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Experimental Investigation of Coir Fiber Reinforced Bio-Composite for Automobile Application

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Abstract:
In today's developing era the concern for the prevention of non-biodegradable resources has attracted researchers to develop biodegradable materials based on green principles. The fibers from agriculture waste give good advantages over conventional synthetic fibers such as low cost and density, non-toxicity and waste disposal problems. In this work coir fibers have been used as the reinforcing agent with corn starch and glycerol as the matrix to increase the effectiveness of coir fibers. The coir fibers were obtained from disregarded coconut shells that if not properly processed constitute an environmental hazard. The composites have been fabricated by injection moulding method followed by high speed mixing and twin screw extrusion process. In this experimental study mechanical and physical properties have been evaluated by changing the proportion and length of the coir fiber and matrix material. The tensile, flexural, impact and hardness tests have been performed on newly fabricated green composites. Depending on their specific characteristics, could find a position within the wide scale of domestic and commercial applications and products. Experimental results showed tensile, static and Dynamic properties of the composites are greatly influenced by the increasing percentage of reinforcement, lengths of the fiber and indicate coir can be used as potential reinforcing material for many structural and non-structural automobile applications.

Keywords: Biodegradable, Coir Fibers, Corn Starch, Glycerol, Injection Moulding, Twin Screw Extrusion

1. Introduction

Due to the exponential growth of the human population, we are facing many environmental problems. It is clear that the advances in science and technology have improved the standard of living of the common man, but at the same time we are facing ecological imbalances and at times, environmental disasters, and it is very urgent, to find solutions. In the field of material science and engineering, there is growing interest in green, environment friendly materials. Coir fibers are annual fiber plants, and they are found to be important sources of fibers for a number of applications (1). In India approximately 20.9 x 105 hector land is cultivated with coir plantations which yield about 5.5 x 104 hg/ha of fiber. Coir is a fiber found between the hard inner shell and the outer coat of coconuts. The natural coir fibers are abundantly found in south India region, especially in the coastal regions of Kerala and Tamilnadu (2, 3). Traditionally, these fibrous materials are being used by the local people for making low cost articles such as mats, ropes, bags etc.

Some research on coir composites has been carried out on the material characterization, while research on the improvement of the mechanical properties of coir reinforced biopolymer composites with varying the fiber length and its proportion. The coir fiber is having poor reinforcing properties like low strength and modulus but it has found interest due to its low density, low thermal conductivity and high elongation. Taking this into account, an advantage of filler particles, such

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as banana fibers and flax fibers can be added to improve the overall mechanical properties.

Rajan et al. (4) reviewed the significance of coir, a lignocellulosic fiber, as a promising material due to its advantageous properties, including good mechanical strength, favorable physical and chemical structure, low cost, and low density. Given the abundant availability of coir fiber in India, its applications extend beyond traditional uses, such as mattresses, to novel industrial and commercial areas. Justiz-Smith et al. (5) explored the potential of various natural fibers, including sugarcane bagasse, banana trunk fibers, and coir from coconut husks, for use as composite materials. They characterized these fibers based on their chemical composition, including ash, carbon, and moisture content, as well as their mechanical properties using standardized testing methods. Among the fibers studied, banana fiber exhibited the highest ash, carbon, and cellulose content, along with superior hardness and tensile strength, whereas coir fiber had the highest lignin content. Lai et al. (6) investigated the effects of different fiber treatment agents, such as alkali, stearic acid, acetone, and potassium permanganate, on the performance of fiber-reinforced composites. Using polypropylene (PP) as the matrix, they fabricated composites through compression moulding. The fiber treatments improved interfacial adhesion between the fiber and PP through various chemical interactions. The results indicated that composites with treated fibers exhibited higher tensile strength and flexural modulus compared to those with untreated fibers.

Akintayo et al. (7) analyzed the mechanical and morphological properties of both native and chemically modified coir fibers. Treatments such as acetylation, oxidation, and mercerization led to an improvement in tensile strength and elongation at break. Additionally, chemical modifications enhanced the thermal stability of raw coir fibers. De Farias et al. (8) employed a low-pressure plasma modification technique using air or oxygen gas to alter the surface of coir fibers. This treatment partially etched the amorphous layer of the fiber, significantly reducing the FTIR signal ratio related to lignin and cellulose by factors of 10 and 20 for air and oxygen plasma-treated fibers, respectively. Oxygen plasma treatment for 7.2 minutes at 80 W power resulted in an increase in tensile strength and modulus by up to 300% and 2000%, respectively. Harish et al. (9) fabricated epoxy-based composites reinforced with coir fibers and compared their mechanical properties to those of glass fiber-reinforced composites. The coir fiber composites demonstrated tensile strength, flexural strength, and impact strength values of 17.86 MPa, 31.08 MPa, and 11.49 kJ/m², respectively, which were lower than those of the glass fiber-reinforced epoxy composites. Despite this, coir fiber composites offer advantages in terms of lower weight and cost. Vijay Kumar et al. (10) developed composite specimens using kenaf and coir fibers as reinforcements with epoxy resin, varying the weight percentages of the natural fibers. Analysis indicated that fiber entanglement produced a synergistic effect. SEM analysis revealed that samples with equal proportions of kenaf and coir fibers exhibited internal voids, attributed to their lower impact energy absorption capacity. Das et al. (11) investigated the physio-mechanical properties of coir fiber-reinforced composites by varying fiber length (3, 6, 9, 12, and 15 mm) and fiber content (5, 10, 15, and 20 wt%). $Al_2O_3$was used as a particulate filler, and epoxy served as the matrix, with the composites fabricated using the hand lay-up method. The highest tensile strength (25.71 MPa), flexural strength (29.75 MPa), and impact strength (14.76 kJ/m²) were observed in samples with a fiber length of 12 mm and a fiber content of 15%. Meanwhile, the maximum hardness and tensile modulus were achieved with a fiber length of 15 mm and 20 wt% fiber content.

Das et al. (12) investigated the influence of fiber length (3, 6, 9, 12, and 15 mm) and fiber content (5, 10, 15, and 20 wt%) on the physio-mechanical properties and water absorption behavior of coir fiber-reinforced epoxy composites fabricated using the hand lay-up method. The highest mechanical properties were achieved at a fiber length of 12 mm and a fiber content of 15 wt%, making these the optimal parameters for improved mechanical performance. The lowest water absorption was observed in composites with a 5 wt% fiber content and a 3 mm fiber length. Scanning electron microscopy (SEM) analysis revealed fiber pull-out and enhanced matrix–fiber adhesion in samples with 5 wt% / 3 mm and 15 wt% / 12 mm fiber content and length, respectively. Monteiro et al. (13) assessed the structural and mechanical properties of polyester composites reinforced with randomly oriented coir fibers. These composites exhibited low strength, making them suitable for non-structural applications. Two types of products were developed: rigid composites with fiber loading below 50 wt% and agglomerates with fiber content exceeding 50 wt%. N.

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Khanam et al. (14) fabricated a hybrid composite using NaOH-treated coir and silk fibers as reinforcements in an unsaturated polyester matrix, employing the hand lay-up method. The fibers were mixed in a 1:1 ratio with lengths of 1, 2, and 3 cm. The best mechanical performance was observed at a fiber length of 2 cm. The study also demonstrated that alkali treatment enhanced the composite properties, yielding improved results. Zaman et al. (15) developed a unidirectional composite using alkali-treated coir fiber with polypropylene (PP) as the matrix, processed through compression molding. Mechanical properties improved with increasing coir fiber content, reaching an optimum at 30 wt%, after which further fiber addition led to a decline in performance. Kumar et al. (16) examined the mechanical properties of a hybrid composite made from alkali-treated short coir and glass fibers, reinforced with phenolic resin. The composites were produced using a combination of hand lay-up and compression molding techniques. The results indicated that hybrid composites exhibited superior mechanical properties compared to coir-phenolic composites, with the best performance achieved at a fiber length of 40 mm and a fiber loading of 40 wt%.

Anupama K. et al.(17) developed nano-composite using manufactured corn starch and cellulose nano-fibrils. Alkali-treated nano-fibrils were incorporated into the corn starch matrix with 30 wt% glycerol as a plasticizer. The mixture was homogenized using a Fluko high-shear mixer at varying proportions before being cast into films. The resulting films, with a thickness of 80 µm, were conditioned at 43% relative humidity for 15 days. Liu J. et al. (18) developed corn starch adhesives by dispersing corn starch in distilled water at a 1:10 ratio, stirring the mixture at room temperature for 2 hours, and incorporating 1.2 wt% sodium thiosulfate (dry basis). The resulting composites were fabricated using a hot compression process. De Carvalho A. J. F. et al. (19) formulated composites using regular corn starch and glycerol, with fiber reinforcement. The starch/glycerol matrix compositions were 70/30, 80/20, and 90/10, while wood pulp fiber content ranged from 5 to 15 wt%. The study revealed that fiber addition significantly enhanced the elastic modulus and tensile properties, with these effects being highly influenced by the glycerol content.

Darwish L. R. et al. (20, 21) developed thermoplastic starch by plasticizing corn starch with 30 wt% glycerine and 20 wt% distilled water. This matrix was reinforced with banana fiber at varying weight fractions and processed using hot compression moulding at 5 MPa and 160 ºC for 30 minutes. Kmetty A. et al. (22) fabricated a micro-cellulose reinforced composite consisting of corn starch, glycerol, and water. The mixture was heated at 85 ºC for 10 hours to produce thermoplastic starch, which was then introduced into a kneading chamber. The kneading process was conducted in two stages: the first at 90 ºC for 2 minutes at 20 rpm, and the second at 120 ºC for 8 minutes at the same speed. The homogenized mixture was subsequently processed using a twin-roll mill to produce sheets with a thickness of 1.6 mm. Girones J. et al. (23) developed a green composite using corn starch and hemp fiber. Initially, corn starch and glycerol were manually premixed, followed by processing with fiber reinforcement in a rheometer at 120 ºC and 60 rpm for 6 minutes. The processed material was then granulated and thermo-pressed to form film plates or specimens. To ensure proper conditioning, the samples were kept in the press for 40 minutes until the temperature dropped to 50 ºC. Da Roz A. L. et al. (24) investigated the impact of plasticizers on corn starch-based composites. A homogeneous mixture of glycerol and corn starch was prepared by mixing at 150 ºC and 60 rpm for 60 minutes. Additionally, 0.5 wt% stearic acid was incorporated as a processing aid. The resulting mixture was hot-pressed at 160 ºC to produce plates with a thickness of 1–2 mm. While the type and amount of plasticizer did not affect the crystallinity of the samples, they significantly influenced their mechanical properties. Teixeira et al. (25) developed composites using cassava starch plasticized with either glycerol alone or a combination of glycerol and sorbitol. Cassava bagasse nanofibers were used as reinforcement. The mixtures were processed at 140 ± 10 ºC in a mixer equipped with roller rotors, operating at 60 rpm for 6 minutes. The processed materials were then compression moulded at 140 ºC to produce plates with thicknessess of 1 and 2 mm. Guimarães et al. (26) analysed and characterized corn starch using X-ray powder diffraction and thermal analysis. X-ray diffraction studies revealed that samples with a fiber, glycerol, and starch ratio of 10:30:60 exhibited a crystalline structure typical of cereals. Thermal analysis confirmed the material's good thermal stability, making it suitable for composite fabrication.

2. Experimental

2.1 Materials

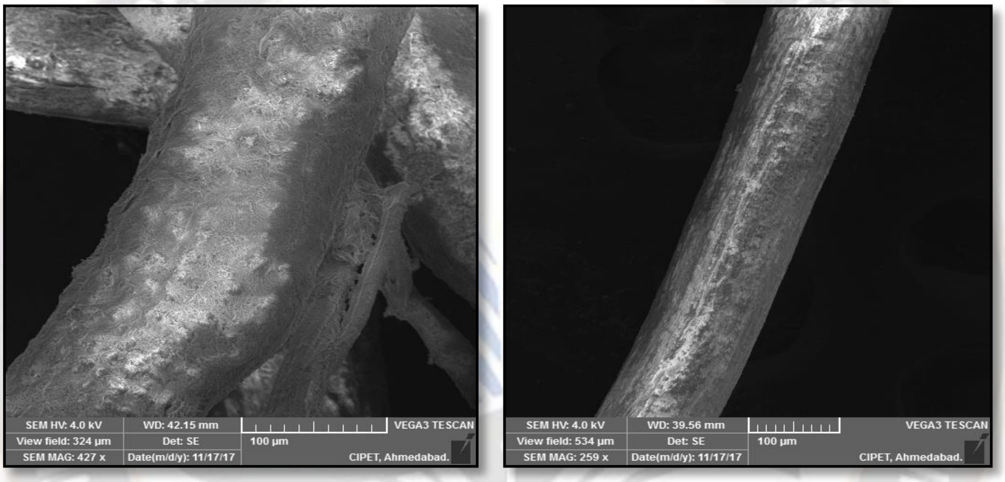
Coir fibers are extracted from the outer husk of coconuts through a process known as retting and decortication. Coir fibers (Maitri Enterprise, Mangrol) are used as a reinforcement material for green composite. Corn starch (Central Drug House (P) Ltd., New Delhi) and glycerol (Qualigens, Thermo Fisher Scientific, Mumbai) are used as a matrix material. Sodium Hydroxide (Qualigens, Thermo Fisher Scientific, Mumbai) is used for alkali treatment of coir fiber.

2.2 Fabrication of Green Composites

2.2.1 Alkali Treatment of Fibers

The coir fibers have been immersed in 5% Sodium Hydroxide (NaOH) at room temperature for 6-8 hrs which activates the hydroxyl (-OH) group of cellulose and lignin. The fibers have been washed with tapped water thoroughly to remove the excess of NaOH and finally dried in hot air oven at 70° for 1 hrs.

Sodium Hydroxide increased the crystalline fraction of fiber due to removal of lignin. Alkaline treatment has two effects on fibers like increases surface roughness resulting in better mechanical interlocking and increases the amount of cellulose exposed on the fiber surface which increases number of possible reaction sites.



(a) **(b)**

Figure 1.SEM micrograph of Coir fiber (a) Non-treated (b) NaOH treated

2.2.2 Preparation of Matrix

Corn starch and glycerol of 75:25 wt% ratio has been taken for high speed mixing (Maliksons High Speed Mixer, Model: HSM 5, Delta Machine Craft, Mumbai). High speed mixing was carried out at 65 °C for approx. half an hour. This process properly mixes corn starch and glycerol before compounding process. After mixing material kept as it is for approximately 24 hours at room temperature.

Twin Screw Extruder (Model: High Torque ZV 20, Specifiq, Specific engineering and Automats, Vadodara) is used for compounding of corn starch and glycerol. Twin screw extruder is having five zones having different temperature controls varying from 80 °C to 120 °C and one die having temperature of 110 °C. Extruded materials were water cooled and then pallets have been made.

2.2.3 Preparation of Specimen

Alkali treated coir fiber and biopolymer matrix pallets have been mixed in the wt % ratio of 10:90, 20:80 and 30:70 respectively. The mixer of coir fibers and biopolymer is again processed in twin screw extruder to make pallets. The samples having different fiber loading of 10, 20 and 30 wt% has been called sample A, B and C respectively. Ten samples of all three types have been moulded and selected for testing.

Injection moulding machine (40T Allplas, M/s Allied International, Agra) augers and compacts the granules coming in from the feed throat and perhaps conduct a bit of preheating before the transition zone. In the compression zone material is melted for the shot while metering zone pumps the plastic forward and generates the back pressure.

2.3 Mechanical Properties of Green Composites

2.3.1 Tensile Test

Tensile strength is the maximum resistance of a material to breaking under tension while tensile modulus is calculated by ratio of stress along an axis to the strain. In this investigation, dimensions, crosshead speed and gauge length are selected as per ASTM D638. ASTM D638 generally used for rigid plastic samples between 1 mm and 14 mm in thickness. Tensile tests have been conducted on the floor mounted Universal Testing Machine (Make – Model: Instron – 3382, Made in England).The experiments are performed at room temperature. There are ten allowable specimen types for ASTM D638 which differ in measurement size depending on the thickness of the specimen and the material. In this work, the specimens used are Type I, which are 3.2 mm thick and are created by injection molding. Type I specimens have an overall length of 165 mm and a width of 13 mm, with a gauge length of 50 mm.

2.3.2 Flexural Test

Flexural strength or bend strength is defined as the stress in a material just before it yields. Flexural modulus or bending modulus is the ratio of stress to strain in flexural deformation or the tendency for a material to bend which indicates the stiffness when inflection. In this test the specimen lies on a support span and load is applied at the center by the nose producing three-point bending. The flexural test was performed as per ASTM D790 standards which measures the fiber required to bend a beam under three point loading condition. In this research work, flexural strength and modulus have been performed as per ASTM D790. ASTM D790 generally used for a variety of shapes but the commonly used size is 3.2 mm x 12.7 mm x 125 mm which is injection moulded. These tests have been conducted on the floor mounted Universal Testing Machine.

A three-point bend fixture consists of a loading nose attached to the moving crosshead and a fixed member with two specimen supports or anvils, which can be adjusted to fit the distance of the specimens' support span. The surface of the anvils and loading nose should be cylindrical and have radii of 5 mm and the length of the cylindrical member should be longer than the width of the specimen. Flexural modulus is an indication of material stiffness when it flexed which can be measured by crosshead displacement.

2.3.3 Impact Test

The Impact test determines the impact resistance of materials. The test measures the ability of a substance to absorb energy without breaking. This test method requires specimens made with a notch which produces stress concentration that increases the possibility of brittle failure. The notch in the specimen minimizes plastic deformation and direct fracture of the part behind the notch. The specimen is clamped into the fixture with the notched side facing the edge of the pendulum. The pendulum is allowed to strike through the specimen. The izod impact test has been performed as per ASTM D256 with a standard specimen size of 64 mm x 1.27 mm x 3.2 mm. Impact strength is measured by dividing impact energy in joule by the thickness of the specimen. The higher resulting number indicates the tougher material. During the test maximum energy that can be stored to break the specimen was noted for the entire specimen for analysis of results. Samples were held vertically on anvil as cantilever.

2.3.4 Hardness Test

The hardness of plastics and rubbers are usually measured by shore scales. Shore hardness is a measure of the resistance of a material to penetration of a spring-loaded needle-like indenter. Shore hardness is measured with an instrument called a durometer. The shore hardness test was calculated as per ASTM D2240 on durometer by the penetration depth of the indenter under the unit load. There are different scales for measuring the hardness of different materials. For each scale, there is a different indenter and specific spring force. These scales were created to provide a reference point when comparing with other materials. Higher number indicates harder material while lower number indicates softer material. In each three types of samples ten specimens were examined and average value is taken for the discussion.

3. Result and Discussion

Table 1. Experimental Results of Coir Fiber Reinforced Green Composites

	Tensile Properties		**Flexural Properties**		**Impact Strength**	**Shore D Hardness**
	Tensile	**Tensile**	**Flexural**	**Flexural**		

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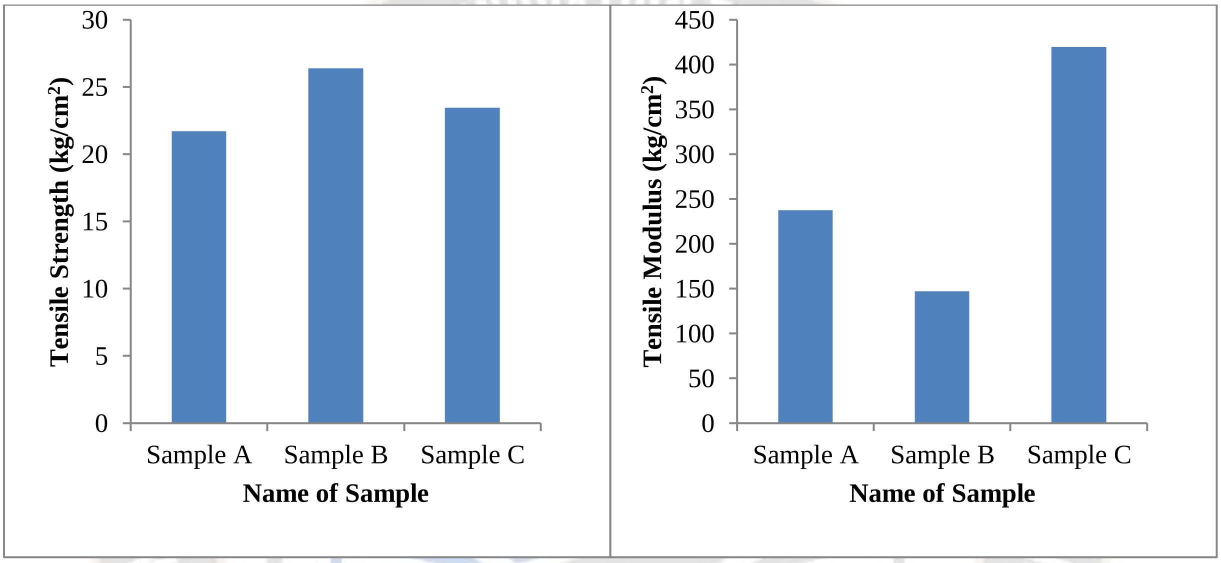
	Strength (Kg/cm^2)	**Modulus (Kg/cm^2)**	**Strength (Kg/cm^2)**	**Modulus (Kg/cm^2)**	**(J/m)**	
Sample A	21.71	237.49	19.99	485.49	64.9	54
Sample B	26.41	147.04	16	345.07	145	53
Sample C	23.45	419.82	15.19	299.08	125	48

3.1 Tensile Test Analysis

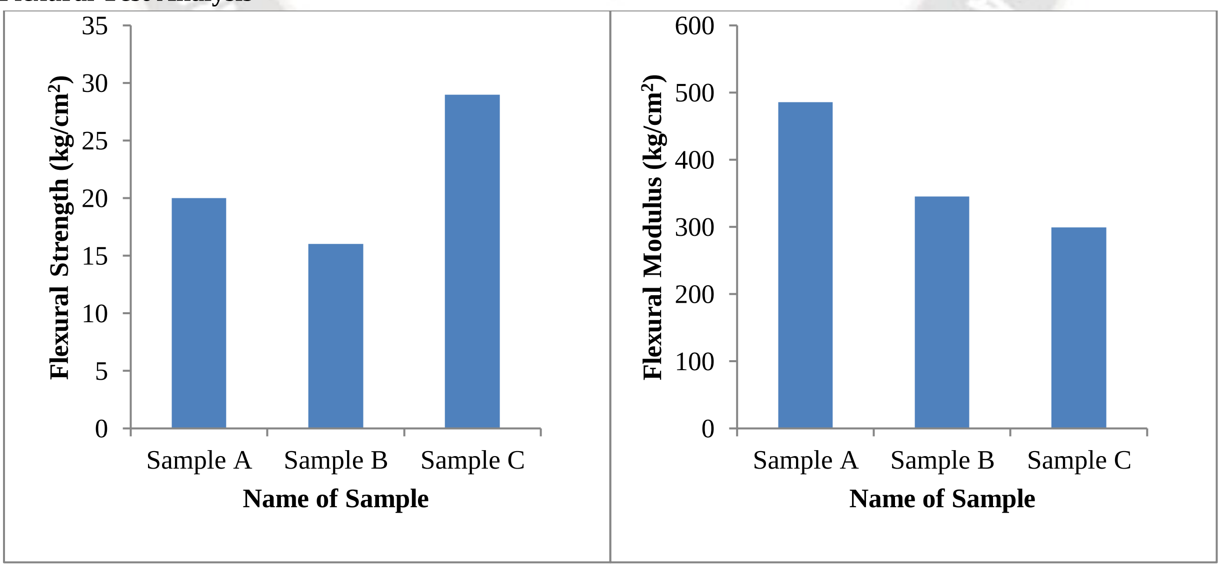
The green composite samples have been tested and the values of tensile strength and modulus are presented in the table 1. It has been observed that the value of tensile strength and modulus increases as fiber content increases. The maximum value for tensile strength and modulus are measured 26.41 kg/cm^2 and 419 kg/cm^2 respectively.



(a) **(b)**

Figure 2. Tensile Properties (a) Tensile Strength and (b) Tensile Modulus

3.2 Flexural Test Analysis

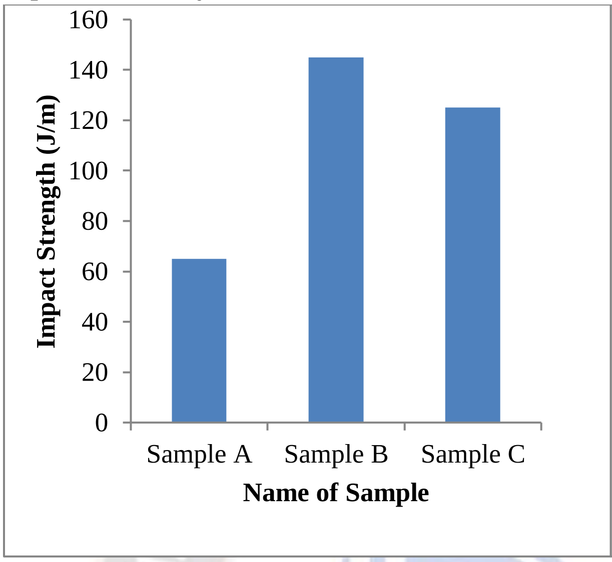


(a) **(b)**

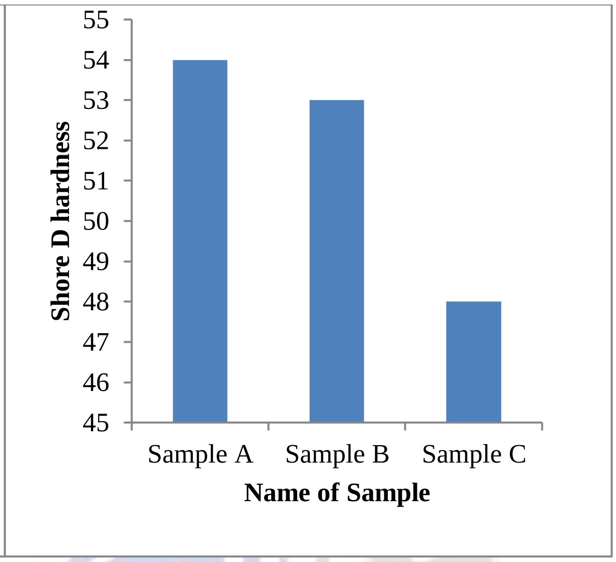
Figure 3. Flexural Properties (a) Flexural Strength and (b) Flexural Modulus

The result of flexural strength and modulus are shown in table 1. It has been practical that flexural strength in case of sample A reaches up to19.99kg/cm^{2}which are highest but as fiber loading increases flexural modulus decreases slowly.

3.3 Impact Test Analysis



(a)



(b)

Figure 4. Impact Strength Property Figure 5. Shore Hardness Values

It has been observed that impact strength of coir fiber reinforced composites is increases up to fiber content of 20% only. The maximum value of Izod impact strength is 145 J/m achieved for sample B.

3.4 Hardness Test Analysis

During experimentation average of ten values has been taken for all three samples and it has been concluded that the value of shore hardness is 54 which is maximum from sample A having list reinforcement part. It shows that inclusion of fiber decreases the hardness of the material.

4. Conclusion

Since last decades of recent developments of synthetic fibers like glass, carbon and aramid, it is noteworthy that natural fibers have gained a new interest, particularly as a replacement of glass fiber in automotive industries. Applications of green composites minimize the amount of waste from the vehicles when they are scrapped which also limit the application of harmful substances and enhance the quantity of recycled stuff used in the production of vehicles. Uses of polymer composites in automobile sector encourage designing the vehicles for simple recycling.

The automotive sector gives benefits of green composites like low density, acceptable mechanical and acoustic properties, health benefits less fogging and very low cost includes the all-purpose reasons for the application of coir fibers. To reduce the weight of cars, producers are looking to replace heavy and complicated automotive parts made of petroleum based materials by using green materials. Natural fiber blended with biopolymer matrix is now usually accepted for automobile application as door liners, roof inner panel, parcel shelves, seat back etc.

In this experimental study coir fiber reinforced and corn starch based green composites have been developed with various combinations by injection moulding process. After testing of mechanical properties following conclusions have been made.

- NaOH treatment is used to change the state of the materials from hydrophilic to hydrophobic.It was observed the removal of wax, pectin, lignin, hemicelluloses from the coir fibers surface.
- This analysis shows that maximum tensile strength and modulus is 26.41 kg/cm^2 and 419.82 kg/cm^2 has been achieved respectively when coir fibers added up to 30% by weight.

- The maximum value of flexural strength and modulus of newly fabricated composites reaches up to almost 20 kg/cm^2 and 485.49 kg/cm^2 for fiber loading of 10%.
- It has been conclude that maximum impact strength can be achieved up to 20% of fiber loading only. After that impact strength decreases slowly.
- Experimental result shows that if fiber loading increases more than 20%, the shore hardness values goes down. There is no significant difference observed when fiber loading increases more than 20%.

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