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Investigation on Mechanical Behaviour of Sugarcane Bagasse Fiber Reinforcement in Polymer Matrix Composites

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Abstract - *A composite material is made by combining two or more materials to give a unique combination of properties, one of the phases is known as reinforcement (in this case fibers) and the other as a matrix which holds the fibres in place. While composites have already demonstrated that it has a high Strength to weight ratio i.e. it is a weight saving material, but the challenge is to make them cost effective. Natural fibers have attracted researchers for their characteristics such as low cost, ease of availability, high strength to weight ratio, high tensile strength, low thermal expansion, bio-degradability etc. The availability of natural fibres in India such as cotton, Sugarcane, Sisal, Pineapple, Banana, Ramie, Bamboo, pulp, Jute, Coir, etc. attracts attention on the development of natural fiber composites. The present work focuses on the development of a polymer matrix composite using Sugarcane bagasse fibers and to study its mechanical behaviour under external loads. The specimens are prepared according to the ASTM standards and testing for mechanical properties such as tensile, flexural and impact energy.*

Key Words: **Composite, Natural fibers, Bagasse, Low cost, External loads.**

1. INTRODUCTION

Over the last several years composite materials and plastics have been the dominant emerging materials. The applications of composite materials have grown rapidly all over the world because of its excellent properties suitable for various applications. While composites have already proved that it is weight-saving materials i.e. light-weight, high strength-to-weight ratio and stiffness properties can replace the conventional materials like metals, wood etc. A composite material is made by combining two or more materials to give a unique combination of properties, one of the phases is known as reinforcement (in this case fibers) and the other as a matrix which holds the fibres in place. We already know that the combination of two or more material that results in better properties than those individual components used alone. In contrast to metallic alloys in which each material retains its separate chemical, physical, and mechanical properties. The reinforcing phase provides the strength and stiffness, reinforcement is usually a fibers which is harder, stronger, and stiffer. The other phase of the composite is the matrix, which holds the fibers in place; the matrix is polymer, metal, or ceramic. The function of the matrix is maintaining the fibers in a proper orientation and protects fibers from abrasion and the environmental conditions. The properties of composite material mostly depend upon the properties of their fibers and matrix materials, volume fraction ratio between fibers and matrix, concentration and orientation of the reinforcement material, and the shape of fibers.

The current challenge is to make composite cost effective. The research for producing composite material economically have resulted in several new techniques for manufacturing component being used in the composites industry; only by improving manufacturing technology alone is not enough to overcome the cost. It is essential that there be integrated research in devolving new composite material such as natural fibers for composites to become competitive with metals.

The availability of natural fibres in India such as cotton, Sugarcane bagasse, Sisal, Pineapple, Banana, Ramie, Bamboo, pulp, Jute, Coir, etc. attracts attention on the development of natural fibers composites. The use of such natural fibers with additives for manufacturing of composite component for improving its performance and application in various fields due to their high strength to weight ratio, non-carcinogenic, and biodegradability. In addition to having comparable mechanical properties, the natural fibers provide better thermal and acoustic insulation properties, due to the presence of a void in the fibers. And they are easy to process on the traditional textile machinery for making reinforcement elements. Natural fibers are easy for processing types of machinery like extruder, pelletizer, or injection molding machine. Natural fibers are lightweight as compared to glass fibers reinforced composites, thereby they are weight saving material in interior and car trim panels can be used in other car components to improve its performance. Natural fibers do not cause any allergies or lung diseases if breathed in or came in contact with. They also provide economic impulse by being a green product, also they provide a marketing advantage.

Due to advantages outlined above along with comparable specific strength and modulus, natural fibers are rapidly replacing glass fibers as reinforcement in automotive interior components, like door trim panel, trunk, and hood liners, etc.

Until a few years back, research was aimed at using natural fibers for reinforcing olefin, polyurethane and few traditional matrix materials. Even with natural fibers reinforcement, it is difficult to segregate the fibers at the end of product life cycle for degradation or composting. Also, the presence of natural fibers in the plastic matrix renders them non-recyclable. Thus, the goal in recent years has been to develop a bio-composite using natural fibers and bio-plastic from renewable resources, which at the end of the product life cycle can be completely biodegraded or composted for energy recovery.

In this research, the present work focuses on the development of a polymer matrix composite using Sugarcane bagasse fibers and to study its mechanical behaviour under external loads. The sugarcane is the most important crop for producing sugar, it is the world largest crop grow in Brazil, India, China, Thailand, Pakistan, Mexico, Colombia, Philippines, and Indonesia. In India production of sugarcane is about 4950000 hectares. Sugarcane crop is mainly used for producing sugar, another use of sugarcane crop is for producing falernum (is a sweet syrup used in Caribbean and tropical drinks), molasses (black treacle used for sweetening and flavoring foods), rum (distilled alcoholic beverage), ethanol and bagasse. Bagasse is the dry fibrous matter that will be extracted from crushed sugarcane after extraction complete of juice from it. Now a day's bagasse is used as fuel in a steam power plant to produce power, for building material, for production of Plywood, paper, and board.

The dried bagasse consists of Cellulose about 45 - 55%, Hemicellulose 20 – 25%, Lignin 18 – 24%, Ash 1 – 4%, and Waxes about 1% [1]. Presently, 85% of total production of bagasse is burned in the industry for generating power and 9% of bagasse is used for the production of alcohol and ethanol, and remaining is used for industrial purpose, but an excess of bagasse is speared on empty fields inside the sugar factory. This waste of bagasse can be avoided by fabricating bagasse base composite for various applications [2].

Visualizing the rate of increasing application of composite material, but the challenge is to make them cost effective. Natural fibers have attracted researchers for their characteristics such as low cost, ease of availability, high strength to weight ratio, high tensile strength, low thermal expansion, bio-degradability etc. so it creates excellent opportunity to fabricate natural fibers composite by using bagasse that's way the present work focuses on the development of a polymer matrix composite using Sugarcane bagasse fibers and to study its mechanical behaviour under external loads. The specimens are proposed to prepare according to the ASTM standards and testing for mechanical properties such as tensile test.

2. LITERATURE SURVEY

In the last several years, the natural fibers attracted researchers due to high availability and demand of lightweight material. For several more applications, the fibers have to be specially prepared or modified regarding-

- Homogeneity of the fiber's properties
- Degrees of elementarization.
- Degree of polymerization and crystallization.
- Good adhesion between fibers and matrix.
- Moisture repellent properties.
- Flame retardant properties.

Paiva et al. (1998) analyzed the impact strength and hardness of sugarcane bagasse composites and showed that impact strength increased and hardness diminished as the fibers volume fraction increased [3]. Vazquez A. et al (1999) reported the processing and properties of bagasse fibers-polypropylene composites. Four different chemical treatments of the vegetal fibers such as isocyanate, acrylic acid, mercerization and washing with alkaline solution were performed in order to improve interface adhesion with the thermoplastic matrix and the effects of the treatment were analyzed by infrared spectroscopy. The study shows that the tensile strength and the elongation at break of the polypropylene matrix composite decrease with the incorporation of bagasse fibers without treatment. The isocyanate and mercerization treatments enhance the tensile properties of the composite. The creep measurements were also carried out on the various composites studied. Optimum results were obtained on materials with treated fibers [4]. Jane M. F.Paiva, E.Frollini (2002) used short sugar cane fibers as reinforcement to obtain fibers reinforces composites. Lignin extracted from sugarcane bagasse was used as a partial substitute of phenol (40w/w). They characterized the composite by mechanical tests such as impact, hardness tests. The whole study showed that it is feasible to replace part of phenol by lignin in phenolic matrices without loss of properties [5]. Hassan et al. (2000) and M.V.desousa et al. (2004) have studied the effect of various processing parameters on the flexural mechanical behaviour of chopped bagasse fibers. They converted the bagasse into a thermoformable material the dimensional stability and mechanical properties of the composites. The study enables the selection of the best combination of bagasse origin, size and molding pressure [6], [7]. Shinichi Shibata, Yong Cao, and Isao Fukumoto (2005) in their work investigated experimentally the flexural modulus of the press molding composites made from bagasse fibers. They numerically predicted flexural modulus by using Cox's model for the composite material. The study concludes that up to 65% of the volume fraction of reinforcement the flexural modulus increases [8]. Cao et al. (2006) have been reported that mechanical properties of biodegradable composites reinforced with bagasse fibers with alkali treatment. The study concludes that up to 13 % improvement in tensile strength, 14 % in flexural strength and 30% in impact strength [9]. P. C. Gope et al (2012) developed bagasse-glass fibers reinforced composite material with 15 wt%, 20 wt%, 25 wt% and 30 wt% of bagasse fibers with 5 wt% glass fibers mixed in resin. Addition of fibers increases the modulus of elasticity of the epoxy. Mixing of bagasse with glass fibers also improves the modulus of elasticity. Addition of bagasse fibers lower the ultimate tensile strength, but the addition of glass fibers further increases the ultimate tensile strength. Bagasse-glass reinforced fibers improve the impact strength of epoxy materials due to fibers has more elasticity in comparison to a matrix material. Increase in bagasse fibers in composite reduces bending strength, but the addition of glass fibers further increases the bending strength [10]. D. Verma (2012) described the advantages of natural fibers composites over the conventional composite. In that, he describes that natural fibers composites are cheaper than plastic products, with more life-cycle span. It attracts the automotive industry because of their low density and ecological advantages, it also has non-carcinogenic and bio-degradable nature. The author also described that bagasse based composites are used in railway coaches and buses for the public transport system. The author tried to use the bagasse-based composites in building and construction such boards and blocks are reconstituted wood, flooring tiles etc. [11]. R.G. Padmanabhan (2015) developed hybrid natural fibers based on polymer composite material. The reinforcement is used as alevera and sugarcane bagasse with Epoxy resin as a matrix. In their report, the alkaline treatment is carried out an alevera and bagasse for important in fibres. The specimen is prepaid with 25%, 30%, 35%, and 40% volume fraction of fibres. The tensile strength increase as the percentage of fibres increases [12]. Pankaj Tripathi (2016) in his work reported, that sugarcane bagasse fibers have enhanced tensile properties, flexural as well as impact properties for the various application. It also analyzed the tensile strength, flexural strength and Hardness of sugarcane bagasse composites increased as fibers volume fraction increased, App. Flexural strength and hardness are increased up to 20% [13].

3. METHODOLOGY

3.1 Reinforcement

Bagasse Fibers - Bagasse was obtained from the sugar factory after extracting complete juice from the sugarcane. The sugar cane bagasse is a widely generated in high proportions in the agro-industry. It is a fibrous residue of sugarcane crop left over after the crushing and extraction of juice from the sugar cane. Bagasse is generally gray-yellow to pale green in color. It is bulky and quite non uniform in size.

Rind (outer-shell) Fibers - Rind is the outer thick walled of sugarcane which is green or reddish color in nature. It is relatively long fibers 8 to 10 cm of length. The strength of the rind fibers is relatively high than the inner fibers.

Pith (inner cells) Fibers - Pith is the spongy white tissues which contain thin fibers inside. Pith consists of cellulose, hemicelluloses and lignin. Pith also contains the water. The length of pith fibers is 6 to 8 cm.

Fig -1: (a) Rind Fibers (b) Bagasse Fibers (c) Pith Fibers

3.2 Matrix

Resin Araldite GY- 250 - Epoxy resins are low molecular weight pre-polymers or higher molecular weight polymers which normally contain glycidyl or oxirane group. The equivalent weight or epoxide number is used to calculate the amount of co-reactant (hardener) to use when curing epoxy resins. Epoxies are typically cured with stoichiometric or near-stoichiometric quantities of curative to achieve maximum physical properties.

Aradur 140-2 BD Hardener - Aradur 140-2 BD Hardener is a medium viscosity, polyamide hardener. When used to cure Araldite low molecular weight solid epoxy resins, it can provide some coating systems with excellent flexibility, toughness and good overall performance properties.

4. FABRICATION

4.1 Fibers Preparation

The bagasse fibers are obtained from the sugar factory, first of all, the unwanted fibers which are not properly crushed into the machine are taken out. The bagasse fibers are washing in water to remove dust and powder form of fibers, then it dried into the sun for 6 hours. The Rind fibers are obtained from the outer skin of crush sugarcane. After extracting, the outer skin fibers is allowing too dry in the sun for complete two days, then the fibers are clean by removing the excess pith over the rind fibers. The pith fibers are extracted from crush sugarcane; the single-single fibers are taken out from the pith by hand than deep into the salt solution for 3 to 4 hours. The fibers are allowed to completely dry in normal room temperature.

4.2 Alkaline Treatment

Bagasse, Rind and Pith fibers were obtained from the sugar factory after extracting complete juice from the sugarcane. The alkaline treatment is used for natural fibers to disruption of hydrogen bonding in the fibers which improves the surface roughness and also used for change the ionization of hydroxyl group to the alkoxide as shown in following reaction-

$$\text{Fibers - OH} + \text{NaOH} \rightarrow \text{Fibers - O - Na} + \text{Water}$$

For alkaline treatment the bagasse fibers is place in 4% of NaOH, and then washed in distilled water and kept for drying in sun for 8 hours. The Rind fibers and Pith fibers is deep in 4% of NaOH solution for 2 hours. And then washed with distilled water and kept for drying in sun for 12 hours. After dipping in the NaOH solution it is observed that the color of fibers is converting into yellow.

Fig -2: Fibers after the Alkaline treatment- (a) Rind Fibers (b) Bagasse Fibers (c) Pith Fibers

4.3 Fabrication of Bagasse Composite Specimen

The composite specimen is prepared as per standard of ASTM of no. D3039/D3039M-17 which is for Standard test method for Tensile Properties of polymer matrix composite material. The size of specimen is 250mm in length, 25mm in width, and 2.5mm in thickness for Random-discontinuous fibers orientation.

The method Use for fabricating the specimen is Hand layup process. The mold is made of plywood and for giving the pressure nut and bolt is used. A laminate paper is used for separate the composite from the mold and also wax is applied over the mold. The resin and hardener used for fabricating the composite material are Araldite GY-250 Resin and Ardor 140-2 BD Hardener, the ratio used of those two is 1:1. The treated bagasse fibers are mixed with the uniform mixture of epoxy resin and hardener in the different proportion of volume fibers ratio of 40%, 50% and 60% of fibers. The epoxy mixed fibers are then placed over the mold and pressurized with the help of nut and bolt. Curing time is 48 hours while curing the care is taken that uniform thickness is maintained throughout the plate. The composite plate is cut in a required dimension according to a standard specimen. The tabs used for holding a specimen inside the jaws of UTM (universal testing machine) are made of paper tape to get the grip, as shown in the photo. Specimen-A have 60% of volume fraction ratio, Specimen-B have volume fraction ratio of 50% and Specimen-C have 40% volume fraction ratio.

4.4 Morphology of Specimen

- Specimen having yellowish color. Visibility of random oriented bagasse.
- If epoxy hardener solution ratio increases then composites becomes wetted, and when epoxy hardener solution ratio decreases there will be rough surface.
- Smooth and glossy surface due to presence of epoxy and hardener.
- Flexible due to elastic property of epoxy.

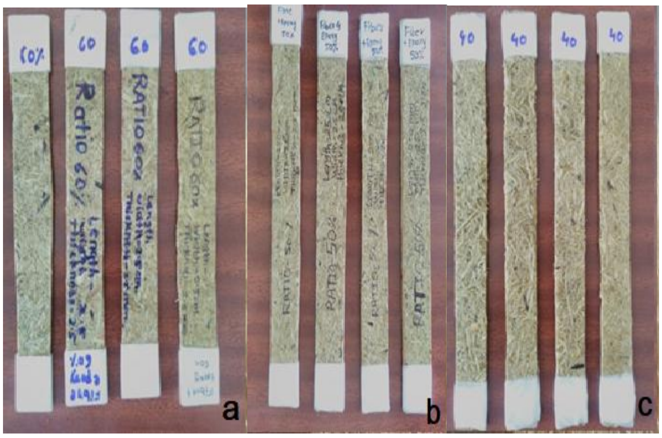

Fig -3: Specimen - (a) Specimen-A (b) Specimen-B (c) Specimen-C

5. RESULT AND OBSERVATION

This section deals with the results and observation of testing result on the sugarcane bagasse fibers composite specimen. The test is carried out on each 3 different specimens with same volume fraction ratio. The following table 1 describes the composition use for each specimen with volume faction ratio.

Table -1: Composition of specimen

Sr. No.	Composites	Composition
1	Specimen-A	Epoxy + Sugarcane bagasse fibers (60% Volume Fraction)
2	Specimen-B	Epoxy + Sugarcane bagasse fibers (50% Volume Fraction)
3	Specimen-C	Epoxy + Sugarcane bagasse fibers (40% Volume Fraction)

5.1 Weight Calculation

Weight of each specimen

- Weight of specimen A=18.59 gm.
- Weight of specimen B=17.81 gm.
- Weight of specimen C=16.87 gm.

The weight of specimen varies because of variation in volume fraction ratio. As volume fraction ratio increases weight of specimen increases, similarly density of specimen also increases. The table 2 shows density of specimen increases as the volume fraction ratio increases.

Table -2: Density of Sspecimens

Reno.	Composites	Density (g/cm3)
1	Epoxy + Sugarcane bagasse fibers (60% Volume Fraction)	1.08
2	Epoxy + Sugarcane bagasse fibers (50% Volume Fraction)	1.14
3	Epoxy + Sugarcane bagasse fibers (40% Volume Fraction)	1.19

5.2 Tensile Test

The Tensile tests were conducted on composite test specimen. In this test, the specimen is subjected to a controlled tension load until failure occurs. Properties that are directly measured by tensile test are Load at yield (KN), Yield stress (N/mm2), Load at peak (KN) and Tensile strength (N/mm2).

The result of tensile test of specimen-A having volume fraction ratio is 60% as shown in below table 3. It has been observed that the values found for three test specimen are close to each other for different mechanical properties which indicate that the manufacturing is preferable for given test specimen.

Table -3: Tensile testing result of Specimen -A

	Specimen 1	Specimen 2	Specimen 3	Average
Load at yield (KN)	1.30	1.15	1.25	1.23
Yield stress (N/mm2)	20.85	25.20	24.80	23.61
Load at peak(KN)	2.75	2.50	2.70	2.65
Tensile strength (N/mm2)	43.20	40.00	44.00	42.40

The result of tensile test of specimen B having volume fraction ratio is 50% as shown in below table 4.

Table -4: Tensile testing result of Specimen -B

	Specimen 1	Specimen 2	Specimen 3	Average
Load at yield (KN)	1.55	1.95	1.35	1.61
Yield stress (N/mm2)	20.85	31.20	24.80	25.61
Load at peak (KN)	3.75	4.35	3.00	3.70
Tensile strength (N/mm2)	60.00	69.60	48.50	59.36

The result of tensile test of specimen C having volume fraction ratio is 40% as shown in below table 5.

Table -5: Tensile testing result of Specimen -B

	Specimen 1	Specimen 2	Specimen 3	Average
Load at yield (KN)	0.65	0.60	0.85	0.70
Yield stress (N/mm2)	10.40	20.00	24.80	18.40
Load at peak (KN)	1.35	1.20	2.05	1.53
Tensile strength (N/mm2)	21.60	19.20	32.80	24.53

It observes that specimen B of 50% volume fraction ratio show high strength to weight ratio as compared to specimen A and specimen C of volume fraction ratio of 60% and 40% respectively. So it is preferred to use a 50% volume frication ratio for manufacturing of different products which required high strength to weight ratio. For 60% volume frication less fiber strength obtained as in composite material most of the load is taken by fibers as compared to matrix, plasticity property have been observed during testing which leads to low strain as compared to specimen-B. In order to obtain high strength it is necessary to have appropriate volume frication in specimen-C were volume friction of 40% used cause to less bonding between matrix and Reinforcement. It has been observed that flaws on the surface on test specimen and rough surface due to fewer matrixes.

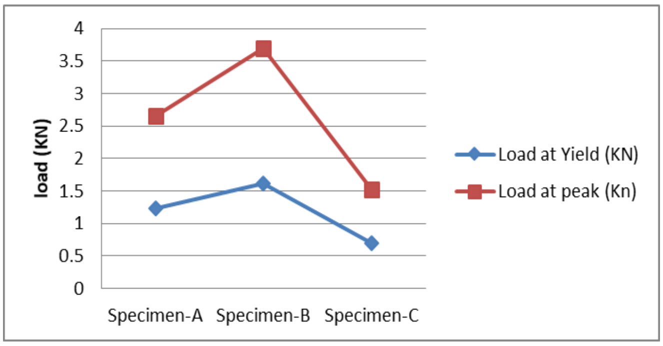

Chart -1: Load at yield and Load at yield of Specimens

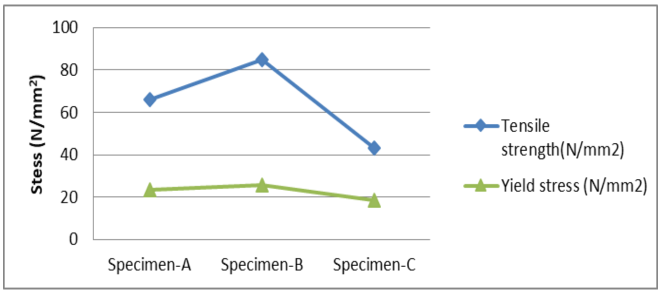

Chart -2: Yield stress and tensile strength of Specimens

From above Chart 1 the specimen B is having considerable increase of load at peak (3.70KN) and load at yield (1.61 KN). It is very evident that load at peak and load at yield increases with increasing volume fraction of sugarcane bagasse fibers. From above Chart 2 the specimen B is having considerable increase of yield stress (25.61 N/mm2) and load at tensile strength (59.36 N/mm2). It is very evident that yield stress and tensile strength increases with increasing volume fraction of sugarcane bagasse fibers.

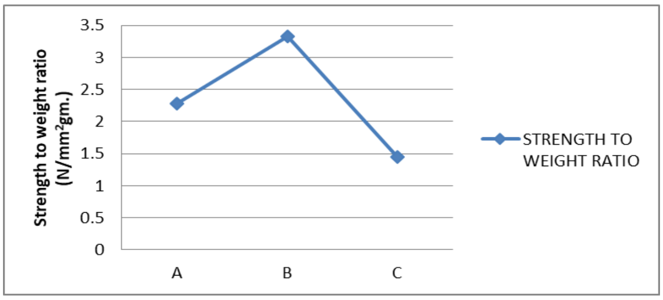

Chart -3: Strength to weight ratio of specimens

6. CONCLUSIONS

Natural fiber composite has the superior properties over the artificial fiber due to the degradation property of bagasse fiber so it is convent to use natural fiber composite for low strength and low cost product manufacturing. Volume fraction ratio of sugarcane bagasse was studied to demonstrate the effect of volume of fiber on the mechanical properties of the composites and to study the practicability of processing these agro-residue with thermoplastics.

The modification of volume fraction was successfully accomplished and it was verified that effectively the tensile strength for 50% volume fraction fiber is superior to other volume fraction Density changes with the volume fraction of matrix and reinforce materials and effect of change in density of composite directly observed on the mechanical properties of material. 60% of volume fraction ratio it has less amount of fiber, which are primary load bearer element that's leads to degradation in mechanical properties. 40% of fiber the matrix cannot handle or hold the amount of fibers together that's leads to degradation in mechanical properties.

7. Future Scope

By using different type of chemical treatment for bagasse fibers can improve the mechanical properties. Other epoxy-hardener polymeric matrix system, with use of different types of chemical agent can be studied. The Hybrid composite with the bagasse fibers can be studied this will give better mechanical properties. By using Rind (outer-shell) fibers and Pith (inner cells) fibers different composite can be prepared with different length of fibers. Length can be factor in improving the mechanical properties of the composite. By placing the Rind (outer-shell) and Pith (inner cells) fibers at different angles, this affects the mechanical properties of the composites.

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