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An Empirical Study and Analysis of Environmental Effect & Mechanical Properties of Bagasse Fiber Reinforced Polymer Composite

Tapan kumar Bugudei[1*], Manas Samal[2]

[1,2]*Assistant Professor, Department of Mechanical Engineering, CUTM, Rayagada, India*

Abstract - *Natural fiber-reinforced polymer composite materials are rapidly growing both in terms of their industrial applications and fundamental research as they are renewable, low, completely or partially recyclable and biodegradable. In order to produce cost effective polymer reinforced composites and to reduce the destruction of ecosystem, researchers have come up with new manufacturing trends for composite using natural fibers which are partially biodegradable, for which plants such as sugarcane, flax, cotton, hemp, jute, sisal, kenaf, pineapple, banana, wood etc., used from time immemorial as a rich source of lignocellulosic fibers are more often applied as the reinforcement of composites. The sugar cane residue bagasse an underutilized renewable agricultural material can successfully be utilized to produce composite by suitably bonding with resin for value added product. Visualizing the increased rate of utilization of natural fibers the present work has been undertaken to develop a polymer matrix composite (epoxy resin) using bagasse fiber as reinforcement and to study its mechanical properties and environmental performance. The composites are to be prepared with different volume fraction of bagasse fibers. The composites are then to be treated at different environment such as subzero, steam, saline water and natural conditions for various time lengths. From the preliminary study, the present work has shown promising results for these room temperature cured polymer matrix bagasse waste reinforced composites. The homogeneous characteristics of the fabricated composites as well as the level of their mechanical properties enable them to have practical applications similar to those normally associated with wooden agglomerates.*

Key Words: Fiber Reinforced Polymer Composite; Bagasse Fiber (Sugarcane); Sub-zero Treatment.

1. INTRODUCTION

This Natural fibers or natural fibres are produced by plants, animals, and geological processes. They can be used as a component of composite materials, where the orientation of fibers impacts the properties. Natural fibers can also be matted into sheets to make products such as paper, felt or fabric. The earliest evidence of humans using fibers is the discovery of wool and dyed flax fibers found in a prehistoric cave in the Republic of Georgia that date back to 36,000 BP. Natural fibers can be used for high-tech applications, such as composite parts for automobiles. Compared to composites reinforced with glass fibers, composites with natural fibers have advantages such as lower density, better thermal insulation, and reduced skin irritation. Further, unlike glass fibers, natural fibers can be broken down by bacteria once they are no longer in use. India endowed with an abundant availability of natural fiber such as Jute, Coir, Sisal, Pineapple, Ramie, Bamboo, Banana etc. has focused on the development of natural fiber composites primarily to explore value-added application avenues. Such natural fiber composites are well suited as wood substitutes in the housing and construction sector. The development of natural fiber composites in India is based on two pronged strategy of preventing depletion of forest resources as well as ensuring good economic returns for the cultivation of natural fibers.The developments in composite material after meeting the challenges of aerospace sector have cascaded down for catering to domestic and industrial applications. Composites, the wonder material with light-weight; high strength-to-weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, wood etc. The material scientists all over the world focused their attention on natural composites reinforced with Jute, Sisal, Coir, Pineapple etc. primarily to cut down the cost of raw materials. [1, 2, 3 & 8].

1.1 Natural Fiber Composites: Initiative in Development Product

Natural fibres are lignocelluloses in nature. These composites are gaining importance due to their non-carcinogenic and bio-degradable nature [6-9]. The natural fiber composites can be very cost effective material especially for building and construction industry (panels, false ceilings, partition boards etc.) packaging, automobile and railway coach interiors and storage devices. This also can be a potential candidate in making of composites, especially for partial replacement of high cost glass fibers for low load bearing applications. However in many instances residues from traditional crops such as rice husk or sugarcane bagasse or from the usual processing operations of timber industries do not meet the requisites of being long fibers [11,12 &13]. This biomass left over are abundant, and their use as a particulate reinforcement in resin matrix composite is strongly considered as a future possibility. Large varieties of sugar cane grow abundantly in many parts of India. Cane is crushed in a series of mills (Fig -1,2 &3), each consisting of at least three heavy rollers. Due to the crushing, the cane stalk will break in small pieces, and subsequent milling will squeeze the juice out. The juice is collected and processed for production of sugar. The resulting crushed and squeezed

cane stalk, named bagasse, is considered to be a by-product of the milling process [4,5 & 10]. Bagasse is essentially a waste product that causes mills to incur additional disposal costs. [7 & 10].

Fig -1: Extraction of sugar juice from cane in a sugar cane Plant

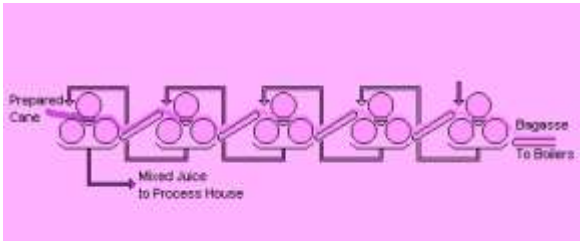

Fig -2: Current technological processes for extraction of sugar juice from cane in a sugar cane Plant

Fig -3: Bagasses from Sugar Plant

1.2 Literature Survey

"Polymer matrix composites (PMC's) are frequently considered to be immune to environmental effects, but the properties of PMC's can be degraded by service environments. The mechanisms of environmental degradation of PMC's are briefly discussed and the postulate that exposure to high pressure water results in permanent mechanical damage to PMC's is evaluated experimentally. As a results no evidence of permanent mechanical damage was found" [14]. "CFR PETU composites with good mechanical properties, and basic knowledge of the material's response to moisture exposure and thermal-oxidative aging was obtained. However, a large quantity of future research is needed to fully characterize the processing of PETU, its responses to environmental exposure, and the effect of dynamic loading on material properties" [15]. "The degradation of an IM7/997 carbon fiber-reinforced epoxy exposed to ultraviolet radiation and/or condensation has been characterized. Based on observations of physical and chemical degradation it has been established that these environments operate in a synergistic manner that causes extensive erosion of the epoxy matrix, resulting in a reduction in mechanical properties" [16]. "Through application of silane coupling agents to the reinforcement fibres, the flexural composite properties were subsequently improved by as much as 38%. Finally, in order to enhance the fire retardancy and hence the applicability of the composite, fire retardants were applied to the resin, and their effectiveness was tested by means of flame rating and thermo gravimetric analysis (TGA), respectively"[17]. "In the biomedical and bioengineered field, the use of natural fibre mixed with biodegradable and bio-resorbable polymers can produce joints and bone fixtures to alleviate pain for patients. A comprehensive review on different kinds of natural fibre composites will be given. Their potential in future development of different kinds of engineering and domestic products will also be discussed in detail"[18].

2. Materials and Methods

Bagasse Fiber : The sugar cane bagasse is a residue widely generated in high proportions in the agro-industry. It is a fibrous residue of cane stalks left over after the crushing and extraction of juice from the sugar cane. Bagasse is generally gray-yellow to pale green in colour. It is bulky and quite non uniform in particle size. The sugar cane residue bagasse is an underutilized, renewable agricultural material that consist of two distinct cellular constituents. The first is a thick walled, relatively long, fibrous fraction derived from the rind and fibro-vascular bundles dispersed throughout the interior of the stalk. The second is a pith fraction derived from the thin walled cells of the ground tissue. The main chemical constituents of bagasse are cellulose, hemicellulose and lignin. Hemicellulose and cellulose are present in the form of hollow cellulose in bagasse which contributes to about 70 % of the total chemical constituents present in bagasse. Another important chemical constituent present in bagasse is lignin. Lignin acts as a binder for the cellulose fibers and also behaves as an energy storage system. Fig.3.1 is the SEM micrograph of the cross section of a raw bagasse fibre, which exhibits the cellular structure of the fibre. In the present work volume fractions of bagasse fibers (5%, 10%and 20% by weight) have been taken as reinforcement in the polymer matrix.

2.1 Preparation of Composites

The following procedure has been adopted for the preparation of the specimen.

(a) Bagasse fiber preparation:-

Fresh bagasse fibers were collected after they were crushed for extracting juice by using a hand crushing machine. These fibers were then spread on a water proof sheet to reduce the moisture content. After approximately two weeks, the long bagasse fibers were shortened into a length of 10mm, breadth of 1mm and width of 1mm with a pair of scissors. Small size fibers were selected in order to design a composite with consistent properties. Due to the low moisture content of the bagasse samples, no fungi grew during the storage. The bagasse samples were then cleaned via pressurized water for about one hour. This procedure removes fine bagasse particles, sugar residues and organic materials from the samples. Then the fibers were dried with compressed air.

(b) Composite preparation:-

A wooden mold of dimension (120x100x6) mm was used for casting the composite sheet. The first group of samples were manufactured with 5, 10, 20 % volume fraction of fibers. For different volume fraction of fibers, a calculated amount of epoxy resin and hardener (ratio of 10:1 by weight) was thoroughly mixed with gentle stirring to minimize air entrapment. For quick and easy removal of composite sheets, mold release sheet was put over the glass plate and a mold release spray was applied at the inner surface of the mold. After keeping the mold on a glass sheet a thin layer (≈ 2 mm thickness) of the mixture was poured. Then the required amount of fibers was distributed on the mixture. The remainder of the mixture was then poured into the mold. Care was taken to avoid formation of air bubbles. Pressure was then applied from the top and the mold was allowed to cure at room temperature for 72 hrs. This procedure was adopted for preparation of 5, 10 and 20% fiber volume fractions of composites. After 72 hrs the samples were taken out of the mold, cut into different sizes and kept in air tight container for further experimentation

2.2 Experimental Procedure

To find out the effect of environment on mechanical properties the composite samples were subjected to various treatments like:

i. Steam treatment
ii. Saline treatment
iii. Sub zero condition

In each conditions a set of composites (5, 10 and 20 % volume fraction) were tested for various time lengths. Steam treatment was conducted at 1000C with 95 % relative humidity. Subzero treatment was conducted at -230C. At the end of the treatment at each condition the dimensions and weight were measured. Change in volume and weights were calculated and were presented in table- 1 to table- 7.

2.3 Characterization

a) Measurement of dimensional change: From the experimental results, dimensional changes of the composites in each case were measured for different weathering conditions.

b) Measurement of weight change: The weight changes of the composites for different volume fraction of fibers were measured for different weathering conditions.

c) Mechanical properties : The mechanical properties viz. stress, strain behaviour of the composites was evaluated after various treatments. The samples were tested using three point bend test method from which flexural strength and inter laminar shear stress were found out.

2.4 Calculations

(i) Change in dimension and volume: Initial volume was calculated for each composite. During the experimentation after every 8 hrs, change in volume was calculated by taking out the samples from the environment they were subjected to. Cumulative volume change was found out after each test.
(ii) Moisture absorbtion: Same procedure was followed for finding out the cumulative change in weight. The amount of moisture absorbed by the various composites for various environmental treatments was also calculated from the change in weight.
(iii) Flexural strength: The composites after treated in various weathering conditions, the three point bend test was carried out in an UTM 201 machine in accordance with ASTM D2344-84 to measure the flexural strength of the composites. All the specimens (composites) were of rectangular shape having length varied from 100-125 mm, breadth of 100-110 mm and thickness of 4-6 mm. A span of 100 mm was employed maintaining a cross head speed of 10mm/min. The flexural strength and inter laminar shear stress found out from the experiment are presented in table - 7.The flexural interlaminar shear strength (ILSS) of the composite which is the maximum shear stress that a material can withstand before it ruptures, was calculated using the equation

$$\sigma m = 3f/4bt$$

Where σm is the ILSS, f is the load, b is the width and t is the thickness of the specimen under test. The maximum tensile stress was found out form the equation.

$$\tau m = 3fl/2bt2$$

Where τm is the maximum tensile stress and l is the gauge length.
The composite specimens of dimensions (l =100-125, w =100-110, t =4 to 6) mm, were cut from the rectangular slabs of the composites. After exposing the composites to various environmental conditions viz. steam, saline and subzero treatments, the changes in the different properties are evaluated. The results are tabulated in table- 1 to table- 7.

2.2 Fractographic Analysis

The fracture surface of the samples impregnated with bagasse as received without any treatment is shown in fig 3.6, Comparing fig 3.6 the following are worth noting. The fracture surface of normal composite (Fig 4) shows crack propagation along fiber-fiber interfaces. Fiber pullouts are the predominant mode of failure in case of composite exposed to steam treatment (Fig 4).Fiber pull outs show

details of the fiber surface indicating that good wetting of the polymer to the fiber is achieved. The structure of samples exposed to subzero (fig 4) shows a different kind of morphology. No crack is observed on the fiber however origination of crack along fiber matrix interface is visible.
Fracture surface of the samples exposed to saline water shown in fig 4 exhibit a different morphology. Matrix cracking and debonding of composite from the fiber is visible. It appears that because of cracking of matrix debris are formed. These debris are distributed and remains on the surface . Probably the mono layer formed are responsible for absorbing the load bearing capacity between the matrix and the fiber so as to exhibit higher strength than that of the composites exposed to other environmental conditions.

2.2 Results and Discussion

Chart-1 to Chart-3 shows the cumulative volume change for different volume fraction of reinforcement subjected to steam, saline and subzero treatment.It is seen from the plot that changes in volume for 20% composite is minimum. All these curves show similar trends with variation in magnitudes. Initially the change in volume increases for all the composites. Beyond certain time of exposure about 48 hrs the change in volume for 5 and 10 % of composites stabilized where as for 20 % linearity in curve was observed after 24 hrs. This may be due to the swelling of the fibers. The exposed area for 20 % reinforcement is much less in comparision to 5 and 10%. Hence the fibers are not getting chance to swell more which results in less volume change. Fig 3.3 shows volume change of the composites subjected to saline water. Here also the same trend is observed but the difference is that even after 56 hrs of treatment saturation for 20% reinforcement is not achieved. This may be due to the rate of swelling. The rate of swelling gets affected because of interaction of electron rich species with sodium ions which forms a mono layer. Mono layer thus formed is preventing swelling. Chart-4 to Chart-6 shows the change in volume under subzero treatment for the composite. A large variation in magnitude for the change in volume was observed for the composites. Linearity in the curves is not achieved even after 28 hrs of treatment. This may be due to less intermolecular hydrogen bonding. Therefore it is taking more time to reach the saturation.

Chart-4 to Chart-6 shows the percentage change in weight for different time of exposure under varying environmental condition for the composites. All these plots show similar trends but with variation in magnitudes (of weight). Beyond certain time of treatment about 48 hrs for steam and saline water whereas about 20hrs for subzero treatment linearity in the curves are observed, which is indicative of saturation of moisture absorption. Chart-7 shows the variation in shear stress for the composite in natural, steam, saline and subzero environment. It is clear from this plot that, there is decrease in stress value for 10% reinforcement, but the variation is large whereas for 20% reinforcement the variation is almost negligible. It also appears from the plot that for subzero treatment the variation is higher. This may be due to the rigidity of the epoxy matrix or/and debonding of the fibers for the long time exposure in subzero conditions. Chart-8 shows the variation in flexural strength for the composite in natural, steam, saline and subzero environment. The plot shows that, the samples with 20% fibre volume fraction possessed the minimum strength for normal conditions. But in case of steam, saline and subzero conditions, the strength decreased up to 10% and then further increased for 20% fibre volume fraction of composites.

Table -1: Cumulative volume change for 5, 10, 20% fiber volume fraction composites in steam treatment

Types of Composite	5%			10%			20%		
Treatment Hours	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)
0	4.82	5.880	1.060	7.735	8.813	1.078	8.328	9.396	1.068
16	4.82	6.360	1.940	7.735	9.500	1.765	8.328	9.624	1.296
24	4.82	6.990	2.170	7.735	9.720	1.985	8.328	9.688	1.360
32	4.82	7.145	2.325	7.735	9.810	2.045	8.328	9.718	1.390
40	4.82	7.255	2.435	7.735	9.870	2.103	8.328	9.748	1.360
48	4.82	7.365	2.745	7.735	9.930	2.165	8.328	9.782	1.394
56	4.82	7.438	2.838	7.735	9.990	2.225	8.328	9.816	1.428
64	4.82	7.458	2.858	7.735	9.990	2.225	8.328	9.816	1.428

Table -2: Cumulative volume change for 5, 10, 20% fiber volume fraction composites in saline treatment

Types of Composite	5%			10%			20%		
Treatment Hours	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)	Initial Vol. (mm³)	Final Vol. (mm³)	Difference (mm³)
0	4.82	5.880	1.060	7.735	8.813	1.078	8.328	9.396	1.068
16	4.82	6.360	1.940	7.735	9.500	1.765	8.328	9.624	1.296
24	4.82	6.990	2.170	7.735	9.720	1.985	8.328	9.688	1.360
32	4.82	7.145	2.325	7.735	9.810	2.045	8.328	9.718	1.390
40	4.82	7.255	2.435	7.735	9.870	2.103	8.328	9.748	1.360
48	4.82	7.365	2.745	7.735	9.930	2.165	8.328	9.782	1.394
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64	4.82	7.458	2.858	7.735	9.990	2.225	8.328	9.816	1.428

Table -3: Cumulative volume change for 5, 10, 20% fiber volume fraction composites in subzero condition

Types of Composites	5%			10%			20%		
Treatment Hours	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)
8	4.62	5.680	1.060	7.735	8.813	1.078	8.328	9.396	1.068
16	4.62	6.560	1.940	7.735	9.500	1.765	8.328	9.624	1.296
24	4.62	6.990	2.370	7.735	9.720	1.985	8.328	9.688	1.300
32	4.62	7.145	2.525	7.735	9.810	2.045	8.328	9.718	1.330
40	4.62	7.255	2.635	7.735	9.870	2.105	8.328	9.748	1.360
48	4.62	7.365	2.745	7.735	9.930	2.165	8.328	9.782	1.394
56	4.62	7.458	2.838	7.735	9.990	2.225	8.328	9.816	1.428
64	4.62	7.365	2.745	7.735	9.930	2.165	8.328	9.782	1.394

Table -4: Cumulative weight change for 5, 10, 20% fiber volume fraction composites in steam treatment

Types of Composites	5%			10%			20%		
Treatment Hours	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)
8	4.62	5.680	1.060	7.735	8.813	1.078	8.328	9.396	1.068
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32	4.62	7.145	2.525	7.735	9.810	2.045	8.328	9.718	1.330
40	4.62	7.255	2.635	7.735	9.870	2.105	8.328	9.748	1.360
48	4.62	7.365	2.745	7.735	9.930	2.165	8.328	9.782	1.394
56	4.62	7.458	2.838	7.735	9.990	2.225	8.328	9.816	1.428
64	4.62	7.145	2.525	7.735	9.810	2.045	8.328	9.718	1.330

Table -5: Cumulative weight change for 5, 10, 20% fiber volume fraction composites in saline treatment

Types of Composites	5%			10%			20%		
Treatment Hours	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)
8	4.62	5.680	1.060	7.735	8.813	1.078	8.328	9.396	1.068
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64	4.62	7.145	2.525	7.735	9.810	2.045	8.328	9.718	1.330

Table -6: Cumulative weight change for 5, 10, 20% fiber volume fraction composites in subzero treatment

Types of Composites	5%			10%			20%		
Treatment Hours	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)	Initial Vol. , (mm)	Final Vol. , (mm)	Difference , (mm)
8	4.62	5.680	1.060	7.735	8.813	1.078	8.328	9.396	1.068
16	4.62	6.560	1.940	7.735	9.500	1.765	8.328	9.624	1.296
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56	4.62	7.458	2.838	7.735	9.990	2.225	8.328	9.816	1.428
64	4.62	6.560	1.940	7.735	9.500	1.765	8.328	9.624	1.296

Table -7: Flexural strengths of 5, 10 and 20% fiber volume fraction composites

Types of Composites	Conditions	Shear stress(MPa)	Flexural strength(MPa)
5%	Normal	2.047	59.72
	Steam	0.705	31.8
	Saline	1.677	113.9
	Subzero	1.057	35.94
10%	Normal	1.387	48.56
	Steam	0.556	18.98
	Saline	0.764	26.37
	Subzero	0.862	23.39
20%	Normal	1.087	31.06
	Steam	0.959	32.58
	Saline	1.123	38.82
	Subzero	1.368	47.21

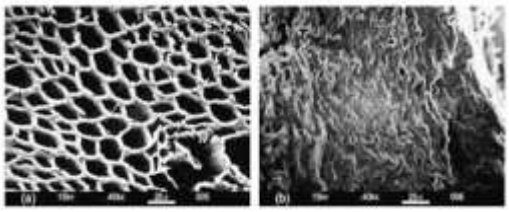

Fig -4: SEM micrographs of the cross section of a bagasse fiber

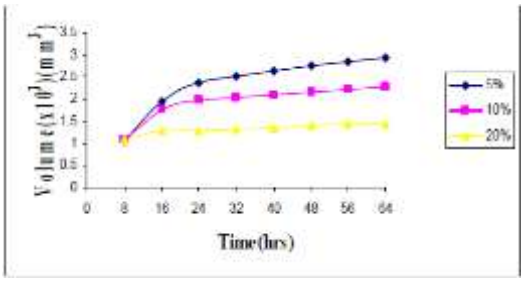

Chart -1: Cumulative Volume Change in Different Volume Fraction of Composites for different time of exposure under steam treatment

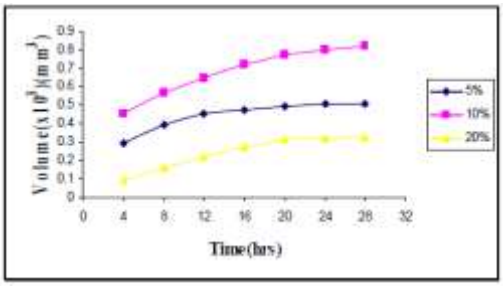

Chart -2: Cumulative Volume Change in Different Volume Fraction of Composites for different time of exposure under saline treatment

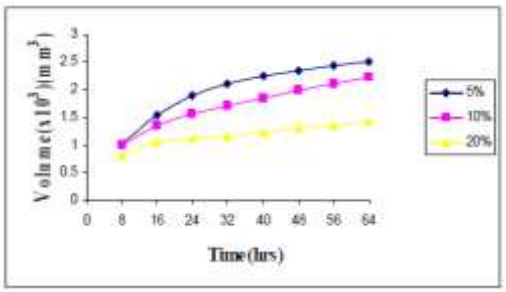

Chart -3: Cumulative Volume Change in Different Volume Fraction of Composites for different time of exposure under subzero treatment

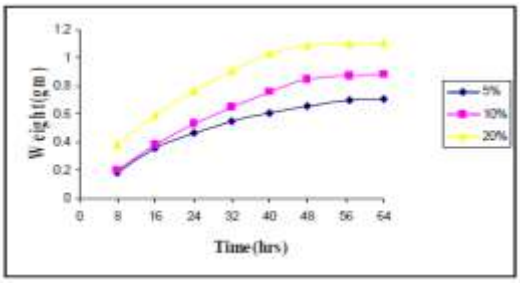

Chart -4: Time dependent cumulative weight change (due to % of moisture absorption) for different volume fraction of composites exposed to steam treatment, saline treatment, subzero treatment

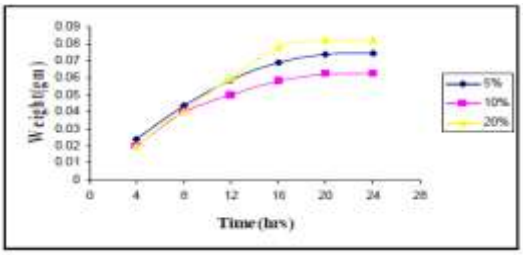

Chart -5: Time dependent cumulative weight change (due to % of moisture absorption) for different volume fraction of composites exposed to steam treatment, saline treatment, subzero treatment

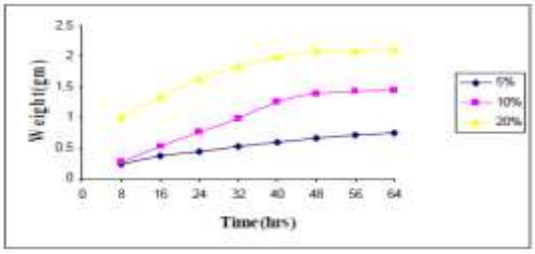

Chart -6: Time dependent cumulative weight change (due to % of moisture absorption) for different volume fraction of composites exposed to steam treatment, saline treatment, subzero treatment

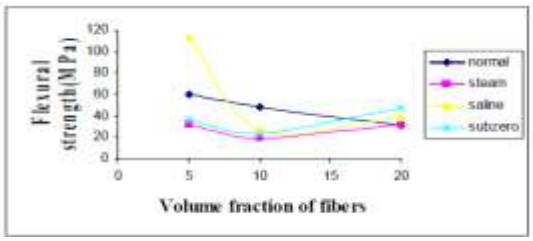

Chart -7: Variation of the shear stress of the composites for various treatments

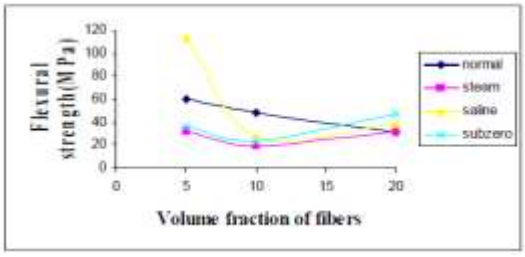

Chart -8: Variation of the flexural strength of the composites for various treatments

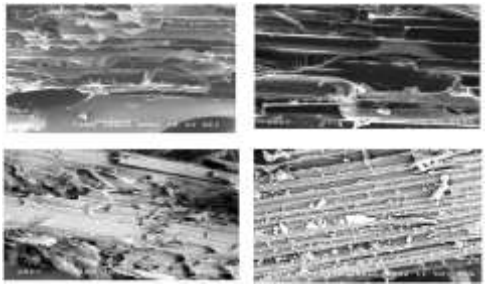

Fig -5: SEM micrographs of the cross section of a bagasse fiber

3. CONCLUSION

Bagasse fiber can successfully be utilized to manufacture polymer based composite thereby providing increased profitability for the sugar industry. The volume and weight change of the composite attains stability after certain period of exposure. The shear stress of the composite is very sensitive to the treatments. The shear stress decreases with increase in fiber volume fraction. Least swelling is observed with the composites subjected to saline water. From the SEM studies it is clear that fiber-pullouts were the predominant mode of failure.

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BIOGRAPHIES

Mr. Tapan kumar Bugudei, received his Bachelor Degree in Mechanical Engineering in 2016 from BPUT, Rourkela, India and in 2019 received his M.Tech degree in Mechanical Engineering from GIET (Autonomous),Gunpur, Rayagada, India. He is currently working as Asst. Professor under the Department of Mechanical Engineering at Centurion University, Rayagada, India. His area of interest includes Composite Materials, Non-Traditional Machining and Production and Operation Management. He has presented and published many papers in National & International conferences and journals.

Mr. Manas Samal, received his Bachelor Degree in Mechanical Engineering in 2016 from CUTM, Paralakhemundi, Gajapati, India and in 2019 received his M.Tech degree in Mechanical Engineering from GIET (Autonomous), Gunpur, Rayagada, India. He is currently working as Asst. Professor under the Department of Mechanical Engineering at Centurion University, Rayagada, India. His area of interest includes Machine Design, Composite Materials, and Production and Operation Management. He has presented and published many papers in National & International conferences and journals.