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Evaluation of mechanical properties of natural hybrid fibers, reinforced polyester composite materials

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Abstract: The composite materials are replacing the traditional materials, because of its superior properties such as high tensile strength, low thermal expansion, high strength to weight ratio. The developments of new materials are on the anvil and are growing day by day. In this work the effect of glass fibre hybridization with the randomly oriented natural fibers has been evaluated. The sisal (S), banana (B), E-glass synthetic fibers were chopped and reinforced with polyester matrix. Six layers were prepared in the following stacking sequence of S/B/G, S/G/B, G/S/B, G/S/B/G/S/B/G, S/G/B//S/G/B, B/G/S/B/G/S. The mechanical properties like impact strength, flexural strength and tensile strength were investigated and compared. It was observed that the addition of two and three layer of glass fiber can improve the mechanical properties like tensile, Flexural and impact strength.

Keywords: sisal, banana, polyester resin, E-glass, compression moulding

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1 Introduction: Natural fibers are found superior to the artificial fibers with the properties like less weight, low density, eco-friendly, high specific strength etc. However, it has some of the disadvantages like poor surface characteristics, more moisture absorption, quality variations, etc. These natural fiber composites are commonly used in automobiles, packaging industries, aerospace, and construction and so on. The tensile load carrying capacity of the natural fibre reinforced composites are found to be increasing with the fibre content up to an optimum level and then start declining. Cellulosic fiber reinforced plastics materials are low cost, light-weighted, have enhanced mechanical properties, free from health hazard, and thus have the potential for structural applications. Despite the attractiveness of natural fiber reinforced polymer matrix composites, they suffer from lower modulus, lower strength, and relatively poor moisture resistance compared to synthetic fiber reinforced composites such as glass fibre reinforced plastics. Sisal fiber is one of the most widely used natural fibre sand is very easily cultivated. It has short renewal times and grows wild in the hedges of railway tracks. Nearly 4.5 million tons of sisal fibre is produced every year throughout the world. Tanzania and Brazil are the two main producing countries [1 - 4]. Sisal is a hard fiber extracted from the leaves of the sisal plant (Agave sisalana). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East. Sisalfibers are extracted from the leaves. Natural fiber composites combine plant-derived fibers with a plastic binder. The natural fiber components may be wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, banana leaf fibers, bamboo, wheat straw or other fibrous material. The advantages of natural fiber composites include lightweight, low-energy production, and environmental friendly; to name a few. The use of natural fibers reduces weight by 10% and lowers the energy needed for production by 80%, while the cost of the components 5% lowers than the comparable fiber glass-reinforced componenent. Mechanical properties of banana fibre were observed that the failure of banana fiber intension is due to pull-out of micro fibrils accompanied by tearing of cell walls. The tendency for fiber pull-out decrease with increasing speed of testing. Nilza investigated the potentials of banana, coir and sisal fibers in composites. In their work, fiber samples were subjected to standardized characterisation tests such as ash and carbon content, water absorption, moisture content, tensile strength, elemental analysis and chemical analysis. Results revealed that the banana fiber exhibited the highest ash, carbon and cellulose content, hardness and tensile strength, while coconut the highest lignin content. Many researchers in the past have developed composites using natural fibers such as bamboo **[4–6],** coir **[7, 8]**, sisal **[9–12]** and banana **[13–15]** to name the few. Hybrid composites are materials are made by combining two or more different types of fibers in common matrix. Hybridization of two types of short fibers having different lengths and diameters offers some advantages over the use of either of the fibers alone in a single polymer matrix. Most of the studies are on the hybridization of natural fibers with glassfibers to improve the properties **[11–13].** The main parameters which affect the mechanical properties of the composites are fiber length, weight ratio, fiber orientation and interfacial adhesion between fiber and matrix **[14].** The effect of fiber volume fraction in the strength properties of short fibre reinforced cement was studied by Karam **[15].** He modified the existing model in order to calculate the strength of the composites. The mechanical properties of hybrid short fiber composites can be evaluated using the Rule of Hybrid Mixtures equation, which is widely used to predict the strength and modulus of hybrid composites .The mechanical properties of natural fibre reinforced composites highly depend on the interface adhesion property between the fibres and the polymer matrix as have been reported by many researchers **[5–8].** Natural fibres contain cellulose, hemicelluloses, pectin's and lignin and are rich in hydroxy1 groups, natural fibres tend to be strong polar and hydrophilic materials whilst polymer materials are a polar and exhibit significant hydrophobicity. In other words, there are significant problems of compatibility between the fibre and the matrix due to weakness in the interfacial adhesion of the natural fibres with the synthetic matrices. Therefore, surface modification of natural fibres by means treatment is one of the largest areas of recent researches to improve compatibility and interfacial bond strength. The present study aims to develop natural fibre composite from Agave (Agave Americana) fibre, one of the most widely used natural fibres in yarns, ropes, twines, carpets, mats and handicrafts. Agaves are succulent plants of a large botanical genus of the same name, belonging to the family Agavaceae. Chiefly Mexican, they occur also in Asia, North America and in central and tropical South America. In India it is available in wild. The main objective of this work into analyse the mechanical and thermal behaviours of raw and alkali treated Agave continuous fibre reinforced epoxy composites.Natural fibre composites are receiving more attention during the last thirty years due to their ecologically friendly behaviour specially when considering carbon foot print. Their low price in comparison with the synthetic fibre composites as well as their renewable nature helped in attracting the lights towards development of research in this field **[11].** On the other hand, natural fibres are also disadvantaged due to the presence of other undesired properties such as high moisture content, low tensile strength in comparison with carbon fibres, low thermal stability and irregular surface quality. In addition, the natural polar characteristic of natural fibres act as an obstacle regarding the compatibility to many non-polar matrix types which limits the use of the natural fibres in many useful industrial applications **[2–4].** One of the most industrially promising natural fibres is the sisal fibre (Agave sisalana). Fibres are extracted from the plant leaf which contains three main types of fibres: arch fibres, conducting fibres and structural fibres. The sisal fibre type which is commercially interesting is the structural fibre because of its durability as they do not split or fibrillate during extraction process

2 Sisal fiber and its extraction: Sisal plants are more familiar with the tropics and sub tropics region as they can grow better at a temperature of more than 300K. These plants consist of sword shaped leaves of normally 2m length and a typical plant produces around 100 leaves during its life span of more than five years. It contains about 500-700 fibers, which are normally used to make ropes, carpets etc. The matured leaves standing at an angle of more than 50^{o} to the upright of the plant are cut. The next stage in which the leaves are initially crushed by the rollers of rounded knife edges followed by repetitive beaten is called decortications. During this process, the fibers are extracted by squeezing out the pulpy content of the leaf. Finally the fibers are dried in sunlight for 2-3 days after washing them in clean water to remove the dusts and unwanted contents in it.

3 Banana fiber and its extraction: The banana fibers are extracted from the pseudo stem of the banana plant. These are growing up to 7-10 feet depending upon the region and climatic conditions. The length of the stalk depends upon the height of the plant and its width is about 2-5 cm with a thickness of 1–2 cm. The fibers are located at the outer sheath of the stalk. The qualified stalk of the plant is cut to a length of 100 cm and its outer sheath is removed. Then these sections are crushed between two roller drums with scraping blades at its circumference to remove the pulpy material between the fibers. The process of stripping the fibers from the stalk is known as tuxies. Finally the fibers are completely cleaned in water to remove the waste materials and then dried in sunshine for a few days to remove the moisture content. Table 1 shows the physical properties of banana and sisal fiber.

Table (1): Physical properties of sisal and banana fibers

Properties	Sisal fibre	Banana fibre
Density(kg/m^3)	1450	1350
Flexural modulus(GPa)	13.5	4
Tensile strength(MPa)	67	56
Young's modulus(GPa)	3.7	3.5
Elongation at break (%)	2.4	2.6
Cellulose (%)	66	63
Hemi cellulose (%)	13	18
Lignin (%)	10	5
Moisture content (%)	10	11

4 E-Glass fiber: E-Glass fiber is one of the most generally used artificial fibers, manufactured with the raw materials such as limestone, silica, clay and dolomite. These ingredients are melted and extruded through bushings which have multiple small orifices to obtain filaments. The extruded filaments are coated with chemicals to obtain required size. The filaments are wounded together to form roving. The diameter of the filaments and the number of filaments in a roving determine its weight. The chopped fiber (5mm length) selected for this work is E-Glass of (610GSM).

5 Poly Ester Resin: The unsaturated resins formed by the reaction of dibasic organic acids and polyhydric alcohols polyesters resins are used in sheet moulding compound, bulk moulding compound and the toner of laser printers unsaturated polyesters are condensation polymers formed by the reaction of polymers, organic compounds with multiple alcohol or hydroxyl functional groups. The use of unsaturated polyesters resins are thermosetting and as with other resins cure exothermically the use of excessive catalyst can therefore, cause charring or even ignition during the curing process. The table 2 shows the properties of polyester resin. The blending ratio of the resin with the hardener is 10:1 by weight.

Table (2): Mechanical properties of polyester resin

Tensile strength (MPa	Tensile modulus (GPa)	Flexural strength, (MPa)	Flexural modulus,(GPa)
35-60	03-04	50-70	03-04

6 Mechanical testing

Tensile test: The ability of the material to stretch without breaking is termed as tensile strength. The tensile strength of the laminate was measured by the ASTM standard (American Society for Testing and Materials) ASTM: D3039. The specimen should ensure that the breakage should occur in the expected region and its necessity depends on the localization of the breakage. The ends of the specimen were clamped between the jaws. The movement of the jaw offers tensile force on the specimen. This force was recorded with respect to the change in gauge length. The tensile test was done on the FIE make Universal Testing Machine (UTM – Model UTE 40 with maximum load capacity of 400 kN). The samples were tested at a loading rate of 5 mm/min. Specimen which was cut from the three different types of laminates were subjected to tensile test for three samples per laminate to get an average value. The tensile test specimens of various laminates are shown in Figure (1).

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Figure (1): Tensile test specimen of various laminates

Flexural test: A flexural test imposes tensile stress on the convex side and compressive stress on the concave side of the specimen which causes a shear stress along the centre line. It measured the force required to bend the beam. The flexural test was performed on the KA LPAK UTM (Model no. KIC-2-0200-C with a capacity of 20 KN). The geometrical dimension of the nominal specimen was made according to the standard ASTM: D790. The specimens were placed between two supports at a distance of 50 mm and the load was applied at the centre which is called as three point bending test. The load was applied at a rate of 5 mm/min till the specimen fractures and breaks. The fabricated specimen for the flexural testis shown in the Figure (2). The maximum load at failure was used to calculate the flexural stress.

Impact test: The capability of the material to withstand suddenly applied load is its impact strength. The impact strength of the laminates was tested by Izod impact test rig. This test measured the kinetic energy needed to initiate the fracture and to continue until the breakage of specimen. The standard dimension for the Izod test is ASTM: D4812. The test specimen was kept vertically with the help of grippers and the pendulum was blown from one side which strokes it with kinetic energy. The energy absorbed by the material before it fractured is recorded on the scale which was used to measure the toughness and ductility. The different Izod impact testing specimens are shown in Figure (3).

Figure (2): Flexural test specimen of various laminates.

Figure (3): Impact test specimen of various laminates.

7 Result and discussion:

Tensile properties: The tensile strength capabilities of the six different kinds of laminates are determined by testing in the UTM. The tensile properties of the laminates are listed in Table 3. It has been clear that the tensile strength is increased with the addition of the glass fibers with the natural one. The elongation at break is much higher for the laminates having two glass fibers placed as the skin layers than that of the three glass fiber laminate, i.e., one at center layer and the remaining two as outer layers. The sample load vs displacement curve for the GSGBG laminate is shown in Figure(4)

Impact properties: The impact test is carried out for analysing the capability of six different stacking sequences. The energy loss is found out by using izod impact testing machine. Breakage of the specimen starts with the crack propagation due to loss of adhesion between fibers and matrix and then initiates fiber breakage and pullout

Table (3): Mechanical properties hybrid composites

S. No	**Layer sequence**	**Tensile Load (N)**	**UTS (N/mm^2)**	**Impact strength(J)**	**% of elongation**
1	SGBGS	3144	41.93	1.65	2.61
2	BGSGB	3071.3	40.95	1.43	2.11
3	GSGBG	3833.16	51.106	2.35	2.55
4	SBG	3308.84	44.122	1.45	2.52
5	SGB	3169.45	47.022	1.53	2.58
6	GSB	3409.68	45.45	1.86	2.47

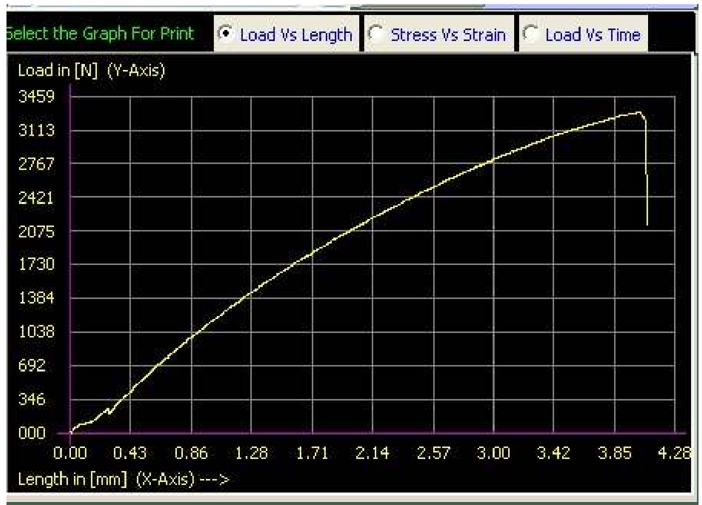


Figure (4): Load Vs deflection curve (GSGBG)

Stress Vs strain curve (GSGBG)

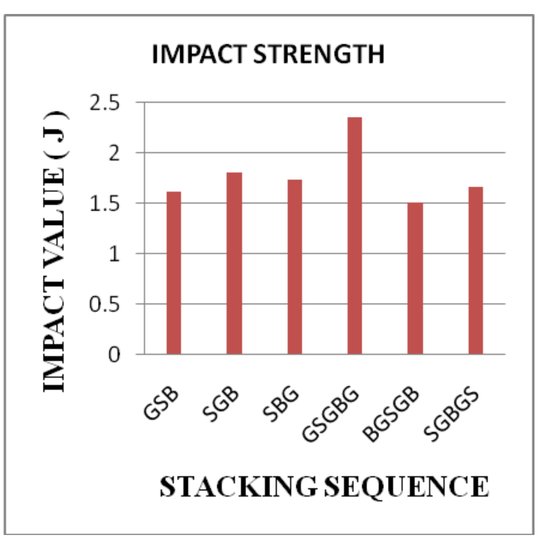
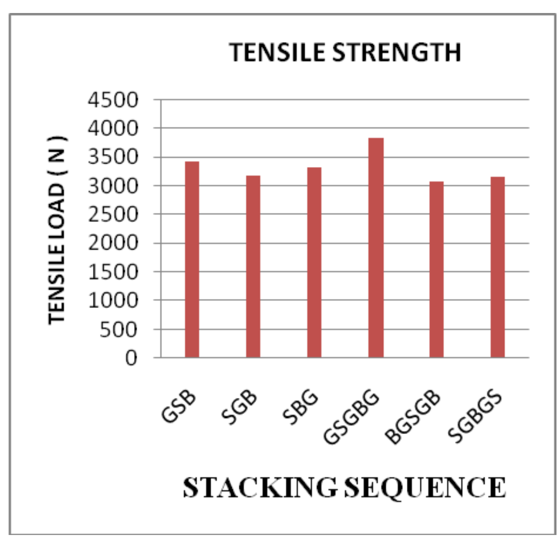


Figure (5).Impact strength graph



Tensile strength plot

8 Conclusions: The mechanical properties of the hybrid combination of glass with banana, sisal and banana–sisal were studied in this work. The laminates were manufactured by the compression moulding process and tested according to ASTM standard. From the obtained results, the following conclusions are derived.

(1) The maximum tensile strength of 51 MPa is observed for the laminate having banana–sisal hybrid combination with three layers of glass fiber.

(2) Better impact energy is obtained in the sisal fiber laminate with three alternate layers of glass fibre

(3) From the observations, the hybrid composite laminates are showing moderate performance than the glass fiber composites. Hence it is suitable for the medium load applications such as welding shield, visor, window door, two wheeler bumper, and automobile body panel

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