloxane on the tensile characteristics of jute fiber-thermoset composites. The result showed that the handling by siloxane on the jute fabrics alkalized enhanced on tensile characteristics from jute-polyester and jute epoxy composites.

Stocchi et al. [64] investigated the influence of handling on the tensile properties of woven jute/vinyl ester fabric composites at two various period of time of handling. The results presented that composites with 4 hour alkali handled mats beneath biaxial stress present important enhancement in the cooperation of stiffness to composites on 24 hour alkali handled mats beneath untreated mats and biaxial stress.

Vimala, [65] studied the modified effect of Jute fibers by treatment with phthalic anhydride and succinic anhydride at various concentrations of 5%, 10%, 20% and 30% by retting method. The different retention times of 3, 6, 12, 24, 36 and 48hours were maintained during both phthalicylation and succinylation. The tensile strength of composites was showed increment with increment fiber volume fraction. The tensile strength of the PJF composite was displayed to be higher than that of SJF and standard composites at each fibers volume fraction. The supreme tensile strength observed in PJF composites was 81.827MPa. The maximum flexural strength observed in PJF composite was 142.701MPa whereas the lowest flexural strength observed in standard composites was 94.309MPa.

Leela [66] investigated the influence t of successive alkali treatments and fiber loading on tensile characteristics of short fiber of Jute reinforced polypropylene composites. It was shown that when fiber loading increases tensile strength increase too. Nevertheless after loading 20% fiber with concentration 10%NaOH in the fiber treatment, the strength decrement again. The modulus of the composite with treated fibers has increased considerably when liken to plain PP and unhandled fiber reinforced PP composite. Also there was little increment in the strength of composite with handled fibers compared to composite with unhandled fibers.

Gopinath [61] studied the mechanical characteristics of fiber of jute reinforced composites with epoxy and polyester resin matrices. The tensile strength for polyester/jute and epoxy/jute composites was observed to be 9.23N/mm^2 and 12.46 N/mm^2 respectively. The 5% concentration from NaOH handled fiber of jute reinforced composites showed height tensile strength than 10% concentration from NaOH handled fiber reinforced epoxy composite by 18.67 % and for polyester composites the results observe an increment of 16.67 %. The tensile modulus of polyester/jute composite showed 0.811 GPa and that of epoxy/jute composite showed 1.046 GPa.

2.5 Studies of Untreatment for Jute Fiber Reinforced Composite Laminates

Naidu 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.

Khan et al. [33] 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.

Khan et al. [68] 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.

Verma 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 (MAPE) up to 1 %.

Andersen et al. [70] 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.

Hinrichsen et al. [71] examined the effects fiber of jute on the mechanical characteristics of neat biodegradable polymer (Biopol), the mechanical characteristics of the outcome composites, bending strength, tensile strength and impact strength. Observe an increment when liken with neat Biopol. For jute Biopol the tensile strength of was improved by 50%, whilst impact strength and bending strength of the composites were improved by 30% and 90% compared with neat Biopol.

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

Bisariaa [73] studied the influence length of fiber on mechanical characteristics of randomly direction short jute fiber reinforced epoxy composite. The outcome show that the flexural and tensile characteristics were noticed maximum for the composite with 15 mm fiber length while the impact characteristics were noticed maximum for the composite with 20 mm fiber length.

2.6 Studies of Treatment for Natural Fiber Reinforced Composite Laminates

Cordeiroa et al. [74] 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. [75] 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 an intermediate lime water and character handling depicts calcium ions' fixation at fibers surface of compared to a calciumchloride handling which does not.

Arbelaiz et al. [76] improve hybrid composite by combining of glass and flax fibers in polypropylene matrix. Higher mechanical properties of hybrid composites showed with 30 wt.% glass fiber loading than those for fiber of flax bundle/PP and altered by maleic anhydride grafted polypropylene MAPP, it result higher modulus compared than unmodified hybrid composites.

May-Pat et al. [77] studied treatments influence of fiber surface on the necessity work of crack of high density polyethylene HDPE-continuous henequen fiber-reinforced composites. The outcome appeared that the mechanical characteristics and the fracture behavior of a NFPC depend on the characteristics of region and constituents of the interphase, or fiber surface, where the stress transfer happened. Moreover, the tailoring of the interphase by various types of surface handling and cautiously characterizing it supplies a best information of the behavior of the NFPCs. Furthermore, various treatments for fiber surface alter the natural fiber microstructure specifically under higher loading values.

Perumal et al. [78] 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 characteristics. The concentration of alkali on the fiber surfaces showed best mechanical characteristics of the resulted composite.

Francis et al. [79] studied the influence of various chemical handling on the mechanical characteristics and properties of oil palm-sisal hybrid fiber reinforced natural rubber composites. It was shown that with chemical handling, the values of torque increment which lead to bigger crosslinking. Likewise, alkali treatment displayed increment in tensile strength of the composites compared with unhandled composites and with 4% concentrations of NaOH handled fibers, maximum tensile strength for resulted composites was saw.

Paridah et al. [80] 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.

Yousif [81] 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.

2.7 Studies Hybrid Fiber Reinforced Composite Laminates

Thiruchitrambalam [82] studied the influence of sodium lauryl sulphate (SLS) and alkali on mechanical characteristics of banana/kenaf woven hybrid composites and hybrid composites. The result showed SLS treatment observed better enhancement in impact, tensile and flexural strength of woven and non-woven hybrid composites liken to alkali handled composites

Amico [83] investigated the mechanical characteristics of sisal-glass hybrid composites. It was shown that the simple handling of drying or washing/drying sisal fibers enhanced the tensile and flexural characteristics of the sisal composites.

Jawaid et al. [84] examined the impact characteristics of oil palm EFB and jute fiber reinforced on epoxy as hybrid composites. The outcome show that the impact strength of neat EFB composites was more than of hybrid composites. The hybrid composite with EFB/Jute/EFB arrangement has best impact strength than sequence of Jute/EFB/Jute hybrid composites.

Jawaid [85] 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.

Venkateshwaran et al. [86] 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.

Ramesh et al. [87] investigated impact conduct of Jute/Sisal and fiber of glass reinforced hybrid composites. The outcome showed that the impact absorption energy by JGFRP composite specimen was best than the SJGFRP and SGFRP composite specimens. Based on the notices of the experiment, it was suggested that these light weight hybrid composites can be utilized as an alternate reinforcing material to men-made fiber reinforced polymer composites for mediume load applications.

2.8 Conclusions of The Literature Review

The following conclusions can be obtained from the literature review:

1. Natural fiber reinforced composites material is becoming essential structural materials in numerous engineering applications where better mechanical properties, too high strength and specific stiffness are required.
2. Some of these studies are concentrated on new methods to improvement the mechanical properties by hybridization on natural fiber reinforced composite materials due to their enhanced and better characteristics than their individual constituent
3. Also, it is seen from the literature another procedure to enhance the 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.
4. There is 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

PRODUCTION OF COMPOSITE LAMINATES AND DETERMINATION OF MECHANICAL PROPERTIES

3.1 Introduction

This chapter concerned with a summarized presentation about the manufacture of composite laminates, production of specimens and experimental procedure of impact, flexural, and tensile tests. Some general information about the constituents of the prepared composites like jute fiber, glass fiber, treatment with NaOH and epoxy resin system, and the fabrication technique with hand layup technique, was described.

3.2 Materials

3.2.1 Jute Fiber

Jute is multicell in construction. The 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 and hemicellulose in differing quantities [23]. The jute fiber was supplied by local market, Turkey. Figure 3.1 shows jute Fiber that used in this study. The physical and chemical characteristics of jute fiber were recorded in the Table 3.1and 3.2 respectively [88].

Figure 3.1 Jute fiber.

Table 3.1 Physical characteristics of jute fiber [88]

Density (g/cm3)	1.3
Young's modulus (GPa)	26.5
Strength (MPa)	393-773
Elongation at break (%)	1.5-1.8

Table 3.2 Chemical composition of jute fiber [88]

Constituents	%
Cellulose	60 – 62
Hemi Cellulose	22 - 24
Lignin	12 – 14
Others	1 – 2

3.2.2 Glass Fiber

Fiber glass indicate to a strong material and lightweight that consists of thinly fibers of glass that can be changed into a woven layer or utilized as reinforcement. Fiberglass is less stiff and stronger than carbon fiber-based composites, but cheaper and less brittle. [39, 40]. Plain weave E-glass fabric with an areal density of (200 g/m^2) was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey that is used in this thesis. Glass fiber was shows in Figure 3.2.

Figure 3.2 Glass fiber.

3.2.3 Epoxy Resin

Epoxy resins were formed from a lengthy chain molecular structure with reactive fiber at either end. Epoxy resin is easily and quickly curved at any temperature from 50 to 150c depending on the choice of curing agent. In this work, EPIKOTE MGS LR160 was used as epoxy resin [89]. Figure 3.3 show epoxy resin. The physical properties of epoxy was given in the Table 3.3 measured at 25°C. The epoxy was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey.

Figure 3.3 Epoxy Resin

Table 3.3 Physical characteristic of the epoxy resin [90]

Properties	Epoxy (EPIKOTE MGS LR160) specification
Density [g/cm³]	1.13 – 1.17
Viscosity [mPas]	700 – 900
Refractory index	1.548 – 1.553

3.2.4 Hardener

Hardener was utilized as a curing agent which was mixed with epoxy in suitable proportions which helps to solidify the wet composite. Generally, the hardener and epoxy resin having ratio 100:25 was used in composite fabrication. Figure 3.4 show hardener [89]. The physical properties of hardener was given in the Table 3.4 measured at 25°C. The hardener was supplied by DOST Chemical Industrial Raw Materials Industry, Turkey.

Figure 3.4 Hardener

Table 3.4 Physical characteristic of the hardener [90]

Properties	Hardener (EPIKOTE MGS LH160) specification
Density [g/cm³]	0.96 – 1.00
Viscosity [mPas]	10 – 50
Refractory index	1.517 – 1.520

3.2.5 Fiber Surface Treatments

The treatment on fibers were about 2 h under ambient situation with NaOH solutions of concentrations of 1% at 25 ^{o}C. 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 60 ^{o}C for 24 hr until wholly dry. Figure 3.5 shows jute fiber immersing in sodium hydroxide.

Figure 3.5 Jute fiber immersing in sodium hydroxide

3.3 Hybrid Fiber Reinforced Composite

In order to fabricate jute/glass/epoxy composites after treatment jute fiber, hand lay-up technique was utilized. At first, the hand lay-up mechanism was employed to fabricate laminated samples. The fiber of jute was put down and epoxy was poured equally throughout the layer. Another layer was arranged closely. Thus, the eight layers were utilized to fabricate composite laminate and utilize the stacking that need it to conduct the tests. Then, the laminate was compressing molded by hot press device. From these laminates, the samples for the mechanical test were fabricated according to ASTM standards. The hybrid fiber reinforced composites were fabricated by combination of jute fiber and glass fiber with various stacking sequences. Nine configurations were produced as J_8, G_8, $G_3J_2G_3$, J_4G_4, $G_2J_4G_2$, GJ_6G, JGJ_4GJ, $J_2G_1J_2G_1J_2$ and J3G2J3.

3.3.1 Production of Hybrid Composite Laminates

Production of hybrid composite laminates, fibers were cut with a suitable dimension 300 mm × 250 mm that enough to get specimens for testing by EC cutter Figure 3.6. The proportion of epoxy (EPIKOTE MGS LR160) to hardener (EPIKOTE MGS LH160) was 100:25±2 by weight and prepared with suitable and enough amount.

Figure 3.6. Electric cuter

Firstly epoxy and hardener were mixed at a constant speed with mechanical steerer for 5 minutes to get a homogenous matrix. Mixer shown in Figure 3.7.

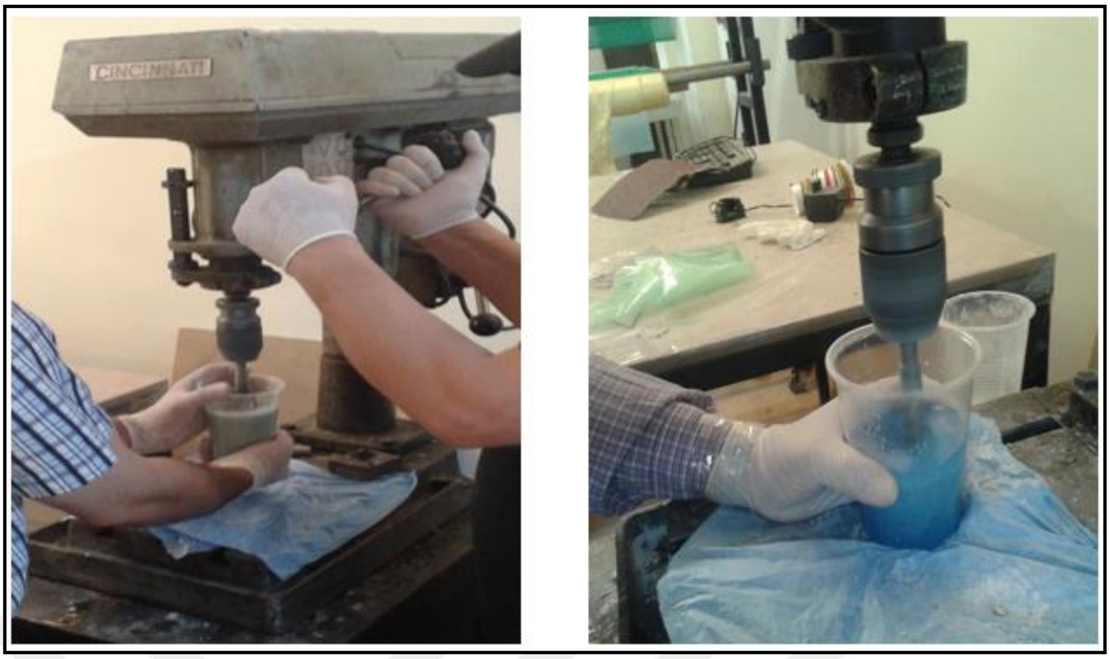


Figure 3.7. Mixer

After completing hand lay up on composite laminate, the laminated fabrics were put it on the hot press Figure 3.8 and subjected to 0.4 MPa pressure for 1 h curing time with 80°C temperature.

Figure 3.8 Hot press

The composite laminates that produced were cooled until room temperature under constant pressure about three hours. Finally, the composite laminate was taken away from the hot press to get a fine finished composite laminates and hybrid composite configuration as shown in Figure 3.9. And Figure 3.10 shows the hybrid configuration that fabricated in this study.

Figure 3.9 Composite laminates

The produced composite laminates in a size of 300 mm × 250 mm was cut to the required size of specimens using CNC machine as shown in Figure 3.11 according to the ASTM standards. ASTM D 790 [91] used for flexural test, ISO 179/92 for impact test and ASTM D-638 [92] used for tensile test. The stacking J_8, G_8, $G_3J_2G_3$, J_4G_4, $G_2J_4G_2$, GJ_6G, JGJ_4GJ, $J_2G_1J_2G_1J_2$ and $J_3G_2J_3$ were prepared to show hybridization effects with treatment jute fiber.

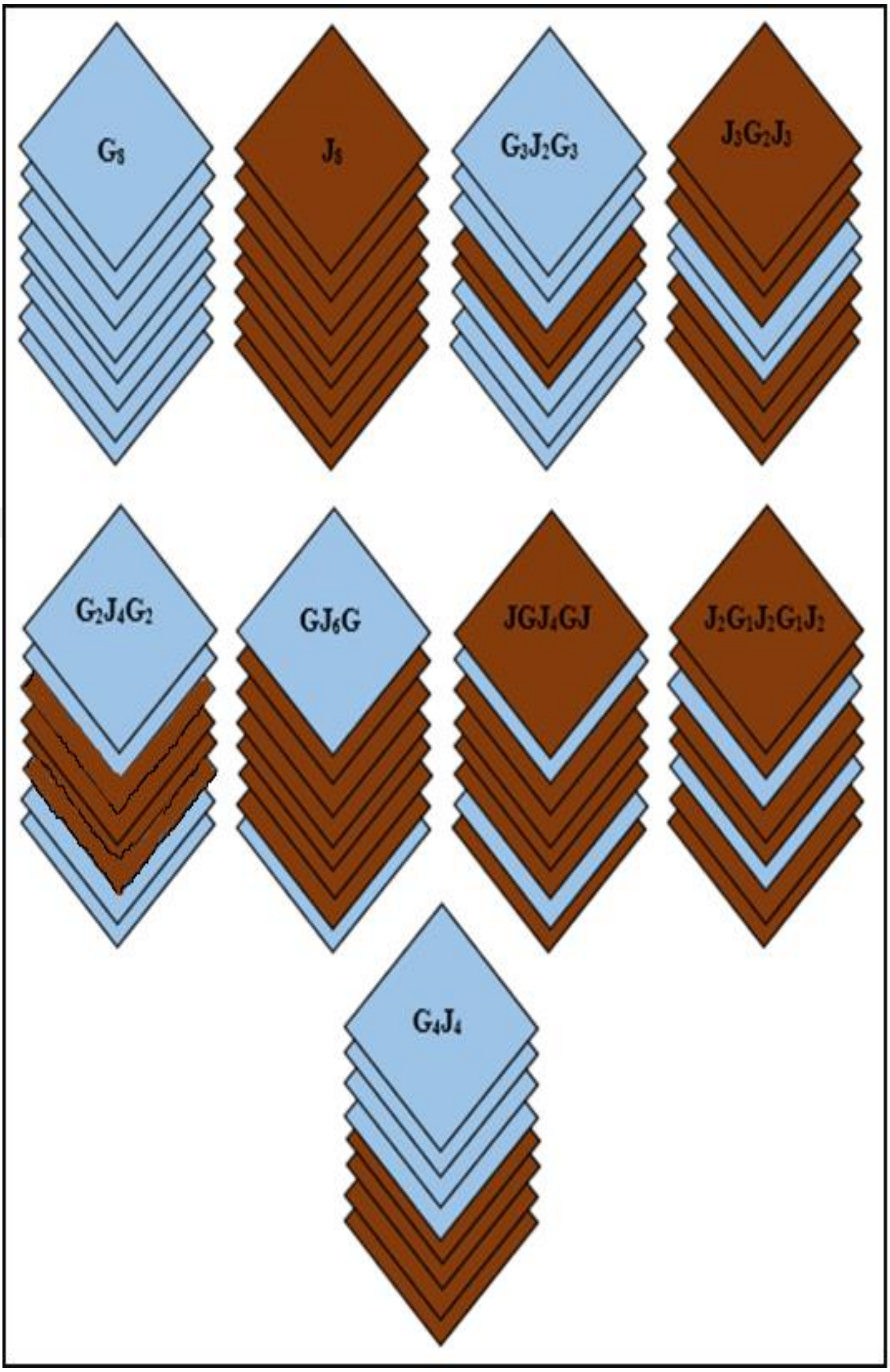
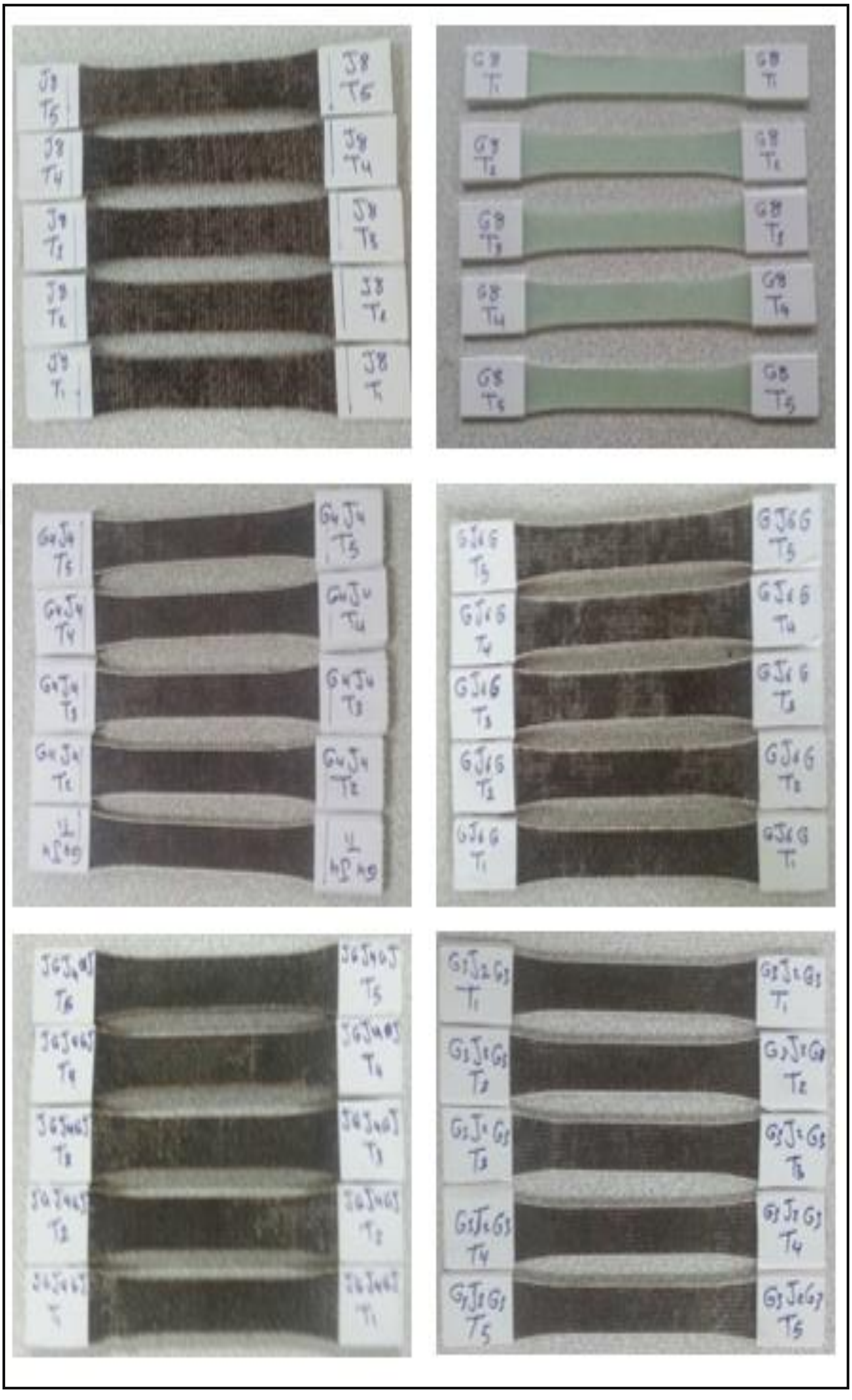


Figure 3.10 Hybrid configurations

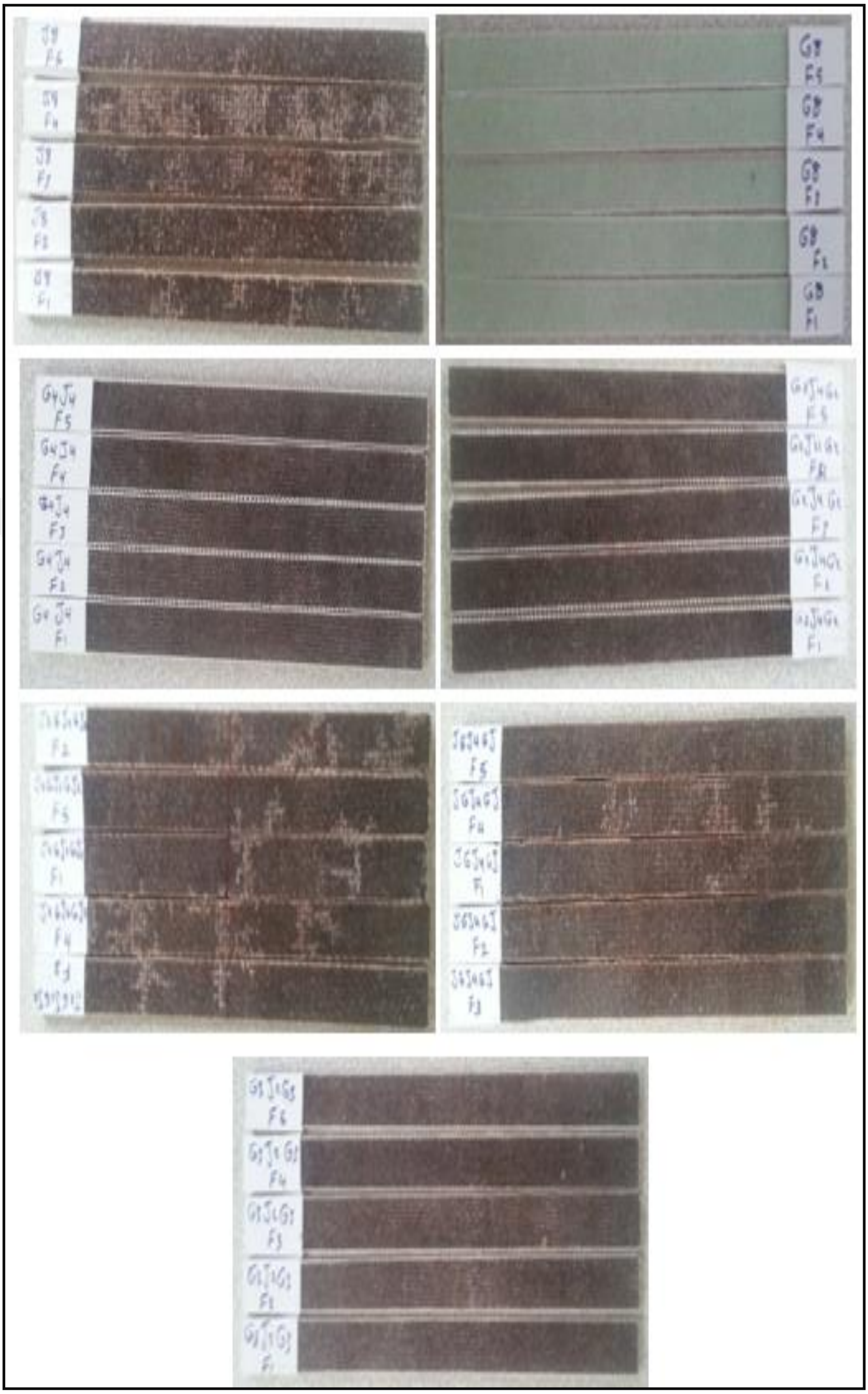
Figure 3.11 CNC-Cutting specimen

3.3.2 Preparation of Test Specimens

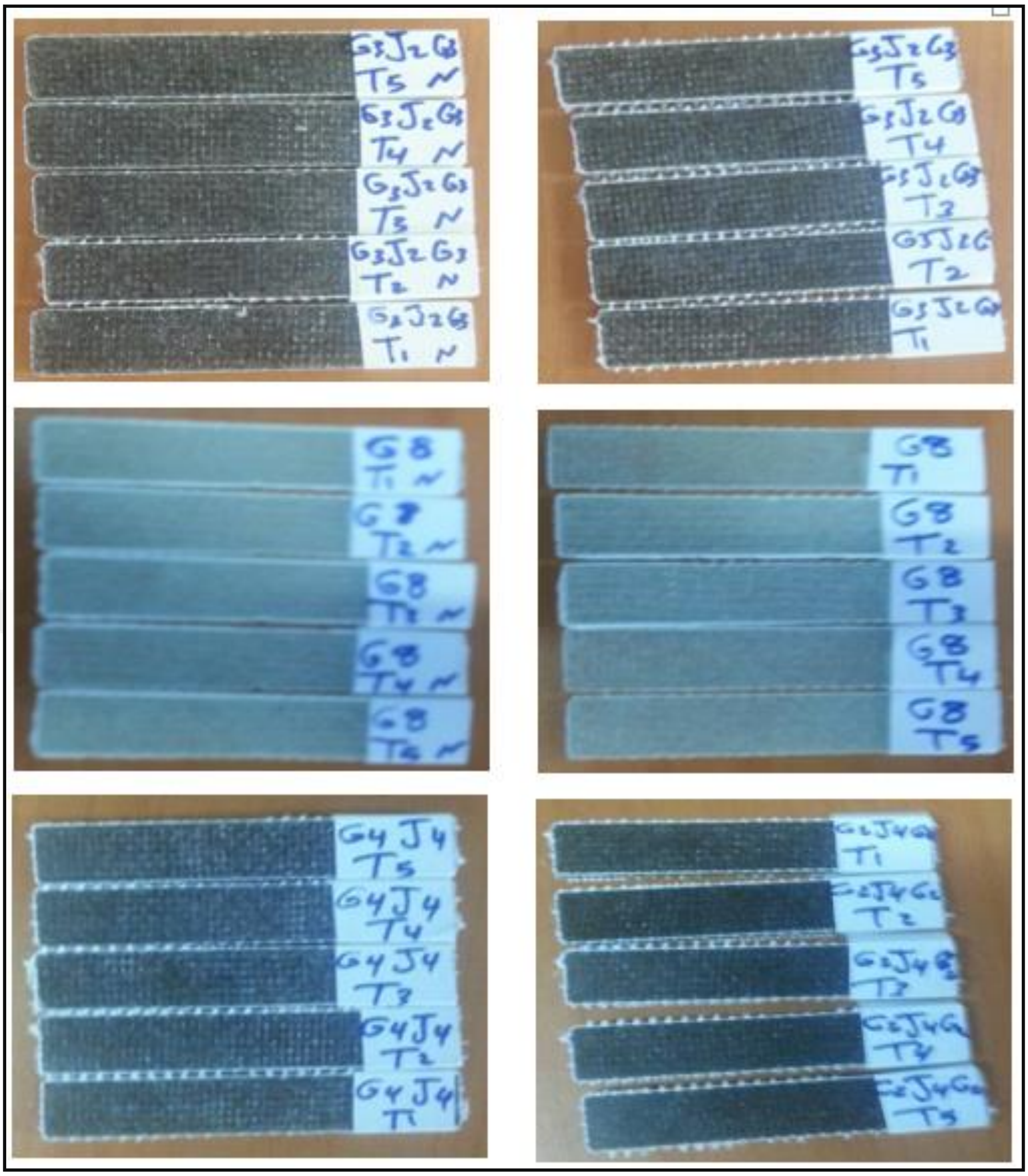
After the production method completed the test samples were produced from the sheet to the desired size according ASTM standards D-790-00 for flexural test, ASTM standards D638-00 for tensile test and ISO 179/92 for impact test using CNC machines. Samples for impact test, tensile test and flexural test have been prepared for testing hybrid composites was presented in Figure 3.12.



(a)



(b)



(c)

Figure 3.12 Specimens of (a) tensile test (b) flexural test (c) impact test

3.4 Determination of Mechanical Properties

The flexural and tensile strength characteristics of the composite specimens were determined at room temperature utilizing the AG-X series-Shimadzu testing machine (Kyoto, Japan) Figure 3.13. Appropriate samples were prepared with a size of 165 mm × 13 mm for a gauge length of 50 mm for tensile test and 200 mm × 12.7 mm for flexural test. The thickness of tensile, flexural and impact specimens was changed depended on type and number of layers (glass or jute) that used to fabricate the laminates. The crosshead speed was 2 mm/min for tensile test and 3 mm/min for flexural test. And for impact test the Köger 3/70 model Charpy impact test machine, as given in Figure 3.18 was used in the tests with 55 mm ×10 mm dimension of test specimen for flatwise and edgewise. Five samples were examined at least for each compound, and the average value was calculated.

Figure 3.13 Shimadzu AG-X series testing machine

3.4.1 Determination of Tensile Properties

Test of tensile was a fundamental materials science test in which a specimen is loaded to a controlled tension until broken. The values from the test were commonly utilized to choose a material for quality control, for an application, and to predict how a material will respond under other kinds of forces. Characteristics that were directly determined via a tensile test were ultimate maximum elongation, tensile strength and reducing in area. From these quantifications the following Characteristics can also be measured: strain-hardening properties, Young's modulus, yield strength, and Poisson's ratio. Figure 3.14 display tensile test.

Figure 3.14 Tensile test

3.4.1.1 Tensile Specimen

Tensile characteristics of samples were producing according to the ASTM standards (D638-00) standard test technique, a suitable sample cutting to make test with L= 165 mm, w =13 mm. Figure 3.15 show the tensile test specimen with dimensions.

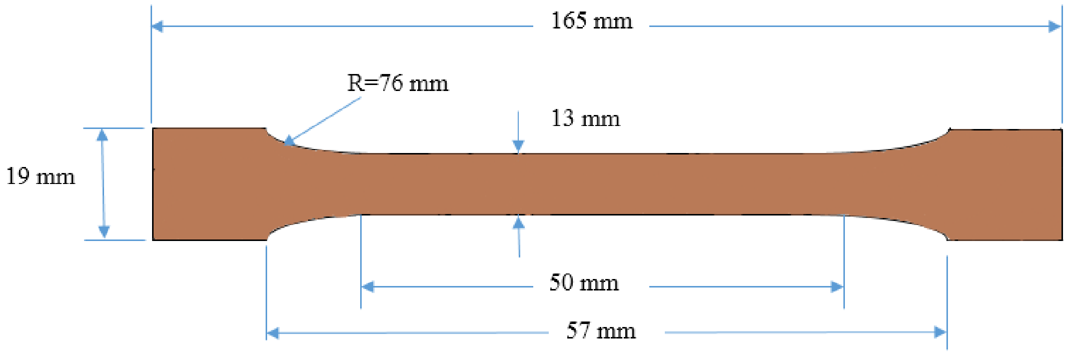


Figure 3.15 The dimensions of the tensile samples according to ASTM 638-00

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

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

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:

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

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 break. Then tensile strength (σ_t) was calculated to utilize the stress and strain data's that's found from the testing machine.

3.4.2 Determination of Flexural Properties

Flexural strength, as well called as bend strength, fracture strength or modulus of rupture is a material characteristic, which was the stress in a material only before it yields in test of flexure. The transversal bending test is most much utilizing, in which a sample having just a rectangular or circular cross-section is bent till yielding or broken utilize a flexural test in three point method. The flexural strength represents the maximum stress in the material that experienced at its moment of failure. It is evaluated in terms of stress. Figure 3.16 show flexural test.

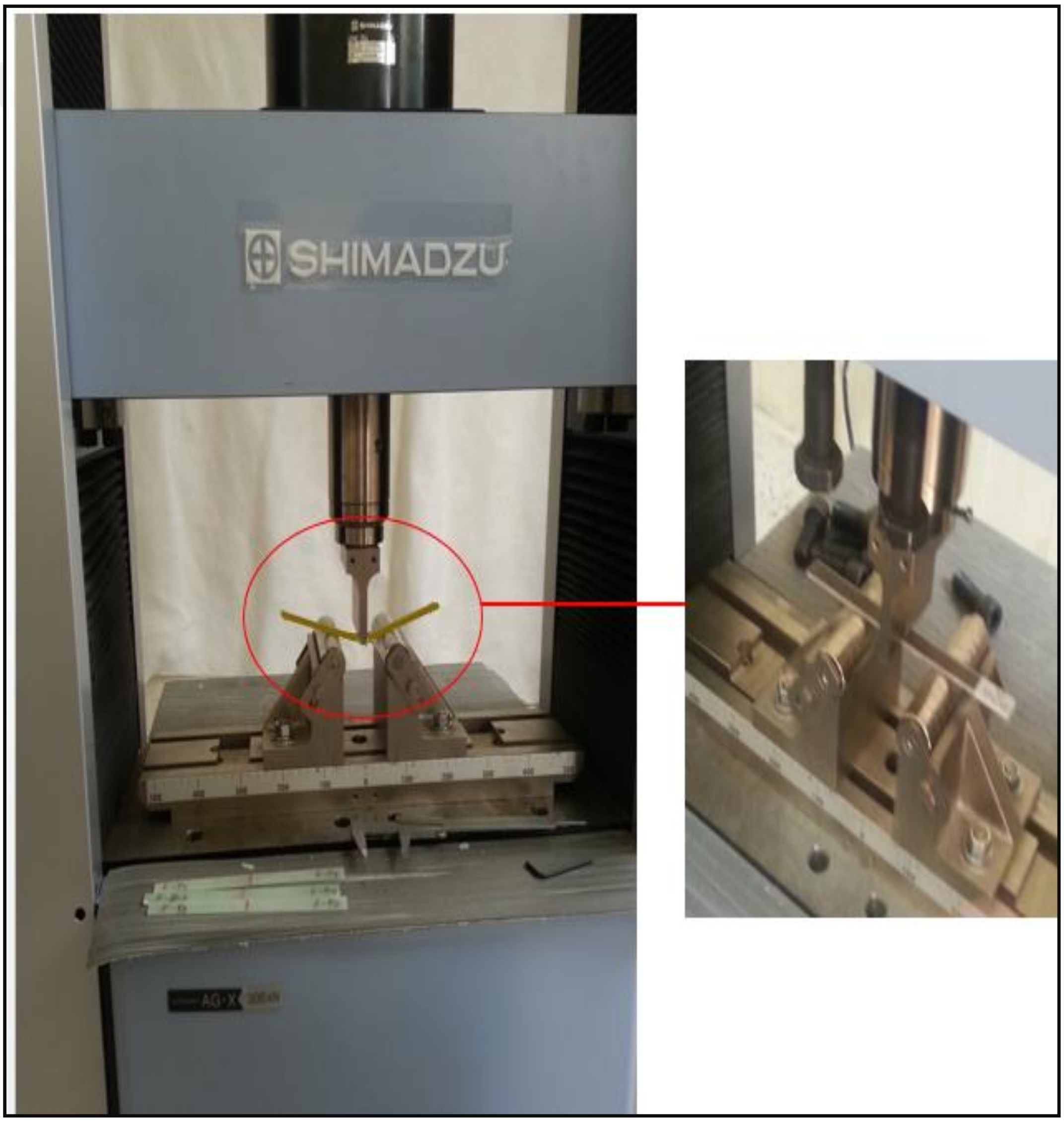
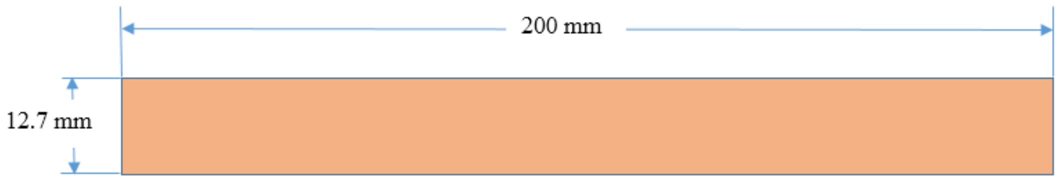


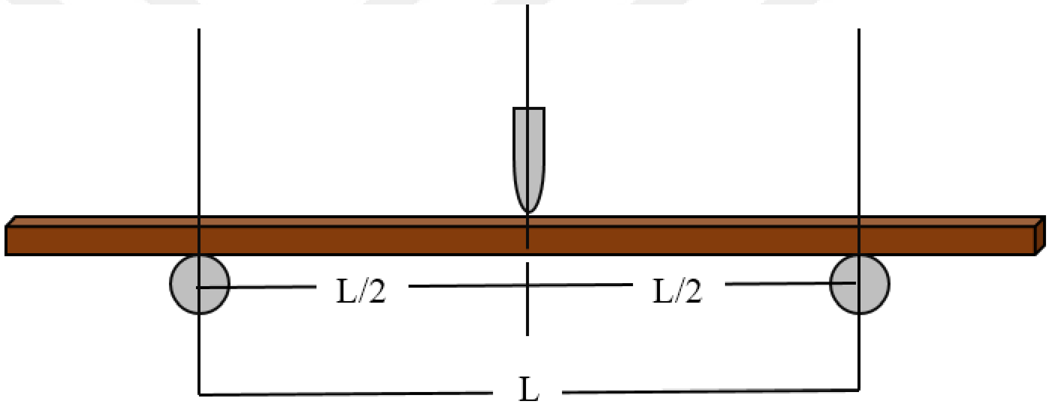
Figure 3.16 Flexural test

3.4.2.1 Flexural specimen

Flexural characteristics of samples were selected depended on the ASTM D790- 00 standard test technique, Figure 3.17 a show that samples, a suitable sample 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 3.17 b.



(a)



(b)

Figure 3.17 (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 [91].

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

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

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

Where L, h and b square measure the span, depth and width of the specimen respectively, m is that the slope of the tangent to the initial line a part of the load deflection diagram, D is that the highest deflection before break and P is that the load at a set point on the load-deflection diagram.

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 3.18 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. Edgewise specimens and flatwise specimens are illustrated in Figure 3.19.

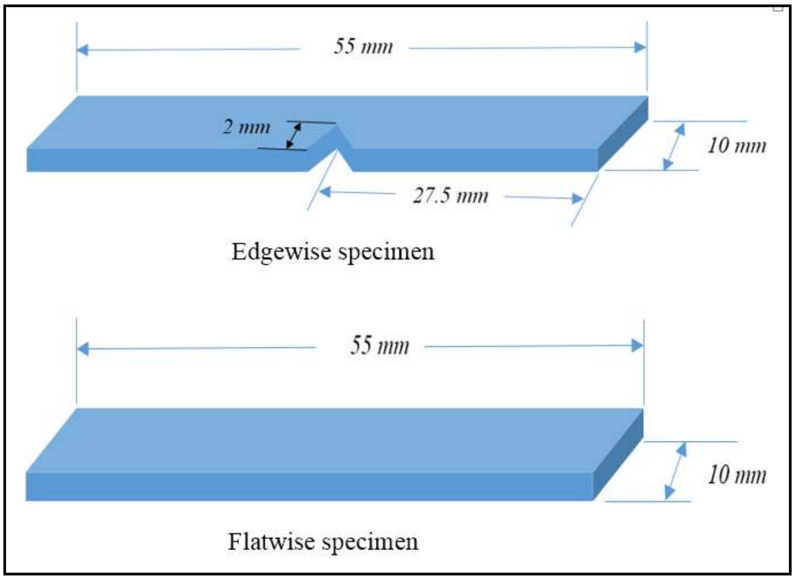


Figure 3.18 Flatwise and edgewise specimens.

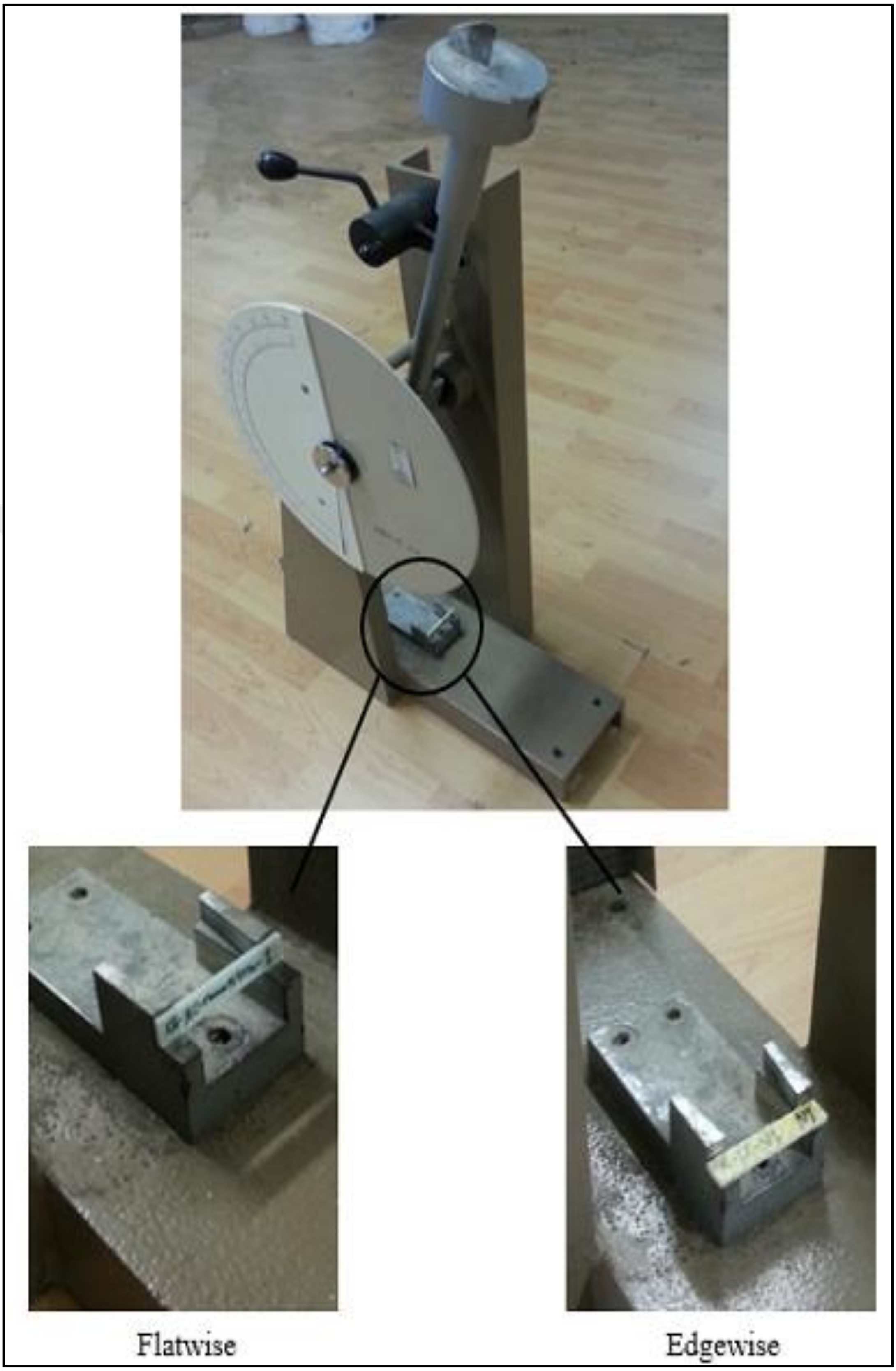


Figure 3.19 Charpy impact test (flatwise and edgewise impact loadings)

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

$$E = E_a - E_b \qquad (1)$$

$$a_{cu} = \frac{E}{b \times h} \qquad (2)$$

where, E, E_a, E_b, in Equation (1) represent the absorbed impact energy, potential energy of the weighted pendulum before and after impact respectively, and a_{cu} , h and b in Equation (2) represent impact toughness, thickness of test sample and width of the test sample, respectively. Figure 3.20 shows all the parameters.

Average values and standard deviations for the impact absorption energy and impact toughness were used to assess the effect of stacking sequence.

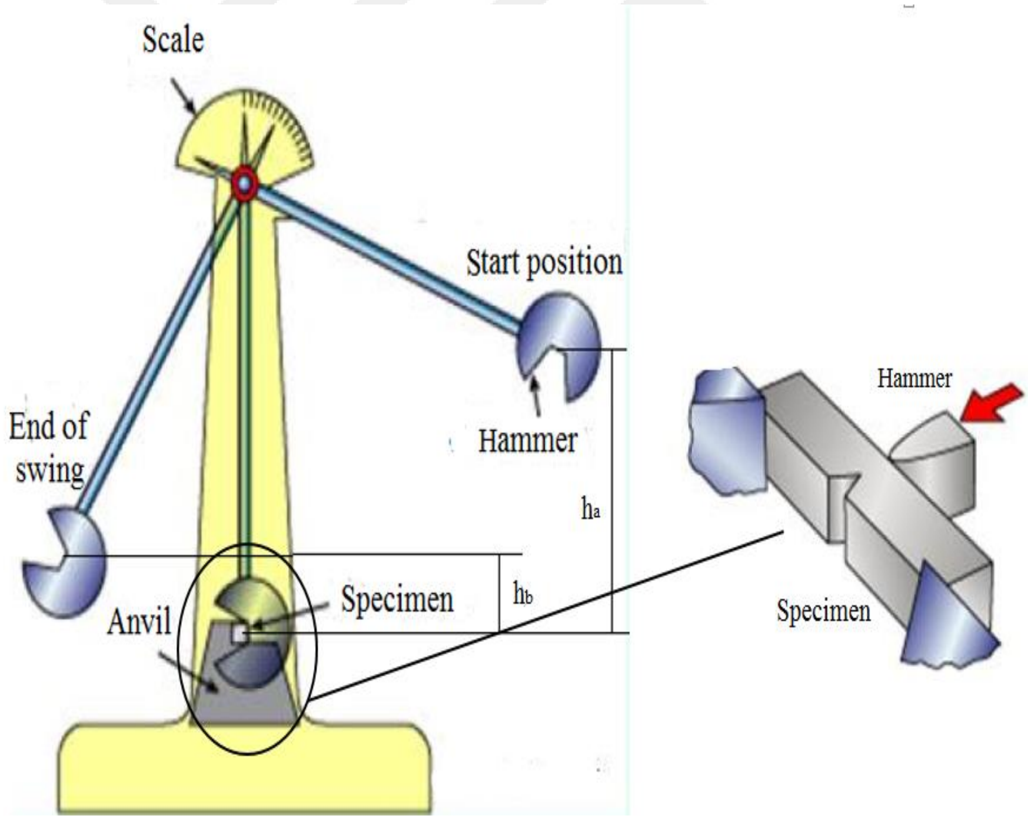


Figure 3.20 Pendulum before and after impact.

CHAPTER 4

EXPERIMENT RESULTS AND DISCUSSION

4.1 Introduction

The results found from the experimental work on the flexural, tensile and impact testing of various laminate composites were presented using several tables and figures, which represent the value of the flexural strength, flexural modulus, relationship force with displacement curve, tensile strength, tensile modulus, relationship stress with strain curve, impact toughness and impact energy of the prepared composite laminates of jute/glass/epoxy, with several configuration of hybrid fiber reinforced composites laminates.

4.2 Laminate Stacking Sequence

Whole the laminates were manufacture with total 8 plies by different position and number of glass layers to get different stacking sequences as shown in Table 1.1 G4J4/G mean the impact side was glass, and J4G4/J mean the impact side was jute. Thickness of laminates were changed according to amount of jute layer. Its varies from 1.6 mm to 6.2 mm. Maximum thickness was 6.2 mm for full jute composite layer (J_8). Laminates were grouped according to weight percentage of jute fiber on a composites and results were inspected by using this percentage.

Table 4.1 Configurations of laminate

		wt.% of fibers		
Configuration	Sequence	Glass	Jute	Thickness (mm)
G_8	GGGGGGGG	100	0	1.6
$G_3J_2G_3$	GGGJJGGG	75	25	2.65
$G_2J_4G_2$	GGJJJJGG	50	50	4.1
G_4J_4/G	GGGGJJJJ	50	50	4.1
J4G4/J	JJJJGGGG	50	50	4.1
$J_2GJ_2GJ_2$	JJGJJGJJ	25	75	5.9
$J_3G_2J_3$	JJJGGJJJ	25	75	5.9
JGJ_4GJ	JGJJJJGJ	25	75	5.9
GJ_6G	GJJJJJJG	25	75	5.9
J_8	JJJJJJJJ	0	100	6.2

4.3 Impact Test Results of Jute/Glass laminate

The Charpy impact test was performed to measure the absorbed impact energy for jute/glass/epoxy composite. The impact energy values for edgewise impacted specimens (glass layer in out and jute in middle) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.1.

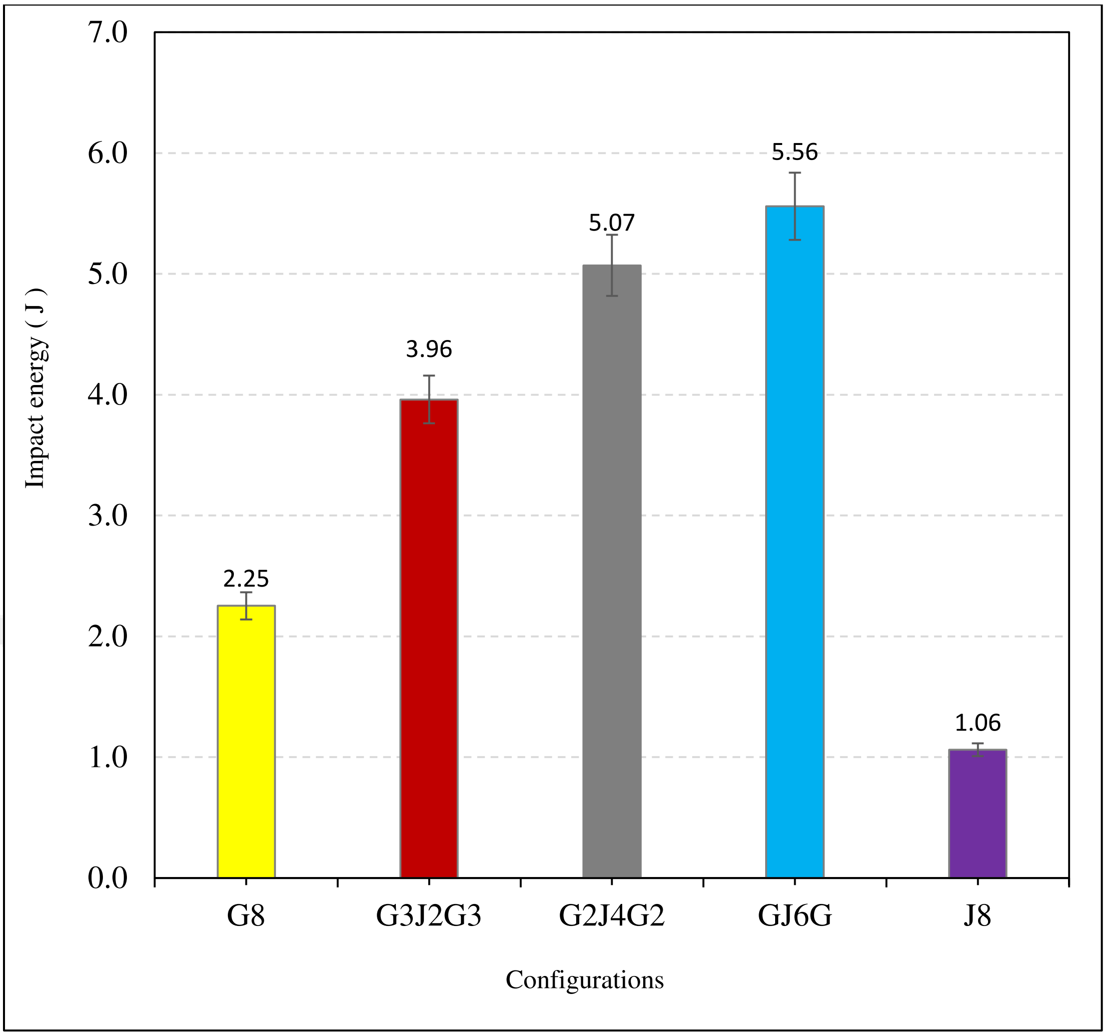


Figure 4.1 Absorbed impact energy values for edgewise specimen of jute, glass and jute/glass (glass layer in out and jute in middle) with epoxy.

From the Figure 4.1 the maximum impact energy with GJ_6G configuration it was 5.56J, and all configurations that content layer of glass in out position from laminates give higher impact energy compared with pure glass or pure jute. These compositions were cheaper than that with 100% glass fiber amount, and with best mechanical characteristics than the 100% jute fiber composition.

The impact toughness values for edgewise impacted specimens (glass layer in out and jute in middle) are plotted against configurations as shown in Figure 4.2.

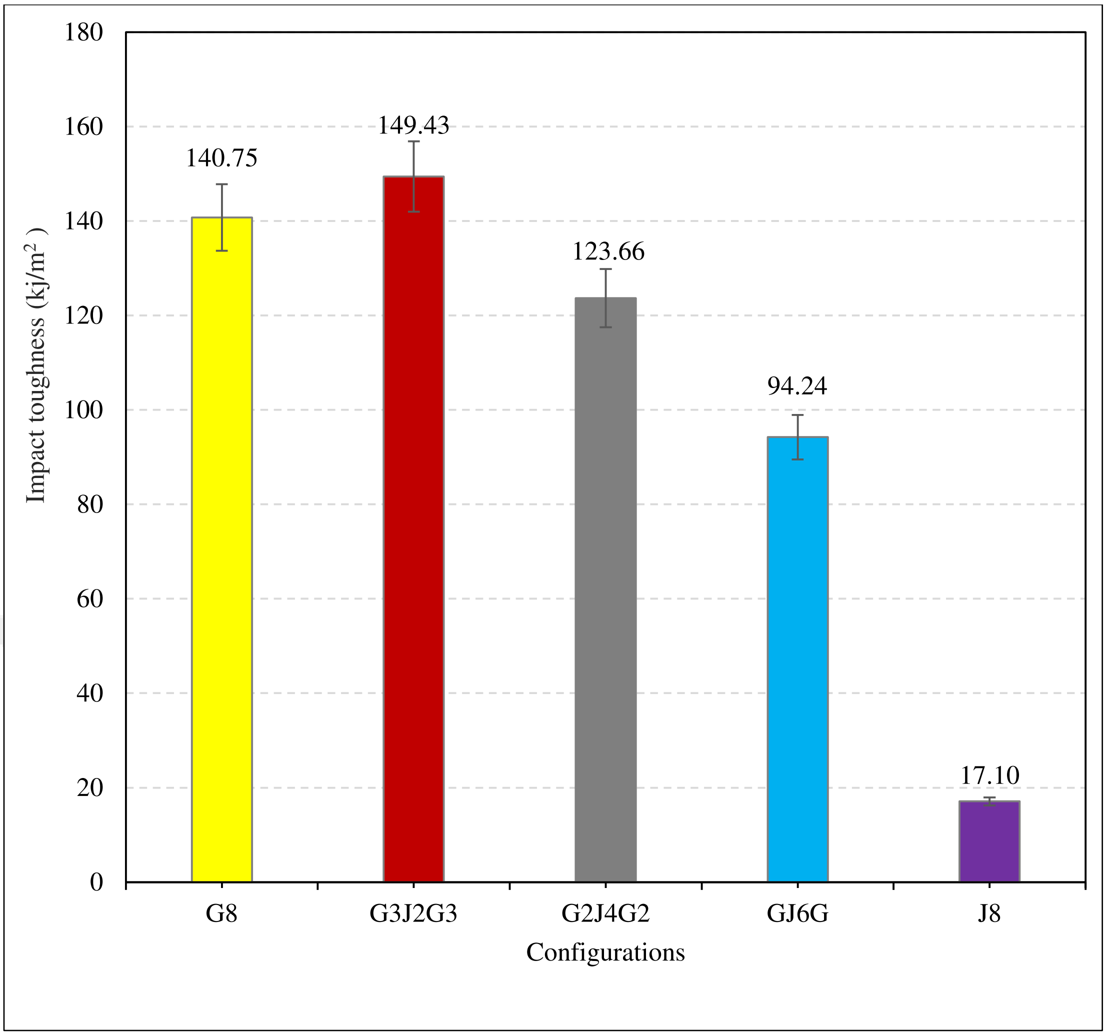


Figure 4.2 Impact toughness values for edgewise specimen of jute, glass and jute/glass (glass layer in out and jute in middle) with epoxy.

From Figure 4.2 the impact toughness the outcome shows that an increment in glass fiber amount generates an increment in impact strength. This increment can be elucidated by the stronger adhesiveness of the matrix to the fiber of glass in relation to the fiber of jute. Thus, the energy is more effectively changed from the matrix to the fiber in the composites with a lot of glass fiber amount. If there was no energy transfer between matrix/fiber, the outcome would be nearly constant [93].

The impact energy values for edgewise impacted specimens (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.3.

From the Figure 4.3 the impact energy of all configurations that content (glass fiber 25 % and jute fiber 75 %) show best value than the pure jute and configuration GJ_6G

give the best value, it was 5.56J and higher from pure glass that give as more reproducibility. From these results, it was noticed that the 25% glass fiber content and 75 % jute content may be technologically interesting especially economically state.

The impact toughness values for edgewise impacted specimens of jute, glass and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) are plotted against configurations as shown in Figure 4.4.

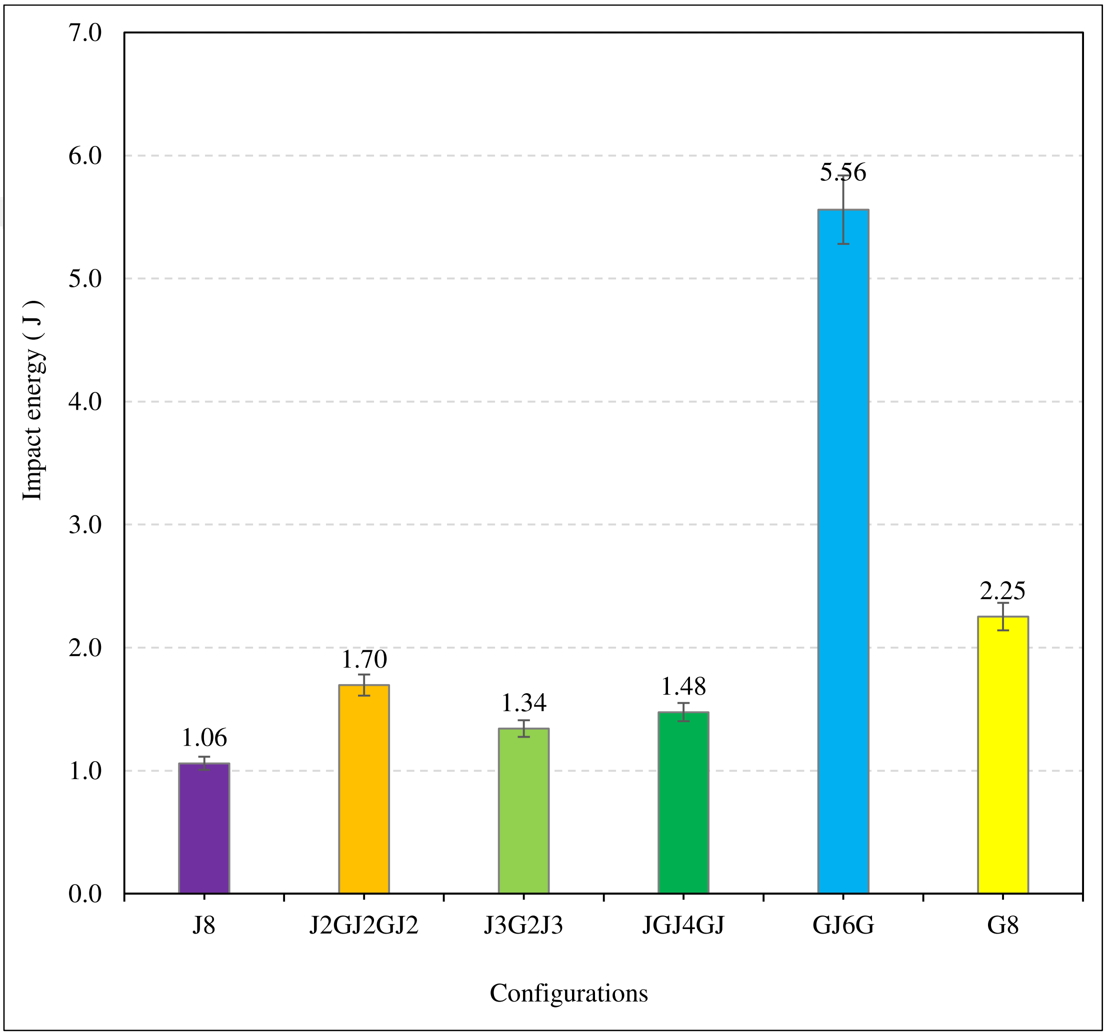


Figure 4.3 Absorbed impact energy values for edgewise specimen of glass, jute and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) with epoxy.

From Figure 4.4 the impact toughness results show that the maximum value in pure glass fiber laminate and the less value with pure jute fiber laminate and there is enhancement when additive glass fiber and best configuration with jute fiber was GJ_6G but less than pure glass fiber laminate.

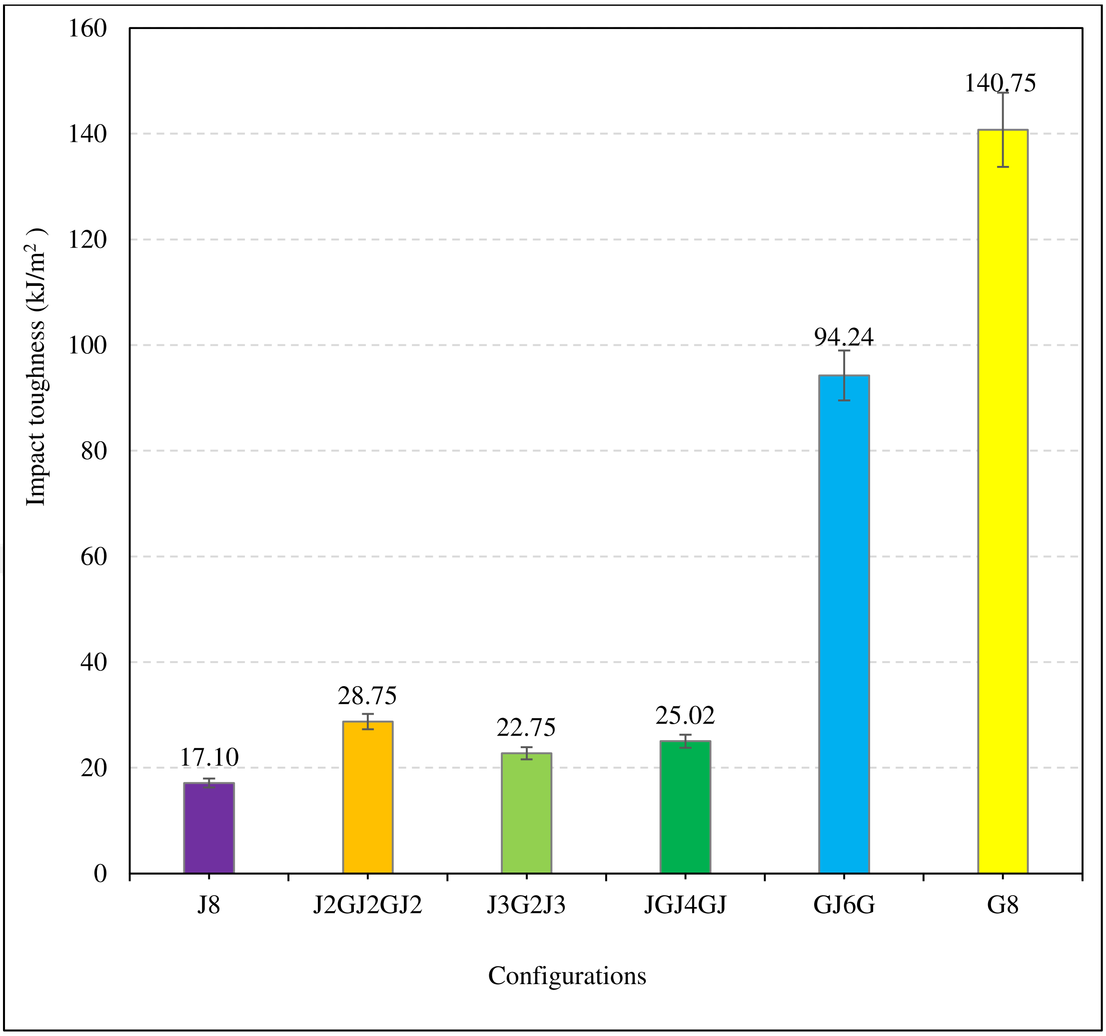


Figure 4.4 Impact toughness values for edgewise specimen of jute, glass and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) with epoxy.

The impact energy values for edgewise impacted specimens (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.5.

From the Figure 4.5 when the laminate content 50% glass fiber and 50 % jute fiber the result show the configuration $G_2J_4G_2$ give result best than G_4J_4 configuration. But the hybrid configuration gives higher result from pure glass and pure jute fiber laminates.

The impact toughness values for edgewise impacted specimens of jute, glass and glass fiber wt.% was 50 % and jute fiber wt.% was 50 % are plotted against configurations as shown in Figure 4.6.

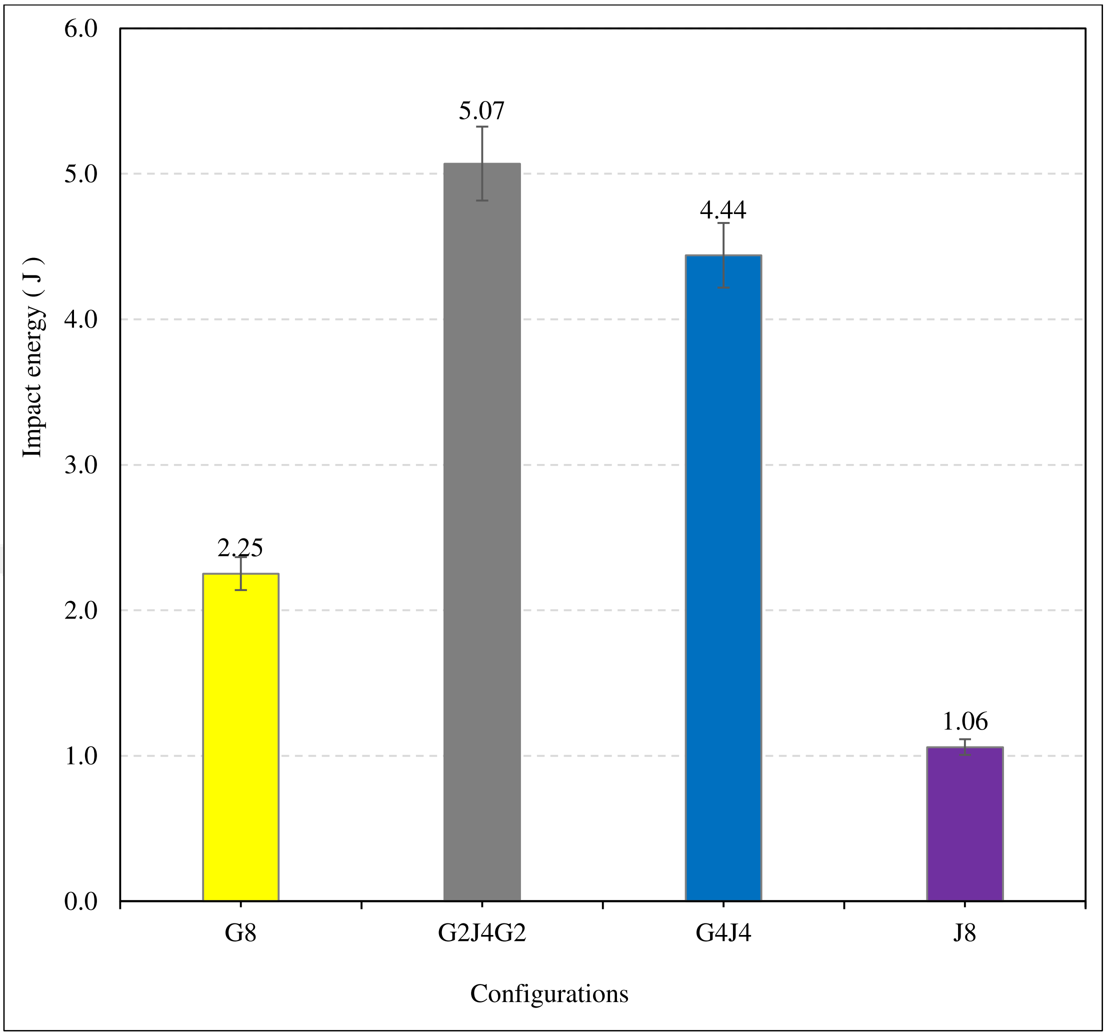


Figure 4.5 Absorbed impact energy values for edgewise specimen of glass, jute and (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) with epoxy.

From Figure 4.6 the impact toughness of $G_2J_4G_2$ was better than G_4J_4 and the result of this hybrid configurations were less than pure glass fiber laminate and higher from pure jute fiber laminate.

The impact energy and impact toughness values for edgewise impacted specimens for all configuration are plotted against stacking sequence and compared with pure glass and jute laminates as shown in Figure 4.7.

The Figure 4.8 show the sample of edgewise specimen after test.

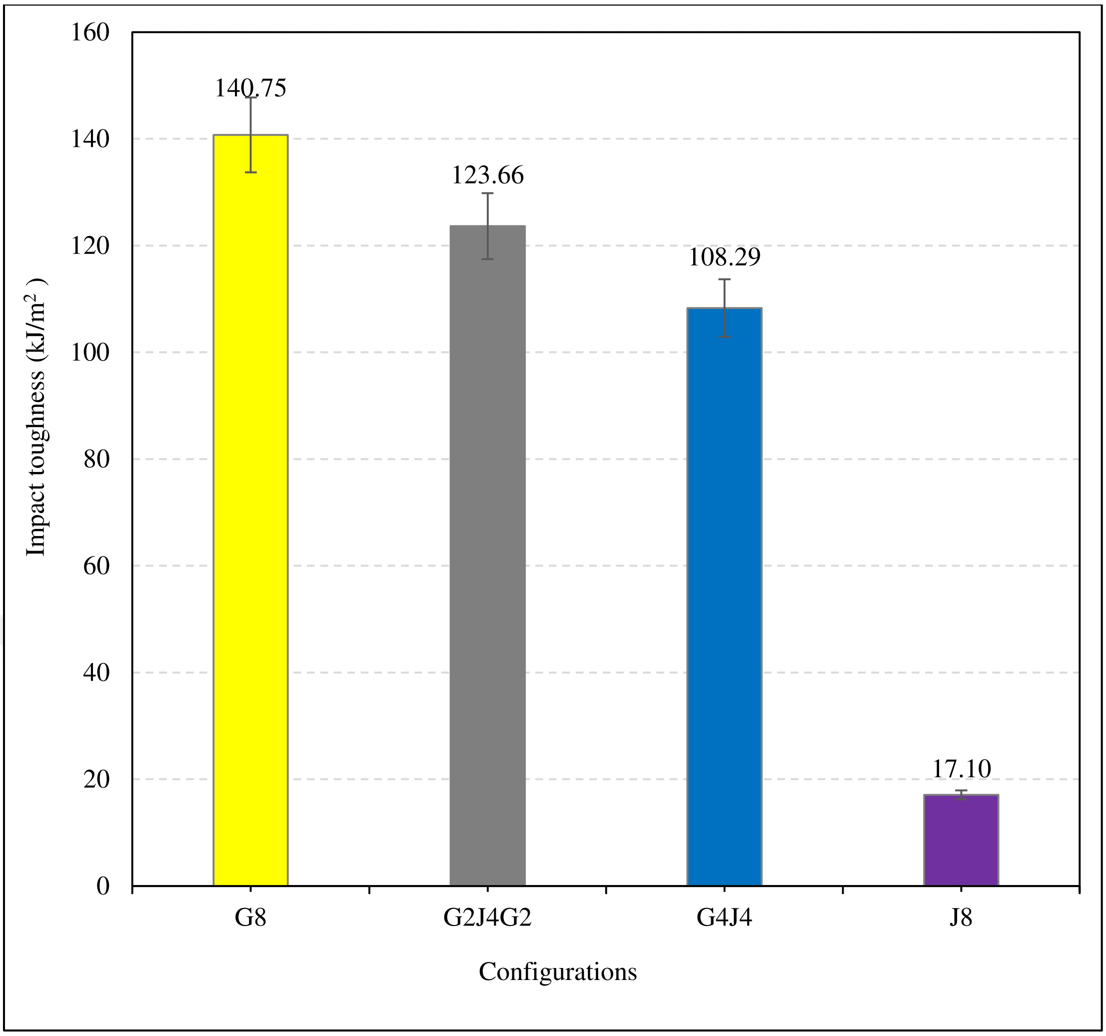


Figure 4.6 Impact toughness values for edgewise specimen of jute, glass and (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) with epoxy.

From Figure 4.8, the fracture that seeing in the specimens of edgewise for impact test show all specimens were separated to two parts that was because of jute fiber make specimen more brittle.

The impact energy values for flatwise impacted specimens (glass layer in out and jute in middle) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.9.

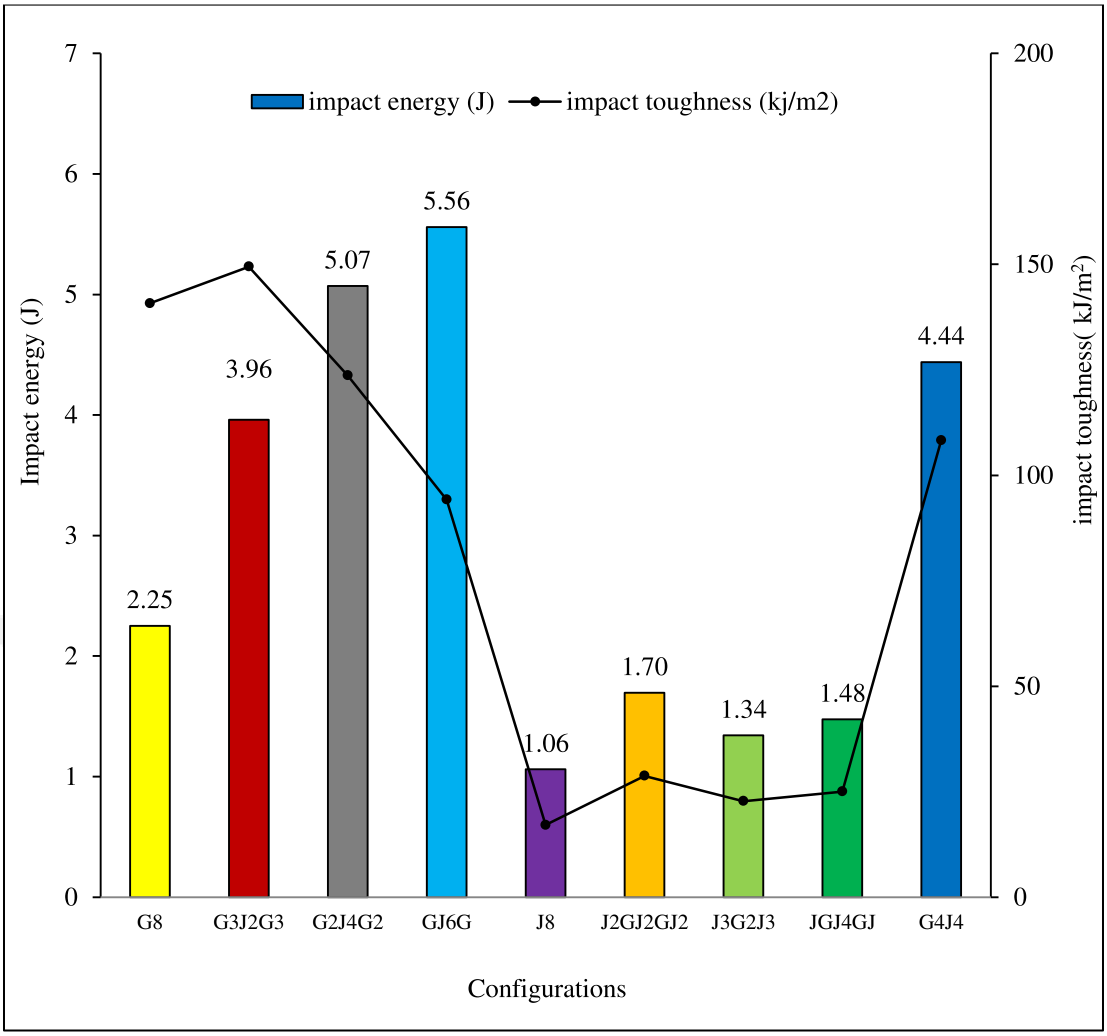


Figure 4.7 Impact energy and impact toughness values for edgewise specimen of jute, glass and jute/glass with epoxy.

Figure 4.8 Sample of edgewise specimen after test.

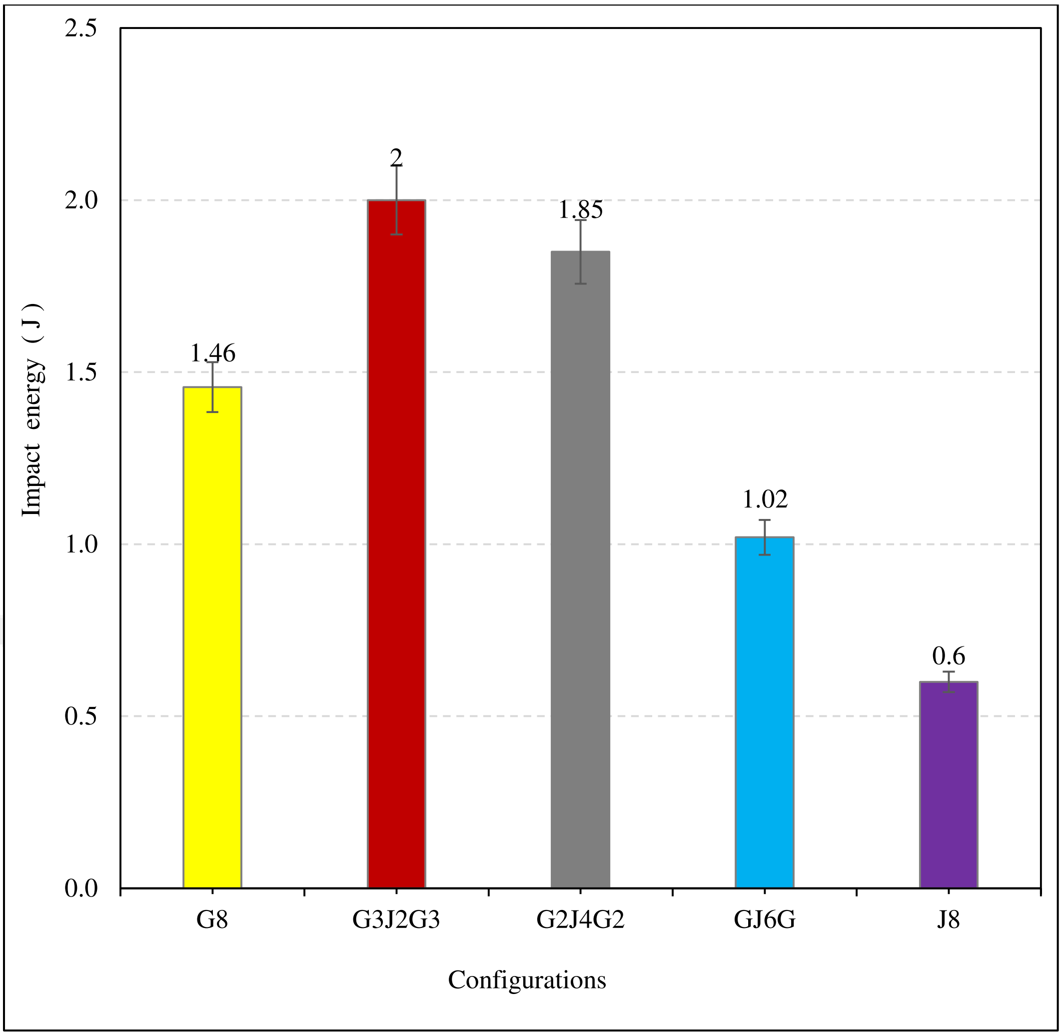


Figure 4.9 Absorbed impact energy values for flatwise specimen of jute, glass and jute/glass (glass layer in out and jute in middle) with epoxy.

From Figure 4.9 the impact energy outcome shows that an increment in glass fiber amount generates an increment in impact energy. This increment can be elucidated by the stronger adhesiveness of the matrix to the fiber of glass in relation to the fiber of jute. Thus, the energy is more effectively changed from the matrix to the fiber in the composites with a lot of glass fiber amount. If there was no energy transfer between matrix/fiber, the outcome would be nearly constant [93]. The result obtained show the configurations $G_3J_2G_3$ and $G_2J_4G_2$ have best value of impact energy higher than pure glass. But the configuration GJ_6G have best value from pure jute and less than pure glass.

The impact toughness values for flatwise impacted specimens (glass layer in out and jute in middle) are plotted against configurations as shown in Figure 4.10.

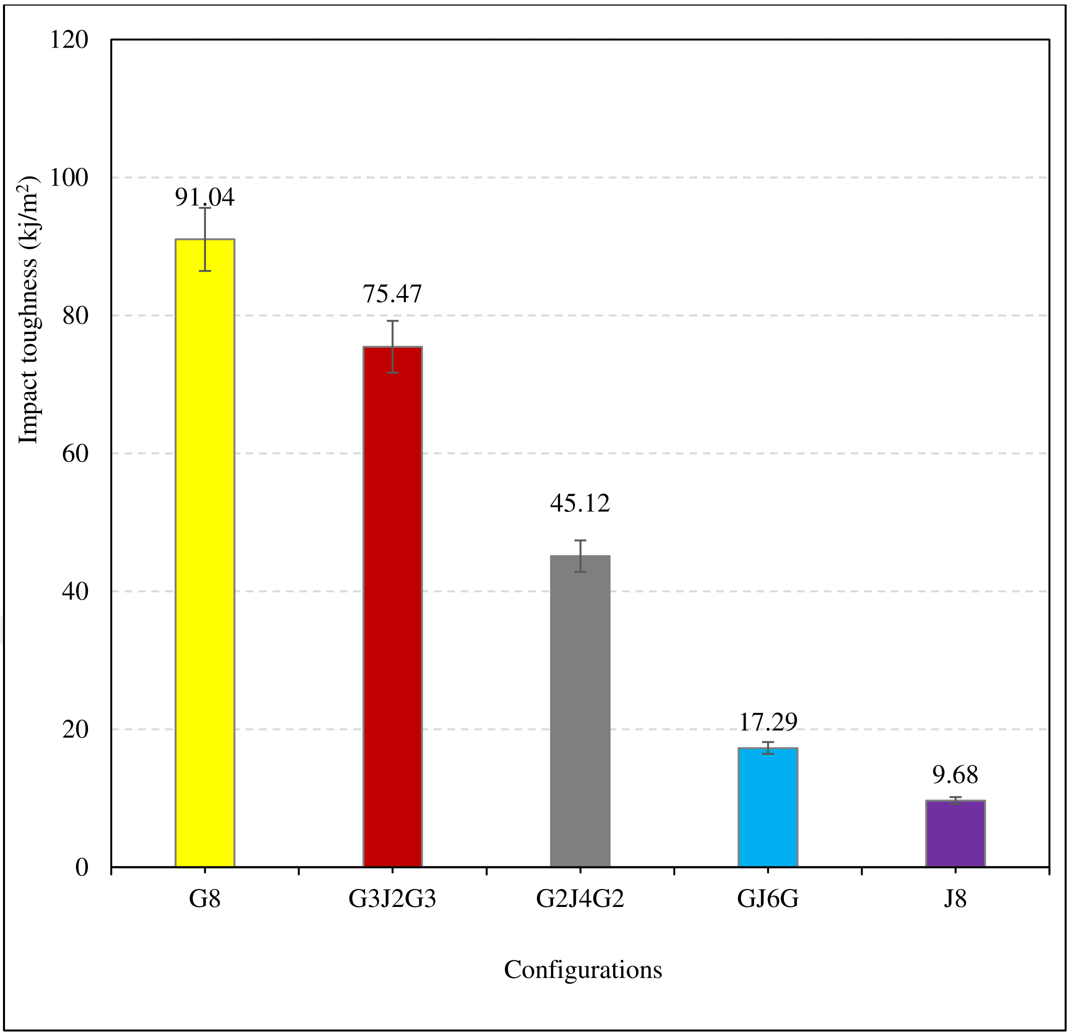


Figure 4.10 Impact toughness values for flatwise specimen of jute, glass and jute/glass (glass layer in out and jute in middle) with epoxy.

From Figure 4.10 the impact toughness outcome shows that an increment in glass fiber amount generates an increment in impact strength until reach to pure glass fiber laminate with maximum value that was 91.04 kj/m^2. This increase because of the stronger adhesiveness of matrix to fiber of glass in relation to the fiber of jute [93].

The impact energy values for flatwise impacted specimens (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.11.

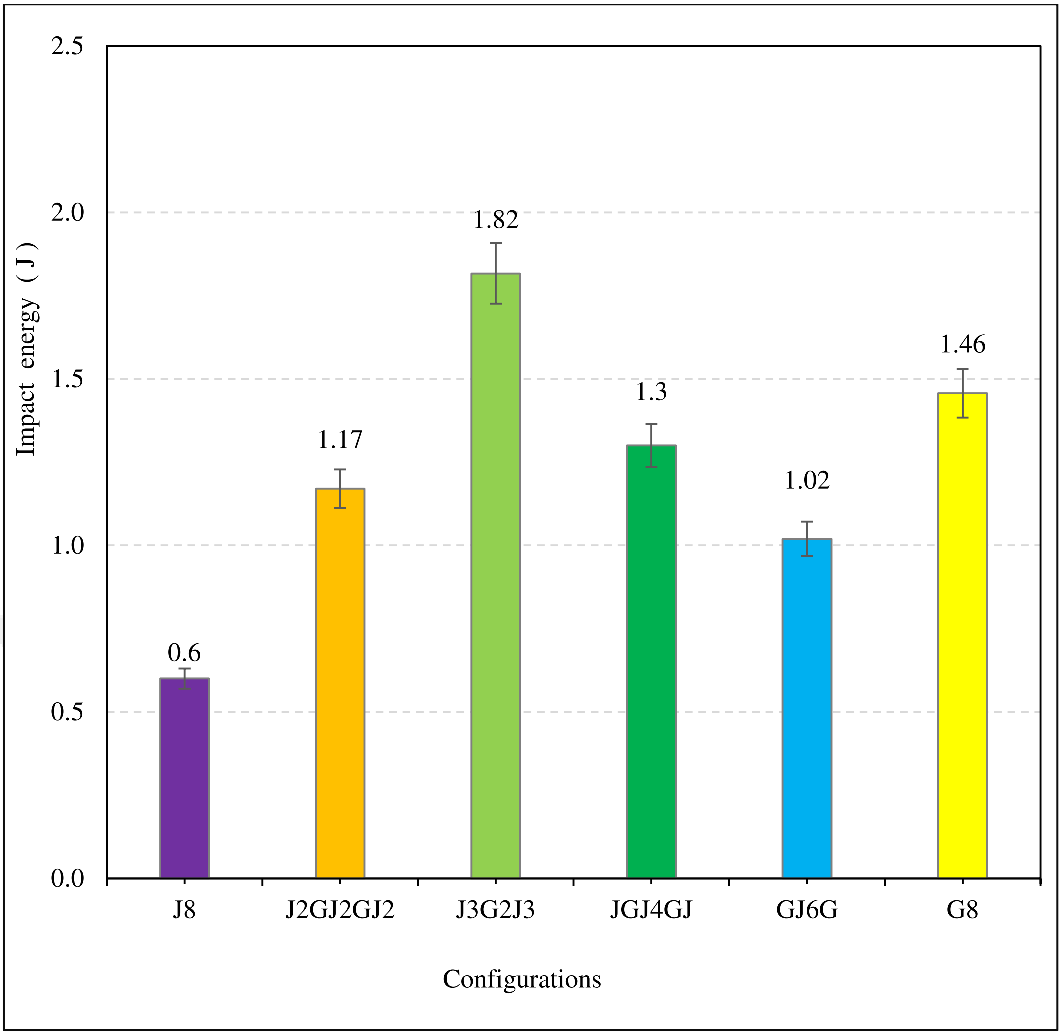


Figure 4.11 Absorbed impact energy values for flatwise specimen of glass, jute and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) with epoxy.

From Figure 4.11 the impact energy of (glass fiber 25 % and jute fiber 75 %) results show that an enhancement when glass fiber but it in middle of laminate and between the jute fiber and the best value was 1.82 J with $J_3G_2J_3$ configuration and higher than pure glass fiber laminate. This is due to difference in pendulum velocity after impacted specimen with glass fiber in the middle of specimen [94].

The impact toughness values for flatwise impacted specimens of jute, glass and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) are plotted against configurations as shown in Figure 4.12. The results of Figure 4.12 similar behavior with results in Figure 4.11 but all values were less than pure glass fiber laminate and higher than pure jute fiber laminate, the best impact toughness of these configurations (glass fiber 25 % and jute fiber 75 %) was 30.79 kJ/m^2 with $J_3G_2J_3$ configuration.

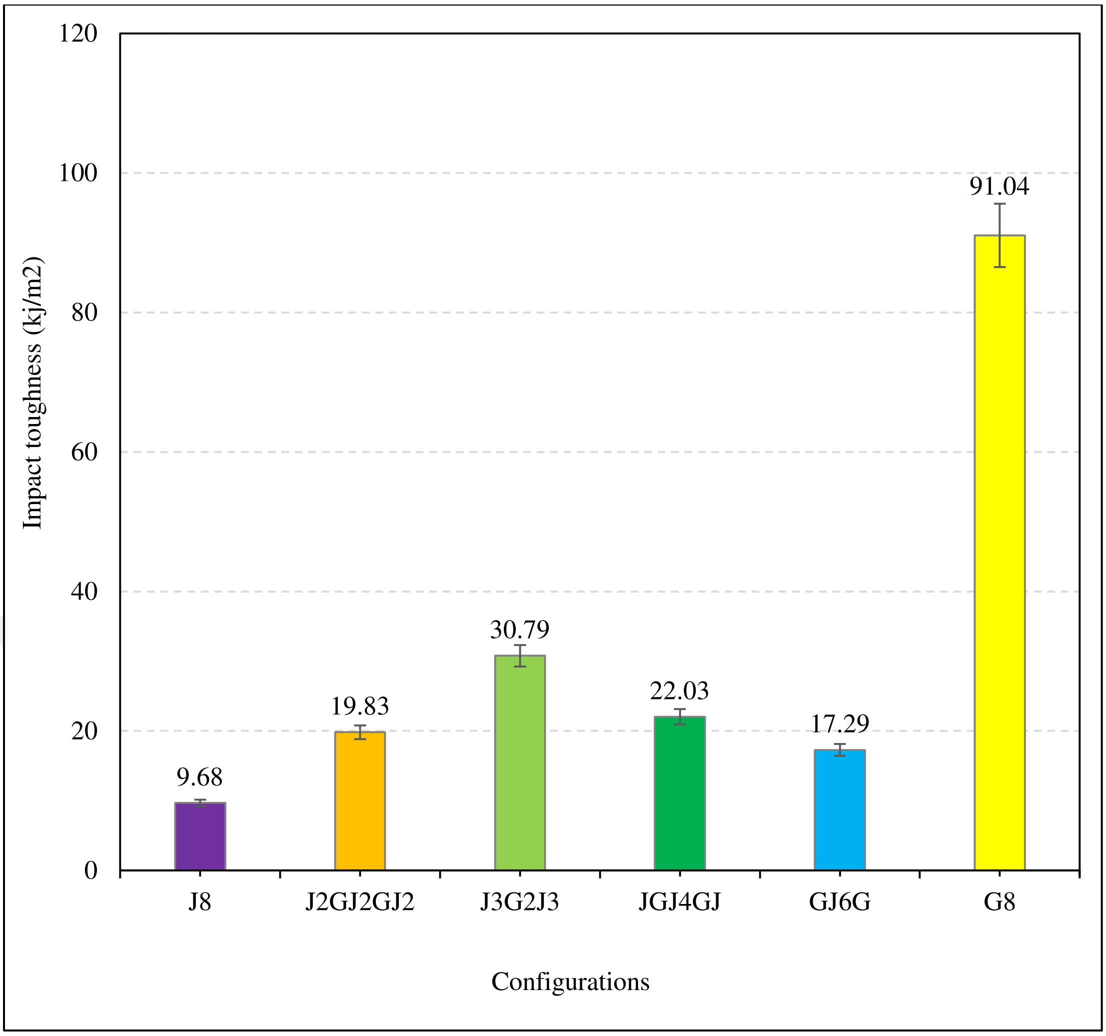


Figure 4.12 Impact toughness values for flatwise specimen of jute, glass and (glass fiber wt.% was 25 % and jute fiber wt.% was 75 %) with epoxy.

The impact energy values for flatwise impacted specimens (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) of laminate are plotted against configurations and compared with pure glass and jute laminates as shown in Figure 4.13.

From Figure 4.13 the impact energy of (glass fiber 50 % and jute fiber 50 %) results show that an enhancement when fabricated a hybrid laminate and the result was more than pure glass fiber laminate and jute fiber laminate that's with configuration $G_2J_4G_2$ and J_4G_4/J. Also show the result of J_4G_4/J best than result of G_4J_4/G.

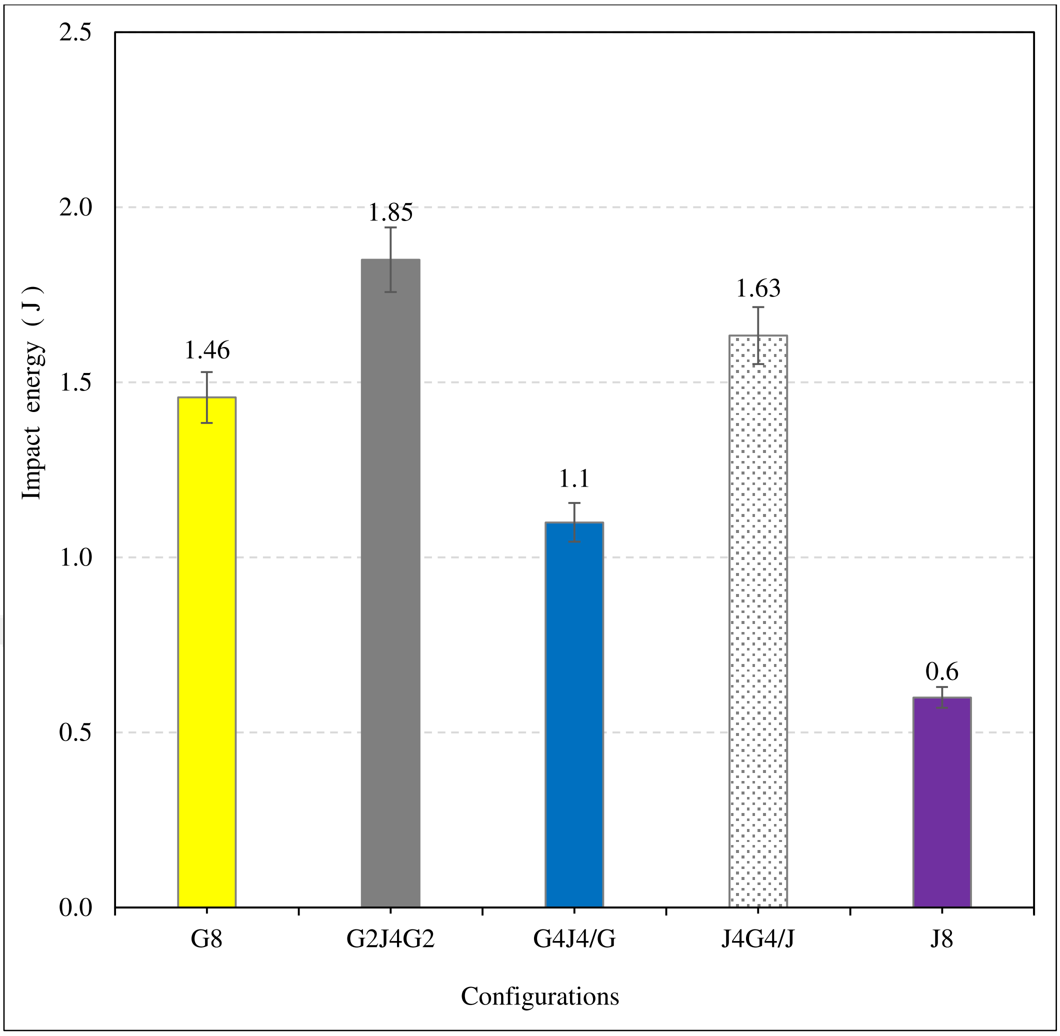


Figure 4.13 Absorbed impact energy values for flatwise specimen of glass, jute and (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) with epoxy.

The impact toughness values for flatwise impacted specimens of jute, glass and (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) are plotted against configurations as shown in Figure 4.14.

From Figure 4.14 the impact toughness results show that the specimens of (glass fiber 50 % and jute fiber 50 %) was best than pure jute fiber laminate but less than pure glass fiber laminate, the maximum value was 45.12 kJ/m^2 with $G_2J_4G_2$ configuration. The impact energy and impact toughness values for flatwise impacted specimens for all configuration are plotted against stacking sequence and compared with pure glass and jute laminates as shown in Figure 4.15.

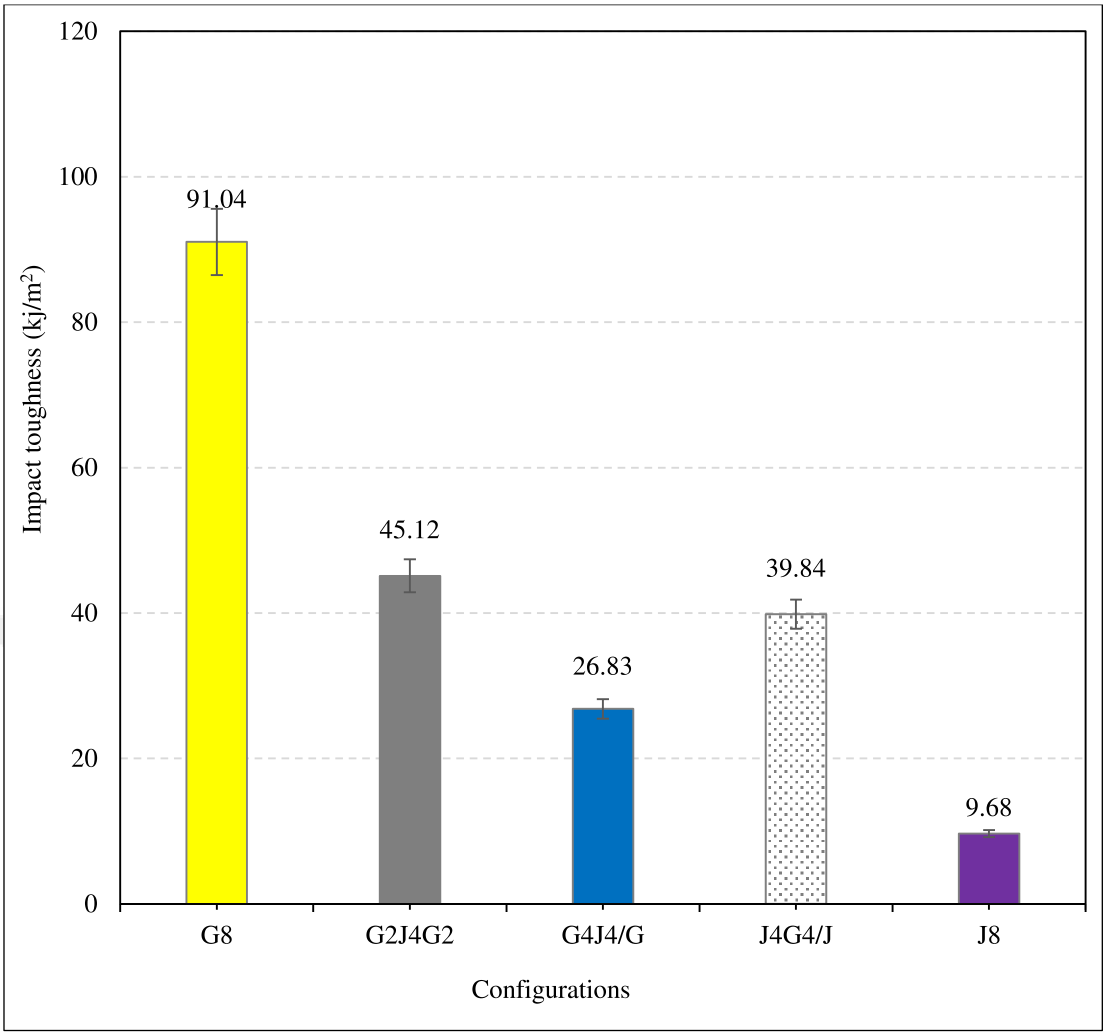


Figure 4.14 Impact toughness values for flatwise specimen of jute, glass and (glass fiber wt.% was 50 % and jute fiber wt.% was 50 %) with epoxy.

From the picture of specimens of impact after test as shown in Figure 4.16 the picture number 1, 7, 8 and 9 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 parts. As well as in picture number 3, 4 and 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 impacted surface near to the point of impact, and the specimens were separated two parts. For picture 2 pure glass layer and picture 6 that consists of 4-layer glass and 4-layer jute and the impact side was glass show stressed region and the colure of specimen was changed, no fiber breakage and a small amount of delamination compared with other specimens.

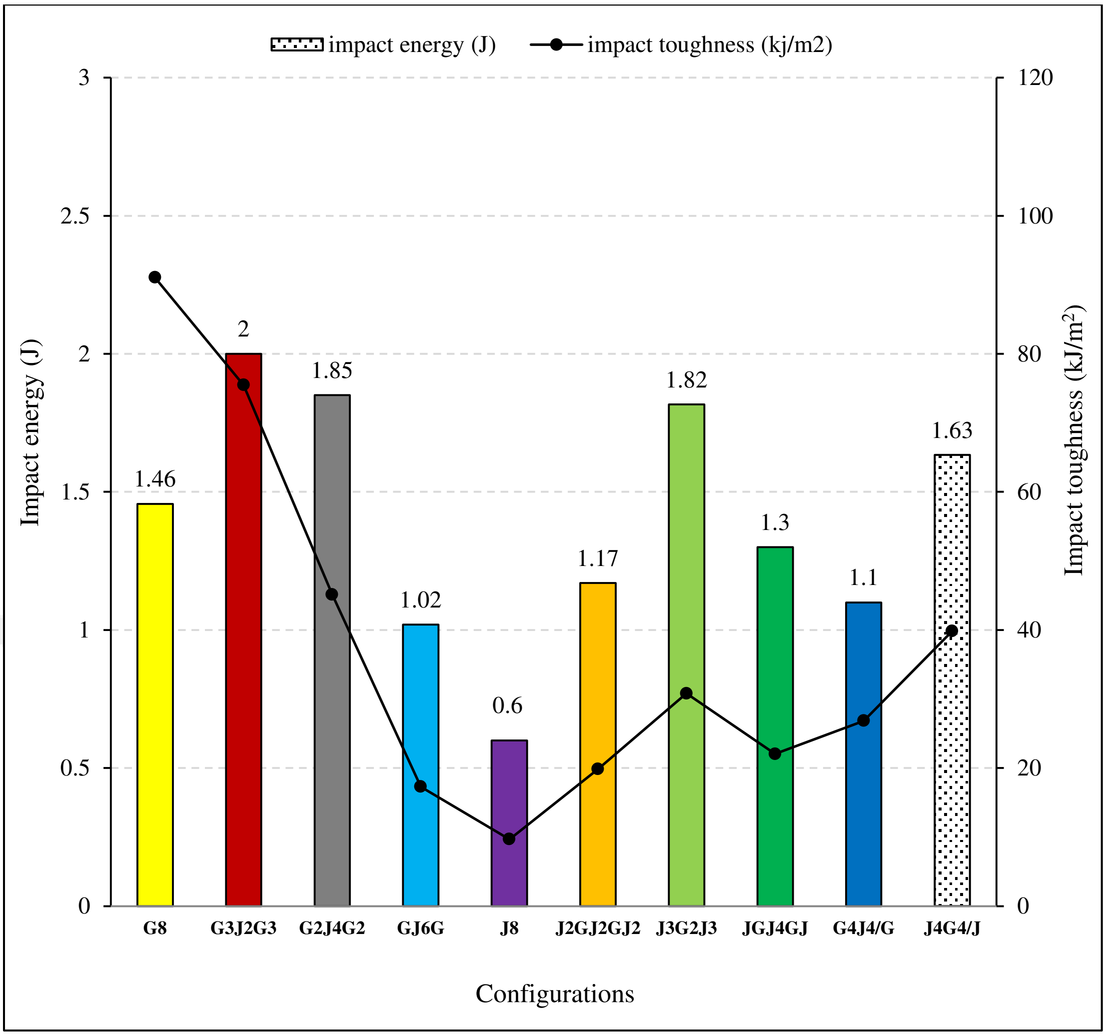


Figure 4.15 Impact energy and impact toughness values for flatwise specimens of jute, glass and jute/glass with epoxy.

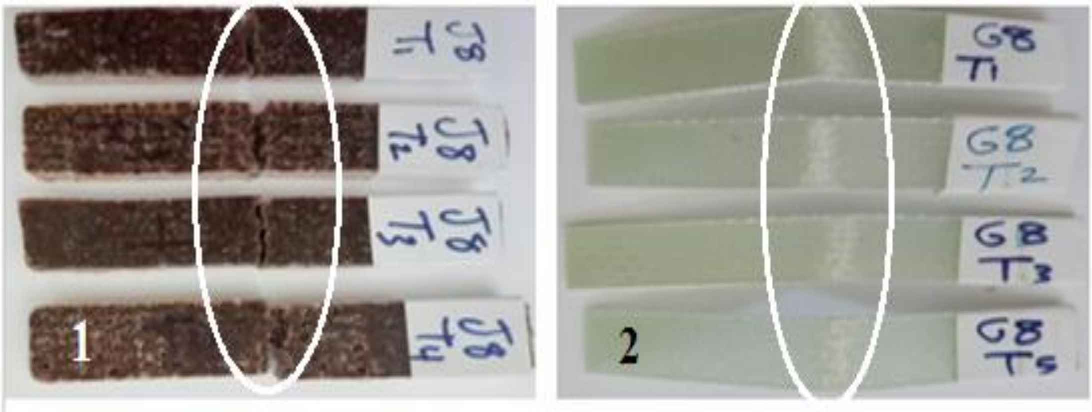


Figure 4.16 Sample of flatwise specimen after test.

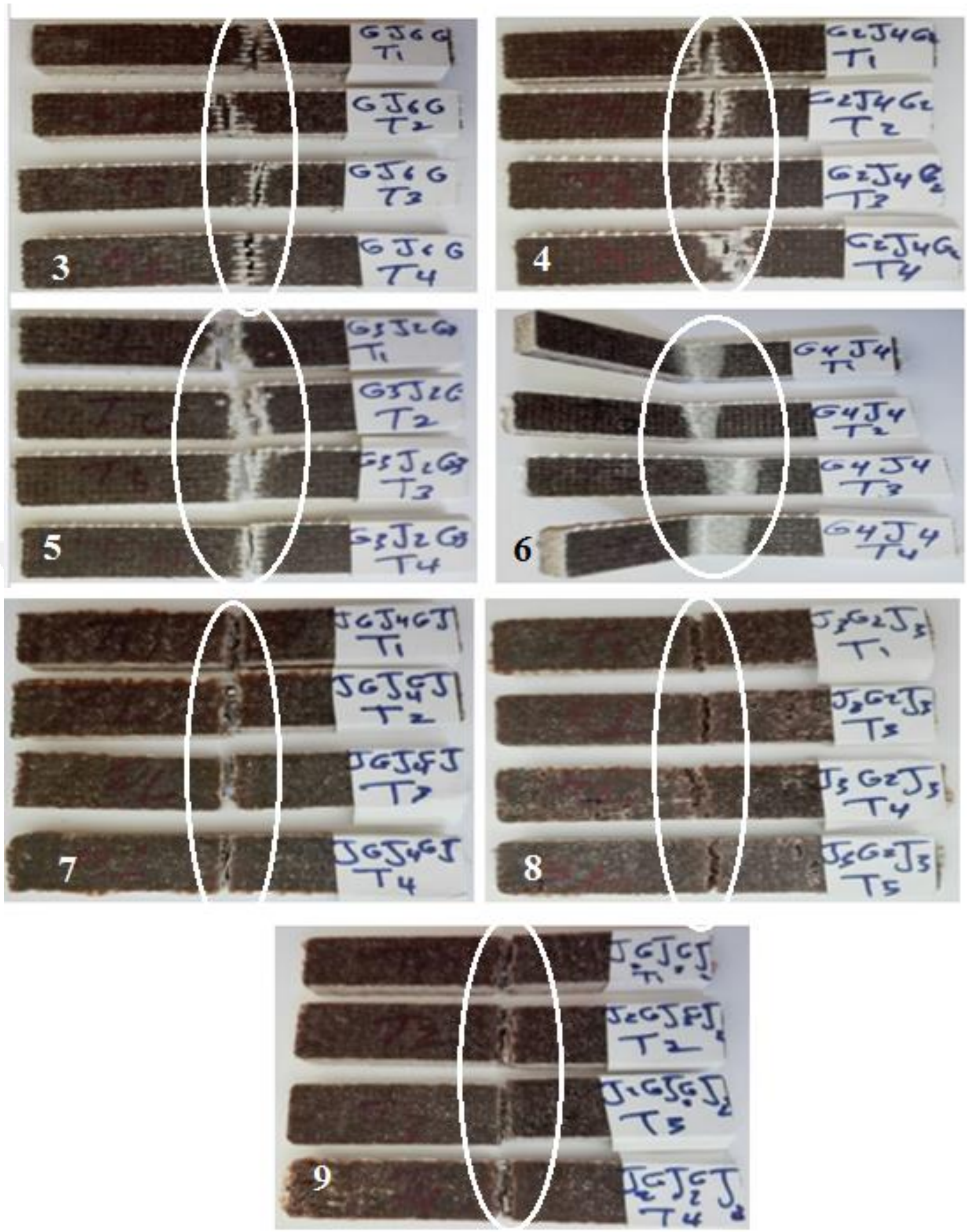


Figure 4.16 (Continue) Sample of flatwise specimen after test.

4.4 Flexural Test Results for Jute, Glass and Jute/Glass (Several Configurations) with Epoxy.

During the experimental tests which carried out on the samples of the hybrid composites jute, glass and jute/glass (several configurations) with epoxy by fabricated varied arrangement of jute/glass as shown in the Table 4.1 the flexural strength was obtained by conducting flexural testing. The test sample had been prepared depending to ASTM-D-790-10 standard. It is noticed that the highest flexural strength was 459.04 MPa with G_8 laminate, as shown in the Figure 4.17.

Table 4.2. Flexural strength values of hybridization of jute, glass and jute/glass (several configurations) with epoxy.

	G2J4 G2	G3J2 G3	J8	J2GJ2 GJ2	G8	J3G2 J3	JGJ4 GJ	GJ6 G	G4J4
Sp.	Flexural strength (MPa)								
1	274.84	431.24	95.91	98.74	448.75	92.42	123.47	94.54	157.55
2	272.60	363.57	83.48	82.49	449.77	89.91	137.47	116.84	155.74
3	297.54	407.98	81.52	94.35	478.60	87.82	125.47	136.07	164.60
4	276.40	421.17	82.19	74.36	464.06	95.52	144.38	131.70	158.88
5	255.56	432.26	80.21	94.13	454.02	79.86	128.45	130.03	150.99
Av.	275.39	411.25	86.54	88.81	459.04	89.11	131.85	121.84	157.55

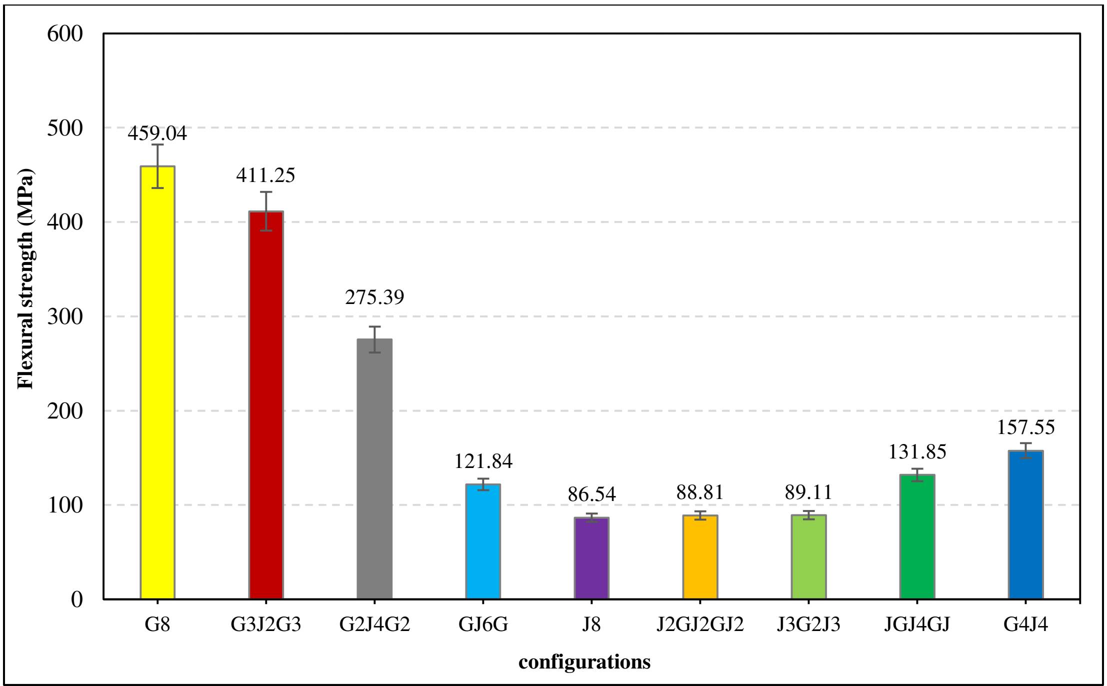


Figure 4.17 Variation of flexural strength for jute, glass and jute/glass (several configurations) with epoxy.

The results of flexural modulus are recorded in Table 4.3 and plotted against configurations. It is noticed that the highest flexural modulus was 7.81 GPa with G_8 laminate, as shown in Figure 4.18

Table 4.3. Flexural modulus values of hybridization of jute, glass and jute/glass (several configurations) with epoxy

	$G_2J_4G_2$	$G_3J_2G_3$	J_8	$J_2GJ_2GJ_2$	G_8	$J_3G_2J_3$	JGJ_4GJ	GJ_6G	G_4J_4
Sp.	Flexural modulus (GPa)								
1	2.46	3.03	3.87	0.77	14.82	5.28	4.77	0.96	1.80
2	5.48	1.70	1.50	1.25	10.85	1.03	5.43	2.51	1.75
3	1.24	4.33	3.97	1.93	2.94	1.14	4.01	2.42	0.77
4	0.48	6.93	3.80	2.68	5.56	3.64	1.23	0.54	4.19
5	8.74	21.55	3.77	1.22	4.90	3.02	0.53	1.12	0.51
Av.	3.68	7.51	3.38	1.57	7.81	2.82	3.19	1.51	1.80

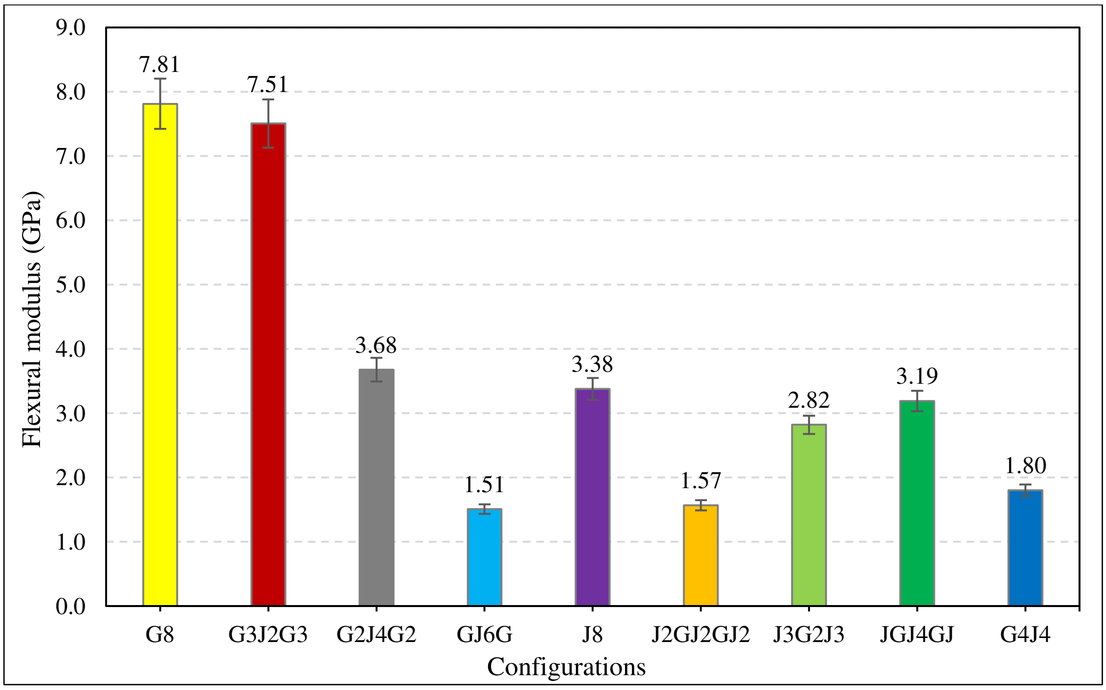


Figure 4.18 Variation of flexural modulus for jute, glass and jute/glass (several configurations) with epoxy.

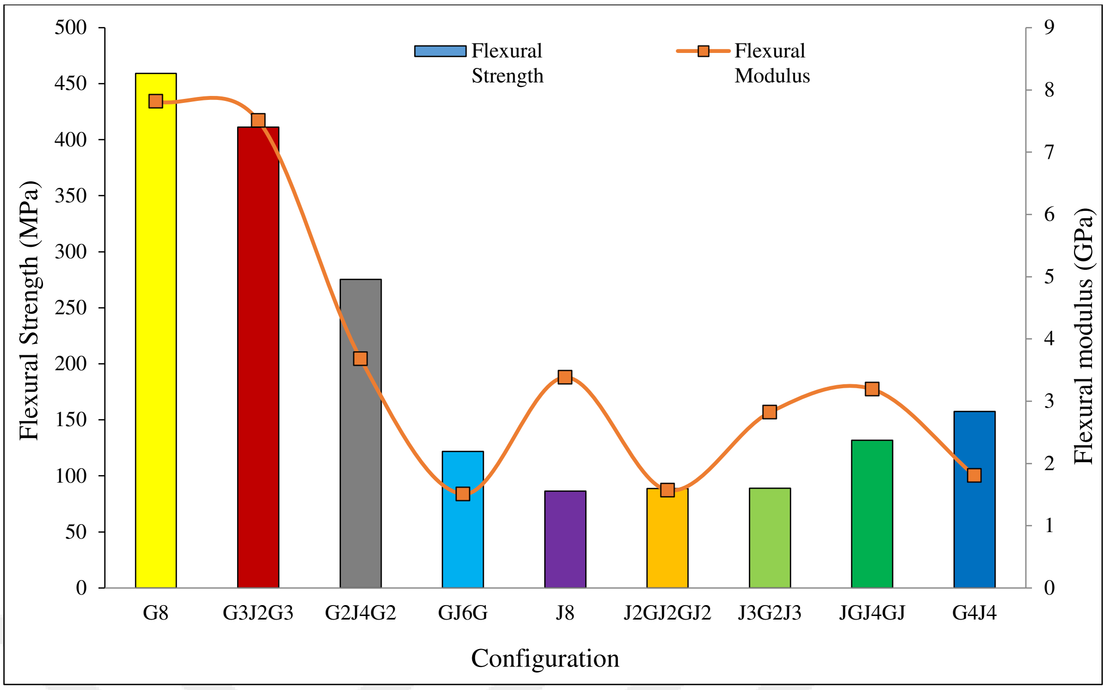


Figure 4.19 Compared between flexural modulus and flexural strength

From Figure 4.19 show compared between flexural modulus and flexural strength. Modulus and flexural strength for laminates with various stacking arrangement are liken in Figures 4.17 and 4.18, respectively. Flexural characteristics are increment with increment in the fiber of glass amount from 0, 25, 50, 75 and 100% of the total fiber weight. It is interesting to observe that the laminate arrangement $G_2J_4G_2$ with glass fiber weight of 50 % higher flexural strength liken to arrangement G_4J_4 with 50% glass fiber weight. Also the laminate with arrangement JGJ_4GJ with 25 % glass fiber weight higher flexural strength compared to sequences $J_3G_2J_3$, $J_2GJ_2GJ_2$ and GJ_6G with 25 % glass fiber. This reveals that, arrangement of glass fiber layers at the extreme and jute fiber layers at the central leads to large enhancement in the flexural strength. This can be explained from the fact that the stiffness and flexural strength are controlled by extreme plies of reinforcement [67]. The laminate G_8 is found to have highest modulus of 7.81 GPa and flexural strength of 459.04 MPa higher than the modulus and strength, of the all jute fiber laminate. By changing the sequence of stacking as in the cases of $J_2GJ_2GJ_2$ and $J_3G_2J_3$ and JGJ_4GJ has enhancement in the flexural characteristics achieved. The laminate J_8 displays minimum flexural strength (86.54MPa) and modulus (3.38 GPa) among all groups. Modulus and flexural strength are controlled by the strength of the extreme plies of reinforcement [67].

Generally, the modulus is very sensitive to the matrix characteristics and fiber/matrix interfacial bonding [95]

The Figure 4.20 show force-displacement curve for the jute, glass and jute/glass hybrid configurations.

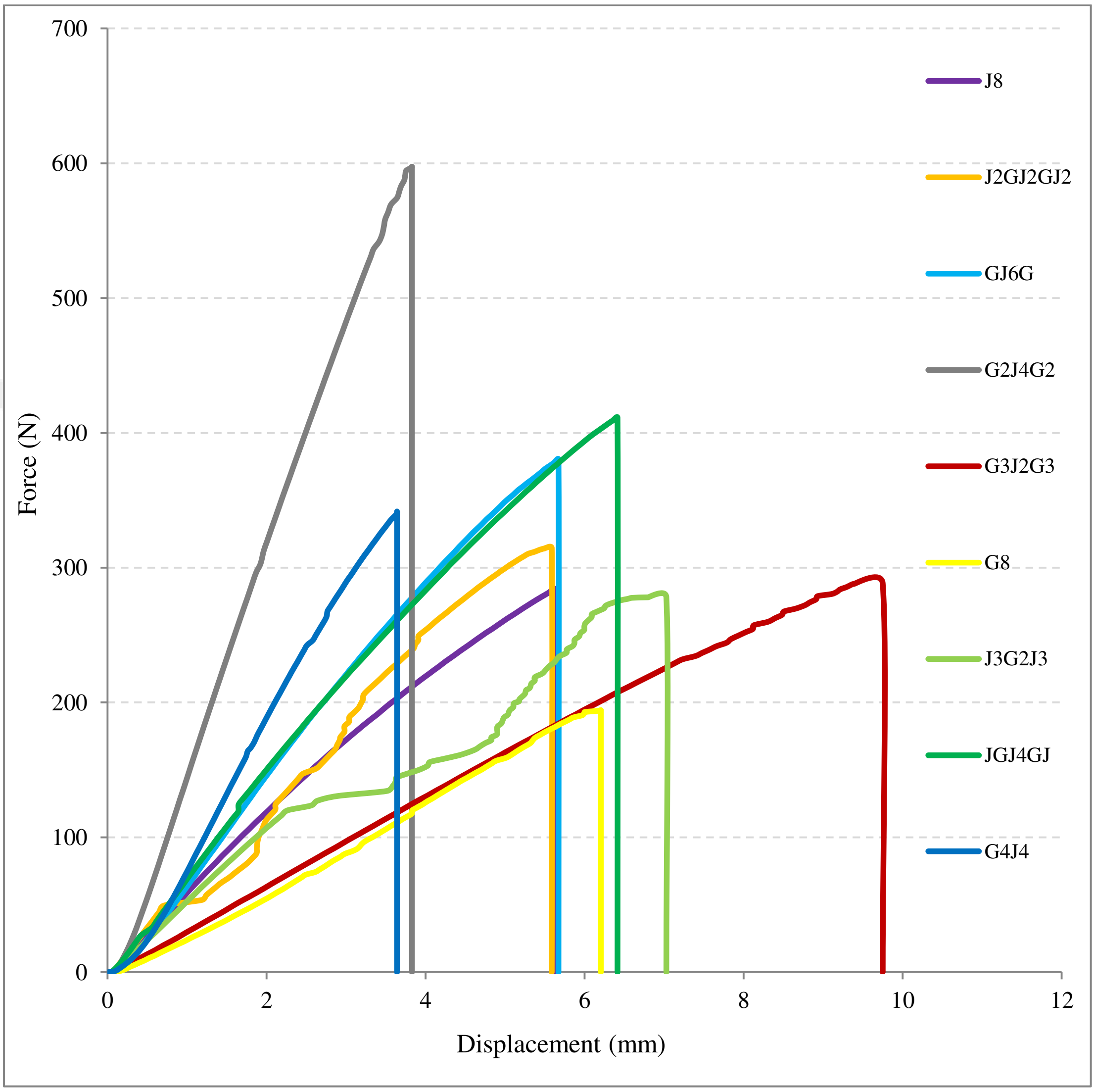


Figure 4.20 Force-displacement curve for the jute, glass and jute/glass hybrid configurations

The force-displacement curve for different hybrid laminate stacking arrangement are shown in Figure 4.20. All the diagrams show non-linear behavior. The point of deviation from curve is the denotation of failure initiation due to improvement of crack on the tension side. The maximum value was 596.9 N/mm for $G_2J_4G_2$ configuration and the minimum value was 194.07 N/mm for G_8 laminate. The maximum displacement was 9.75 mm for $G_3J_2G_3$ configuration because of properties of glass fiber. Also the minimum displacement was 3.64 mm for G_4J_4 configuration.

The Figure 4.21 show flexural specimen of the jute, glass and jute/glass hybrid configurations after test.

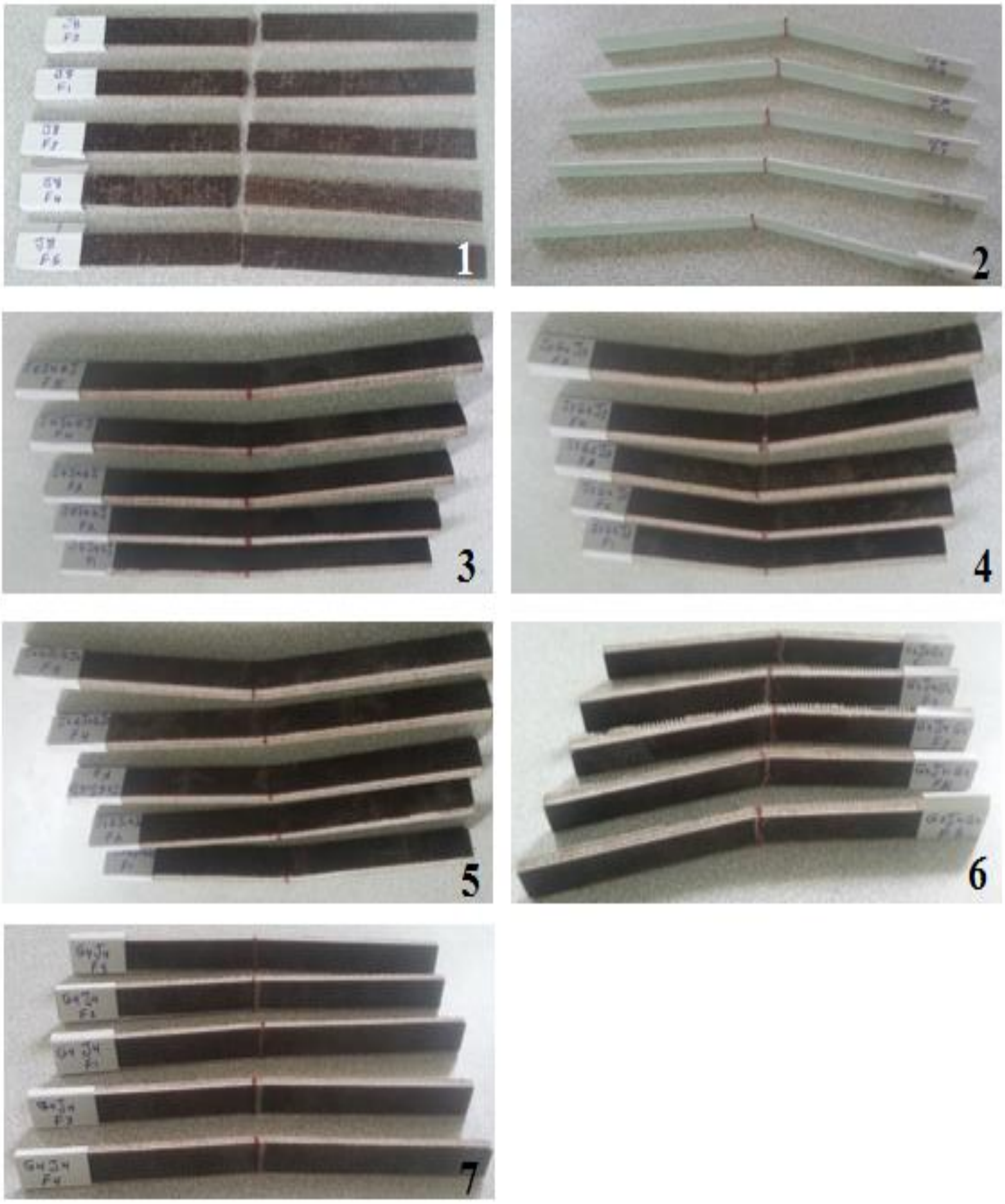


Figure 4.21 Flexural specimens after test

From Figure 4.21 the picture number 1 that laminate consist of only jute fiber showed brittle crack that is duo to jute fiber properties. The specimen in picture (2, 3, 4, 5, 6 and 7) 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 of glass fibers were strong and stiffen [42].

4.5 Tensile Test Results of the Jute, Glass and Jute/Glass Hybrid Configurations

The tensile strengths of the prepared composite samples were determined by conducting uniaxial tensile test. The test specimen had been prepared according to ASTM-D-638-10 standard. The variation of tensile strength values against configurations is presented in Figure 4.22.

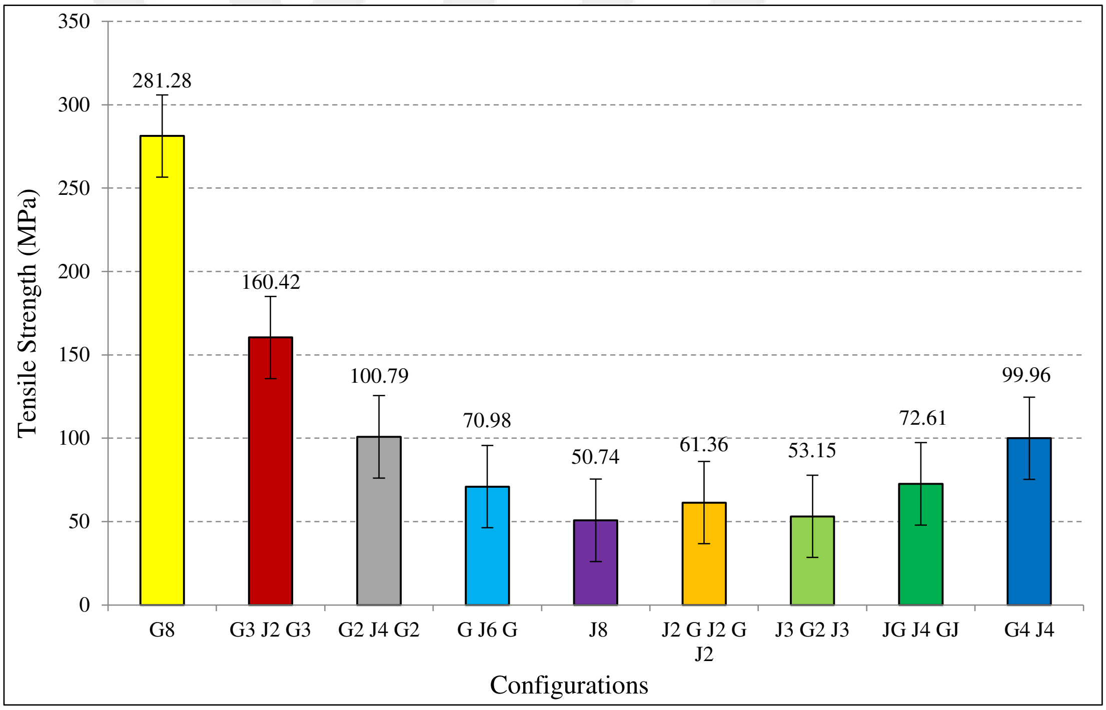


Figure 4.22 Variation of tensile strength for jute, glass and jute/glass (several configurations) with epoxy.

The variation of tensile strength for different laminate stacking arrangement is shown in Figure 4.22. The tensile strength of the composite is affected by the modulus and strength of the fibers [67]. The tensile strength of laminate J_8 when only jute fibers are reinforced in the matrix is found to be 50.74 MPa that's minimum value. Also was found that sharp increment in the tensile strength with the merging of glass fiber as extreme glass layers (GJ_6G, $G_2J_4G_2$, $G_3J_2G_3$ and G_8). The increment in the tensile strength of hybrid composite is ascribed to the reason that, glass fibers are stiffer and stronger than jute fibers [67]. An increment in the tensile strength of 216.16% is showed in 75:25 glass-jute fiber-reinforced hybrid laminate $G_3J_2G_3$ when compared to that of just jute fiber laminate J8. Figure 4.22 reveal that the tensile characteristics are slightly influenced by layering stacking. As well as it is observed that there is small increment in the tensile strength with the merging of glass fiber as middle glass layers ($J_2GJ_2GJ_2$, $J_3G_2J_3$, JGJ_4GJ and G_4J_4). An increment in the tensile strength of 97 % is showed for 50:50 jute-glass fiber-reinforced hybrid laminate (G_4J_4) when compared to that of just jute laminate J8.

The results of tensile modulus are plotted against configurations as shown in Figure 4.23.

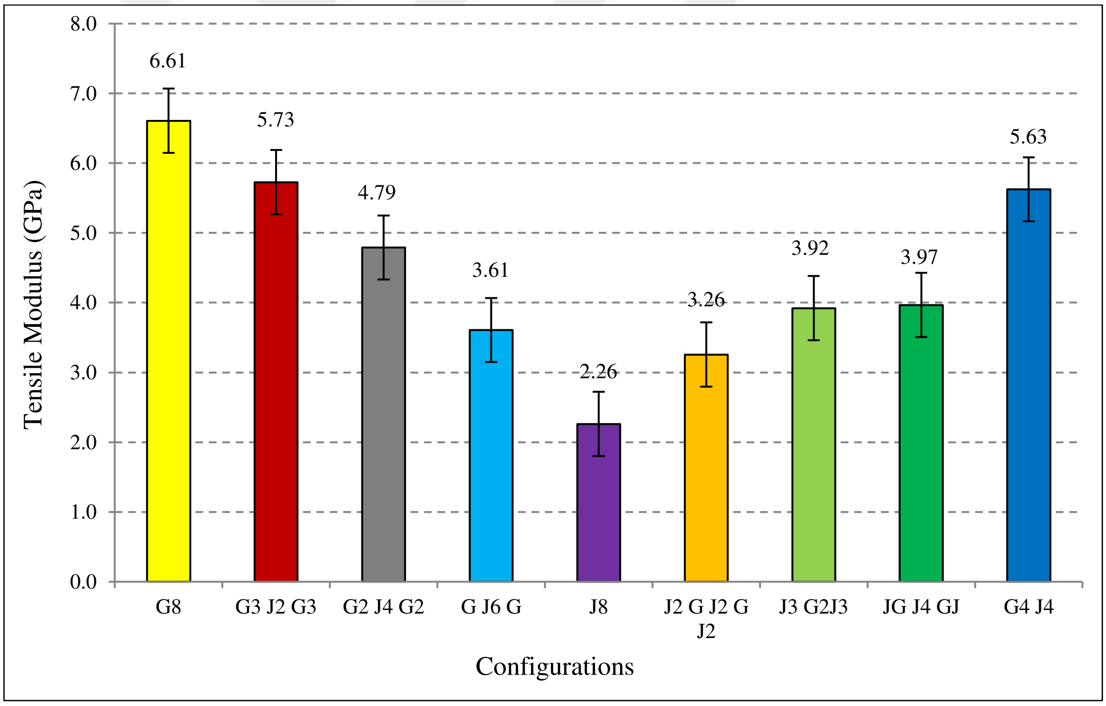


Figure 4.23 Tensile modulus for jute, glass and jute/glass (several configurations) with epoxy

The difference of tensile modulus for different laminate sequence arrangement is shown in Figure 4.23. It is noticed that the highest tensile modulus was 6.61 GPa with G8 laminate. The tensile modulus of laminate configurations increases gradually with increase in glass fiber in the extreme glass plies ($G_2J_4G_2$, $G_3J_2G_3$, and

G_8). Also there are small increment in tensile modulus with increment in glass fiber in the middle glass plies ($J_2GJ_2GJ_2$, $J_3G_2J_3$, JGJ_4GJ and G_4J_4). The increase modulus of hybrid composite is ascribed to the reason that, glass fibers are stiffer and stronger than jute fibers [67]. Figure. 4.23 reveal that the tensile characteristics are slightly influenced by layering sequence.

The Figure 4.24 show stress-strain curve for the jute, glass and jute/glass hybrid configurations.

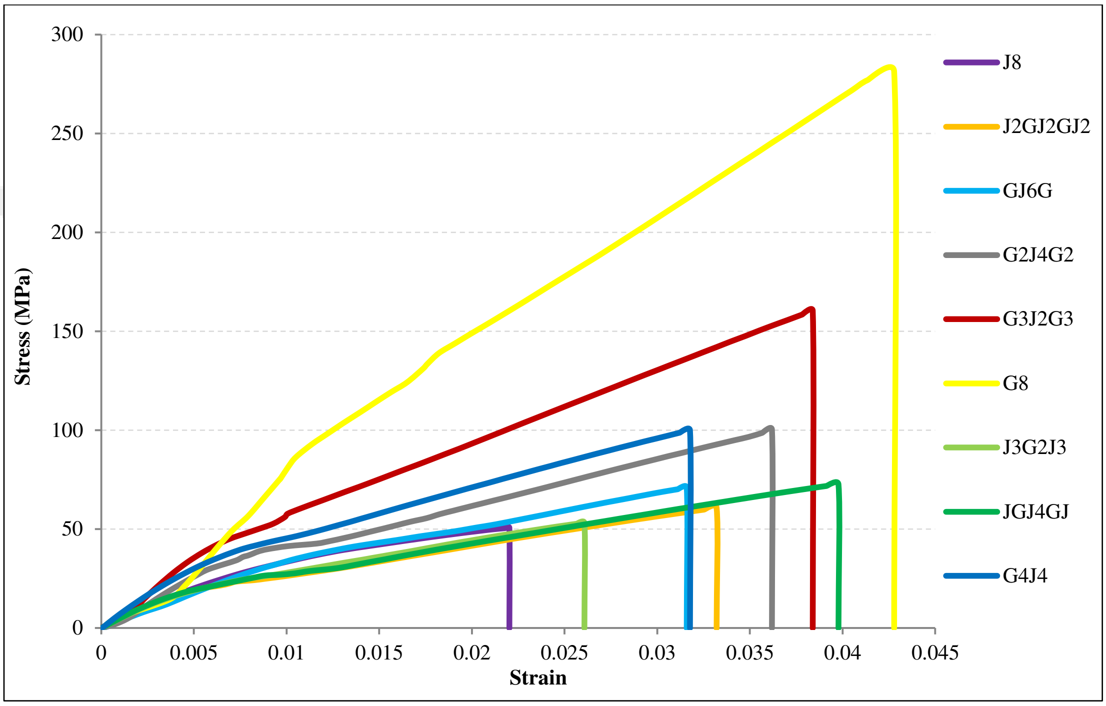


Figure 4.24 Stress-strain curve for the jute, glass and jute/glass hybrid configurations

The stress–strain diagram as shown in Figure 4.24 for jute, glass and seven jute/glass laminates and epoxy resin. The best laminate was pure glass (G_8) with stress value 281.27 MPa and strain 0.0427, the less value was in pure jute (J_8) laminate with stress 50.74 MPa and strain 0.022. The initial linear portion of the jute fiber laminate diagram show the elastic behavior of the composite. The deviation from curve is denotation of the starting of initial matrix cracking, and the first major alter in slope in the diagram is the sign of a major crack in the matrix or the beginning of fiber failure. The rest of the drops in the diagrams are denotation of progressive failure of fibers as the applied load increment, and the end of the diagram represents the supreme stress which is because of fiber fracture and may be fiber pull-out [67]. When epoxy filled into the glass fibers, it made them stiffer and controlled the crack propagation and prevented fiber failures like breakage and fiber pull-out from matrix [96]. The variation in the initial tangent modulus got from experiment and rule of mixture is because of the nature of the fibers and initial stretching [67]. The Figure 4.25 shows specimen of jute, glass and jute/glass hybrid configurations after test

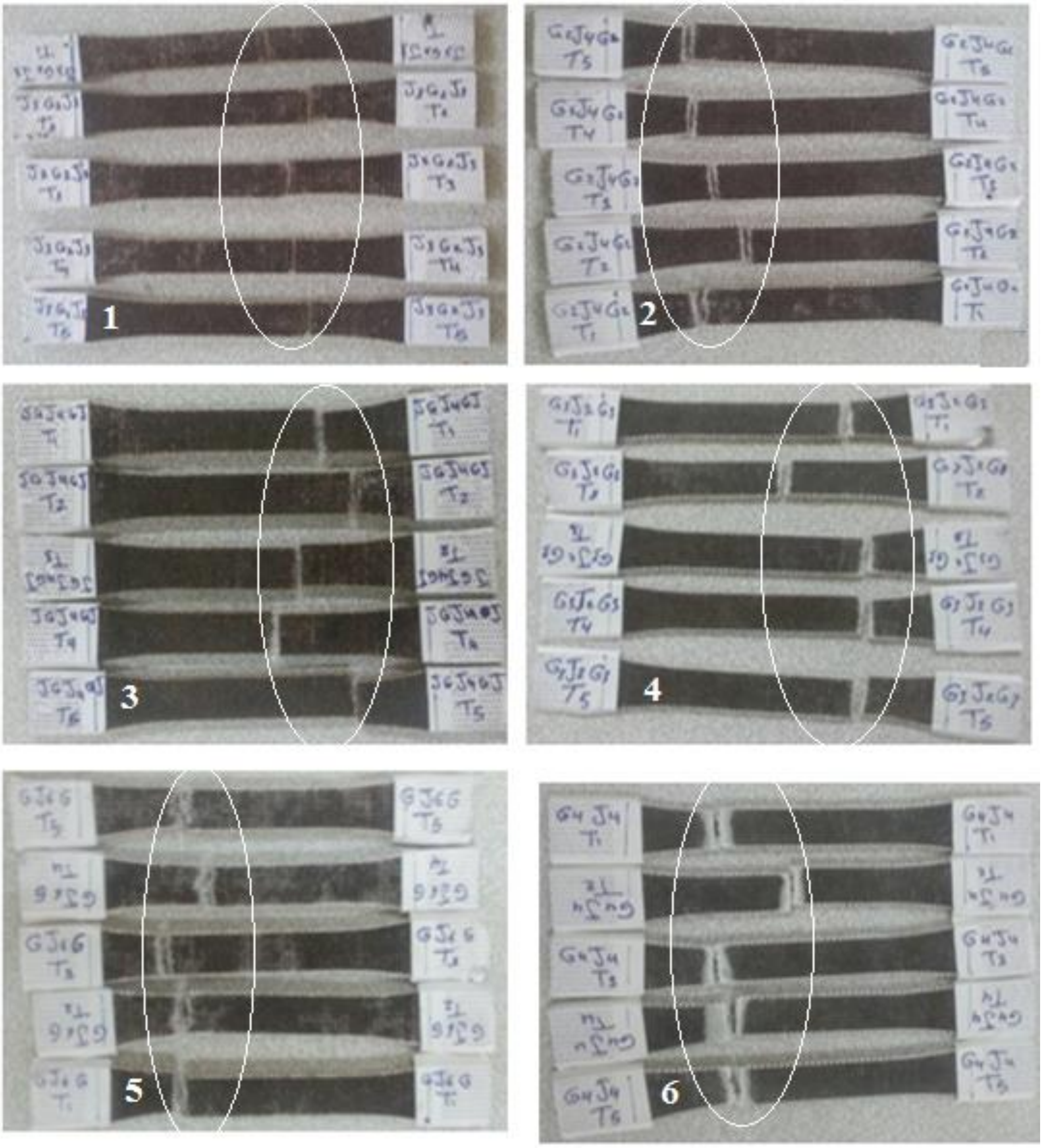


Figure 4.25 Tensile specimens after test

From Figure 4.25 the notice of failed samples revealed that failure in jute/glass/jute laminates is sudden with no or less pull out of jute fibers as shown in picture number 1 and 3 with sequence $J_3G_2J_3$ and JGJ_4GJ that content jute fiber location in outside of laminate, whereas in hybrid laminates, failure is governed by breakage and extensive fiber pull out as shown in picture number 2, 4, 5 and 6 with sequence $G_2J_4G_2$,

$G_3J_2G_3$, GJ_6G and G_4J_4. One reason for this may be because of greater extensibility of glass fibers (2.5–3.0) than jute fibers (1.5–1.8) [97]. However, the failure mode displays breakage and less pull-out of fibers.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

In this study, low velocity impact, tensile and flexural behavior of jute/glass composite laminate consisting of an epoxy matrix were investigated. The tensile and flexural test are determined by using a 300 kN Shimadzu AG-X series universal testing machine. The impact behavior of each specimen were determined by performing Charpy impact test. The jute/glass hybrid fiber reinforced composites laminates were fabricated using hand layup technique. The hybrid composite laminates were prepared with several stacking configurations. The following conclusions can be highlighted from the study.

5.2 Conclusion

- For hybrid composite laminate with arrangements of jute/glass (GJ_6G, $G_2J_4G_2$ and $G_3J_2G_3$) that glass layer location in out and jute in middle with epoxy, the outcome showed that the arrangement of GJ_6G reinforced epoxy had the maximum impact energy for edgewise specimen and it is 5.56J. But impact toughness is 149.43 kJ/m^2 with $G_3J_2G_3$ configuration. While the result for flatwise specimen show the configuration $G_3J_2G_3$ is the maximum value of impact energy it was 2 J, and impact toughness is 75.47 kJ/m^2 with same configuration.
- For hybrid composite laminate with arrangements of jute/glass (GJ_6G, JGJ_4GJ, $J_3G_2J_3$ and $J_2GJ_2GJ_2$) that glass fiber wt.% was 25 % and jute fiber wt.% was 75 % with epoxy, Also the outcome showed that the arrangement of GJ_6G reinforced epoxy had the maximum impact energy for edgewise specimen and it is 5.56J, and impact toughness is 94.24 kJ/m^2 with same configuration. While the result for flatwise specimen show the configuration $J_3G_2J_3$ is the maximum value of

impact energy it was 1.82 J, and impact toughness is 30.79 kJ/m^2 with same configuration.

- For hybrid composite laminate with arrangements of jute/glass (GJ_6G, JGJ_4GJ, $J_3G_2J_3$ and $J_2GJ_2GJ_2$) that glass fiber wt.% was 50 % and jute fiber wt.% was 50 % with epoxy, the outcome showed that the arrangement of $G2J_4G2$ reinforced epoxy had the maximum impact energy for edgewise specimen and it is 5.07J, and impact toughness is 123.66 kJ/m^2 with same configuration. While the result for flatwise specimen show the configuration $G_2J_4G_2$ is the maximum value of impact energy it was 1.85 J, and impact toughness is 45.12 kJ/m^2 with same configuration.
- For composite laminate with configuration G4J4 the result showed the best impact energy and impact toughness done when impacted jute side of specimen.
- For hybrid composite laminate with arrangements of jute/glass (GJ_6G, $G_2J_4G_2$, $G_3J_2G_3$, JGJ_4GJ, $J_3G_2J_3$, G_4J_4 and $J_2GJ_2GJ_2$). The result of flexural strength showed the best configuration is $G_3J_2G_3$ with value 411.25 MPa and flexural modulus 7.51 GPa with same configuration.
- For hybrid composite laminate with arrangements of jute/glass (GJ_6G, $G_2J_4G_2$, $G_3J_2G_3$, JGJ_4GJ, $J_3G_2J_3$, G_4J_4 and $J_2GJ_2GJ_2$). The result of tensile strength showed the best configuration is $G_3J_2G_3$ with value 160.42 MPa and tensile modulus 5.73 GPa with same configuration.

5.3 Recommendation

- In future works, nanoparticles such as nanosilica, nonoclay and nanographene can be added to epoxy and hardener.
- Other kind of processes can be applied to mix up nanoparticles with resin in order to investigate how these new processes can affect the mixture in term of optimal scattering.
- Different chemical concentrations and solutions can be used in order to modify jute fiber surface.

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