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Evaluation of Material Sustainability of Natural Fibers mixed with Glass Fiber Reinforced Composites

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Abstract: *The increasing demand for sustainable and lightweight composite materials has led to significant research in natural fiber-reinforced composites (NFRCs). This study explores the mechanical properties, durability, and performance of hybrid composites that combine natural fibers (such as jute, flax, or hemp) with glass fiber-reinforced polymers (GFRP). The goal is to evaluate how natural fibers enhance material sustainability while maintaining the structural integrity of traditional GFRP composites.*

A series of experimental tests are conducted on hybrid composites with varying natural-to-glass fiber ratios to assess tensile strength, flexural strength, impact resistance, and water absorption characteristics. Scanning Electron Microscopy (SEM) is used to examine fiber-matrix adhesion and failure mechanisms. The influence of fiber treatment methods (alkali treatment, saline coupling agents) on bonding strength and moisture resistance is also analyzed.

The results indicate that natural fibers improve biodegradability and reduce material weight while glass fibers provide high strength and stiffness. However, challenges such as moisture absorption and reduced durability are observed, requiring surface modifications and resin selection for optimization. This research provides valuable insights for automotive, aerospace, and construction industries, where eco-friendly yet high-performance composites are increasingly sought after.

Key Words: ASTM, Sisal fibres, banana fibre, glass fibre mat and epoxy resin.

I. INTRODUCTION

A composite material is made by combining two or more dissimilar materials. They are combined in such a way that the resulting composite material or composite possesses superior properties. Which are not obtainable with a single constituent material.

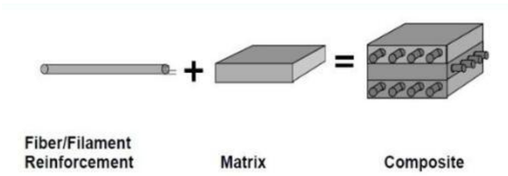


Fig 1.1 Fabrication of Composite material

The components do not dissolve or completely merge. They maintain an interface between each other and ad in concert to provide improved, specific or synergistic

Characteristics not obtainable by any of the original components acting singly. Bone is a simple example of a natural composite material having the best properties of its constituents. Bone must be strong and rigid; yet flexible enough to resist breaking under normal use. These requisite properties are contributed by its components gives the required softness. The inorganic component, made up of calcium phosphate, gives it the required strength and rigidity. The most common synthetic composite material is glass fibre reinforced plastics (GRP) which is made out of plastics and glass fibre.Matrix

Matrix is also known as binder material. It (i) provides shape to the composite material, (ii) makes the composite material generally resistant to adverse environments and (iii) protects reinforcement material from adverse environments. The materials which constitute matrix of composite materials are plastics, metals, ceramics and rubber.

Fibres: The fibres are the load carrying members in the composite material. They are bonded together by using matrix material. Based on formation and they are classified into two types.

1. Natural Fibre: Natural fibres are used as conventional reinforcement materials. Natural fibres are low-cost fibres with low density and high specific properties. These are biodegradable and nonabrasive, unlike other reinforcing fibres. Natural fibres include those produced by plants, animals, and geological processes. They are biodegradable over time. The various types of natural fibres are sisal, banana, palm, bamboo, etc.
2. Man-Made Fibres: Man-made fibre, whose chemical composition, structure, and properties are significantly modified during the manufacturing process. The chemical compounds from which man-made fibres are produced are known as polymers, a class of compounds characterized by long, chainlike molecules of great size and molecular weight. Some of the inorganic fibres are aramid, boron, carbon, glass, etc…

Resin: The resins are used as the bonding material in the composite. The resins are chemical composition, which forms the adhesive bonding. The resin affects the physical properties, fabrication and ultimate properties of composite materials. Variations in the composition, physical state, or morphology of a resin and the presence of impurities or contaminants in a resin may affect handle ability and process ability, lamina/ laminate properties, and composite material performance and long-term durability. Primary Function is “To transfer stress between reinforcing fibres and to protect them from mechanical and environmental damage”.

II. MATERIAL DETAILS

In the fabrication of the composite material we used two organic fibre and one inorganic fibre. They are,
- Sisal fibre
- Banana fibre
- Glass fibre
- Epoxy resin

2.1 Sisal Fibre
Sisal fibre made from the large spear shaped tropical leaves of the Agave Sisal and plant. Sisal fibre is extracted by a process known as decortications, where leaves are crushed and beaten by a rotating wheel set with blunt knives, so that only fibres remain.

Fig 2.1 Sisal fibres

Physical property	Sisal fibre
Density (kg/m3)	1350
Elongation at break (%)	2-3
Cellulose content (%)	63-64
Tensile strength (MPa)	54
Young’s modulus (GPa)	3.4878
Lumen size (mm)	5

Table 2.1 Physical properties of sisal fibre

2.2 Banana Fibre

Different parts of banana trees serve different needs, leaves as food wrapping, and fibre and paper pulp. Banana fibre is a multiple celled structure. The lumens are large in relation to the wall thickness. Cross markings are rare and fibre tips pointed and flat, ribbon like individual fibre diameter range from14 to 50 microns and the length from 0.25 cm to 1.3 showing the large oval to round lumen.

Banana fibre is a natural fibre with high strength, which can be blended easily with cotton fibre or other synthetic fibres to produce blended fabric & textiles..

Fig 2.2Banana Fibre

Physical property	Banana fibre
Density(gms/cc)	1.35
Elongation (%)	1-3.5
Cellulose content (%)	65/5
Elastic Modulus (GPa)	8-20
Volume Resistivity (Ω cm x 10^5)	6.5-7

Table 2.2 Physical property of banana fibre

2.3Glass Fibres

Over 95% of the fibres used in reinforced plastics are glass fibres, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced. Their low density, resistance to chemicals, insulation capacity are other bonus characteristics.

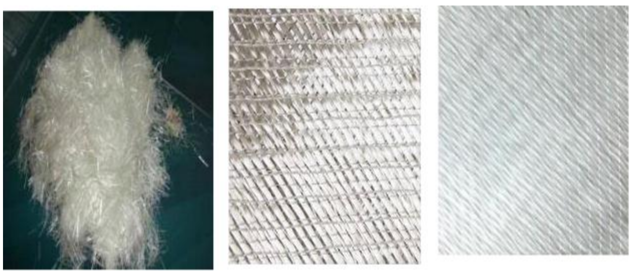


Fig 3.3 Glass fibres

Properties	Glass fibre
GSM	360 gsm
Orientation	plain-woven fabric
UTS	40 Gpa

Modulus	1.0 Gpa
Density	**3.3** g/cc

Table 3. 3 Physical properties of Glass fibre

2.4 Epoxy Resin

Epoxy is a general description of a family of polymers which are based on molecules that contain epoxide groups. An epoxide group is an oxidant structure, a three-member ring with one oxygen and two carbon atoms.

Fig 2.4 Epoxy resin

Epoxies are used widely in resins for prepares and structural adhesives. The advantages of epoxies are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing.Processing techniques include autoclave molding, filament winding, press molding, vacuum bag molding, resin transfer molding, and pultrusion. Curing temperatures vary from room temperature to approximately 350°F (180°C). The most common cure temperatures range between 250° and 350°F (120° and 180°C). The use temperatures of the cured structure will also vary with the cure temperature. Higher temperature cures generally yield greater temperature resistance. Cure pressures are generally considered as low pressure molding from vacuum to approximately 100 psi (700 kPa).

III. FABRICATION DETAILS

3.1 Preparing The Mold

Remove any dust and dirt from mold. The mold is of new fibreglass was applied with soft wax and buff with soft towel. Spray or brush with PVA, parting compound and allow it to dry. The mold material is well-cured fibreglass, so apply three coats of hard wax, carnauba type, buffing between each coat.

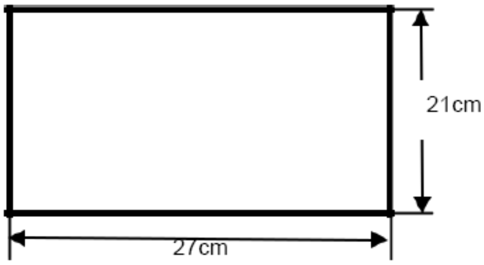


Fig3.1 Mold Specimen

In this mold there are several orientation of fibre has been prepared for several testing and also to analysis which orientation is best for the tests like tensile, impact and flexural strengths. The hand lay-up process is used for fabrication.

3.2handlay-Upprocess:

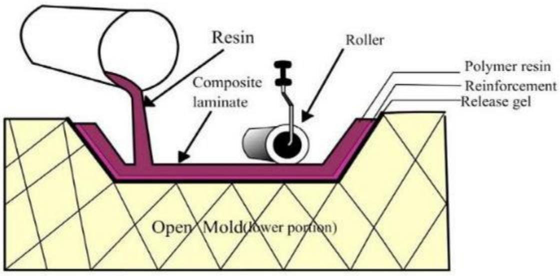


Figure 3.2 Hand lay-up process

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats is cut as per the mold size and placed at the surface of mold after Perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed. The schematic of hand lay-up is shown in figure 3.2. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperature is **24-48 hours**.

Materials used	
Matrix	Epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester, polyurethane resin
Reinforcement	Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax etc.) (all these fibers are in the form of unidirectional mat, bidirectional (woven) mat, stitched into a fabric form, mat of randomly oriented fibers)

Table 3.1 Raw materials used in hand lay-up method

3.3 Applying The Gel-Coat

The gel-coat is to be brushed on the layers from 1 to 10 layers, allow first coat to cure and then apply the second coat to make sure there are no light spots. When gel-coat has cured long enough that your fingernail cannot easily scrape it free (test at edge of mold where damage will not show on part) then proceed with next step.

3.4 Lay-Up Skin Coat

Natural (sisal and banana) and Glass fibre mats of dimension 270×210 mm are cut from the big roll. Brushes catalysed resin over gel-coat, and then apply the mat. Work with roller adding more resin where necessary until all white areas in mat fibres have disappeared and all air bubbles have escaped. Resin-rich areas weaken the part. Where rollers will not reach, brushes must be used. When this step is complete clean all tools in acetone. Allow skin coat to cure before next step.

3.5 Reinforcement Of Natural And Glass Fibers

Apply each layer as in step 3, but it will not be necessary to wait for curing between these layers. Be sure to shake all acetone out of brushes and rollers before applying resin. Acetone drips can result in uncured spots in the lay-up.

3.6 Trim

The natural (sisal and banana) and glass fibre laminate which hangs over the edge of the mold can be trimmed off easily with razor knife on the trim stage, of the period after the lay-up has gelled but before it has hardened.

3.7 Cure

It take time for curing from 24 hours to 48 hours, depending upon turnover desired, temperature, canalization, and nature of the part. In a female mold, longer cure will affect shrinkage and easier parting. In the case of the male mold, the part comes off more easily before it shrinks appreciably.

IV. TESTING METHODS

The main objective is to determine the material properties (Tensile Strength, Flexural Strength, and Impact Strength) of natural fibre reinforced composite material by conducting the following respective tests.

- Tensile Test
- Flexural Test
- Impact Test

4.1 Tensile Test

The fabricated composite is cut using a saw cutter to get the dimension of the rectangular specimen for tensile testing as per ASTM: D638 standards.

Composite specimens of dimensions 165 × 19 × 4 mm in fig 4.1.Specimen were placed in the grips and were pulled at a speed of 5 mm/min until failure occurred.

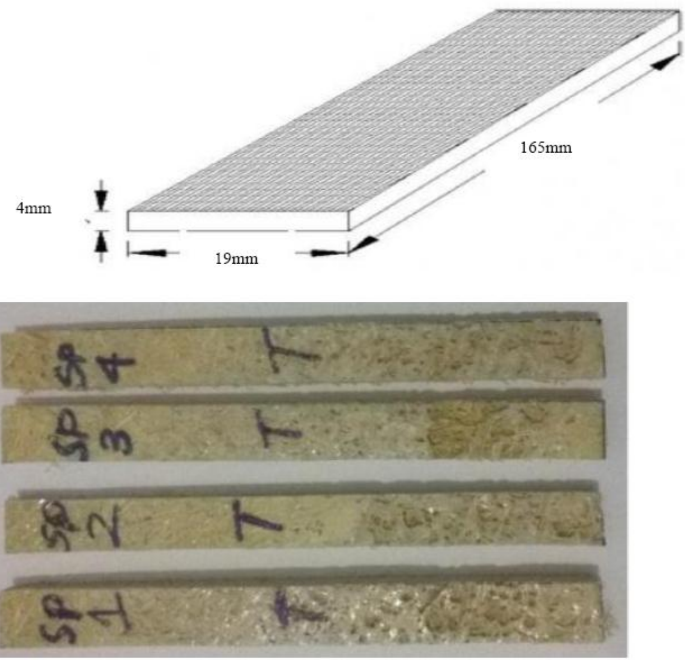


Fig 4.1 Tensile test specimens

The strain gauge was used to measure the displacement. The test is carried out in universal testing machine make FIE (Model: UTN 40, SNo, 11/98- 2450) at room temperature (303K). The test was carried out using a universal testing machine at a room temperature with 40% relative humidity. The tensile stress is recorded with respect to increase in strain. The specimen was placed in the grip of the tensile testing machine and the test is performed by applying tension until it undergoes fracture. The corresponding load and strain obtained are plotted on the graphs.

4.2 Flexural Test

The Flexural testing commonly known as three-point bending testing is performed on the same tensile testing machine as per the ASTM: D790 Standards. Composite specimens of dimensions 130 × 12 × 4 mm in fig 4.2.Specimen were horizontally placed on two supports and load was applied at the centre. Flexural modulus could be found by the ratio of stress to strain in the flexural deformation.

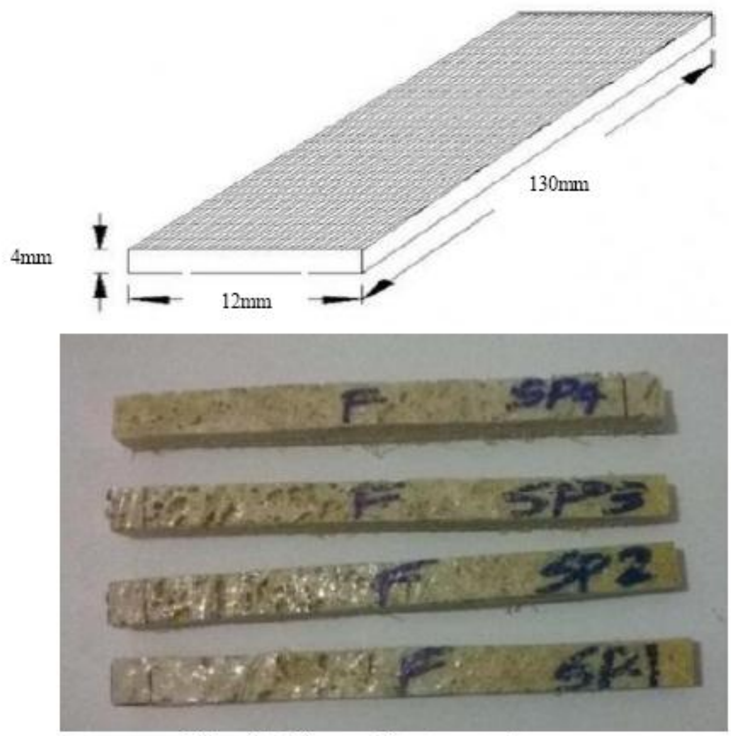


Fig 4.2 Flexural test specimens

It determines the tendency of the material to bend. In the 3 point testing of the material the flexural strength could be found out by secant method where initial strain point is zero. It is expressed in MPa.

4.3 Impact Test

The impact specimen is prepared according to the required dimension following the ASTM-A256 standard. Composite specimens of dimensions 63.5 × 12.7 × 3.2 mm in fig 4.3.Specimen were placed in vertical position and hammer was released to make impact on specimen and CRT reader gives the reading of impact strength.

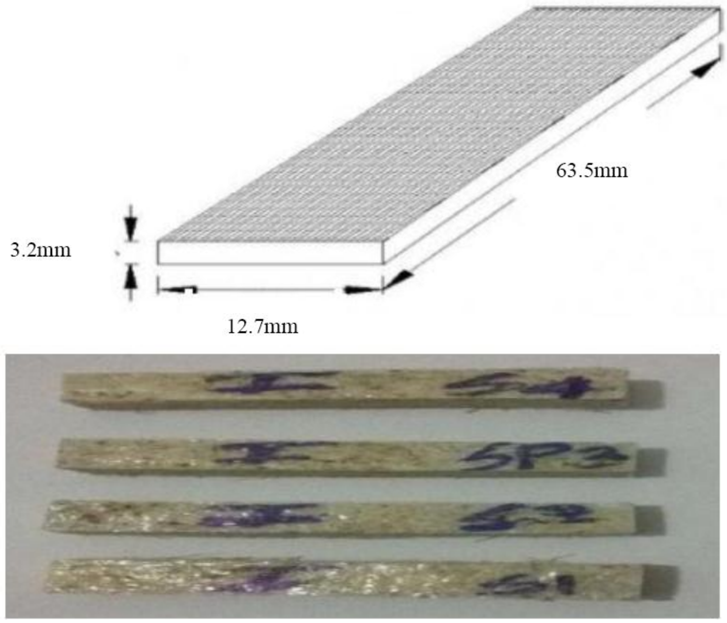


Fig 4.3 Impact test specimens

The test is carried out in Izod test setup. During the testing process, the specimen must be loaded in testing machine and allows the pendulum until it fractures or breaks. Using the impact test, the energy required to break the material can be measured easily and can be used to measure toughness of the material and the yield strength.The energy measured would be in Joules.

V. RESULT AND DISCUSSION

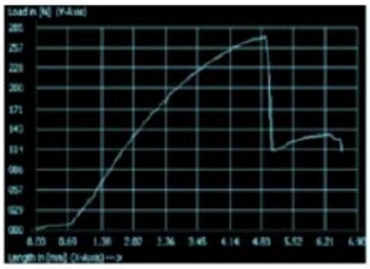
5.1 Flexural Test

The composite samples are tested in the universal testing machine (UTM) in fig 5.1 and stress-strain curve is plotted.The typical graph generated directly from machine for flexural test for Sisal, Banana and Glass composite sample specimens testing.

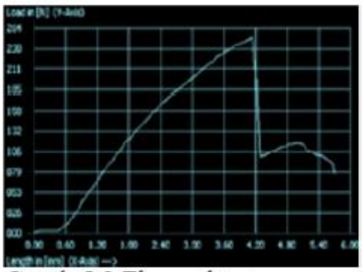
And plotted graphs for Graph 5.1,5.2,5.3 and

Fig 5.1 Flexural load comparison of diffecomposite Specimens

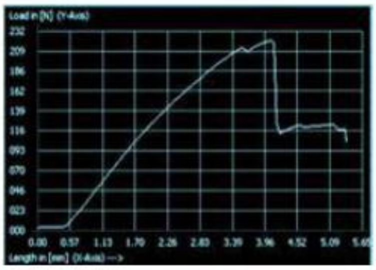
Flexural properties of different composite samples are tested and results are plotted. The results indicate that theultimate flexural strength for the composite with sample 3 specimen is higher than the other composite with sample 1,2 and 4 specimens.



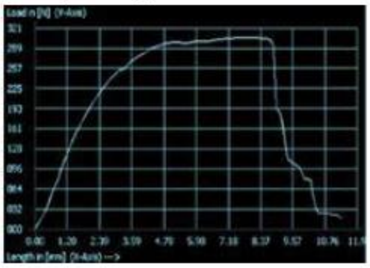
Graph 5.1 flexural test on sample 1Specimen



Graph 5.2 Flexural test on sample 2 Specimen



Graph 5.3 Flexural test on 4Specimen



Graph 5 .4 Flexural test on sample sample 3Specimen

The composite sample specimen testing and flexural load reading given in table 5.1. The readings are taken from the UTM machine. Given specimens are withstand maximum flexural strength.

Sample specimen	**CS Area [mm^2]**	**Peak Load [N]**	**Flexural strength [MPa]**	**Flexural Modulus [GPa]**
1	144.000	221.108	12.092	4.947
2	144.000	271.276	14.835	52.208
3	144.000	306.023	16.736	223.069
4	144.000	251.646	13.762	18.727

Summary Report

Sample Specimen	**CS Area [mm^2]**	**Peak Load [N]**	**Flexural Strength [MPa]**	**Flexural Strength [GPa]**
Min	144.0	221.108	12.092	4.947
Max	144.0	306.023	16.736	223.069
Avg	144.0	262.513	14.356	74.738
Std Dev.	0.000	35.602	1.947	100.859
Variance	0.000	1267.467	3.791	10172.567
Median	144.00	261.461	14.299	35.468

Table 5.1 Flexural test values on UTM machine

The Specimens are withstanding maximum flexural load and its flexural values taken from given graphs 5.1, 5.2, 5.3 and 5.4.

5.2 Tensile Test

The composite samples are tested in the universal testing machine (UTM) in fig 5.2 and the stress-strain curve is plotted. The typical graph generated directly from the machine for tensile test for composite specimen samples is presented in Graph 5.5.The composite sample specimen tensile strength to withstand maximum load and its load shown in graph 5.5 and table 5.2.

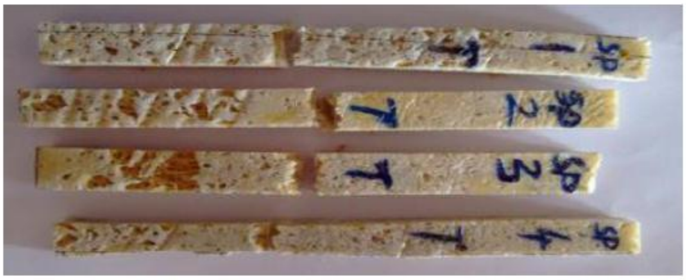
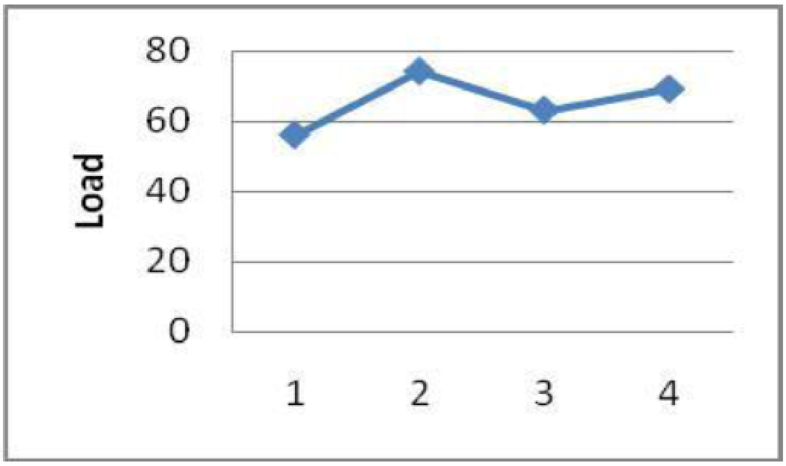


Fig 5.2 Tensile Strength comparison of different composite Specimens



Graph 5.5 Tensile test for samplespecimens

Sample Number	Tensile Strength (MPa)
1	56
2	74
3	63
4	69

Table 5.2 Tensile test of different composite samples

5.3 Impact Test

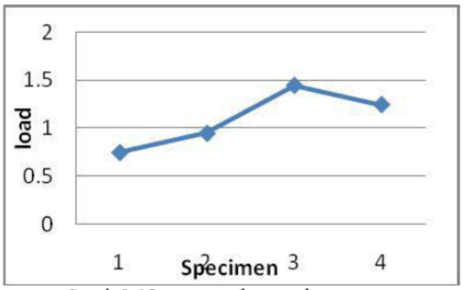
For analysing the impact property of the different specimens an impact test is carried out. Impact test carried out for the present study is Izod impact test. The energy loss is obtained from the Izod impact machine. The impact response in Sisal, Banana and Glass fibre composites of Izod impact test is presented in fig 5.3. The resultsindicated that the maximum impact strength is obtained for sample 3 specimen of sisal, banana and glass fibre composites.

Fig 5.3Impact load comparison of different composite Specimens

Sample Number	Izod Impact Value for 7mm Thick specimen in J
1	0.75
2	0.95
3	1.45
4	1.25

Table 5.3 Izod Impact test values

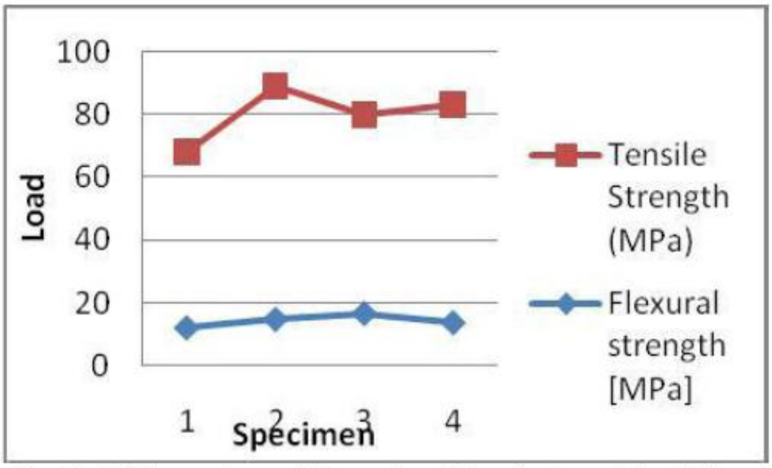
From the tabular coloumn 5.3 shows that numerical values of four specimenImpact loads. Those are represented in joules. The thickness of the impact specimen is 7mm.



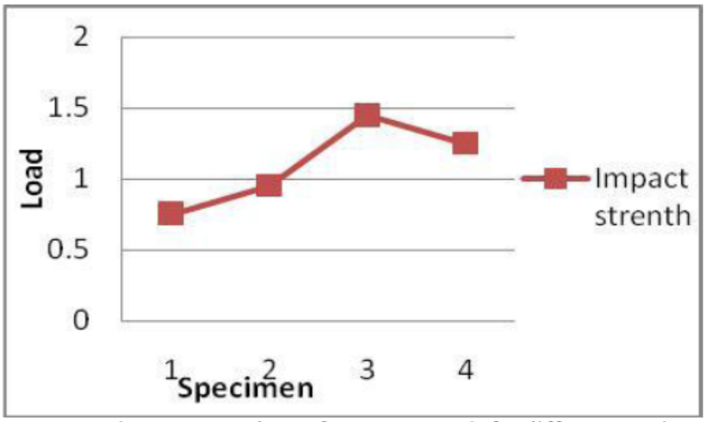
Graph 5.6 Impact test for sample specimens

5.4 Comparisons

Comparisons between the flexural, tensile and impact strength are represented in graph 5.7.The specimen performing better tensile strength when compared to the flexural strength. Comparison between tensile strength and



Graph 5.7 Comparison of Flexural and Tensilestrengthfor different



Graph 5.8 Comparison of Impactstrength for different specimens

flexural strength are shown in graph 5.7.Both of that are represented in (pa).From the graph 5.8 the maximum impact loads are withstanding 1.45j.

VI. CONCLUSION

The sisal and banana with glass fibre hybrid composite specimens are prepared and subjected to tensile, flexural loading and impact strength. From the experiment, the following conclusions are derived.

- The sisal and banana with glass fibre composite samples possess good tensile strength and can withstand the strength up to 65.5 MPa.
- The composite specimen is withstanding the maximum flexural strength of 14.356 MPa.
- The composite specimen is withstanding the maximum impact strength of 1.1 J.
- From the results, it can be concluded that sisal and banana with glass fibre composites performing better for tensile loading.
- And this type of composite material are better impact strength for withstand.
- The performance of these glass fibre composites is lower than that of the natural fibre, it has been used in many application which requires medium strength.

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