Fabrication and Characterization of Jute-Glass Fiber Reinforced Polyester Hybrid Composites

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Abstract

The potentiality of natural fiber-plastic composites using wood, jute, sisal, coir, or hemp, etc., as reinforcing fiber in a thermosetting resin matrix has received considerable attention from scientists all over the world. In polymer composite fabrication system, hybridization of jute fibers with synthetic fibers is one of the techniques adopted to overcome some of the limitations (poor mechanical properties and moisture resistance) that have been identified for jute fiber reinforced composites. In the present study, the effect of hybridization on mechanical properties of jute and glass mat reinforced polyester composites has been evaluated experimentally. The development of composite materials based on the reinforcement of two or more fiber types in a matrix leads to the production of hybrid composites. In the present work, hessian jute cloth, non-woven E-glass and polyester resin were used to prepare jute/polyester, glass/polyester and jute-glass hybrid polyester composites by hand lay-up and heat press molding techniques and their mechanical properties were evaluated for different stacking sequences. In Jute/polyester and glass/polyester composites, mechanical properties such as tensile properties, bending properties and impact strength increase with the increases of stacking sequences. In case of jute-glass hybrid composites, the composites which content more glass layer than that of jute layer shows the higher mechanical properties. Water uptake (%) of these composites demonstrate that water absorption rate is initially higher for jute/polyester composite and at a stage it become steady (31.11%), but in case of glass/polyester and jute-glass hybrid composites the absorption rate is very low which is almost less than 1% due to the hydrophobic nature of glass fiber and polyester resin. Soil degradation test of all types of composites were evaluated and the deterioration of the mechanical properties revealed for all the composites where jute/polyester composites showed the higher degree but E-glass/polyester composites retained major portion of its original integrity and their hybrid declined more than glass but less than jute composites.

Keywords: Mechanical; Reinforced; Hybrid; Matrix; Composite

1. Introduction

The concept of hybrid or mixed fiber in the composite system is the principle of combining materials to optimize their value. Mixing two or more types of fiber in one matrix allows even closer tailoring of composite properties to suit specific requirements that cannot be achieved with a single fiber species. Fiber reinforced polymer composites are now-a-days gained huge attention worldwide due to its unique and versatile properties over the conventional household and construction materials such as wood, metals and reinforced concrete due to their limited properties [1]. The versatile characteristics of the composite materials are low cost, light weight, high mechanical properties, ease of installation, good process ability, relatively good resistance to environmental agents and fatigue, etc. They are extensively used as materials in making automobile and aircraft structures, electric packaging to medical equipment, and space vehicle to home building [2].

Composites are combinations of materials differing in composition, where the individual constituents retain their separate identities [3, 4]. Among all the synthetic fibers, glass fibers are now dominant due to their low cost and comparatively better physic-mechanical properties. Glass fibers are produced when thin strands of silica-based or other formulations of glass are extruded into many fibers with small diameters appropriate for textile processing [2, 5]. Jute **Fig. 1** is an attractive natural fiber for use as reinforcement in composite because of its excellent mechanical properties, low cost, renewable nature and much lower energy requirement for processing. It is produced in large scale in tropical area

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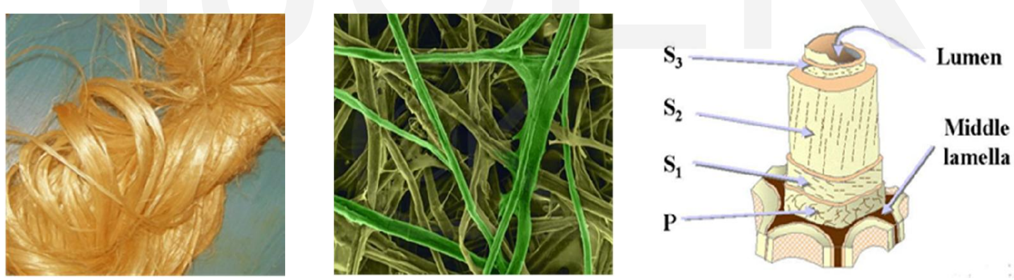
like Bangladesh, Indian and Latin America and it is already identified as potential candidate for reinforcing agent in composite fabrication. Jute fabrics are also called Hessian cloth. Jute composed of mainly á-cellulose, hemicelluloses, and lignin[6] [7].

By mixing two or more types of fiber in a resin to form hybrid composite it may be possible to create a material possessing the combined advantages of the individual components and simultaneously mitigating their less desirable qualities. In addition, it should be possible to tailor the properties of such materials to suit specific requirements. Hybrid fiber reinforced materials can be made in two separate ways either by intimately mingling the fibers in a common matrix, or by laminating alternative layers of each type of composite [8, 9] [10] .

During the last few years, many researchers have studied the various properties (Physical, mechanical, electrical, thermal and structural etc.) of jute/glass fiber hybrid composites that were prepared for household application. Considerable amounts of research work have done in different parts of the world. In this section a survey on the reported works on jute/glass fiber based polymer matrix hybrid composites can be cited .Composites are produced when two materials are joined to give a combination of properties that cannot be attained in the original materials [11].

Matrix Phase + Reinforcement Phase = Composites

The above equation depicts how composites are prepared. It must have a matrix and reinforcement. Matrix may be metal, ceramic, polymer, and reinforcement may be organic and inorganic materials such as natural fibers, glass fibers, carbon nanotube etc. The last point provides the main impetus for the development of composite materials. In fiber reinforced plastics, fibers and plastics with some excellent physical and mechanical properties are combined to give a material with a new and superior property [12]. Fibers have very high strength and modulus but this is only developed in very fine fibers, with diameters in the range 7-15 ìm, and they are usually very brittle. Plastic may be ductile or brittle but they usually have considerable resistance to chemical environments. By combining fiber and resin a bulk materials is produced with a strength and stiffness close to that of the fibers and with the chemical resistance to the plastic. In addition, it is possible to achieve some resistance to crack propagation and an ability to absorb energy deformation [13].

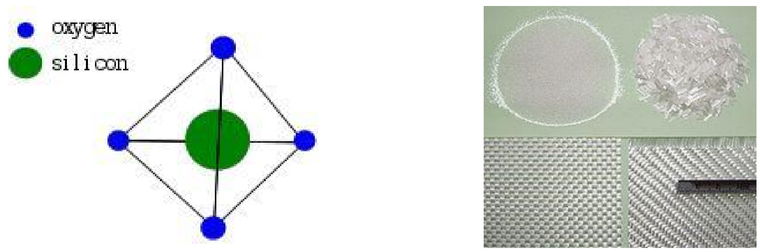


Jute Fiber structure   Cellulose Fibers from Print Paper (SEM x1080)   Jute fibre

Fig. 1 Jute Fiber & its morphological view

The cell wall of a fibre is made up of a number of layers: the primary wall and the secondary wall (S), which again is made up of the three layers (S1, S2 and S3)**.** A well carded textile filament of jute is a dead tissue consisting of fiber cells numbering about 20 to 80 and having dimension of about 10 to 100 mm in length and 0.03 to 0.06 mm in breadth [14]. Glass, carbon, Kevlar, and boron fibers are being used as reinforcing materials in fiber-reinforced plastics, which have been widely accepted as materials for structural and nonstructural applications. Natural fibers from plants such as jute, bamboo, coir, sisal, and pineapple are known to have very high strength and hence can be utilized for many load-bearing applications [11, 15]. The chemical composition of jute fiber **Fig. 1** is shown in Table 3.3. The main structural element of jute fiber is cellulose, which is held entirely within the cell units whereas the lignin and hemicelluloses are distributed throughout the entire body of the fiber serving as a cementing material [16, 17].

Jute reinforced composite was defined as the impregnation of jute fiber with monomer which is then polymerized. This process forms cross-linked polymer. The properties of product depend on the quality of jute, the monomer, the oligomer and the details of processing[18, 19]. Glass fiber has roughly comparable properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle [20, 21].



Molecular structure of glass Glass reinforcements

Fig. 2 Molecular structure of Glass & Glass reinforcement

The technique of heating and drawing glass **Fig. 2** into fine fibers has been known for millennia; however, the use of these fibers for textile applications is more recent [22]. Hybrid composite of glass and jute fibre can be fabricated initially by the hand lay-up technique for making the sheet-moulding compound and subsequently by using a compression-moulding machine. 10-ply hybrid laminates containing 8 inner plies of untreated/silane/ titanate/TDI treated jute fibre sandwiched between two outer plies of glass fibre (weight content of jute : 25-27%) can be made by the aforesaid process. Curing is done at 80℃ under a pressure of approx. 2 X 10^5 N/m^2 for 90 min[11, 23].

2. Experimental

2.1. Materials

Jute woven fabric (Hessian Cloth, 1×1 plain weave) was used as reinforcement which was collected from the local market of Dhaka, Bangladesh. Glass fiber non-woven (400 GSM) collected from SHCP, Singapore. Unsaturated polyester resin **Fig. 3** collected from SHCP, Singapore. Methyl ethyl ketone peroxide (MEKP) collected from SHCP, Singapore.

Jute woven fabric (Hessian cloth, 1×1 plain weave) Glass fiber non-woven Polyester resin

Fig. 3 Jute woven fabric, Nonwoven Glass Fiber & Polyester resin

2.2. Instruments

An electric balance (HP 200) was used for the measurement of weight of the samples. Hydraulic Press **(**Model: 3856, S/N: 3856-409**)** is for cold press, to control the current through the coil thereby controlling the temperature of the die. The composites were prepared by using an aluminum die. For removing moisture from composites specimen and jute hessian cloth Drying Oven (Model: AA-160, Denver Instrument Company) was used. To cut the composites for various testing the grinding machine was used. A universal testing machine (UTM) (Model: H50KS-0404, HOUNSFIELD Series S, UK) range was used for quick and reliable tensile measurements. Universal Impact Tester (HUNG TA INSTRUMENT CO. LTD., Taiwan) is used for the impact strength test.

2.3. Methods

2.3.1. Preparation of Composites

At first, jute woven fabric and non-woven glass were cut into the desired size. As jute content moisture so it was dried at 100ºC for 1 hour in a drying oven. In Jute/polyester and glass/polyester composites, mechanical properties such as tensile properties, bending properties and impact strength increase with the increases of stacking sequences. The matrix material was prepared by mixing unsaturated polyester resin and 10% MEKP, mixed thoroughly before applying in the fiber. It is prepared three types of composites with different stacking sequences, these are jute fiber reinforced polyester composites (J1, J2, J3, J4, J5), glass fiber reinforced polyester composites (G1, G2, G3, G4, G5) and jute-glass fiber reinforced polyester hybrid composites (H1, H2, H3, H4, H5, H6, H7, H8, H9).

2.3.2. Determination of Mechanical Properties

2.3.2.1. Tensile Strength

Tensile test is a measurement of the ability of a material to applied forces tending to pull it apart and observe the extent of material stretches before breaking. Different types of plastic materials are often compared based on tensile property data (i.e. strength, modulus, and elongation data).

As a testing machine, the machine of a constant-rate-of-crosshead movement, containing a stationary member carrying one grip, and a moveable member carrying the second grip, is used. Test specimen dimensions vary considerably depending on the requirements and are described in related section in the ASTM book of standards. The specimens are conditioned using standards of procedures. The recommended test conditions are 23±2ºC as a standard laboratory atmosphere and 50±5% relative humidity .Tensile strength of the composites was performed according to ASTM Designation: D638-03. The test specimen was cut in a size length ≈ 120mm, width ≈ 15mm.

2.3.2.2. Bending Test

Flexural strength is the ability of the material to applied bending forces perpendicular to the longitudinal axis of the specimen. The stresses induced by flexural load are a combination of compressive and tensile stresses and properties are calculated in terms of the maximum stress and strain occurring at the outside surface of the test bar. These test methods are generally applicable to rigid or semi-rigid materials .Two basic methods, including a three-point loading system utilizing center loading on a sample supported beam, and a four-point loading system utilizing two load points, are employed to determine the flexural properties. The former is designed particularly for materials undergoing small deflections, whereas the latter particularly for materials with large deflections during testing. The test specimens used for flexural testing are obtained from sheets, plates or molded shapes by cutting as bars with rectangular cross-section. Static Bending tests were carried out according to ISO 14125 methods with cross-head speed of 60mm/sec and span distance 25mm.

2.3.2.3. Impact Test

The impact properties of the polymeric materials depend mainly on the toughness of the material. Toughness can be described as the ability of the polymer to absorb applied energy. The molecular flexibility has a great significance in determining the relative brittleness of the material. Impact energy is a measure of toughness, and the impact resistance is the ability of a material to resist breaking (fracture) under a shock-loading.

2.3.2.4. Water Uptake

Water uptake (wt. %) of the composites was performed according to ASTM Designation: D570-99. The test specimen was cut in a size length ≈ 39mm, width ≈ 10mm. The cut samples were kept in an oven at 105ºC for 1 hr. It was taken out from the oven and immediately weighed. Composite samples were immersed in a static water bath at 25ºC for different time interval. After certain periods of time, samples were taken out from the bath and wiped using tissue paper, then weighed.

2.3.2.5. Soil Degradation Test

Composites samples were buried in soil (having at least 25% moisture) for 6 weeks. After 6 weeks, samples were withdrawn carefully, washed with distilled water and dried at 105ºC for 6 hours and kept room temperature for 24 hours and then measured the mechanical properties.

3. Results & Discussions

The jute-glass hybrid composites, the composites which content more glass layer than that of jute layer shows the higher mechanical properties **Table 1** .Textile composite materials are composed of fibres, yarn or fabric system and matrix material that is bind and protect the fibres. At first, jute woven fabric and non-woven glass were cut into the desired size. As jute content moisture so it was dried at 100ºC for 1 hour in a drying oven. In Jute/polyester and glass/polyester composites, mechanical properties such as tensile properties, bending properties and impact strength increase with the increases of stacking sequences.

Table 1 Comparison of mechanical properties of jute/polyester, glass/polyester and jute/Glass/polyester hybrid composites.

Symbol	Stacking Sequence	TS (MPa)	Eb%	TM (MPa)	BS (MPa)	BM (MPa)	IS (kJ/m²)
J5	JJJJJ	88.4	8	3602	123.9	5182	20.97
G5	GGGGG	165	13.3	2553	301.2	8700	63.49
H5	JGJGJ	120.5	9.9	4331	178	5477	37.56
H6	GJGJG	124.5	11.3	3278	217.4	7786	46.36
H7	JGJGJG	129.2	12.7	3049	242.4	7712	42.39
H8	JGJGJGJ	143.5	10.9	3179	195.8	5126	48.66
H9	JGJGJGJGJ	145.2	12.8	4867	180.3	5099	56.51

3.1. Tensile Strength (TS)

The employed process to prepare the specimens and the molecular orientation has a significant effect on tensile strength **Fig. 4** values. A load applied parallel to the direction of molecular orientation may yield higher values than the load applied perpendicular to the orientation. Injection molded specimens generally yield higher values than the samples molded in compression.

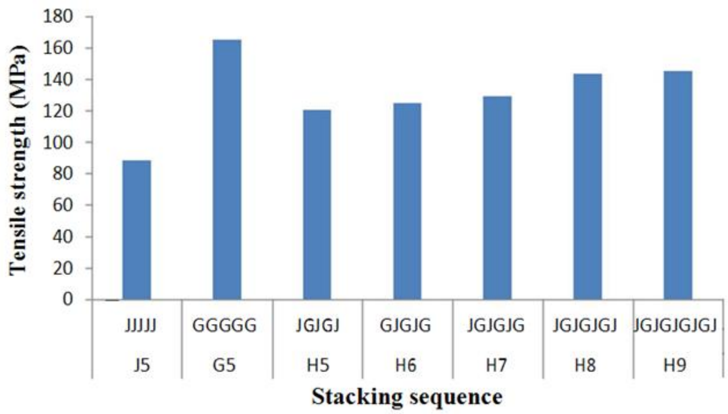


Fig. 4 Comparison of tensile strength (TS) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

Fig. 4 shows that TS of J5, G5, H5, H6, H7, H8 and H9 were 88.4, 165.0, 120.5, 124.5, 129.2, 143.5 and 145.2 MPa respectively. Here, five layer jute/polyester composite shows the lowest TS of 88.4 MPa and that of glass/polyester shows the highest TS of 165.0 MPa. Different stacking sequence of jute-glass/polyester hybrid composites shows TS from 120.5 to 145.2 MPa. So we found that, only glass/polyester composite demonstrate the superior TS over only jute/polyester and their hybrid composites. As the strain rate, the change in strain value per unit time, is increased the ensile strength and modulus values increase.

3.2. Elongation at break (%)

shows that, Eb% of J5, G5, H5, H6, H7, H8 and H9 were 8.0, 13.3, 9.9, 11.3, 12.7, 10.9 and 12.8% respectively. Here, five layer jute/polyester composite shows the lowest Eb% of 8.0% and that of glass/polyester shows the highest Eb% of 13.3%. Different stacking sequence of jute-glass/polyester hybrid composites shows Eb% from 9.9 to 12.8%. It is found that, only glass/polyester composite demonstrate the superior Eb% over only jute/polyester and their hybrid composites.

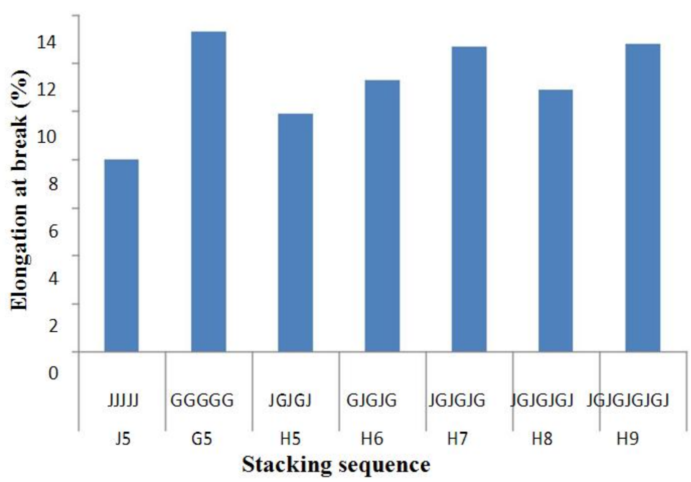


Fig. 5 Comparison of elongation at break (Eb%) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

3.3. Tensile Modulus (TM)

Figure 6 shows that TM of J5, G5, H5, H6, H7, H8 and H9 were 3602, 2553, 4331, 3278, 3049, 3179 and 4867 MPa respectively. Here, five layer glass/polyester composite shows the lowest TM of 2553 MPa and jute-glass/polyester hybrid shows the highest TM of 4867 MPa. Different stacking sequence of jute-glass/polyester hybrid composites shows TM from 3049 to 4867 MPa **Fig. 6**.

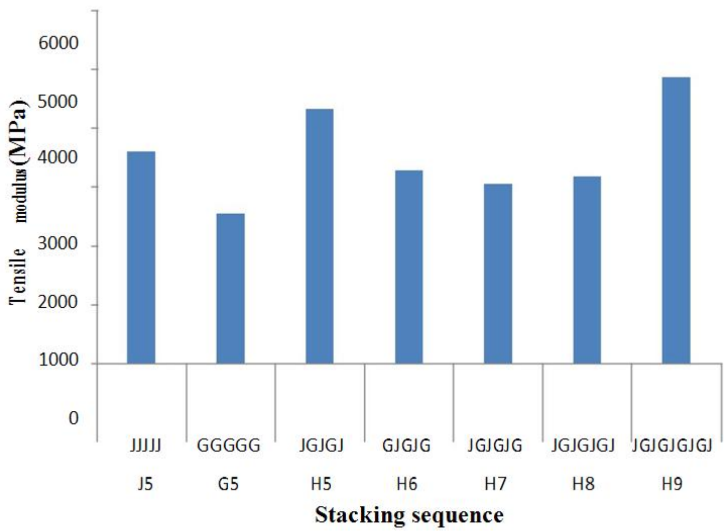


Fig. 6 Comparison of elongation at break (Eb%) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

The specimen with high degree of molecular orientation perpendicular to the applied load will show higher values than the one which is parallel to the applied load with the parallel ones. Another factor is the environmental temperature; there is an inverse proportion between it and the flexural strength and modulus.

3.4. Bending Strength (BS)

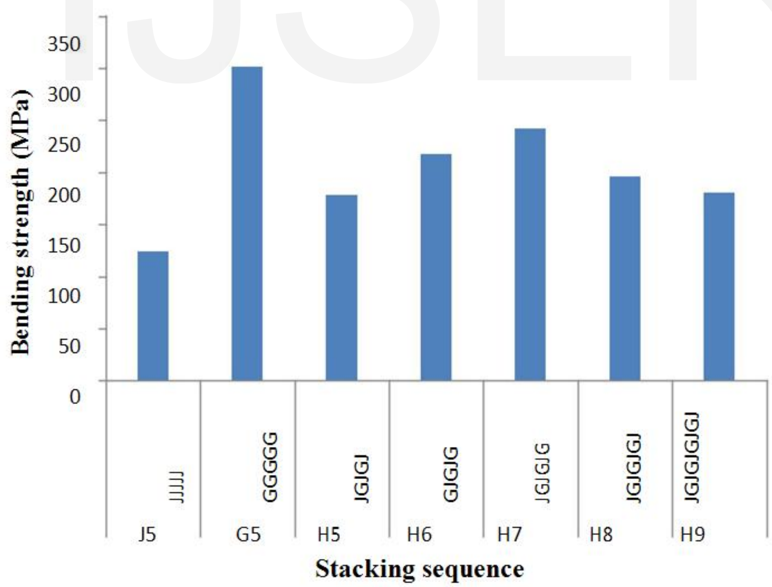


Fig. 7 Comparison of bending strength (BS) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

Fig. 7 shows that, BS of J5, G5, H5, H6, H7, H8 and H9 were 123.9, 301.2, 178.0, 217.4, 242.4, 195.8 and 180.3 MPa respectively. Here, five layers jute/polyester composite shows the lowest BS of 123.9 MPa and that of glass/polyester shows the highest BS of 301.2 MPa. Different stacking sequence of jute-glass/polyester hybrid composites shows BS from 178.0 to 242.4 MPa. It is found that, only glass/polyester composite demonstrate the superior BS over only jute/polyester and their hybrid composites.

3.5. Impact Strength (IS)

Fig. 8 shows that, IS of J5, G5, H5, H6, H7, H8 and H9 were 20.97, 63.49, 37.56, 46.36, 42.39, 48.66 and 56.51 kJ/m² respectively. Here, J5 composite shows the lowest IS of 20.97 kJ/m² and G5 shows the highest IS of 63.49 kJ/m². Different stacking sequence of jute-glass/polyester hybrid composites shows IS from 37.56 to 56.51 kJ/m². It is found that, only glass/polyester composite demonstrate the superior BM over only jute/polyester and their hybrid composites.

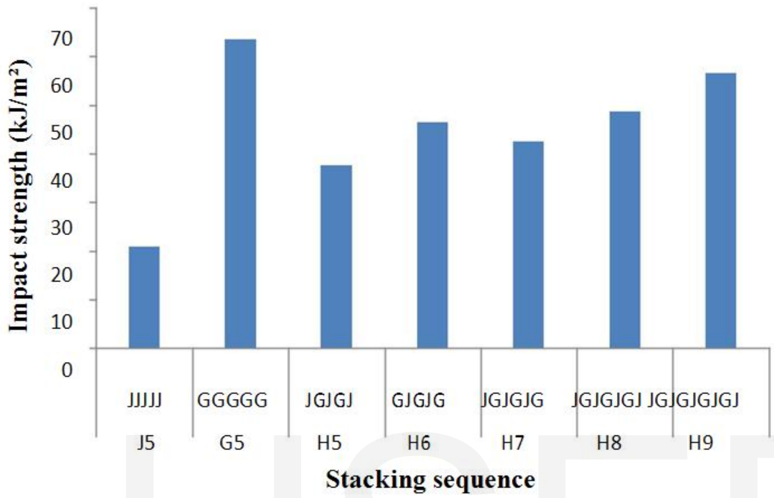


Fig. 8 Comparison of impact strength (IS) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites

3.6. Water Uptake (%)

Table 2 Comparison of water uptake (%) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

Soaking	Water Uptake (%)		
Time (min)	J5	G5	H9
0	0	0	0
5	16.56	0	0
10	16.89	0	0
20	17.67	0	0
30	18.00	0	0
50	18.89	0	0.01
80	19.44	0	0.01
120	20.67	0	0.01
180	21.33	0.001	0.02
240	22.22	0.002	0.02
1440	31.11	0.004	0.05
1500	31.11	0.004	0.05

In case of J5, the composite rapidly absorb water up to first 5 minutes, then it steadily increased 31.11% for 1500 minutes (25 hours) and then the absorption rate is very slow **Table 1**.**Fig. 9** shows that, water uptake (%) of J5, G5 and H9 up to

1500 minutes (25 hours).

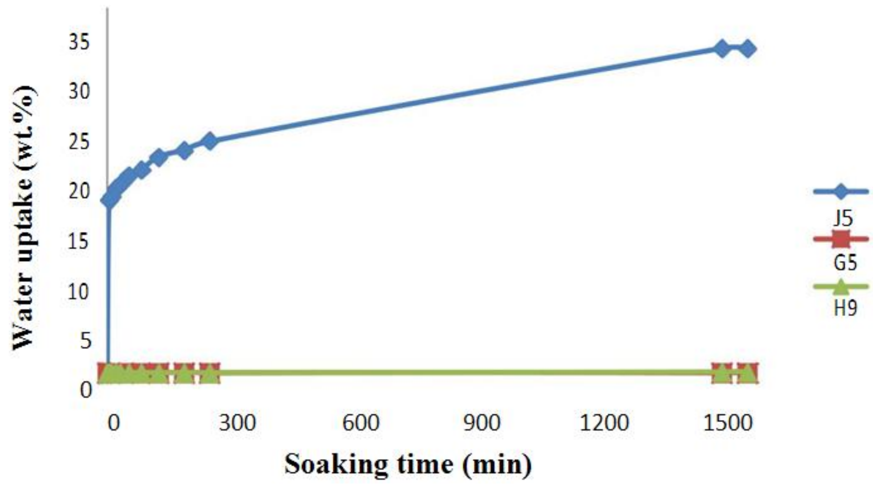


Fig. 9 Comparison of water uptake (%) of jute/polyester, glass/polyester and jute-glass/polyester hybrid composites.

The rate of loading has a significant effect on the behavior of the polymer during testing. At high rates of impact, even rubber-like materials may exhibit brittle failure. All plastics are notch-sensitive. A notch or a sharp corner in a fabricated part creates a localized stress concentration, therefore, both the notch depth and notch radius have an effect on the impact behavior. Larger radius will have a lower stress concentration, resulting in higher impact energy of the base material. The temperature increase lowers the impact resistance drastically. The impact strength is usually higher in the direction of flow. In addition, processing conditions and types play an important role in determining the impact behavior as well as in the case of degree of crystallinity, molecular weight and the method of loading.

3.7. **Soil Degradation Test**

Table 3 Soil degradation test of Jute reinforced polyester composite (J5).

Mechanical Properties	Before 6 weeks	After 6 weeks
Avg. Tensile Strength (MPa)	88.4	60.8
Avg. Elongation at break (%)	8.0	3.6
Avg. Tensile Modulus (MPa)	3602	3048
Avg. Bending Strength (MPa)	123.9	103.5
Avg. Bending Modulus (MPa)	5182	4022
Avg. Weight (gm)	15.96	15.05

The discontinuous fiber composites (jute fiber/PP and E-glass fiber/PP) were subjected to soil degradation at ambient condition for up to 6 weeks. After 6 weeks of soil degradation, jute composites **Table 3** lost almost 16% and 8% of TS and TM respectively. On the other hand, glass fiber composites **Error! Not a valid bookmark self-reference.** lost only 1.3 and 1.7% of TS and TM respectively.

Table 4 Soil degradation test of Glass reinforced polyester composite (G5).

Tensile Properties	Before 6 weeks	After 6 weeks
Avg. Tensile Strength (MPa)	165.0	152.7
Avg. Elongation at break (%)	13.3	9.0
Avg. Tensile Modulus (MPa)	2552	3510
Avg. Bending Strength (MPa)	301.2	269.5
Avg. Bending Modulus (MPa)	8700	6712
Avg. Weight (gm)	19.53	19.42

Table 5 Soil degradation test of jute-glass fiber reinforced polyester composite (H9).

Tensile Properties	Before 6 weeks	After 6 weeks
Avg. Tensile Strength (MPa)	145.2	117.1
Avg. Elongation at break (%)	13.0	7.5
Avg. Tensile Modulus (MPa)	4867	3308
Avg. Bending Strength (MPa)	180.3	150.5
Avg. Bending Modulus (MPa)	5099	4640
Avg. Weight (gm)	33.74	32.38

With time jute composites showed phenomenon loss of strength and modulus **Table 5**. The losses of strength are 22 and 3% respectively for jute/PP and glass/PP composites in 6 weeks. This is clear that E-glass fiber composites retained much of its tensile properties than that of the jute composites during soil degradation. Finally the strength and modulus of jute composites decreased almost 23 and 11% respectively after 6 months. On the other hand, E-glass composites showed only 5.8 and 6% loss of FS and FM respectively in the same period.

4. Conclusions

In this article, effect of stacking of jute and glass mat on mechanical properties of jute/glass fibre reinforced polyester composites have been experimentally studied and the variation in mechanical properties are explained by studying the fracture features and crack profiles with scanning electron microscopy. Mechanical properties of the composites were improved with the increase of stacking sequences. It is seen that the Jute/ Polyester composite shows better mechanical properties compared to other two jute/glass or Glass Polyester composites. In jute-glass hybrid composites, better mechanical properties found where glass fiber layer is more than that of jute layer. Experiments were carried out to analyze the effect of jute and glass fiber stacking sequence on the mechanical properties of jute/polyester composites, glass/polyester composites and jute-glass/polyester hybrid composites.

Also water uptake (%), soil degradation and effect of gamma radiation were analyzed & investigated. In jute/polyester composites, better result found for five layers of jute and same in the glass/polyester composites. Water uptake (%) of jute polyester composite is much higher than that of glass and hybrid composites where water absorption of glass and jute-glass hybrid composites is negligible. In soil degradation test, it has been found that jute/polyester composites are biodegradable, glass fiber shows a very little degradation and their hybrid shows moderate degradation. Various structures of jute woven fabric can be used and woven glass roving can also be used instead of non-woven glass. Thermal properties, dielectric behavior, hardness, SEM etc. can also be measured. Jute fibers such as jute fiber lap from carding machine, jute felt, jute caddies etc. can also be used to prepare such composites and study their properties.

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