EFFECT OF ENVIRONMENT ON MECHANICAL PROPERTIES OF BAGASSE FIBER REINFORCED POLYMER COMPOSITE

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Mechanical Engineering

By

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Department of Mechanical Engineering

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Rourkela

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CERTIFICATE

This is to certify that thesis entitled, "EFFECT OF ENVIRONMENT ON MECHANICAL PROPERTIES OF BAGASSE FIBER REINFORCED POLYMER COMPOSITE" submitted by Ms. PUNYAPRIYA MISHRA in partial fulfillment of the requirements for the award of Master of Technology Degree in Mechanical Engineering with specialization in "Production Engineering" at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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ABSTRACT

In recent years the natural fiber composites have attracted substantial importance as a potential structural material. The attractive features of natural fibers like jute, sisal, coir and banana have been their low cost, light weights, high specific modulus, renewability and biodegradability. Natural fibres are lignocellulosic in nature. These composites are gaining importance due to their non-carcinogenic and bio-degradable nature. The natural fiber composites can be very cost effective material especially for building and construction industry. 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. Bagasse contains about 40% cellulose, 30% hemicellulose, and 15% lignin. The present use of bagasse is mainly as a fuel in the sugar cane mill furnaces. It is felt that the value of this agricultural residue can be upgraded by bonding with resin to produce composites suitable for building materials.

Keeping this in view 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 prepared with different volume fraction of bagasse fibers. Experiments have been conducted under laboratory conditions to asses the effect of different environment such as subzero, steam, saline water and natural conditions on the mechanical properties of the composites. The change in weight, volume and dimensions are studied for various treatments. Shear strength of the composites was evaluated by three point bend test as per ASTM D2344-84. The volume fraction of composites having greater mechanical properties was taken for the second phase of experimentation. The second phase of experiment involves treatment of bagasse fiber with acetone and study of their environmental performance. The fibers were washed in soxhlet extractor. Micro structural examinations were also made to get an idea about the effect of treated and untreated fibers on the mechanical properties of the composites.

LIST OF FIGURES

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1.1   BACKGROUND:

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   WHY A COMPOSITE?

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications.

While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composites industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling, quality assurance, manufacturing, and even program management for composites to become competitive with metals.

The composites industry has 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 fibres 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.

Whilst 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.

1.3 DEFINITION OF COMPOSITE

The most widely used meaning is the following one, which has been stated by Jartiz [1] "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form".

The weakness of this definition resided in the fact that it allows one to classify among the composites any mixture of materials without indicating either its specificity or the laws which should given it which distinguishes it from other very banal, meaningless mixtures.

Kelly [2] very clearly stresses that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength to resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them.

Beghezan [3] defines as "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings", in order to obtain improved materials.

Van Suchetclan [4] explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

1.4 CHARACTERISTICS OF THE COMPOSITES

Composites consist 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'.

Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from 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.

1.5   CLASSIFICATION

Composite materials can be classified in different ways [5]. Classification based on the geometry of a representative unit of reinforcement is convenient since it is the geometry of the reinforcement which is responsible for the mechanical properties and high performance of the composites. A typical classification is presented in table1.1. The two broad classes of composites are (1) Particulate composites and (2) Fibrous composites.

1.5.1   Particulate Composites

As the name itself indicates, the reinforcement is of particle nature (platelets are also included in this class). It may be spherical, cubic, tetragonal, a platelet, or of other regular or

irregular shape, but it is approximately equiaxed. In general, particles are not very effective in improving fracture resistance but they enhance the stiffness of the composite to a limited extent. Particle fillers are widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage.

1.5.2 Fibrous composites

A fiber is characterized by its length being much greater compared to its cross-sectional dimensions. The dimensions of the reinforcement determine its capability of contributing its properties to the composite. Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement having a long dimension discourages the growth of incipient cracks normal to the reinforcement that might other wise lead to failure, particularly with brittle matrices.

Man-made filaments or fibers of non polymeric materials exhibit much higher strength along their length since large flaws, which may be present in the bulk material, are minimized because of the small cross-sectional dimensions of the fibre. In the case of polymeric materials, orientation of the molecular structure is responsible for high strength and stiffness.

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                          ┌─────────────────────────┐
                          │   Composite materials    │
                          └─────────────────────────┘
                    ┌───────────────┴──────────────────┐
          ┌─────────────────────────┐      ┌──────────────────────────────┐
          │ Fiber reinforced        │      │ Particle reinforced          │
          │ composites              │      │ composites                   │
          └─────────────────────────┘      └──────────────────────────────┘
```

| Single layer composite | | Multi layered composites | | Random orientation | Preferred orientation |

| Continuous fiber reinforced | | Discontinuous fiber reinforced composites | Laminates | Hybrids |

| Unidirectional reinforcement | Bi-directional reinforcement | Random orientation | Preferred orientatio |

Table: 1 .1   Classification of composites

Fibers, because of their small cross- sectional dimensions, are not directly usable in engineering applications. They are, therefore, embedded in matrix materials to form fibrous composites. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage due to handling. In discontinuous fibre reinforced composites, the load transfer function of the matrix is more critical than in continuous fibre composites.

1.6 COMPONENTS OF A COMPOSITE MATERIAL

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the 'matrix'), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

1.6.1 Role of matrix in a composite

Many materials when they are in a fibrous form exhibit very good strength property but to achieve these properties the fibres should be bonded by a suitable matrix. The matrix isolates the fibres from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibres in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibres and evenly distributive stress concentration.

1.6.2 Materials used as matrices in composites

In its most basic form a composite material is one, which is composed of at least two elements working together to produce material properties that are different to the properties of those elements on their own. In practice, most composites consist of a bulk material (the matrix) and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix.

(a) BULK PHASES

(1) Metal Matrices

Metal matrix composites possess some attractive properties, when compared with organic matrices. These include (i) strength retention at higher temperatures, (ii) higher transverse strength, (iii) better electrical conductivity, (iv) superior thermal conductivity, (v) higher erosion resistance etc. However, the major disadvantage of metal matrix composites is their higher densities and consequently lower specific mechanical properties compared to polymer matrix composites. Another notable difficulty is the high-energy requirement for fabrication of such composites.

(2) Polymer Matrices

A very large number of polymeric materials, both thermosetting and thermoplastic, are used as matrix materials for the composites. Some of the major advantages and limitations of resin matrices are shown in Table 1.2.

Table 1.2

Advantages and limitations of polymeric matrix materials

Advantages	Limitations
Low densities	Low transverse strength
Good corrosion resistance	Low operational temperature limits
Low thermal conductivities	
Low electrical conductivities	
Translucence	
Aesthetic Colour effects	

Generally speaking, the resinous binders (polymer matrices) are selected on the basis of adhesive strength, fatigue resistance, heat resistance, chemical and moisture resistance etc. The resin must have mechanical strength commensurate with that of the reinforcement. It must be easy to use in the fabrication process selected and also stand up to the service conditions.

Apart from these properties, the resin matrix must be capable of wetting and penetrating into the bundles of fibres which provide the reinforcement, replacing the dead air spaces therein and offering those physical characteristics capable of enhancing the performance of fibres.

(3)   Ceramic Matrices

Ceramic fibres, such as alumina and SiC (Silicon Carbide) are advantageous in very high temperature applications, and also where environment attack is an issue. Since ceramics have poor properties in tension and shear, most applications as reinforcement are in the particulate form (e.g. zinc and calcium phosphate). Ceramic Matrix Composites (CMCs) used in very high temperature environments, these materials use a ceramic as the matrix and reinforce it with short fibres, or whiskers such as those made from silicon carbide and boron nitride.

(b)   REINFORCEMENT

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibres used in composites have different properties and so affect the properties of the composite in different ways. For most of the applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways for assembling fibres into sheets and the variety of fibre orientations possible to achieve different characteristics.

(c)   INTERFACE

It has characteristics that are not depicted by any of the component in isolation. The interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical, chemical etc. The matrix material must "wet" the fibre. Coupling agents are frequently used to improve wettability. Well "wetted" fibres increase the interface surfaces area. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibres via the interface. This means that the interface must be large and exhibit strong adhesion between fibres and matrix. Failure at the interface (called debonding) may or may not be desirable.

1.7 TYPES OF COMPOSITE MATERIALS:

The composite materials are broadly classified into the following categories as shown in fig 1.1 (a-e);

1.7.1 Fiber-Reinforced Composites:

Reinforced-composites are popularly being used in many industrial applications because of their inherent high specific strength and stiffness. Due to their excellent structural performance, the composites are gaining potential also in tribological applications. In this type composite the second phase is in the form of fibers dispersed in the matrix which could be either plastic or metal. The volume fraction (Vf) varies from a few percentage to as high as 70%. Usually the fiber reinforcement is done to obtain high strength and high modulus. Hence it is necessary for the fibers to posses' higher modulus than the matrix material, so that the load is transferred to the fiber from the matrix more effectively.

1.7.2 Dispersion Hardened Material:

In this type of material, fine particles of sizes ranging from 0.01μm to 0.14μm are dispersed in matrix. Their concentration varies from 1% to 15% by volume. These fine particles impede dislocation movement in the material and therefore result in very high strength. Also these materials posses improved high temperature strength and creep resistance.

1.7.3 Particulate composite:

In this type of composites, 1μm to 200μm size particles are dispersed in the matrix and volume fraction is generally between 0.01 Vf to 0.85 Vf.
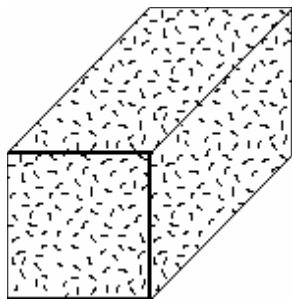
(a) Random fiber (short fiber) reinforced composites
(b) Particles as the reinforcement (Particulate composites)
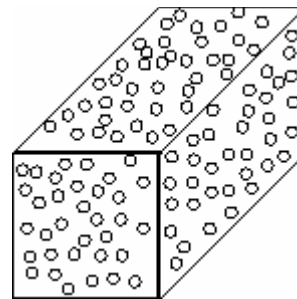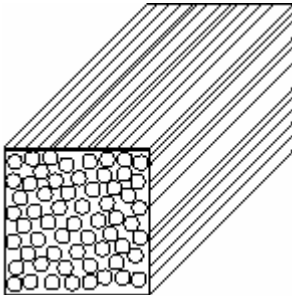
(c) Continuous fiber (long fiber) reinforced
Composites
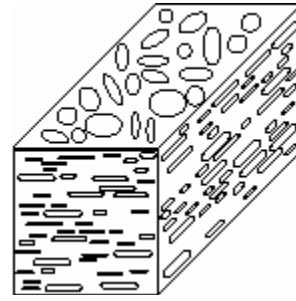
(d) Flat flakes as the reinforcement
(Flake composites)
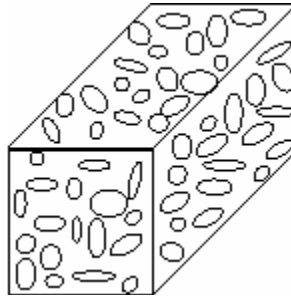
(e) Fillers as the reinforcement (Filler composites)

Fig 1.1 Classification of composite materials

1.8   NATURAL FIBER COMPOSITES: Initiative in Product Development

Natural fibres are lignocellulosic 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. 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), 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 [10]. Bagasse is essentially a waste product that causes mills to incur additional disposal costs.
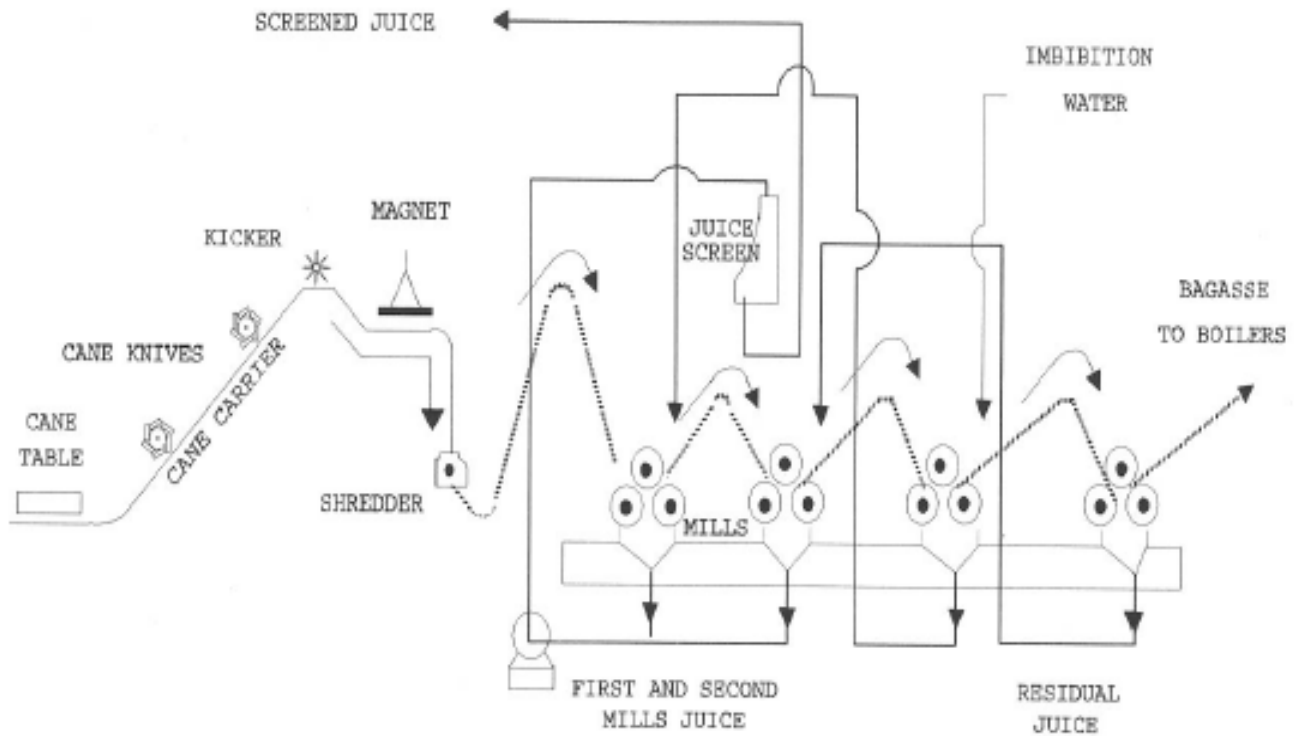
Fig. 1.2 Current technological process for extraction of sugar juice from cane in a sugar cane mill

Bagasse is a fibrous residue that remains after crushing the stalks, and contains short fibers (Fig. 1.3). It consists of water, fibers, and small amounts of soluble solids. Percent contribution of each of these components varies according to the variety, maturity, method of harvesting, and the efficiency of the crushing plant. Table 1.3 shows a typical bagasse composition [10].

Fig. 1.3 Bagasses

Table 1.3

Average Bagasse Composition

ITEM	%
Moisture	49.0
Soluble Solids	2.3
Fiber	48.7
Cellulose	41.8
Hemicelluloses	28
Lignin	21.8

Bagasse is mainly used as a burning raw material in the sugar cane mill furnaces. The low caloric power of bagasse makes this a low efficiency process. Also, the sugar cane mill management encounters problems regarding regulations of "clean air" from the Environmental Protection Agency, due to the quality of the smoke released in the atmosphere. Presently 85% of bagasse production is burnt. Even so, there is an excess of bagasse. Usually this excess is deposited on empty fields altering the landscape. Approximately 9% of bagasse is used in alcohol (ethanol) production. Ethanol is not just a good replacement for the fossil fuels, but it is also an environmentally friendly fuel. Apart from this, ethanol is a very versatile chemical raw

material from which a variety of chemicals can be produced [11]. But again, due to the low level of sucrose left in bagasse, the efficiency of the ethanol production is quite low.

With increasing emphasis on fuel efficiency, natural fibers such as bagasse based composites enjoying wider applications in automobiles and railway coaches & buses for public transport system. There exist an excellent opportunity in fabricating bagasse based composites towards a wide array of applications in building and construction such boards and blocks as reconstituted wood, flooring tiles etc. value added novel applications of natural fibers and bagasse based composites would not go in a long way in improving the quality of life of people engaged in bagasse cultivation, but would also ensure international market for cheaper substitution.

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. The change in weight, volume and dimensions are to be studied for various treatments. Shear strength of the composites has to be evaluated by three point bend test. The volume fraction of composites having greater mechanical properties is to be taken for the second phase of experimentation. The second group of samples will involve bagasse fiber surface treatments, namely (i) unwashed bagasse, (ii) unwashed and treated with acetone, (iii) washed and treated with acetone. The treated fibers along with the samples with highest mechanical properties with washed fibers already manufactured will be taken for comparision of mechanical properties subjecting them to different environmental treatments. Micro structural examinations will be made to ascertain the fracture behaviour of the composite.

Keeping all this in view the entire work has been divided into five chapters.

In the second chapter work related to present investigations available in literatures are presented.

The third and fourth chapters represent the preparation of specimens for the composites, their treatments and characterization.

In fifth conclusions have been drawn from the above studies mentioning the scope for future work.

2.   LITERATURE SURVEY

Fiber reinforced composites are popularly being used in many industrial applications because of their high specific strength and stiffness. Due to their excellent structural performance, these composites are gaining potential also in tribological applications [12]. In this type of composites the second phase is in the form of fibers dispersed in the matrix which could be either plastic or metal. Usually the fiber reinforcement is done to obtain high strength and high modulus. Hence it is necessary for the fibers to posses higher modulus than the matrix material, so the load is transferred to the fiber from the matrix more effectively. Natural fibers to the maximum extent fulfill these criteria and therefore have drawn world wide attention as a potential reinforcement material for the composites.

Natural fibers currently used as reinforcements in composite materials include jute, sisal, pineapple, abaca and coir [13], [14], [15], [16], [17], [18], [19], [20], [21] and [22]. The abundance and low cost of natural fibers combined with their low density and reduced wear on processing machinery makes these fibers suitable for use in composite materials. Synthetic fibers such as carbon or glass fibers have constant diameters; smooth surfaces and considerable rigidity. On the other hand, natural fibers can be flexible, have variable diameters along the length of each fiber and have rough surfaces. Natural fibers are also sensitive to temperature and moisture and usually have irregular cross section.

The main chemical constituents of bagasse are hemi cellulose and lignin. Hemi cellulose and cellulose are present in the form of holocellulose in bagasse, which contributes more than 70 % of the total chemical constituent 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.

Usamani etal [23] describes the evolution of five water soluble phenolic resin as binders at 5 percent concentration, for oriented and random reinforced bagasse composite. They

tried to determine the amount of resin retained during processing when these phenolics were precipitated on to bagasse fiber.

Monteiro SN. Rodriquez etal. [24] tries to use the sugar cane bagasse waste as reinforcement to polymeric resins for fabrication of low cost composites. They reported that composites with homogeneous microstructures could be fabricated and mechanical properties similar to wooden agglomerates can be achieved.

A.Vazquez, V.A.Dominguez etal. [25] in their work reported the processing and properties of bagasse fiber-polypropylene composites. Four different chemical treatments were done on fiber to improve interface adhesion with the thermoplastic matrix namely isocyanate, acrylic acid, mercerization and washing with alkaline solution. Their result shows that the best results were obtained on materials with treated fibers.

Hassan etal. [26, 27] have converted the bagasse into a thermo formable material through esterification of the fiber matrix. The dimensional stability and mechanical properties of the composites prepared from the esterified fibers were reported in this work.

Paiva etal. [28] analyzed the impact strength and hardness of sugarcane bagasse-resol composites and showed that impact strength increased and hardness diminished as the fiber volume fraction increased.

Jane M. F.Paiva, E.Frollini [29] used short sugar cane fibers as reinforcement to obtain fiber reinforce composites. Lignin extracted from sugarcane bagasse was used as a partial substitute of phenol (40w/w) in resole phenolic matrices. They characterized the composite by mechanical tests such as impact, DMTA and hardness tests. The results as a whole showed that it is feasible to replace part of phenol by lignin in phenolic matrices without loss of properties.

K.Bilba, M.A.Arsene, A. Ouensanga [30] have studied the feasibility of bagasse fiber/cement composites. The influence of different parameters on the setting of the composite material has been studied. This study shows a retarding effect of lignin on the setting of the

composite, for small amount of heat treated bagasse (200^0C) the behaviour of the composite is closely the same as the classical cement or cellulose/cement composite.

M.V.desousa etal. [31] studied the effect of three processing parameters on the flexural mechanical behaviour of chopped bagasse poly-ester composite. The parameters evaluated were: the size of the chopped material, the pretreatment derived from the previous processing of the bagasse material on mills and the molding pressure. The results obtained by them enable the selection of the best combination of bagasse origin, size and molding pressure.

Shinichi Shibata, Yong Cao, and Isao Fukumoto [32] in their work investigated experimentally the flexural modulus of the press molding composites made from bagasse fiber and biodegradable resin. They have also numerically predicted flexural modulus by using Cox's model. They conclude that up to 65% volume fraction of reinforcement flexural modulus increases. Decrease in the flexural modulus was found below 3 mm at the fiber length in the experimental and same trend was shown in the numerical prediction.

Mechanical properties of biodegradable composites reinforced with bagasse fiber with alkali treatment have been reported by Cao etal. [33]. Approximately 13 % improvement in tensile strength, 14 % in flexural strength and 30% in impact strength has been reported.

Yo-Taozheng etal. [34] in their work focused on the effect of benzoic acid as the surface modifier on the mechanical properties of the bagasse fiber. Their result shows that the interface modifier improved significantly on the tensile strength and little on the impact strength of the composite.

After reviewing the existing literature available on natural fiber composites, particularly bagasse fiber composites efforts are put to understand the basic needs of the growing composite industry. The conclusions drawn from this is that, the success of combining vegetable natural fibers with polymer matrices results in the improvement of mechanical properties of the composites compared with the matrix materials. These fillers are cheap and nontoxic, can be obtained from renewable sources, and are easily recyclable. Moreover, despite their low strength, they can lead to composites with high specific strengths because of their low density.

Thus the priority of this work is to prepare Polymer Matrix Composites (PMCs) using bagasse fiber (waste from sugarcane industry) as reinforcement material and to study its weathering behaviour.

3. MATERIALS AND METHODS:

3.1 RAW MATERIALS:

Raw materials used in this experimental work are listed below:

1. Natural fiber (Bagasse)
2. Epoxy resin
3. Hardener

3.1.1 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 under utilized, 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 through out 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.

3.1.2 Epoxy resin

Softener (Araldite LY 556) made by CIBA GUGYE limited having the following outstanding properties has been used as the matrix material.

a. Excellent adhesion to different materials.

b. High resistance to chemical and atmospheric attack.

c. High dimensional stability.

d. Free from internal stresses.

e. Excellent mechanical and electrical properties.

f. Odourless, tasteless and completely nontoxic.

g. Negligible shrinkage.

3.1.3 Hardener

In the present work hardener (HY951) is used. This has a viscosity of 10-20 MPa at 25ºc.

3.2 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 ($\approx$ 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.

3.3   EXPERIMENTAL PROCEDURE:

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

- (a) Steam treatment
- (b) Saline treatment
- (c) Subzero 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 100^0C with 95 % relative humidity. Subzero treatment was conducted at -23^0C. 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 no.3.1 to 3.7.

3.4   CHARACTERIZATION

3.4.1   Measurement of dimensional change

From the experimental results, dimensional changes of the composites in each case were measured for different weathering conditions.

3.4.2   Measurement of weight change

The weight changes of the composites for different volume fraction of fibers were measured for different weathering conditions.

3.4.3   Mechanical properties

The mechanical properties viz. stress, strain behavior 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.

3.5   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. The loading arrangement for the specimen and the photograph of the machine used are shown in fig 3.1 and 3.2. 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 3.7.

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.

$$\tau m = 3fl/2bt^2$$

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 no 3.1-3.7.

3.6   RESULTS AND DISCUSSION

Fig 3.3-3.5 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 3.4 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.

Fig 3.5 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.

Fig 3.6-3.8 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.

Fig 3.9 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.

Fig 3.10 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.

3.7   FRACTOGRAPHIC ANALYSIS

The fracture surface of the samples impregnated with bagasse as received without any treatment is shown in fig 3.11(a-d).

Comparing fig 3.11 (a-d) the following are worth noting. The fracture surface of normal composite (fig 3.11a) shows crack propagation along fiber-fiber interfaces. Fiber pullouts are the predominant mode of failure in case of composite exposed to steam treatment (Fig.3.11b).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 3.11c) 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 3.11d 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 .The result projected in fig3.4 supplements to this. 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.

3.8   CONCLUSIONS

The following conclusions are drawn from this study.

1. Bagasse fiber can successfully be utilized to manufacture polymer based composite thereby providing increased profitability for the sugar industry.

2. The volume and weight change of the composite attains stability after certain period of exposure.

3. The shear stress of the composite is very sensitive to the treatments. The shear stress decreases with increase in fiber volume fraction.

4. Least swelling is observed with the composites subjected to saline water.

5. From the SEM studies it is clear that fiber-pullouts were the predominant mode of failure.

Table-3.1

Cumulative volume change for 5, 10, 20% fiber volume fraction composites in steam treatment

Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
8	3.62	4.680	1.060	7.735	8.813	1.078	7.328	8.396	1.068
16	3.62	5.560	1.940	7.735	9.500	1.765	7.328	8.624	1.296
24	3.62	5.990	2.370	7.735	9.720	1.985	7.328	8.688	1.300
32	3.62	6.145	2.525	7.735	9.810	2.045	7.328	8.718	1.330
40	3.62	6.255	2.635	7.735	9.870	2.105	7.328	8.748	1.360
48	3.62	6.365	2.745	7.735	9.930	2.165	7.328	8.782	1.394
56	3.62	6.458	2.838	7.735	9.990	2.225	7.328	8.816	1.428
64	3.62	6.551	2.931	7.735	10.044	2.279	7.328	8.836	1.448

Table-3.2

Cumulative volume change for 5, 10, 20% fiber volume fraction composites in saline treatment

Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
8	3.575	4.585	1.01	7.888	8.878	0.990	6.177	6.977	0.800
16	3.575	5.115	1.54	7.888	9.228	1.340	6.177	7.207	1.030
24	3.575	5.455	1.88	7.888	9.450	1.562	6.177	7.285	1.108
32	3.575	5.675	2.10	7.888	9.590	1.702	6.177	7.345	1.168
40	3.575	5.825	2.25	7.888	9.730	1.842	6.177	7.405	1.228
48	3.575	5.925	2.35	7.888	9.870	1.982	6.177	7.465	1.288
56	3.575	6.005	2.43	7.888	9.990	2.102	6.177	7.525	1.348
64	3.575	6.085	2.51	7.888	10.11	2.222	6.177	7.585	1.408

Table-3.3

Cumulative volume change for 5, 10, 20% fiber volume fraction composites in subzero condition

Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
4	5.386	5.679	0.293	6.082	6.537	0.455	4.893	4.988	0.095
8	5.386	5.782	0.396	6.082	6.650	0.568	4.893	5.052	0.159
12	5.386	5.837	0.451	6.082	6.728	0.646	4.893	5.111	0.218
16	5.386	5.862	0.476	6.082	6.799	0.717	4.893	5.164	0.271
20	5.386	5.877	0.491	6.082	6.855	0.773	4.893	5.206	0.313
24	5.386	5.890	0.504	6.082	6.879	0.797	4.893	5.213	0.320
28	5.386	5.892	0.506	6.082	6.916	0.817	4.893	5.219	0.326

Table-3.4

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

Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
8	6.910	7.090	0.180	10.970	11.170	0.200	8.540	8.920	0.380
16	6.910	7.270	0.360	10.970	11.350	0.380	8.540	9.130	0.590
24	6.910	7.380	0.470	10.970	11.500	0.530	8.540	9.305	0.765
32	6.910	7.460	0.550	10.970	11.620	0.650	8.540	9.452	0.912
40	6.910	7.520	0.610	10.970	11.726	0.756	8.540	9.577	1.037
48	6.910	7.570	0.660	10.970	11.817	0.847	8.540	9.629	1.089
56	6.910	7.610	0.700	10.970	11.845	0.875	8.540	9.639	1.099
64	6.910	7.620	0.710	10.970	11.850	0.880	8.540	9.648	1.108

Table-3.5

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

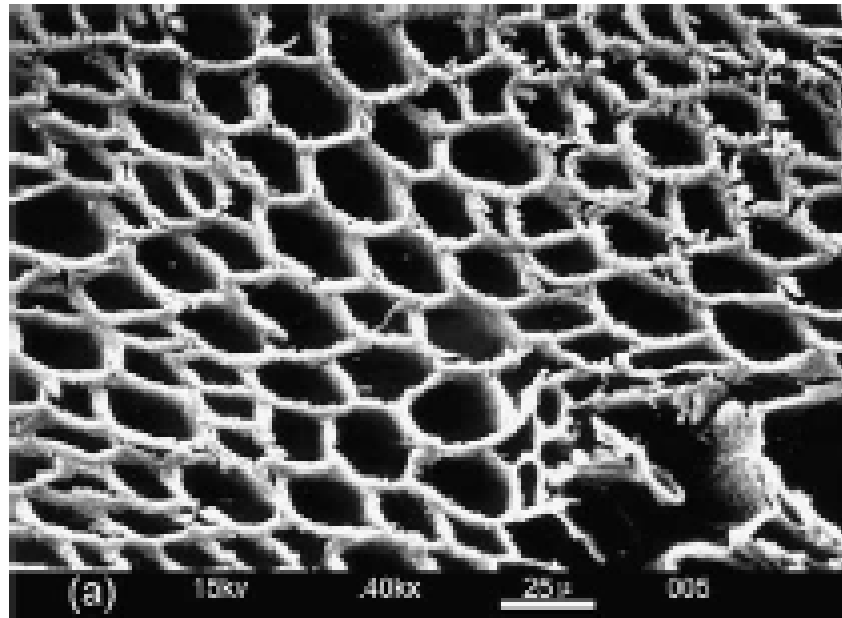| Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
8	8.15	8.39	0.24	7.99	8.26	0.27	8.97	9.14	1.01
16	8.15	8.52	0.37	7.99	8.51	0.52	8.97	9.47	1.34
24	8.15	8.60	0.45	7.99	8.75	0.76	8.97	9.77	1.64
32	8.15	8.68	0.53	7.99	8.97	0.98	8.97	9.97	1.84
40	8.15	8.75	0.60	7.99	9.25	1.26	8.97	10.12	1.99
48	8.15	8.81	0.66	7.99	9.39	1.40	8.97	10.23	2.10
56	8.15	8.87	0.72	7.99	9.42	1.43	8.97	10.23	2.10
64	8.15	8.89	0.74	7.99	9.44	1.45	8.97	10.24	2.11

Table-3.6

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

Volume Fraction of fibers	5%			10%			20%		
Treatment (hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
4	6.470	6.494	0.024	6.970	6.990	0.020	5.320	5.340	0.020
8	6.470	6.514	0.044	6.970	7.010	0.040	5.320	5.360	0.040
12	6.470	6.529	0.059	6.970	7.020	0.050	5.320	5.380	0.060
16	6.470	6.539	0.069	6.970	7.028	0.058	5.320	5.398	0.078
20	6.470	6.543	0.073	6.970	7.032	0.062	5.320	5.402	0.082
24	6.470	6.544	0.074	6.970	7.032	0.062	5.320	5.402	0.082

Table-3.7

Flexural strengths of 5, 10 and 20% fiber volume fraction composites

Volume fraction of fibers (%)	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 3.1 SEM micrographs of the cross section of a bagasse fiber.

Fig 3.2 Testing machine with the specimen in loading position
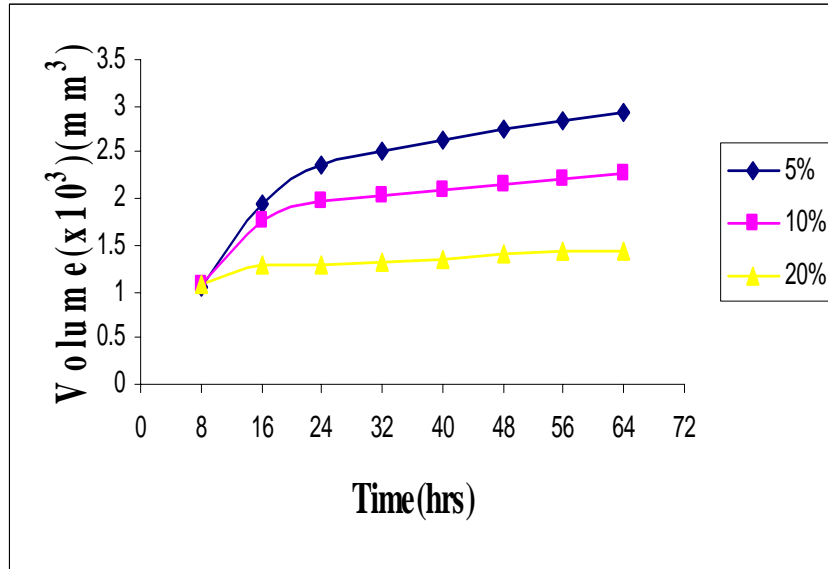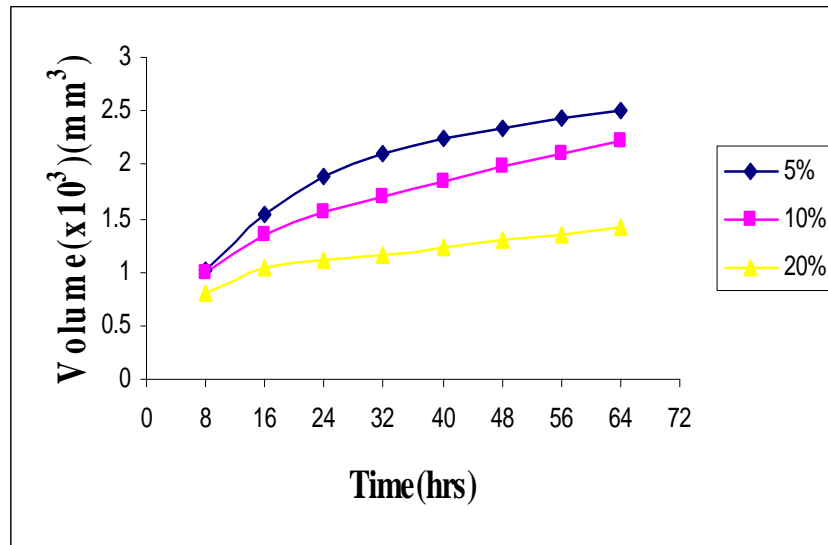
Fig.3.3 Cumulative Volume Change in Different Volume
Fraction of Composites for different time of exposure under steam treatment

Fig.3.4 Cumulative Volume Change in Different Volume
Fraction of Composites for different time of exposure under saline treatment
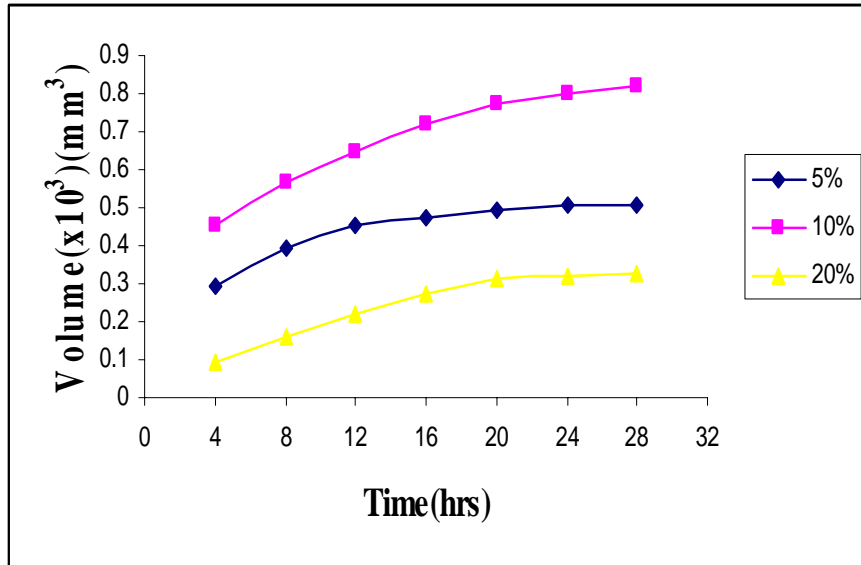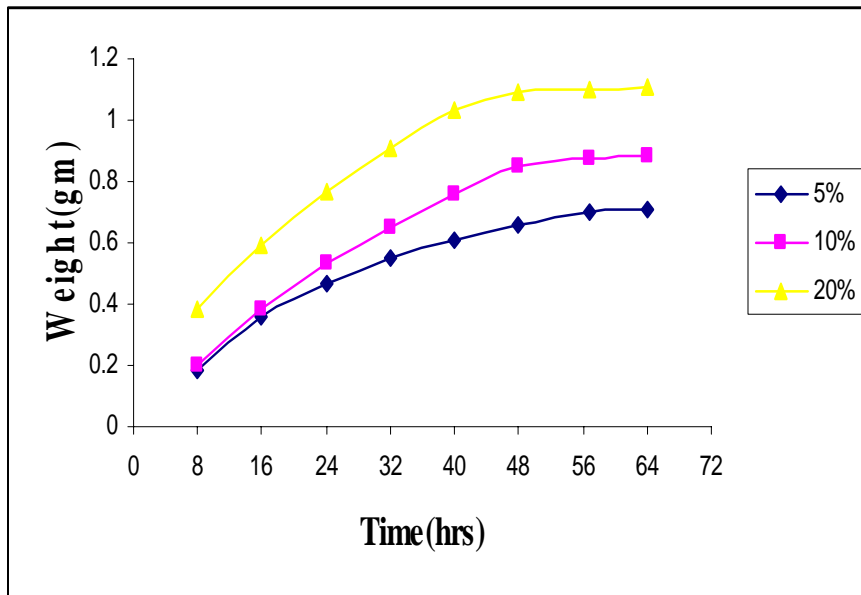
Fig.3.5 Cumulative Volume Change in Different Volume

Fraction of Composites for different time of exposure under subzero treatment

Fig.3.6 Time dependent cumulative weight change (due to %

of moisture absorption) for different volume fraction of composites exposed to steam
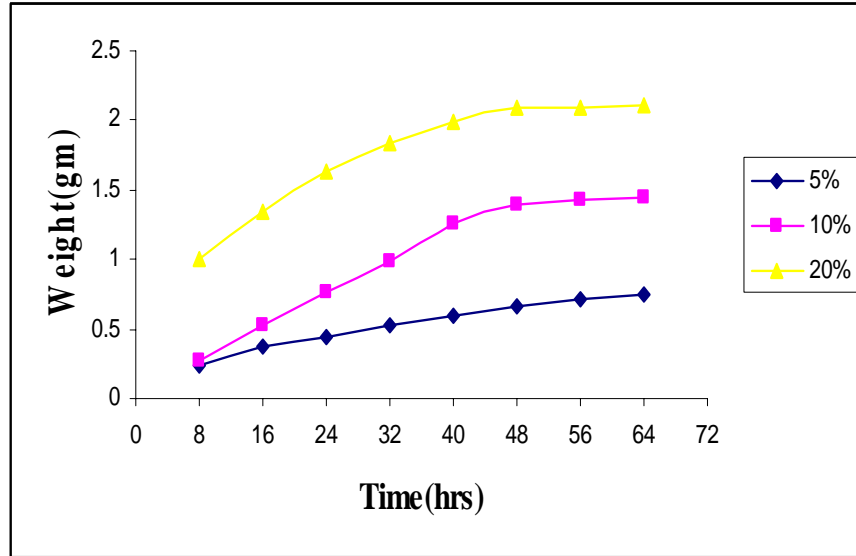
Fig.3.7 Time dependent cumulative weight change (due to % of moisture absorption) for different volume fraction of composites exposed to saline treatment
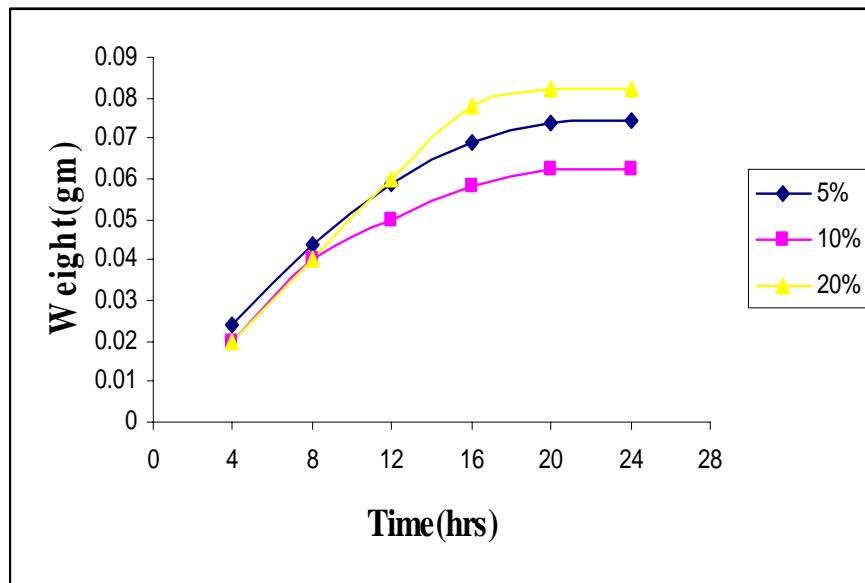
Fig.3.8 Time dependent cumulative weight change (due to % of moisture absorption) for different volume fraction of composites exposed to subzero treatment
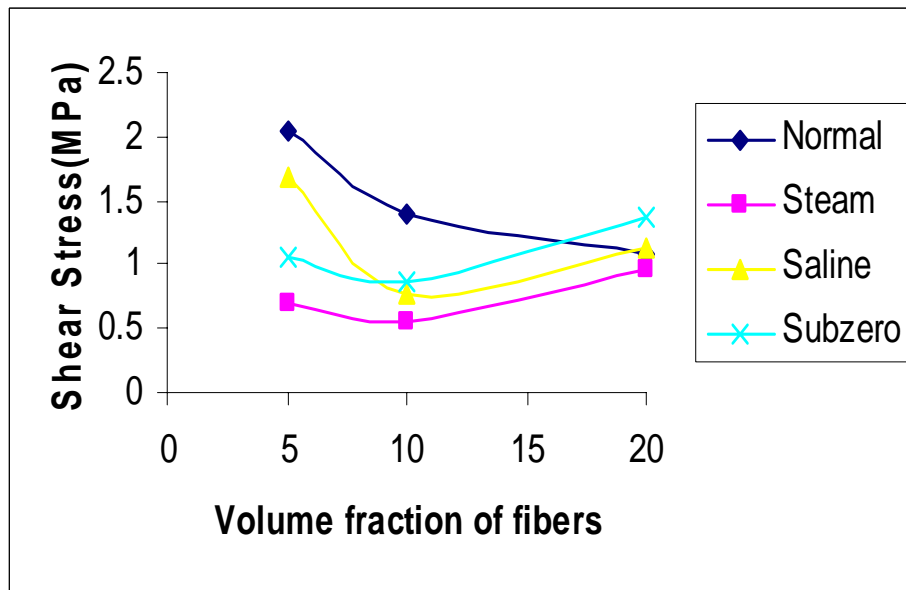
Fig.3.9 Variation of the shear stress of the composites for various treatments
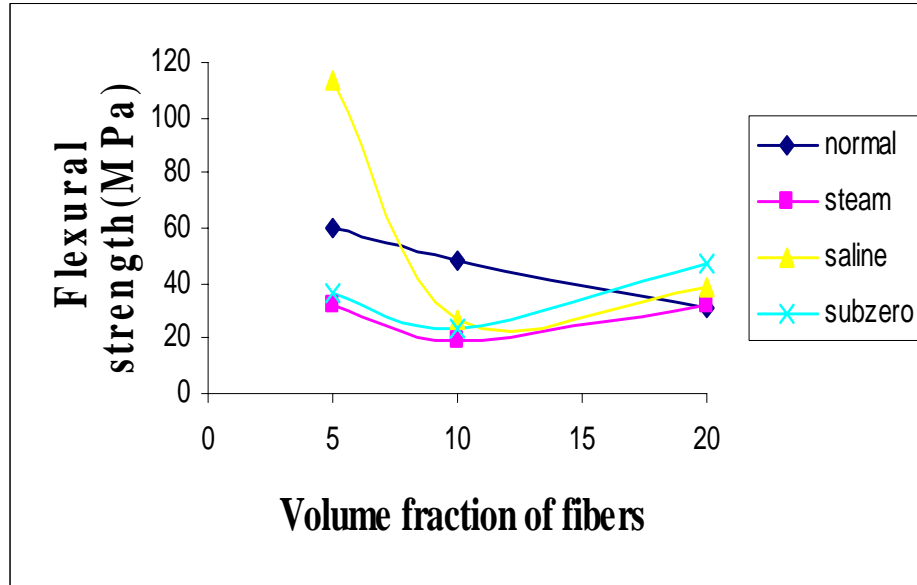
Fig.3.10 Variation of the flexural strength of the composites for various treatments
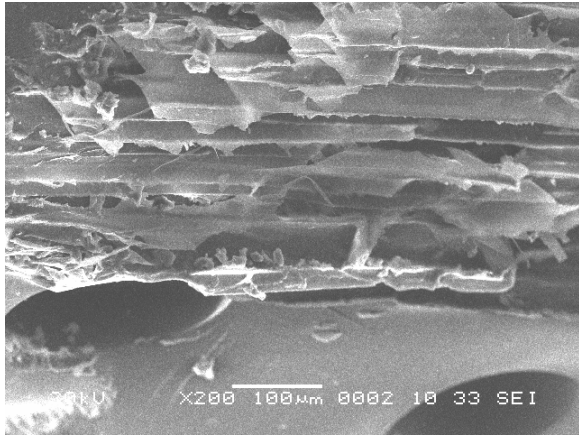
(a) Normal
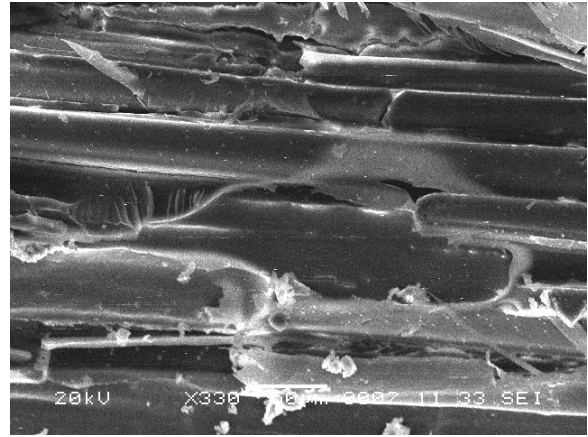
(b) Steam
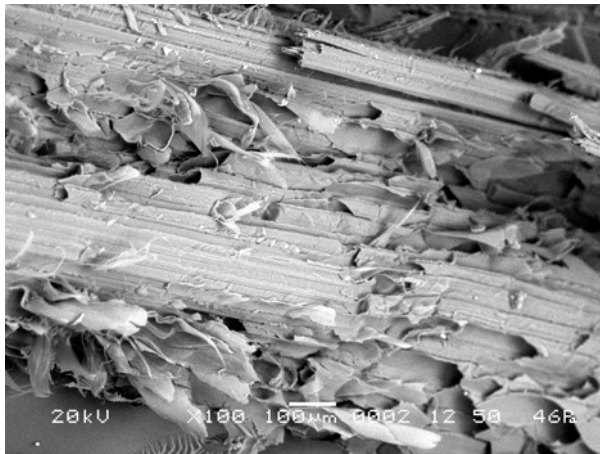
(c) Subzero
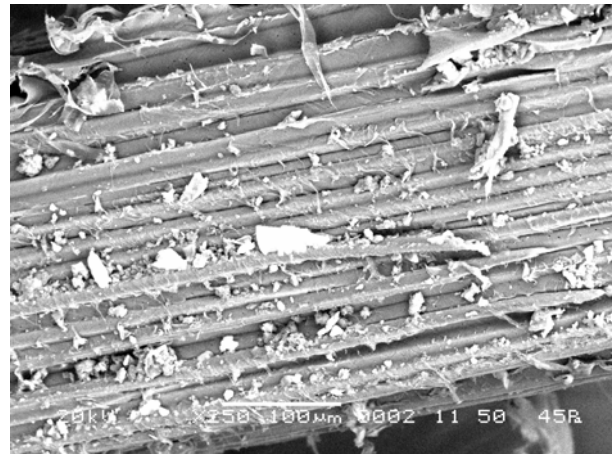
(d) Saline

Fig 3.11 Fracture surface of composites under various treatments

4.1   INTRODUCTION

It is concluded from the previous chapter that the strength of the composites increases with increase in fiber volume fraction when subjected to different environmental treatment. Since the interfacial bonding between the reinforcing fibers and the resin matrix is an important element in realizing the mechanical properties, several authors [35-39] have focussed the studies on the treatment of fibers to improve the bonding with resin matrix. The mechanical properties of the composites are controlled by the properties and quantities of the component materials and by the character of the interfacial region between matrix and reinforcement. Lack of good interfacial adhesion makes the use of cellular fiber composites less attractive. The adhesion between the natural fiber and the polymer matrix can be increased by modifying the fiber surface. Physical modification changes the structural and surface properties of the fiber there by influencing the mechanical bonding with the matrix. But the chemical modification of the fibers such as treatment with acetone alters the surface properties so that better wetting of the fibers with the matrix is possible. This removes the organic residues from the surface of the fibers which enhances the adhesion because natural fibers are coarse in structure, and thus, enable an interlocking mechanism with the matrix.

For the present case to have a good bonding between the fiber and the resin matrix bagasse have been treated with acetone. The subsequent section will elaborate the experimental work done and the results obtained there from to achieve the objective.

4.2   EXPERIMENT

In the present investigation the fibers were treated with acetone and the groups of samples involved are 20 % fiber volume fraction of varying bagasse fiber surface treatment, namely unwashed, washed, unwashed treated with acetone and washed treated with acetone composites.

4.2.1 Acetone treatment of bagasse fibers

The bagasse fibers were washed in soxhlet extractor (fig 4.1) with acetone for approximately 1-1.5hrs. The acetone was evaporated (boiled at 63^0C) and condensed back into the volume with the fibers. This process was repeated four times for each batch. The used acetone was discarded before the new batch was cleaned in the same manner. The acetone changed from transparent to light yellow after treatment due to the presence of waxes and organic materials after the extraction.

All the samples were washed with pressurized water at a temperature of 90^0C for 70 minutes before acetone treatment except unwashed samples.

4.2.2 Composite preparation

The same procedure was followed for preparation of composite as explained in chapter-3, art 3.2 (b). The only difference is that in the present case 20% volume fraction of unwashed, unwashed treated with acetone, washed and washed treated with acetone fibers were taken for preparation of composites. The samples after preparation were taken out of the mold, cut into different sizes and kept in air tight container for further experimentation.

4.2.3 Treatment under various environmental conditions

The effects of environment on the mechanical properties of the composite samples were studied by putting them under different conditions as:
(a) Steam treatment
(b) Saline treatment
(c) Subzero condition

The same procedure was followed for treating the composites under various environmental conditions as explained in chapter-3, art 3.3. Change in volume and weights were calculated and were presented in table no.4.1 to 4.7.

4.2.4 Flexural strength:-

The composites after treated in various weathering conditions. 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 experimental procedure remains same as described in chapter-3, art 3.5 (iii). The flexural strength and inter laminar shear stress found out from the experiment are presented in table 4.7.

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 4.1 to 4.7.

4.3   RESULTS AND DISCUSSION

The results of steam swelling and steam absorption are shown in fig 4.2 and 4.3 respectively. It is observed from the results that the swelling increases with an increase in time up to 56 hrs for unwashed, unwashed treated and washed samples however it stabilizes after 40 hrs for washed treated samples. It is also observed that washed and treated bagasse samples exhibited the least swelling.

Absorption of steam (fig 4.3) increases up to 56 hrs, but the rate of steam absorption is higher in unwashed, unwashed treated and washed samples than washed treated samples. How ever the rate of absorption of moisture is faster at initial period up to about 30-40 hrs then rate of absorption slows down.

During saline treatment (fig 4.4 and fig 4.5) not only moisture absorption takes place but also transport of sodium and chlorine ions do occur leading to some what a chemical reaction with the matrix as well as with the fiber. Due to such effect there is not much deviation of swelling and water absorption amount irrespective of treated and untreated fibers.

Fig 4.7 shows the trend in water absorption from 8 hrs to 56 hrs while fig 4.6 represents the water swelling for sub zero treatment. The rate of absorption of water is linear in all the cases after 40 hrs while for washed treated samples it shows linearity after 24 hrs. The trend in water absorption is washed treated<washed<unwashed treated<unwashed.

The water swelling in washed treated samples is the lowest. It is seen from the plot (fig 4.6) that unwashed fiber has the highest swelling while the unwashed treated and the washed samples lies near to each other. There is dramatic shift for washed treated samples which can be visualized from the plot.

There is little difference in water absorption for washed treated samples with respect to unwashed, unwashed treated and washed samples. This is due to the spongy nature of the pitch of the bagasse which can absorb more water; but the swelling for washed treated samples is much lower because of removal of lignin content in the surface of fibers and fibrils with the acetone.

Fig 4.8 shows the variation in shear stress of the composites under different environmental conditions. The plot shows that the washed and treated fiber composites shows maximum value in all the environmental conditions they are subjected to. It also appears from the plot that for steam treatment the variation is higher where as in subzero condition the variation is almost negligible.

The variations in flexural strength of the composites under various environmental conditions are presented in fig 4.9. It is clear from the plot that the washed and treated fiber composites posses the maximum strength in all the environmental conditions viz. natural, steam, saline and subzero treatment. The flexural strength of the washed treated fiber composites increases by 50 % of the unwashed, unwashed treated and washed fiber composites in normal condition while it is almost double under saline treatment. In case of steam treatment it shows a linear increase in the flexural strength, but the variation is much less under subzero condition. This improved property of the composite is due to the treatment of fiber with acetone which results in dissolution of hemicellulose, development of crystallinity and fibrillation thus creating superior bonding with matrix.

4.4 STUDY OF FAILURE MODES

The composites processed after treating the fiber in acetone has improved the strength properties. The fracture surfaces after exposed to different environment are shown in fig 4.10(a-c).

Samples without any environmental exposure (Fig 4.10a) have shown the least improvement in strength properties. It may be due to pulling out of fibers giving rise to fracture. This implies improper interlayer/ fiber matrix bonding. When the composite is exposed to steam (fig 4.10b) probably fiber-matrix bonding has improved for which there is an improvement of flexural strength. There is no evidence of inter-fibril fracture but pulling out of poolen from the fibers is seen. As explained earlier the fiber breakage was visible for untreated fiber subjected to subzero condition but with treated fiber no such breakage was observed (fig.4.10c) and this may be due to increase in bonding strength between fiber and the matrix. However the sample which has given highest strength exhibit layered and stepped type appearance. When the composite is put in saline environment (fig 4.10d) probably the fiber-matrix interface bonding has been improved. This may be due to propagation of moisture through fibril interfaces; or may be ion exchange (Na^+ + Cl^- etc) in between polymer and natural fibers composition. These reasons might be responsible for enhancing the mechanical properties of the composite.

4.5 CONCLUSION

The following conclusions are drawn from the present work.

1. By comparing the flexural strength of the composites with varying fiber treatment, the best mechanical property results are obtained with bagasse fiber that are both washed and treated with acetone.

2. Acetone treatment increases the property of the fibers by dissolution of hemi cellulose thus creating a superior bonding with the matrix.

Table-4.1

Cumulative volume change in treated fiber composites for steam treatment

Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
8	11.030	11.189	0.159	11.165	11.277	0.112	8.370	8.475	0.105	8.626	8.713	0.087
16	11.030	11.282	0.252	11.165	11.353	0.188	8.370	8.547	0.177	8.626	8.791	0.165
24	11.030	11.374	0.344	11.165	11.414	0.249	8.370	8.600	0.230	8.626	8.827	0.201
32	11.030	11.414	0.384	11.165	11.472	0.307	8.370	8.626	0.256	8.626	8.841	0.215
40	11.030	11.446	0.416	11.165	11.498	0.333	8.370	8.650	0.280	8.626	8.855	0.229
48	11.030	11.475	0.445	11.165	11.509	0.344	8.370	8.672	0.302	8.626	8.858	0.232
56	11.030	11.485	0.455	11.165	11.517	0.352	8.370	8.672	0.302	8.626	8.861	0.235

Table-4.2

Cumulative volume change in treated fiber composites for saline treatment

Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
8	9.516	9.605	0.089	12.340	12.401	0.061	8.076	8.129	0.053	11.549	11.593	0.044
16	9.516	9.666	0.150	12.340	12.443	0.103	8.076	8.174	0.098	11.549	11.634	0.085
24	9.516	9.706	0.190	12.340	12.484	0.144	8.076	8.208	0.132	11.549	11.664	0.115
32	9.516	9.740	0.224	12.340	12.516	0.176	8.076	8.240	0.164	11.549	11.705	0.156
40	9.516	9.757	0.241	12.340	12.543	0.203	8.076	8.261	0.185	11.549	11.719	0.170
48	9.516	9.772	0.256	12.340	12.562	0.222	8.076	8.270	0.194	11.549	11.719	0.170
56	9.516	9.773	0.257	12.340	12.571	0.231	8.076	8.278	0.202	11.549	11.719	0.170

Table-4.3

Cumulative volume change in treated fiber composites for subzero treatment

Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment (hrs)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)	Initial Vol. (mm^3)	Final Vol. (mm^3)	Difference (mm^3)
8	9.064	9.159	0.095	8.765	8.855	0.090	8.090	8.138	0.048	11.130	11.159	0.029
16	9.064	9.223	0.159	8.765	8.900	0.135	8.090	8.180	0.090	11.130	11.184	0.054
24	9.064	9.282	0.218	8.765	8.924	0.159	8.090	8.219	0.129	11.130	11.204	0.074
32	9.064	9.335	0.271	8.765	8.939	0.174	8.090	8.235	0.145	11.130	11.213	0.083
40	9.064	9.377	0.313	8.765	8.950	0.185	8.090	8.254	0.164	11.130	11.221	0.091
48	9.064	9.384	0.320	8.765	8.955	0.190	8.090	8.261	0.171	11.130	11.227	0.097
56	9.064	9.390	0.326	8.765	8.957	0.192	8.090	8.263	0.173	11.130	11.232	0.102

Table-4.4

Cumulative weight change in treated fiber composites for steam treatment

Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment (hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
8	10.52	10.96	0.44	14.10	14.58	0.48	8.46	8.92	0.46	14.63	15.05	0.42
16	10.52	11.23	0.71	14.10	14.79	0.69	8.46	9.05	0.59	14.63	15.20	0.57
24	10.52	11.45	0.93	14.10	14.99	0.89	8.46	9.22	0.76	14.63	15.34	0.71
32	10.52	11.63	1.11	14.10	15.18	1.08	8.46	9.37	0.91	14.63	15.47	0.84
40	10.52	11.81	1.29	14.10	15.32	1.22	8.46	9.49	1.03	14.63	15.60	0.97
48	10.52	11.98	1.46	14.10	15.40	1.30	8.46	9.54	1.08	14.63	15.66	1.03
56	10.52	12.01	1.49	14.10	15.42	1.32	8.46	9.55	1.09	14.63	15.69	1.06

Table-4.5

Cumulative weight change in treated fiber composites for saline treatment

| Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment (hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
8	14.29	14.68	0.39	10.20	10.51	0.31	9.67	9.96	0.29	14.36	14.59	0.23
16	14.29	14.87	0.58	10.20	10.69	0.49	9.67	10.14	0.47	14.36	14.81	0.45
24	14.29	15.05	0.76	10.20	10.86	0.66	9.67	10.27	0.60	14.36	14.93	0.57
32	14.29	15.22	0.93	10.20	11.02	0.82	9.67	10.42	0.75	14.36	15.04	0.68
40	14.29	15.38	1.09	10.20	11.17	0.97	9.67	10.53	0.86	14.36	15.15	0.79
48	14.29	15.54	1.25	10.20	11.30	1.10	9.67	10.66	0.99	14.36	15.19	0.83
56	14.29	15.59	1.30	10.20	11.32	1.12	9.67	10.67	1.00	14.36	15.19	0.83

Table-4.6

Cumulative weight change in treated fiber composites for subzero treatment

| Types of Composites	Unwashed			Unwashed treated			Washed			Washed treated		
Treatment(hrs)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)	Initial Wt. (gm)	Final Wt. (gm)	Difference (gm)
8	14.13	14.33	0.20	12.96	13.15	0.19	12.56	12.73	0.17	9.99	10.14	0.15
16	14.13	14.35	0.22	12.96	13.16	0.20	12.56	12.74	0.18	9.99	10.16	0.17
24	14.13	14.36	0.23	12.96	13.17	0.21	12.56	12.76	0.20	9.99	10.17	0.18
32	14.13	14.37	0.24	12.96	13.19	0.23	12.56	12.77	0.21	9.99	10.17	0.18
40	14.13	14.38	0.25	12.96	13.20	0.24	12.56	12.78	0.22	9.99	10.17	0.18
48	14.13	14.39	0.26	12.96	13.20	0.24	12.56	12.78	0.22	9.99	10.17	0.18
56	14.13	14.39	0.26	12.96	13.20	0.24	12.56	12.78	0.22	9.99	10.17	0.18

Table-4.7

Flexural strength in treated fiber composites

| Types of Composites	Conditions	Shear stress(MPa)	Flexural strength(MPa)
Unwashed	Normal	0.636	20.780
	Steam	0.246	9.517
	Saline	0.681	27.150
	Subzero	1.140	44.110
Unwashed treated	Normal	0.909	31.580
	Steam	0.412	16.090
	Saline	1.123	37.300
	Subzero	1.147	44.270
Washed	Normal	1.087	31.060
	Steam	0.959	32.580
	Saline	1.123	38.820
	Subzero	1.368	47.210
Washed treated	Normal	1.195	46.760
	Steam	1.298	50.250
	Saline	2.012	78.720
	Subzero	1.222	58.440
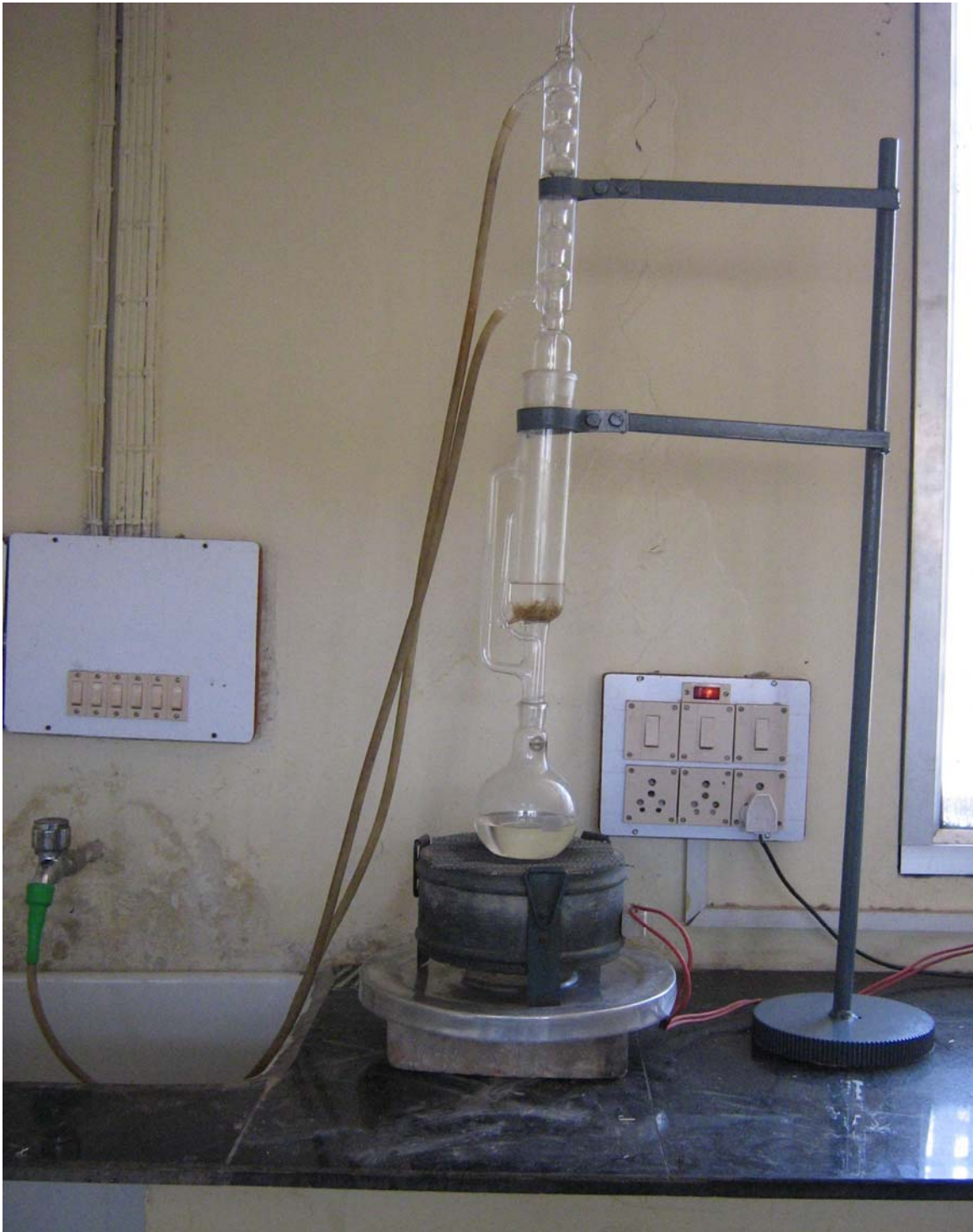
Fig 4.1 Soxhlet extractor
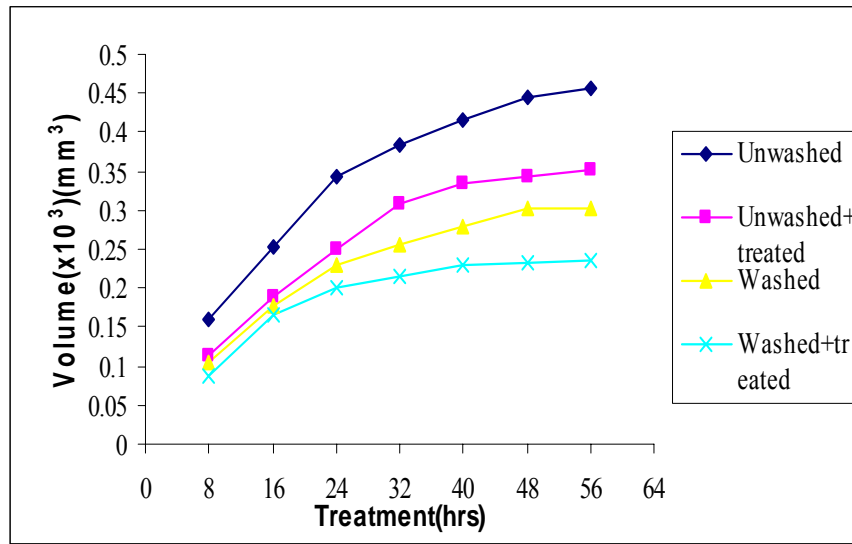
Fig.4.2 Cumulative Volume Change in Different treated fiber
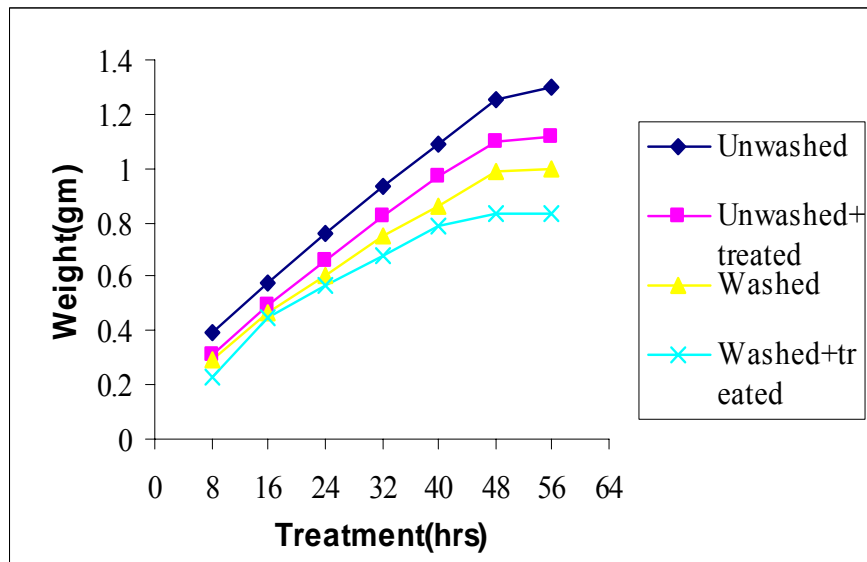Composites for different time of exposure under steam treatment
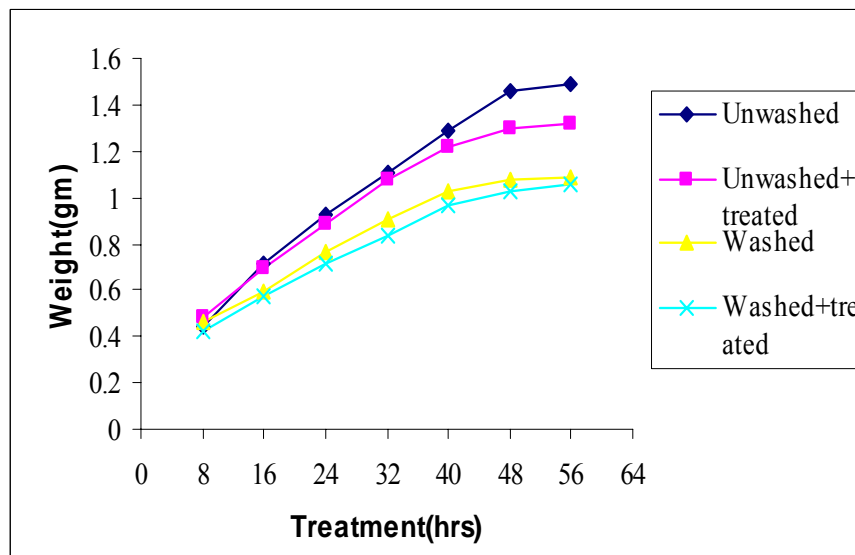
Fig.4.3 Time dependent cumulative weight change (due to %
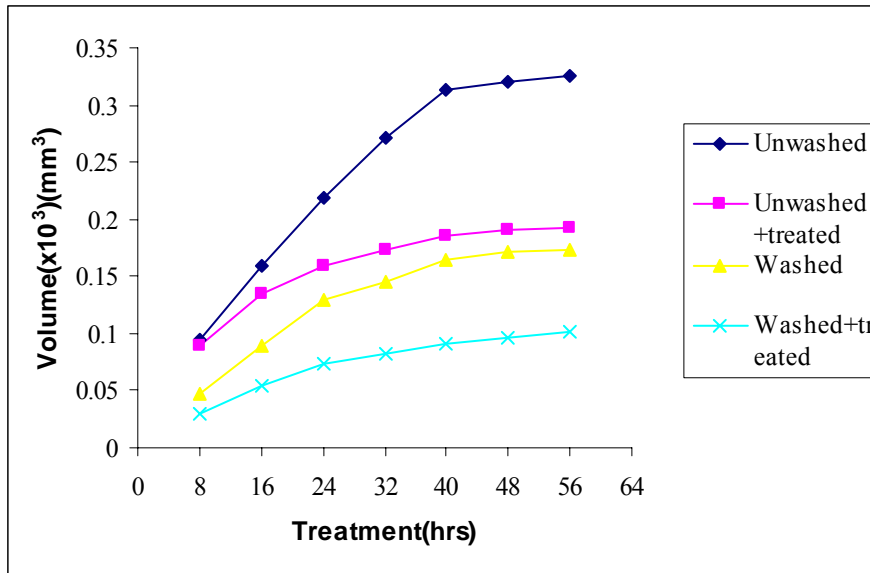of moisture absorption) for different treated fiber composites exposed to steam
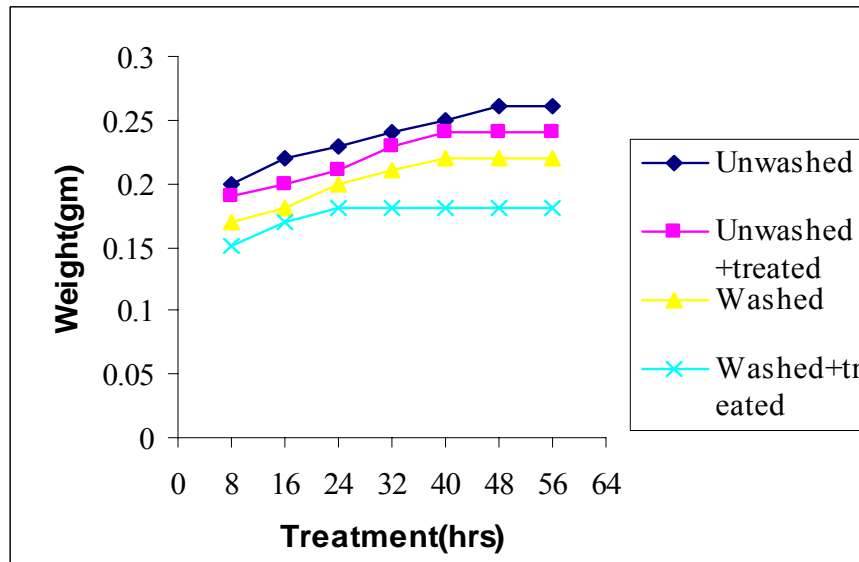
53
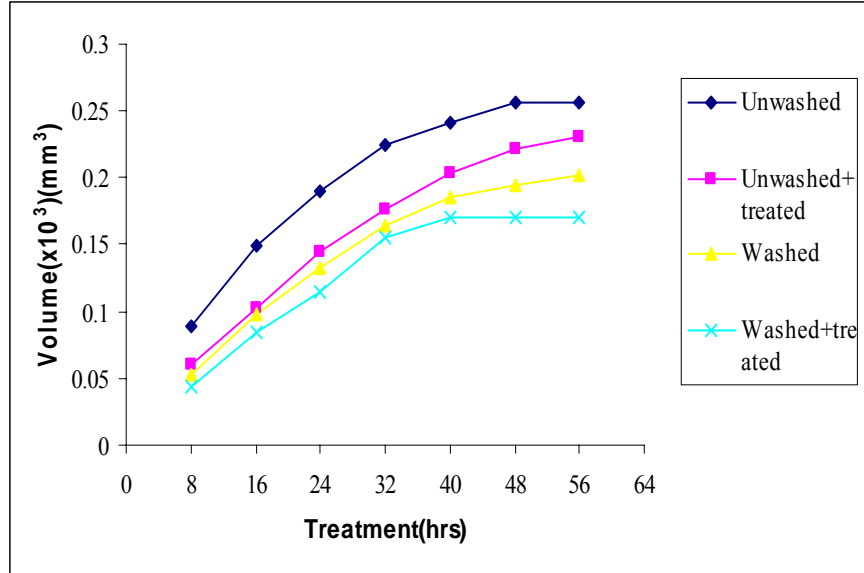
Fig.4.4 Cumulative Volume Change in Different treated fiber
Composites for different time of exposure under saline treatment

Fig.4.5 Time dependent cumulative weight change (due to %
of moisture absorption) for different treated fiber composites exposed to saline treatment
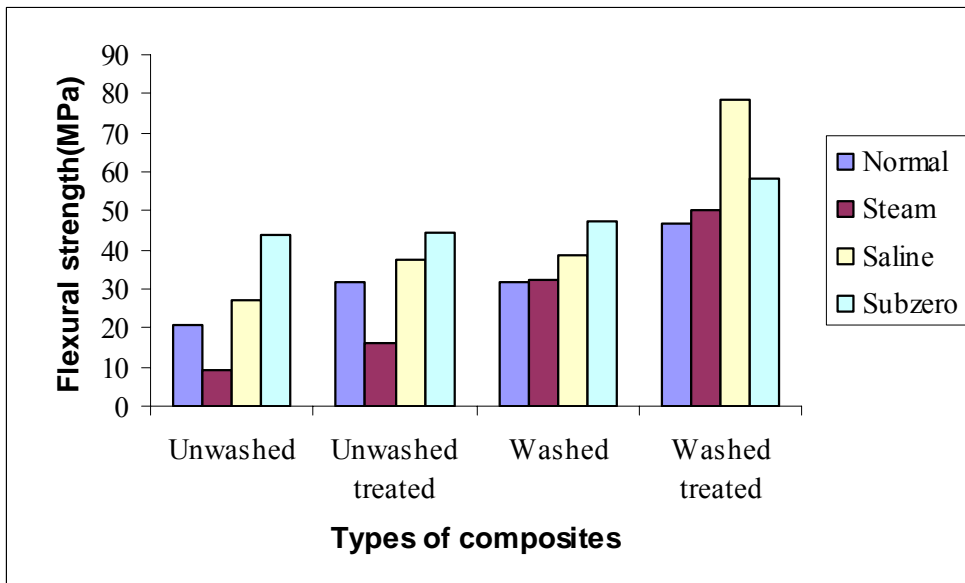
54

Fig.4.6 Cumulative volume change in different treated fiber composites under different time of exposure under subzero condition
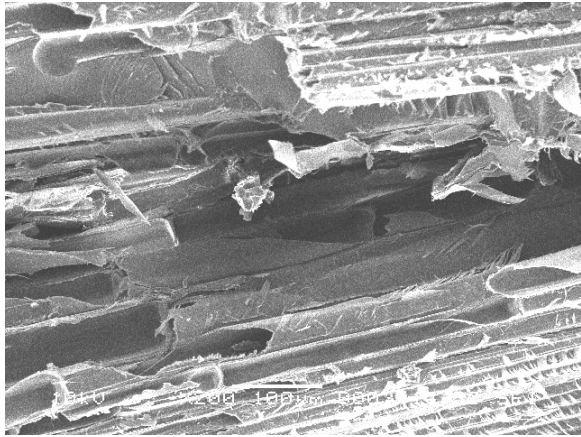

Fig.4.7 Time dependent cumulative weight change (due to % of moisture absorption) for different treated fiber composites exposed to subzero treatment
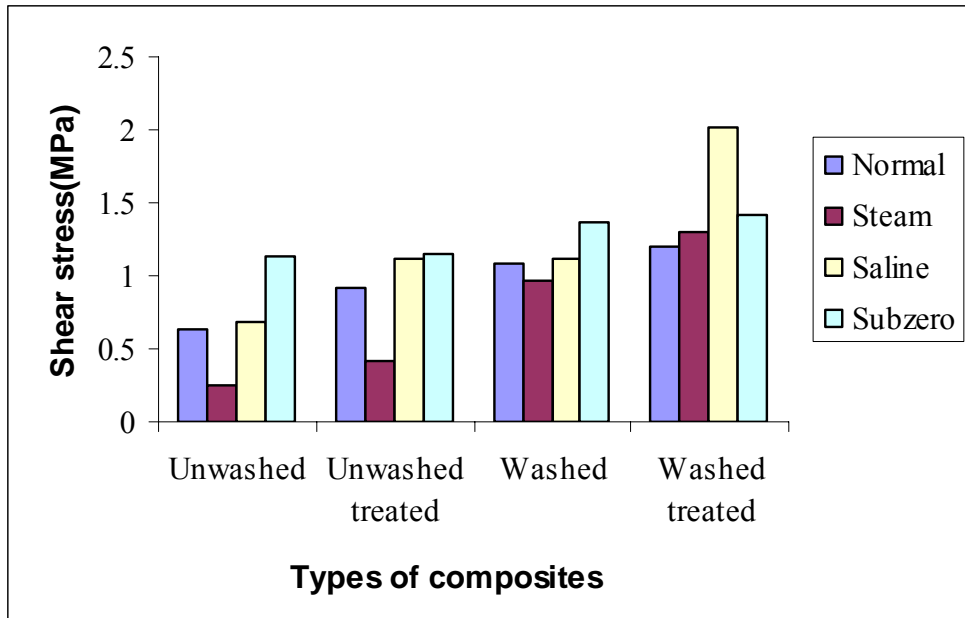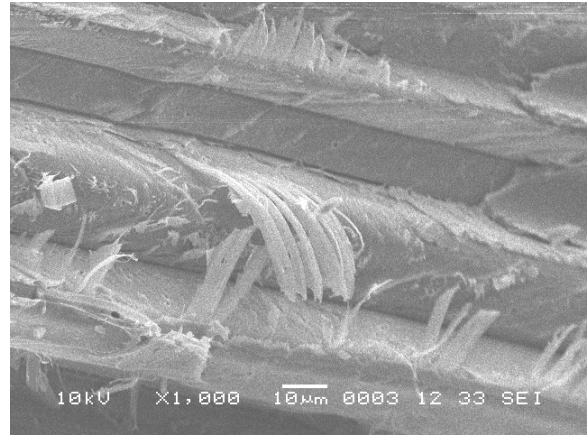
Fig.4.8 Variation of the shear stress of the composites for various treatments
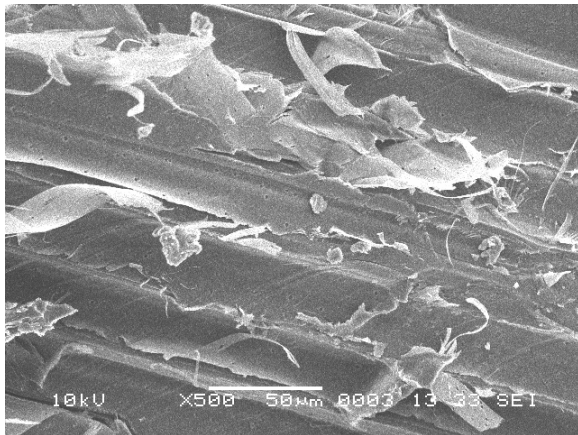

Fig.4.9 Variation of the flexural strength of the composites for various treatments
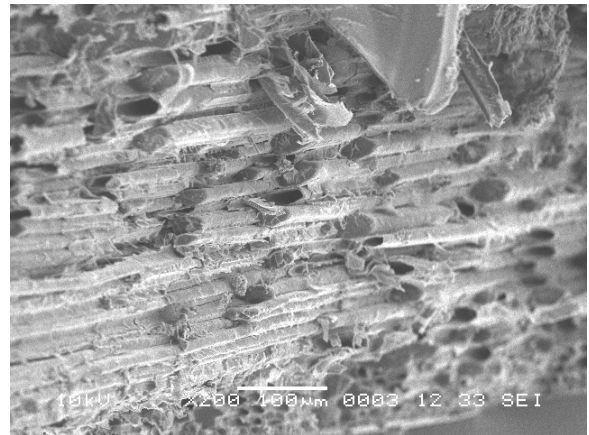
(a) Normal

(b) Steam

(c) Subzero

(d) Saline

Fig 4.10 Fracture surface of the treated fiber composites in various environmental conditions

5.1   CONCLUSIONS

The following conclusions are drawn from the above studies.

1. 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.

2. By comparing the flexural strength of composite with varying fiber treatment, it was evident that best mechanical property results were obtained with bagasse fiber that were both washed and treated with acetone.

3. Results showed that flexural strength could be increased by 50% after reinforcing the polymer with 20% washed and acetone treated bagasse fibers in comparision to raw fibers.

4. From the morphology of the fractured surface (treated under different environment) for the untreated fiber it was found that fiber pull outs were the predominant mode of failure. However some evidence of fiber breakage was also noticed. It is also found (washed and treated samples) that after treating the fiber with acetone the fiber –matrix bonding has improved a lot which results in higher flexural strength.

5. 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.

5.2 RECOMMENDATION FOR FURTHER RESEARCH

⬧ In this study fiber volume fraction of 20% has been used. This can be further increased to find out the optimum filler volume fraction.

⬧ The fiber matrix bonding has been increased by treating the fibers with acetone. Improvements in the process of bagasse cleaning and surface treatment could increase the performance of the composite and provide better competitiveness with respect to other materials in the same structural class. Chemical modification of the fiber surfaces such as dewaxing, treatment with alkali etc. can be tried.

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