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Tensile and Compressive Behaviour of Treated Sisal and Jute Fiber Blended Polypropylene Composite

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Abstract Over the past few years; composite materials have been the dominant among all emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. The mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metals and ceramics. These difficulties can be overcome by reinforcing Natural treated fibers with polymers. Secondly the processing temperature and pressure to make the composite material which act predominantly in the mechanical properties of the composites for this reason polymer matrix composites developed rapidly and soon became popular for structural applications. While thinking about composites the main points to be considered are Cost effectiveness and Environmental friendliness. This paper mainly deals with how effectively composites can be made without compromising its properties compared to other conventional materials to cope up with the changing market strategy.

Keywords: *natural fibers, polymers, FRP, composites, resin*

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1. Introduction

The composites industries have begun to recognize that the commercial applications of composites promise to offer much larger business opportunities than the aerospace sector due to the sheer size of transportation industry. Thus the shift of composite applications from aircraft to other commercial uses has become prominent in recent years. Increasingly enabled by the introduction of newer polymer resin matrix materials and high performance reinforcement fibers of glass, carbon and aramid, the penetration of these advanced materials has witnessed a steady expansion in uses and volume. The increased volume has resulted in an expected reduction in costs. High performance FRP can now be found in such diverse applications as composite armoring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers. For certain applications, the use of composites rather than metals has in fact resulted in savings of both cost and weight. Some examples are cascades for engines, curved fairing and fillets, replacements for welded metallic parts, cylinders, tubes, ducts, blade containment bands etc. Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock & vibration through tailored microstructures. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity. Unlike conventional materials (e.g., steel), the properties of the composite material can be designed considering the structural aspects. The design of a structural component using composites involves both material and structural design. Composite properties (e.g. stiffness, thermal expansion etc.) can be varied continuously over a broad range of values under the control of the designer. Careful selection of reinforcement type enables finished product characteristics to be tailored to almost any specific engineering requirement. While the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience & skills the designer in tapping the optimum potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials.

A composite material consists of two phases. It consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the "reinforcement" or "reinforcing material", whereas the continuous phase is termed as the "matrix". The matrix is usually more ductile and less hard. It holds

the dispersed phase and shares a load with it. Matrix is composed of any of the three basic material type i.e. polymers, metals or ceramics. The matrix forms the bulk form or the part or product. The secondary phase embedded in the matrix is a discontinuous phase. It is usually harder and stronger than the continuous phase. It serves to strengthen the composites and improves the overall mechanical properties of the matrix. Properties of composites are strongly dependent on the properties of their Constituent materials, their distribution and the interaction among them. The nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sanctioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties. Common fiber reinforced composites are composed of fibers and a matrix. Fibers are the reinforcement and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, filler might be added to smooth the manufacturing process, impact special properties to the composites, and / or to reduce the product cost. Common fiber reinforcing agents include asbestos, carbon / graphite fibers, natural fibers beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminium oxide, glass fibers, polyamide, etc. Similarly common matrix materials include epoxy, polyester, polyurethane, polypropylene (PP) etc. Among these resin materials, polypropylene is most widely used. Against this backdrop, the present work has been taken up to develop a Polypropylene based composites with sisal and jute fiber reinforcement and to test their tensile strength and compressive strength.

2. Natural Fiber Reinforced Composite

The interest in natural fiber-reinforced polymer composite materials is rapidly growing both in terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable, and biodegradable. Plants, such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, etc., as well as wood, used from time immemorial as a source of lingo cellulosic fibers, are more and more often applied as the reinforcement of composites. Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative to glass, carbon and man-made fibers used for the manufacturing of composites. The natural fiber-containing composites are more environmentally friendly, and are used in transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products, etc. The use of natural fiber for the reinforcement of the composites has received increasing attention both by the academic sector and the industry. Natural fibers have many significant advantages over synthetic fibers. Currently, many types of natural fibers have been investigated for use in plastics including flax, hemp, jute straw, wood, rice husk, barley, oats, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. Thermoplastics reinforced with special wood fillers are enjoying Rapid growth due to their many advantages; lightweight reasonable strength and stiffness. Some plant proteins are interesting renewable materials, because of their thermoplastic properties.

Natural fibers like (sisal and jute) reinforced polypropylene composites were processed by compression moulding using a film stacking method. The mechanical properties of the different natural fiber composites were tested and compared. Polypropylene composites were found to increase with increasing fiber weight fraction. Natural fiber (NF) reinforced composites, so called eco-composites, is a subject of many scientific and research projects, as well as many commercial programs [1]. The growing global environmental and social concern, high rate of depletion of petroleum resources, and new environmental regulations have forced the search for new composites and green materials, compatible with the environment. Use of natural fiber as reinforcing material is the latest invention of polymer science in order to get higher strength with lower weight composite materials with low cost, low density, specific resistance, biological degradability, CO_2 neutrality, renewability, good mechanical properties, non-toxicity and furthermore the fibers can be easily modified by a chemical agent improving their mechanical and thermal properties [2]. In this work, the sisal fibers and jute fibers were modified by alkali solutions of NaOH.

Biodegradable plastics and bio-based polymer products based on annually renewable agricultural and biomass feedstock can form the basis for a portfolio of sustainable, eco-efficient products that can compete and capture markets currently dominated by products based exclusively on petroleum feedstock. Natural / Biofiber composites (Bio-composites) are emerging as a viable alternative to glass fiber reinforced composites especially in automotive and building product applications. The combination of bio fibers such as kenaf, hemp, flax, jute, henequen, pineapple leaf fiber, and sisal with polymer matrices from both nonrenewable and renewable resources to produce composite materials that are competitive with synthetic composites requires special attention, i.e., bio fiber-matrix interface and novel processing. Natural fiber-reinforced polypropylene composites have attained commercial attraction in automotive industries. Natural fiber-polypropylene or natural fiber-polyester composites are not sufficiently eco-friendly because of the petroleum-based source and the non biodegradable nature of the polymer matrix. Using natural fibers with polymers based

on renewable resources will allow many environmental issues to be solved. This paper evaluates the effect of the alkali treatment on the mechanical properties of jute fibers and its composites. The effect on the processing conditions was also analyzed. Woven jute preforms were used to prepare the composites using the vacuum infusion technique. The fibers were treated with NaOH (5wt. %) for 24 h at room temperature. Single filament tests showed that the treatment was detrimental for the mechanical properties of the fibers. The injection times increased in the treated jute preforms as a consequence of the increase in the exposed area and the flow resistance. The preform permeability decreased, also, in the tubular structure collapse of the fibers, which could reduce the capillary pressure. Flexural and impact properties of the treated jute composites decreased mainly in the lower mechanical properties of the fibers.

3. Natural Fibers and their Countries of Origin

Natural fibers are generally lingo cellulosic in nature, consisting of helically wound cellulose micro fibrils in a matrix of lignin and hemi cellulose. According to a Food and Agricultural Organization survey, Tanzania and Brazil produce the largest amount of sisal. Henequen is grown in Mexico. Abaca and hemp are grown in the Philippines. The largest producers of jute are India, China, and Bangladesh. Presently, the annual production of natural fibers in India is about 6 million tons as compared to worldwide production of about 25 million tons. The countries of Origin of various Natural fibers are given in Table 1.

Table 1. Fiber and Countries of Origin

Sl. No	Fibers	Countries of Origin
1	Hemp	Yugoslavia, China
2	Jute	India, Egypt, Guyana, Jamaica, Ghana
3	Abaca	Malaysia, Uganda, Philippines, Bolivia
4	Coir	India, Sri Lanka, Philippines, Malaysia
5	Sisal	East Africa, , Kenya, Tanzania, India
6	Kenaf	Iraq, Tanzania, Jamaica, South Africa

3.1. Sisal

Sisal fiber is obtained from the leaves of the plant *Agave sisalana*, which was originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia [3]. It is grouped under the broad heading of the “hard fibers” among which sisal is placed second to manila in durability and strength [4]. The name “sisal” comes from a harbor town in Yucatan, Maya, Mexico [5]. It means cold water. They prepared the fibers by hand and used it for ropes, carpets and clothing. Some clothes were called “nequen”, and this is where the present name of Mexican agave, henequen, probably originates. It is one of the most extensively cultivated hard fibers in the world and it accounts for half the total production of textile fibers [6]. The reason for this is due to the ease of cultivation of sisal plants, which have short renewing times, and is fairly easy to grow in all kinds of environments. A good sisal plant yields about 200 leaves with each leaf having a mass composition of 4% fiber, 0.75% cuticle, 8% other dry matter and 87.25% moisture. Thus a normal leaf weighing about 600g yields about 3% by weight of fiber with each leaf containing about 1000 fibers [7]. The fiber is extracted from the leaf either by retting, by scraping or by retting followed by scraping or by mechanical means using decorticators (KVIC, 1980). The characteristics of the sisal fibers depend on the properties of the individual constituents, the fibrillar structure and the lamellae matrix. The fiber is composed of numerous elongated fusiform fiber cells that taper towards each end. The fiber cells are linked together by means of middle lamellae, which consist of hemi cellulose, lignin and pectin. A sisal fiber in cross-section is built up of about 100 fiber cells. The number of cells in cross-section of a coconut fiber ranges from 260 to 584 depending on the diameter of the fiber [8].

3.2. Jute

Jute fiber is obtained from two herbaceous annual plants, white Corchorus capsularis (white jute) originating from Asia and Corchorus olitorius (Tossa jute) originating from Africa. Next to cotton, it is the second most common natural fiber, cultivated in the world and extensively grown in Bangladesh, China, India, Indonesia, Brazil; the jute plant grows six to ten feet in height and has no branches. The stem of the jute plant is covered with thick bark, which contains the fibers. In two or three month time, the plants grow up and then are cut, tied up in bundles and kept under water for several days for fermentation. Thus, the stems rot and the fibers from the bark become loose. Then the cultivators pull off the fibers from the bark, wash very carefully and dry them in the sun. Jute is multi celled in structure. The cell wall of a fiber is made up of a number of layers: the so-called primary wall (the first layer deposited during cell development) and the secondary wall (S), which again is made up of the three layers (S1, S2 and S3). As in all lingo cellulosic fibers, these layers mainly contain cellulose, hemi cellulose and lignin in varying amounts. The individual fibers are bonded together by a lignin-rich region known as the middle lamella.

Cellulose attains highest concentration in the S2 layer (about 50%) and lignin is most concentrated in the middle lamella (about 90%) which, in principle, is free of cellulose. The S2 layer is usually by far the thickest layer and dominates the properties of the fibers. Cellulose, a primary component of the fiber, is a linear condensation polymer consisting of Dan hydro-glucopyranose units joined together by ß-1, 4-glucosidic bonds. The long chains of cellulose are linked together in bundles called micro-fibrils. Jute is one of the most common agro-fibers which obtain high tensile modulus and low elongation at break. The fibers were treated with a sodium hydroxide aqueous solution around 2% by the weight percentage and the fiber is soaked for one hour around 25°C then they were washed with distilled water until all the sodium hydroxide was eliminated, that is until the water no longer indicated any alkalinity reaction [9]. Subsequently the fibers were dried at 60°C for 24 hours. The polypropylene melt mix is applied over the fiber mesh and allowed to impregnate over the pores of the fiber mesh and compaction is made using compression molding.

4. Compression Molding

The compression molding process is a method of molding in which a preheated polymer is placed into an open, heated mould cavity. The mould is closed with a top plug and pressure is applied to force the material to contact all areas of the mould. Throughout the process heat and pressure are maintained until the polymer has cured. While the compression molding process can be employed with both thermo sets and thermoplastics, today most applications use thermo set polymers. Advanced composite thermoplastics can also be compression molded with unidirectional tapes, woven fabrics, randomly orientated fiber mat or chopped strand. Compression molding is a high-volume, high-pressure plastic molding method that is suitable for molding complex, high-strength objects. And with its short cycle time and high production rate, many organizations in the automotive industry have chosen compression molding to produce parts. Design of Electric die is based on the standard dimensions. In a hydraulic press, one flange is attached with the spindle. Dimensions of die are based on the diameter of flange and dimension of bed. The shape of the die is square so that equal distribution of load and better stability can be achieved. Three layers are provided as the frame over the die. It can be used depend upon the thickness of FRP composite to be produced. It can be easily removed when not in use [10]. Table 2 shows the dimensions and specifications of Die and Hydraulic press.

Table 2. Dimensions &Specifications

Dimensions of Hydraulic press	Dimensions of Die	Coil and Press Specifications
Bed length &Width 590×550mm	Male Die 215×215mm	Coil 750W / 350v
Spindle Diameter 162mm	Female Die 230×230mm	Wire 720mm
Flange Diameter 120mm	Layers Height 90mm	Pressure 0.5 ton/sq.in
Height of flange 200mm	Copper Plate 5mm thickness	Capacity 1 ton
Maximum distance spindle Can move to and fro 300mm	Asbestos Sheet 10mm thickness Mica Sheet 1mm thickness	Power 3 hp

5. Electric Die Assembly

The Electric Die is working on the principle of Joule's law. It is expressed as,

$$Q = I^2 \cdot R \cdot t$$

Where,
Q - Heat generated
I - Current
R - Resistance
t - Time

When the supply given to an electric die, then the coil gets heated and heat is transfer to copper plate through the mica sheet. Mica sheet is provided in between the coil and copper plate for the purpose of insulation .From the copper plate heat is transferred to steel plate. In an electric die, heat is needed only at the bottom portion of the male die and upper portion of the female die .In order to restrict the heat transfer to other portion and to prevent the heat loss; an asbestos Sheet of 1cm thickness is used here. Asbestos would not allow the heat to transfer because asbestos is a very good insulator. The Steel plate is provided over the asbestos sheet as a frame. In order to maintain the temperature constant thermostat is used in electric die. A thermostat is a device for regulating the temperature of a system so that the system's temperature is maintained near a desired set point temperature. Figure 1 shows the Hydraulic press setup with male and female die. Figure 2 shows the closed view of both the dies during compression molding.

Figure 1. Hydraulic press setup

Figure 2. Electric Die Assembly

6. Methodology

NaOH Treated samples of sisal fiber and jute fiber mesh were dried in a hot air oven for 30 seconds and the samples were weighed based on the requirement. Here the mesh is weaved with an orientation of $\pm 45^0$ which has maximum tensile and compressive strength [11]. Polypropylene which is the matrix is heated externally at constant temperature is then blended with Natural Resin latex at 7% and vegetable oil is added as ingredient to increase the plasticity. At about 165°C this mixture is poured in the electric die assembly, where the dies are coated with lubricants and fiber mesh made of sisal and

jute are compacted separately with uniform pressure and constant temperature is maintained by the thermostat provided. This process happens until the desired thickness is obtained, then it is kept in a vaccum furnace where high fiber bonding happens with the matrix thereby the delaminating tendency tends to reduce and then it is allowed to cool at room temperature for few hours after that the specimens of required dimensions based on ASTM standards were machined using diamond tool cutter and after finishing process [12]. Separate tests were carried out in Instron type universal testing machine.

Table 3. Polymer and fiber proportions

Specimen	Combination %	Weight (gms)	Total weight (gms)
A	PP-90% FIBER-10%	1350gms 150gms	1500gms
B	PP-80% FIBER-20%	1200gms 300gms	1500gms
C	PP-65% FIBER-35%	975gms 525gms	1500gms
D	PP-55% FIBER-45%	825gms 675gms	1500gms

Table 3 shows the proportions of Polypropylene and fibers (sisal and jute) four samples with different proportions were chosen to undergo tensile and compressive tests.

7. Results and Discussions

7.1. Tensile Test (Sisal) Specimen A

1. Yield Strength:
σ_Y = fy/A = 5.92KN/ 63.5=93.2N/mm^2
C/S Area, A=12.7X5=63.5 mm^2,
2. % Reduction Area:
A_O= 63.5 mm^2, A_F= 63.1 mm^2
= (A_O-A_F/ A_O) x100
=0.629%
3. Young's Modulus (E):
E= stress at any point with in elastic limit/strain
Stress=F/A= 11.74KN/63.5=185N/mm^2
Strain=§L/L= (206.77-203.2) /203.2 =0.0176
(E) =Stress /Strain = 10511.32 N/mm^2
=10.51Gpa
4. % elongation:
= (§L/L) X100 =1.76%
5. Tensile Strength:
Tensile Strength= F/A= 26.7KN/63.5=420 N/mm^2
6. Poisson's ratio:
μ = lateral strain / linear strain
Lateral strain =§b/b= (12.7-12.55)/12.7=0.0118
Linear strain =§L/L =0.0176
μ = lateral strain / linear strain =0.67

Tensile testing was carried out for four samples of Sisal and jute Reinforced composite samples, among that sample D of both sisal and jute proven to have higher Tensile strength. It has been proved that with 45% fiber and 55% matrix which is the combination of binders and fillers has maximum tensile strength [13]. Table 4 and Table 5 shows the tensile properties of Sisal and Jute based polymeric samples.

Table 4. Tensile Properties of Sisal

Properties of sisal	A	B	C	D
Yield strength N/mm^2	93.2	99	108.6	118
Tensile strength N/mm^2	420	429.9	437.7	442.2
% Elongation	1.76%	1.82%	1.96%	2.16%
% reduction area	0.629%	0.755%	0.81%	1.102%
Young's modulus Gpa	10.53	10.71	10.9	11.1
Lateral strain	0.0118	0.0149	0.0188	0.0236
Linear strain	0.0176	0.0182	0.0196	0.0216
Poisson 's ratio	0.67	0.822	0.95	1.09

Table 5. Tensile Properties of Jute

Properties of jute	A	B	C	D
Yield strength N/mm^2	61.4	66.14	77.16	83.5
Tensile strength N/mm^2	322	330.5	341.4	351.96
% Elongation	1.79%	1.83%	1.89%	1.98%
% reduction area	0.299	0.393	0.48	0.629
Young's modulus Gpa	8.1	8.3	8.58	8.74
Lateral strain X10^{-3}	3.93	5.581	7.086	9.448
Linear strain	0.0179	0.0183	0.0189	0.0198
Poisson 's ratio	0.22	0.30	0.37	0.5

7.2. Compressive Test (Sisal) Specimen A

1. % increase in area:
d_O= 12.7 mm, d_F= 17.34mm
A_O= 126.61 mm^2, A_F= 236.15mm^2
= (A_O-A_F/ A_O) x100
=86.5%
2. % compression:
=§h/h
= ((25.4 -11.69) / 25.4) X 100
=53.9%
3. Compressive strength:
Compressive strength = compressive load/ area
=24.2kN /126.61
=191.13 N/ mm^2
4. Poisson's ratio:
μ = lateral strain / linear strain
Lateral strain =§d/d=(17.34-12.7)/12.7=0.37
Linear strain =§h/ h=0.539
μ = lateral strain / linear strain =0.7

Table 6 and Table 7 shows the compressive behaviour of Sisal and Jute fiber based polymeric samples.

Table 6. compressive properties of Sisal

Properties of sisal	A	B	C	D
% increase in area	86.5%	83.7%	79%	75%
% compression	53.9%	52.8%	52.3%	51.7%
compressive strength, N/mm^2	191.3	196.66	202.98	208.53
Lateral strain	0.37	0.355	0.338	0.322
Linear strain	0.539	0.528	0.523	0.517
Poisson 's ratio	0.7	0.67	0.65	0.62

Table 7. compressive behaviour of Jute

Properties of jute	A	B	C	D
% increase in area	61.3%	57.6%	52.5%	45.1%
% compression	35.5%	34.6%	33.3%	31.6%
compressive strength, N/mm^2	261.4	266.9	274.8	284.36
Lateral strain	0.27	0.255	0.234	0.169
Linear strain	0.355	0.346	0.333	0.316
Poisson ‘s ratio	0.76	0.73	0.69	0.53

Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 shows the sisal fiber specimen versus Tensile strength, % Elongation, % Reduction in area, Compressive strength, and % Compression.

Sisal

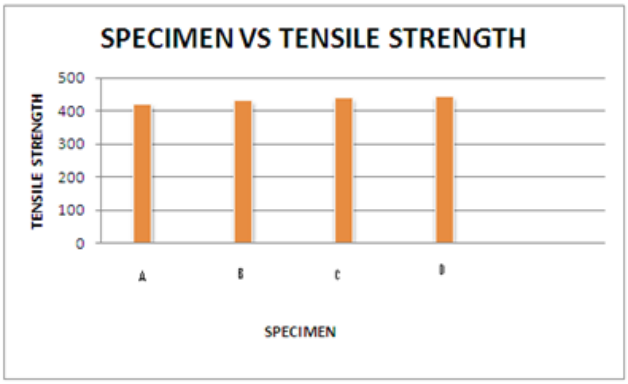

Figure 3. Specimen vs. Tensile strength

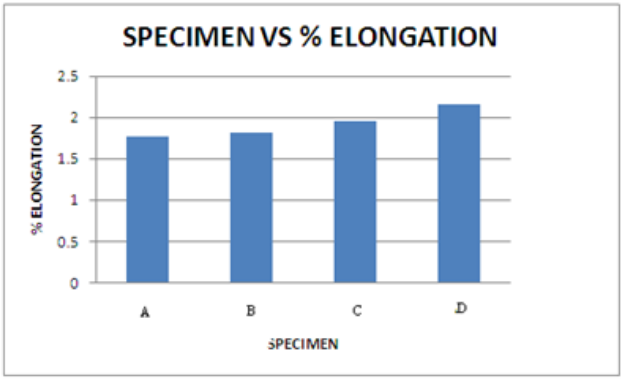

Figure 4. Specimen vs. % Elongation

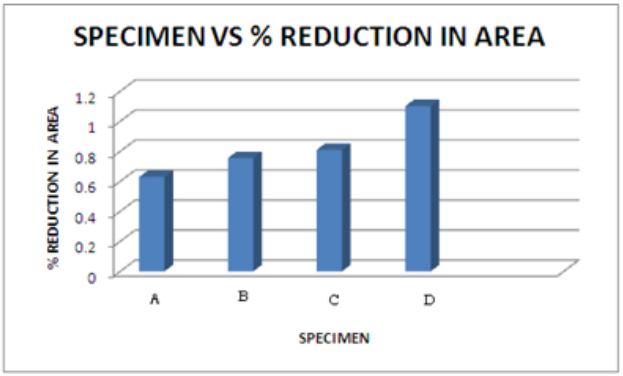

Figure 5. Specimen vs. Reduction in area

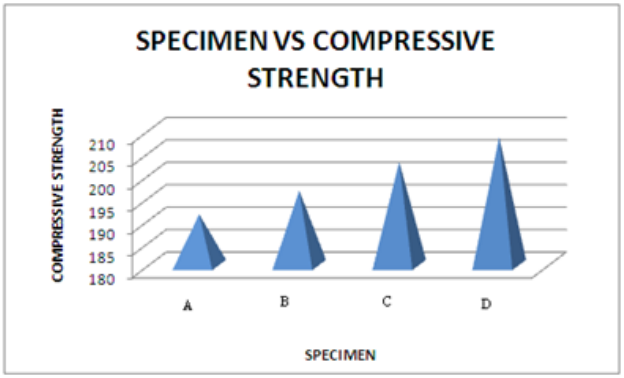

Figure 6. specimen vs. comp strength

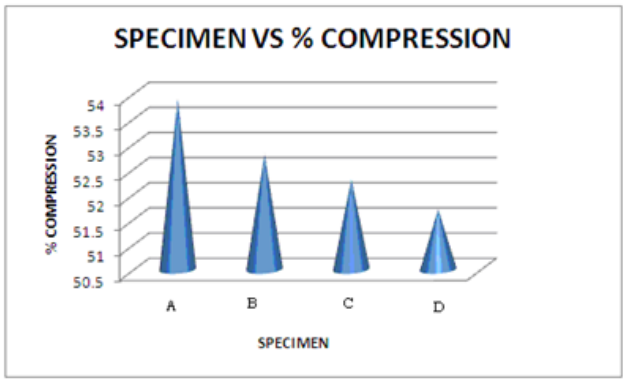

Figure 7. Specimen vs. % compression

Jute

Figure 8, Figure 9, Figure 100, Figure 111, Figure 122 shows the jute fiber specimen versus Tensile strength, % Elongation, % Reduction in area, Compressive strength, and % Compression.

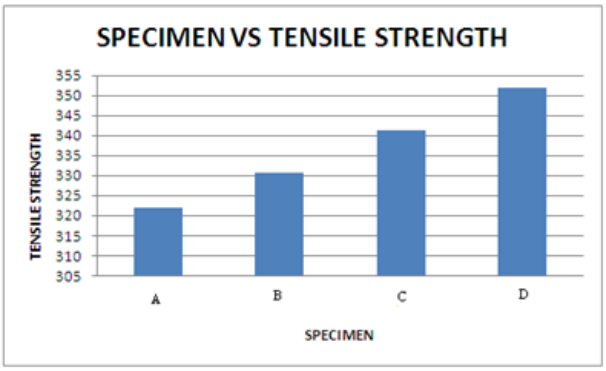

Figure 8. Specimen vs. Tensile strength

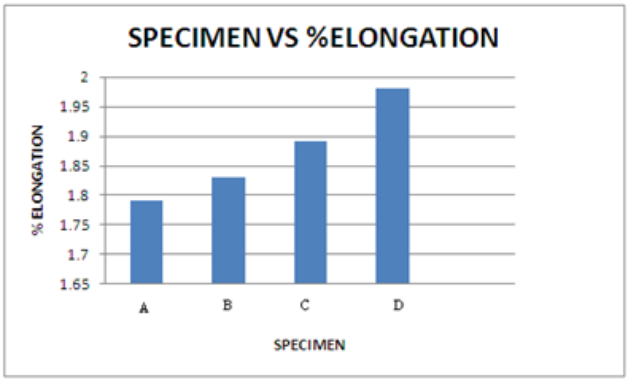

Figure 9. Specimen vs. % Elongation

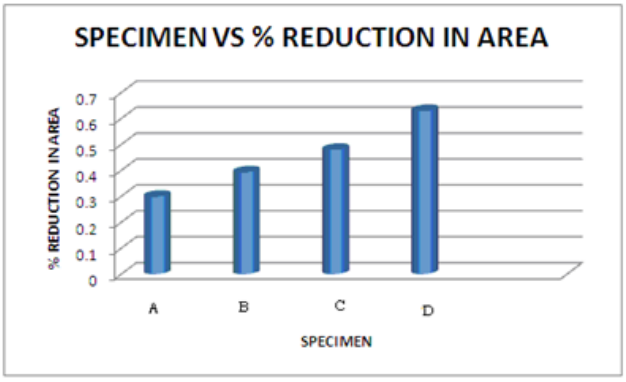

Figure 10. Specimen vs. Reduction in area

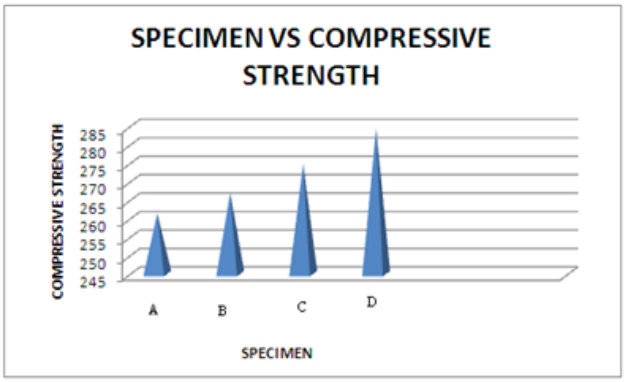

Figure 11. specimen vs. comp strength

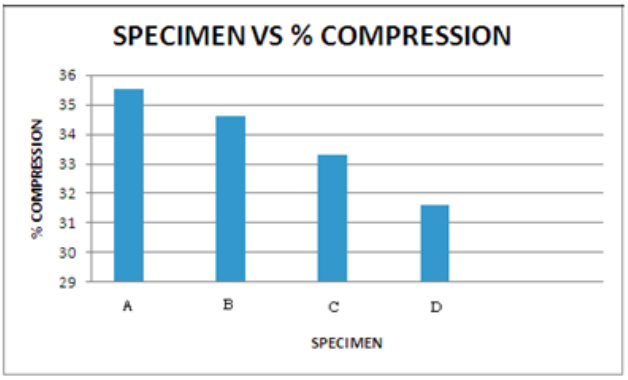

Figure 12. Specimen vs. % compression

Figure 13, Figure 14, Figure 15 shows the Treated sisal fiber mesh, treated jute fiber mesh, and Fabricated polymeric composite in which the specimens has to be machined.

Figure 13. Sisal mesh

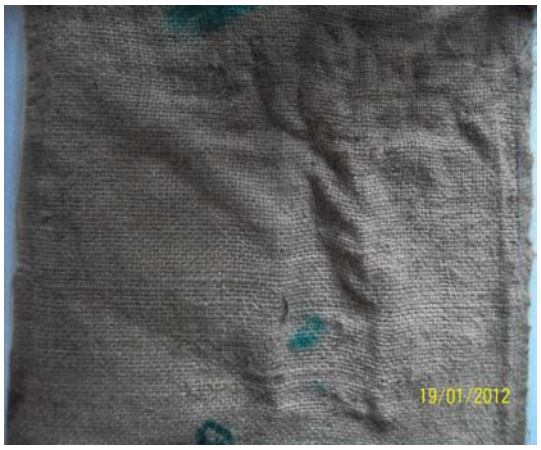

Figure 14. Jute mesh

Figure 15. fabricated composite

8. Conclusion

This work shows that successful fabrication of sisal and jute fiber reinforced polypropylene composites by compression molding technique. A) The mechanical characteristics of these composites can be successfully analyzed using tensile and compression testing process. B) The results indicate that sisal based polypropylene composite has higher tensile strength than jute based composite and jute based polypropylene composite has higher compressive strength than sisal based composite. It is concluded that the inclusion of treated sisal fiber blended with natural latex at optimum proportion with polypropylene increases the tensile strength and compressive strength. This work shows the way for the future researchers to conduct various testing and processing methods with increased physical and mechanical properties in order to satisfy the growing demands.

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