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Mechanical Properties Evaluation of Eucalyptus Fiber Reinforced Epoxy Composites

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Abstract
The paper presents the evaluation of the mechanical properties (i.e.tensile, flexural and compression) of eucalyptus fiber reinforced composite, so as to explore the possibility of its usage as structural material in place of wood. Eucalyptus fiber is anatural fiber which has been used as a reinforcement material in polymer composites, due to its low density and good compression strength compared to other natural fibers. The composites were prepared with 10%, 15%, 20% and 25% fiber content (by volume) and the mechanical properties were studied. The Morphological properties of tensile fracture were studied using Scanning Electron Microscope (SEM). Although eucalyptus fiber reinforced polymer composite showed higher tensile, flexural, compression strength and strain rate with increasing in fiber content, SEM micrographs showed that there is poor fiber/matrix adhesion.

Keywords: eucalyptus reinforced composite, tensile, flexural, compression properties.

1. Introduction

Eucalyptus is one of three similar genera that are commonly named to as "eucalyptus", the others being Corymbia and Angophora. The generic name is derived from the Greek words eu "well" and kalyptos "covered", referring to the operculum on the calyx that initially conceals the flower Eucalyptus tereticornis, known as Mysore gum in India and forest gum in Australia, is one of the most extensively planted eucalyptus species in India [1].The continued success of regenerated eucalyptus fibers over more than 100 years has been based on a broad spectrum of fiber properties. Within the Man-Made Fibers, synthetic fibers are based on crude-oil, but eucalyptus fibers are based on the most naturally occurring organic polymer: Cellulose. Paper mills target for productivity, monetary values and efficiency. Eucalyptus pulp is a raw material for the manufacture of several grades of papers, for each paper grade and paper mill design, differs in the pulp quality requirements. [2]

Plant fibers comprise mostly lignin, cellulose, and hemicellulose. The remaining components are the pectin and wax substances, which are generally referred to as surface impurities [3]. At the molecular level, at which the fiber–matrix interaction is influenced by chemical groups present on the surface of matrix and fiber, the interfacial adhesion is dependent on the physicochemical interaction (e.g. van der Waals forces, acid–base interactions, hydrogen bond) and chemical bonds (covalent bonds). Chemical composition, and also moisture content, of the fibers affect the properties and end employment of them. Since higher cellulose content leads to higher stiffness, natural fibers can be utilized as a reinforcement material for polymers. Because of the fact that high water content, as well as moisture absorption, of the cellulosic fibers cause swelling, poor mechanical properties and instability in dimension come into existence [13]. Lignin content of fiber facilitates reactivity and allows better response to chemical modifications [3]. At the higher grades, the fiber–matrix interface can be characterized by mechanical tests carried out on either single fiber micro-composites or bulk laminate composites.[4]

The review of literature indicated the absence of the work reported on the evaluation of mechanical properties of Eucalyptus fiber reinforced polymer composite. Hence, the scope of this work reported in this paper is to evaluate the mechanical properties by varying fiber volume content. The morphology, chemical composition, moisture absorption and mechanical properties, of Eucalyptus fiber–epoxy composite have been determined.

2. Materials and methods

Composite materials are developed by the compounding of two fabrics; the chosen composite includes following materials.

- Matrix material
- Reinforcements

2.1 Matrix material (Epoxy-L_{12} Resin and hardener-K_6)

Epoxy resin is widely used in industrial application because of their high strength and mechanical adhesiveness characteristic. It is also a likewise solvent and has good chemical resistance over a wide range of temperature. The Density of epoxy Resin is 1.25 g/cc and having a viscosity at 250Oc is 9000-12000 MPa.S, the weight percentage of hardener used in the present investigation is in the proportion of 10:1. [5, 14]

2.2 Reinforcements (eucalyptus fiber)

Eucalyptus fibers are extracted from eucalyptus trees, the art of manufacturing eucalyptus fiber is the transformation of inhomogeneous, contaminated cellulosic pulp fibers into tailor made cellulosic fibers with well-defined physical and chemical properties. It is a renewable polymer which has various molecular structures, this fiber having density 1.3 Dinear, fiber length 44-115mm, usually white in color [6], eucalyptus fiber is shown in Figure. 1

Figure. 1Eucalyptus fiber

2.2.1 Chemical composition of Eucalyptus fiber

Eucalyptus fibers are constituted by two main components: hemicellulose and cellulose, which are known to present very complex structure. Cellulose, which is the main fraction of the fibers, is a semi crystalline polysaccharide made up of D-glucosidic bonds. A large amount of hydroxyl groups in cellulose gives hydrophilic properties to the natural fibers. Hemicellulose is strongly bound to the cellulose fibrils, presumably by hydrogen bonds; [7] Table 1 shows the chemical compositions of eucalyptus fiber [6].

Table 1 Chemical composition of Eucalyptus fiber

Serial No	Composition	Weight in %
1	Cellulose	95
2	Hemicellulose	3
3	Moisture	11-13
4	Ash	0.2-0.3
5	Oil content	0.3-0.4

2.3 Methodology

- Selection of proper matrix and reinforcement materials.
- Estimating the density of eucalyptus fiber
- Calculating the weight fractions.
- Fabrication of composite material by compress mold technique.
- Specimens prepared as per ASTM standards.
- Tests were conducted,
    1. Tensile
    2. Flexural
    3. Compression

3. Experimental Setup

3.1Composite Preparation

The specimen was prepared by sandwich method and lay-uptechnique [15], Eucalyptus fiber (in chopped form) with Epoxy and hardener were mixed in a container and stirred well continuously, the prepared mixture is poured into the mold prepared by acrylic sheets. The mold with mixture is kept for drying minimum duration of 48 hours at room temperature, by keeping 30 kg of load on it. After drying the samples were cut according to ASTM standards. The samples were made at different fiber content: 10%, 15%, 20%, and 25% (by mass) is presented in table 2

Table 2 Specimen composition with volume fraction

Epoxy Resin	Eucalyptus fiber
90 %	10%
85 %	15%
80%	20%
75%	25%

3.2 Tensile test

Tensile test was conducted by using Universal Testing Machine (TFUC-1000), the tensile test specimens were prepared according **ASTM D3039** standard, the dimension view of specimen is shown in Figure 2. The specimen is in rectangular shape having length, width & thickness in mm 245x25x9 respectively.

Figure. 2Tensile test specimen

3.3 Flexural test

Flexural test was conducted by using Universal Testing Machine (TFUC-1000), the flexural test specimens were prepared according **ASTM D790** standard, the dimension view of specimen is shown in Figure 3. The specimen is in rectangular shape having length, width & thickness in mm 150x25x9 respectively.

Figure.3 Flexural test specimen

3.4 Compression test

Compression test was conducted by using Universal Testing Machine (TFUC-1000), the compression test specimens were prepared according **ASTM D695**standard, the dimension view of specimen is shown in Figure 4, and the specimen is in rectangular shape having length, width and thickness in mm 25x13x9 respectively.

Figure. 4Compression test specimen

4. Results and Discussions

4.1 Tensile properties

The event of fiber content on tensile strength of eucalyptus fiber and epoxy resin composite is represented in Figure 5.From Figure 5 it is noted that, as the load increases deformation goes on increases.The maximum deformation 7.45mm is observed for 25% fiber at 17.7 KN, than the other three compositions. The composite specimen with 25% fiber has more tensile strength compared to other three compositions. It is noticed that the tensile strength increases with increase in fiber content. Several factors affect the tensile strength of composites, are the strength of fibers and matrix, fiber content and interfacial bonding between the fibers and matrix [8].

In general, fiber with higher cellulose content exhibits better mechanical properties, because cellulose increases the potency of the fiber by providing uniform molecular orientation and builds better adhesion matrix [9, 19].Only in 10% fiber content specimen the matrix percentage is more; it tends to absorb of maximum load by matrix. So, it leads to failure of the specimen by the failure of the matrix and participation of fiber in carrying the load is almost negligible. Hence specimens are brittle in nature, due to this resistance to deformation is less, in 25% fiber content specimen fiber percentage is more compared to 10% fiber content specimen and therefore the resistance to deformation and load carrying capacity is high. Good tensile strength also depends to a greater extent on effective and uniform stress distribution [8].

The increasing tensile strength may be due to fiber content which has a higher stiffness than the matrix. With the 10 % fiber content fewer fibers are fused with the matrix, thus, at some spots there will be fewer fibers than other spots. At this spot, elongation will be high because it is high in the matrix. At other spots there will be more fibers which will ensue in less elongation, thus less deformation is in 10% specimen When fiber content is increased; fibers will be distributed in the entire mold [8]. Therefore, the mold should not have spots with fewer fibers, spots with fewer fibers may cause high elongation; thus more deformation is in 25% specimen.

Figure 6 presents the stress–strain behavior of eucalyptus fiber and epoxy resin composite. It can be observed that stress increases linearly with the increase of the strain, however, when it reaches certain stress values, nonlinear behavior is noticed for the10%, 15%, 20% and 25% fiber loading, where strain increases at low stress before undergoing failure. Table 3 shows the tensile properties for all the four specimens.

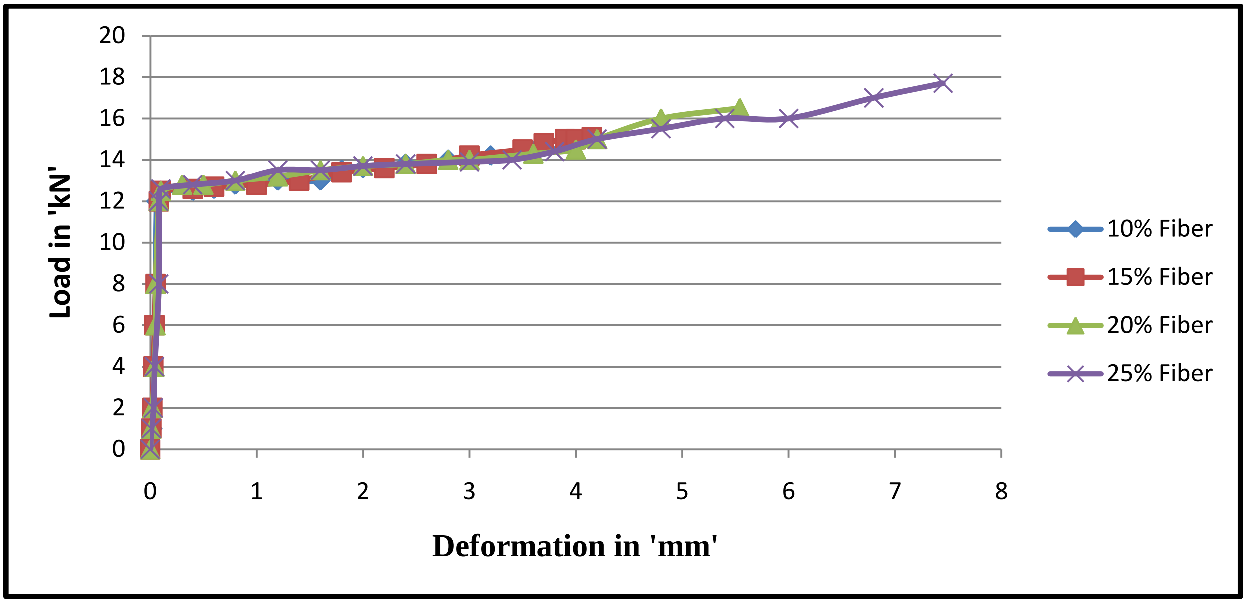

Figure. 5 Effect of fiber content on tensile strength of eucalyptus fiber and epoxy

Table 3 Tensile Properties

Sample	Tensile strength (MPa)	Young's modulus (MPa)	Tensile elongation (%)	Modulus of toughness (MPa)
10% fiber content	58.4	0.0106×10^6	0.56	0.321
15% fiber content	60.4	0.01372×10^6	0.45	0.2718
20% fiber content	66	0.01178×10^6	0.56	0.3696
25% fiber content	70.08	0.01044×10^6	0.66	0.469

4.2 Flexural properties

The effect of fiber content on Flexural strength of Eucalyptus fiber reinforced Epoxy composites presented in Figure 7. It clearly indicates that, the variation in the weight fraction of fiber content does not have much variation in load bearing capacity and the ability to withstand bending of the composite. The composite specimen with 25% fiber content has maximum deformation (2.81mm) at load (13.5KN), than the other three compositions. From the Figure it is observed that, the load is almost linear for the entire specimens, and also 20% and 25% fiber content specimens have similar resistance against deformation, after some level 20% fiber content specimen gradually decreases in deformation compared to 25 % fiber content, this is due to increasing in fiber content. In each composition, the flexural behavior of the specimen is being nearest to the average value of the flexural strength. If the fibers are well distributed with matrix, a higher flexural strength of material can be obtained. Better execution of composite is attained due to homogeneous distribution of fiber in the matrix; as a result stress transfer between fiber and matrix is more effective, and affecting positively on the performance [10]. As the specimen showed low resistance to bending and large displacement without rupture, the epoxy resin can be characterized as ductile-brittle material. Flexural strength is controlled by an extreme layer of reinforcement [18]. No specimen has failed by delamination during loading, and failure mode shows fiber pull out and fiber failure. The crack always initiates on the tension side of the beam and slowly propagates in an upward direction [11]. Table 4 shows the flexural properties for all the four specimens

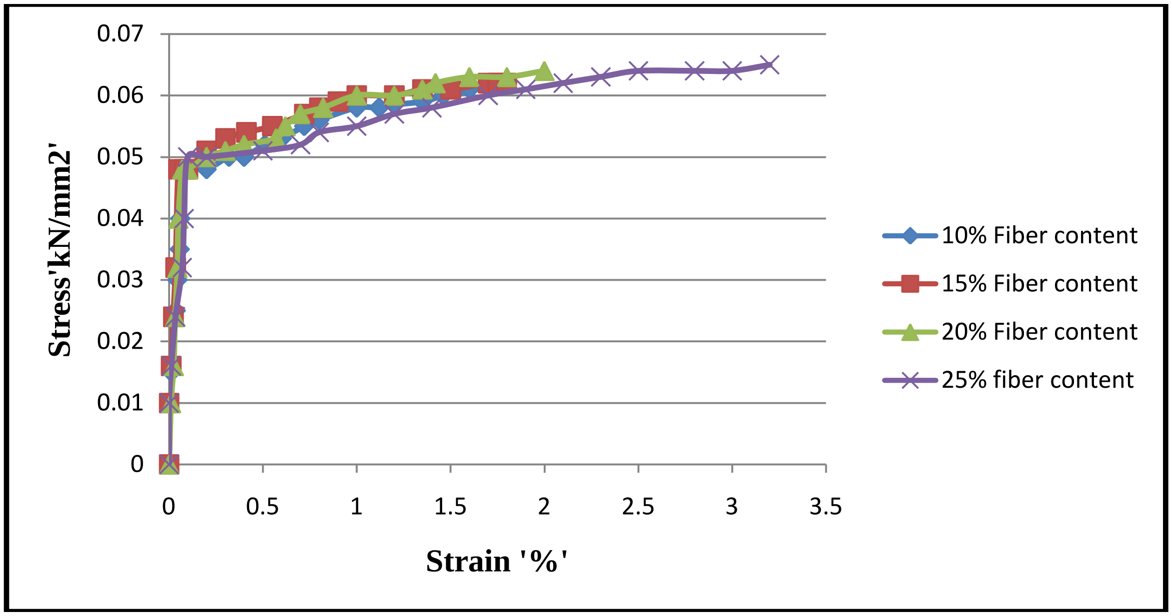

Figure 6. Stress versus Strain for tensile test

Figure. 8 present the stress–strain behavior of eucalyptus fiber and epoxy resin composite. It can be observed that stress increases linearly with the increase of the strain (%), however, when it reaches certain stress values, nonlinear behavior is noticed for the 15%, fiber loading, where strain increases constantly at low stress before undergoing failure. The high strain rate for low fiber content is attributed to the nature of Epoxy composites [8].

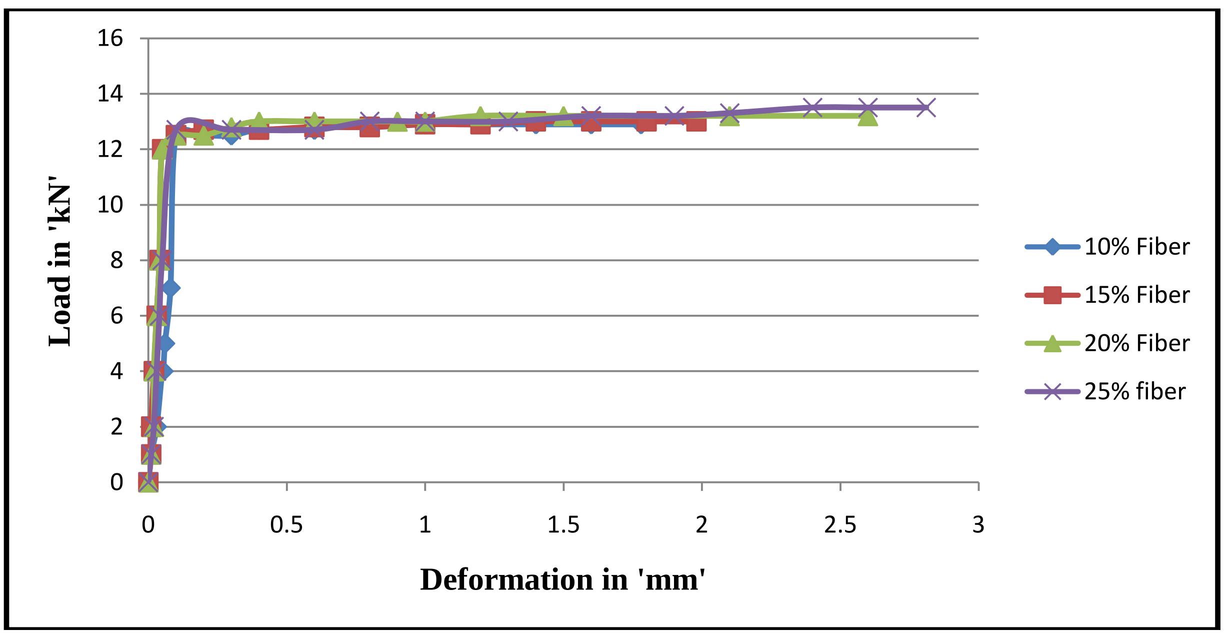

Figure. 7 Effect of fiber content on flexural strength of eucalyptus fiber and epoxy

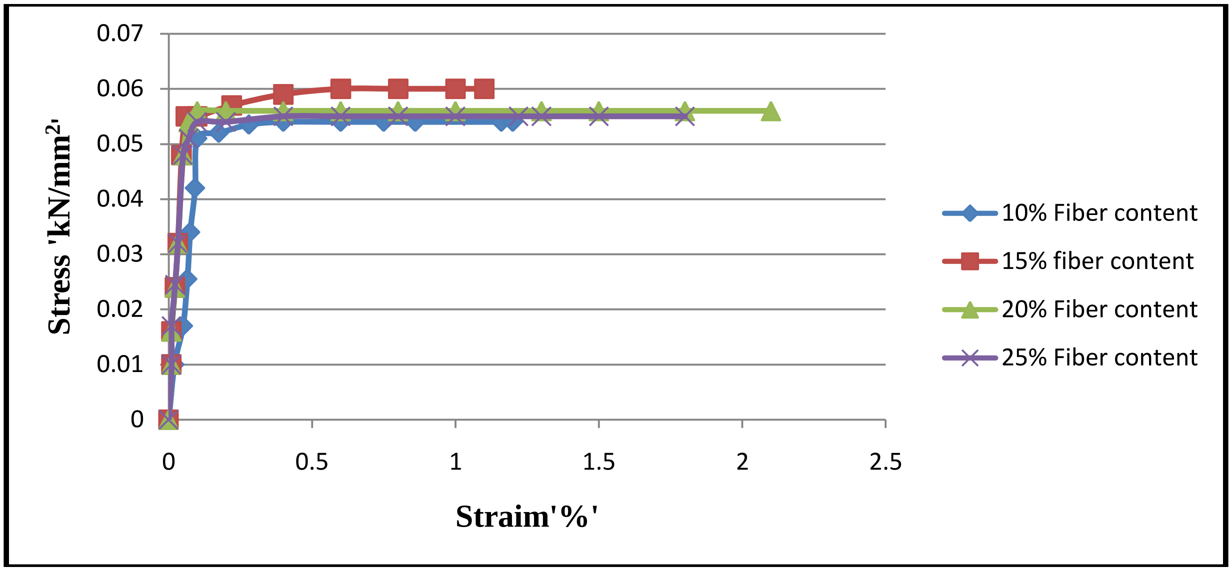

Figure.8 Stress versus Strain for flexural test

Table 4 Flexural properties

Samples	Flexural strength (MPa)	Young's modulus (MPa)	Modulus of resistance (MPa)
10% fiber content	57.34	10.7512×10^{3}	6.1153×10^{-5}
15% fiber content	57.74	10.826×10^{3}	4.493×10^{-5}
20% fiber content	58.67	8.8005×10^{3}	4.797×10^{-5}
25% fiber content	60.00	8.1819×10^{3}	3.467×10^{-5}

4. 3 Compression properties

The effect of fiber content on the compression strength of Eucalyptus and Epoxy resin composite is presented in Figure9. It is observed that, 25 % fiber content specimen exhibit maximum deformation (6.42mm) at minimum load (21.3KN), than 20% fiber content specimen. In tensile and flexural test 25% fiber content specimen has maximum deformation at maximum load, but in this case 25% fiber content specimen has less load than 20% fiber content specimen, this may be caused by specimen area has improper mixing of fiber and epoxy resin. The longitudinal compressive strength mainly depends on the intensity of the resin; in general composite specimens under compression fail by shear or kinking [11].

In the present work specimens are mostly subject to shear and compression type of failure mode. Figure. 10 show the stress–strain behavior of eucalyptus fiber and epoxy resin composite. It can be observed that stress increases linearly with the increase of the strain (%), however, when it reaches certain stress values,nonlinear behavior is noticed for the 15% and 20% fiber loading where strain increases nonlinearly in low stress before undergoing failure. Table 5 shows compression properties for all the four specimens.

Table 5compression properties

Samples	Compressive strength (MPa)	Young's modulus (MPa)	True strain (%)
10% fiber content	182.051	4.5512×10^{3}	4.00
15% fiber content	187.60	2.345×10^{3}	8.00
20% fiber content	191.42	2.392×10^{3}	8.00
25% fiber content	182.05	1.577×10^{3}	11.53

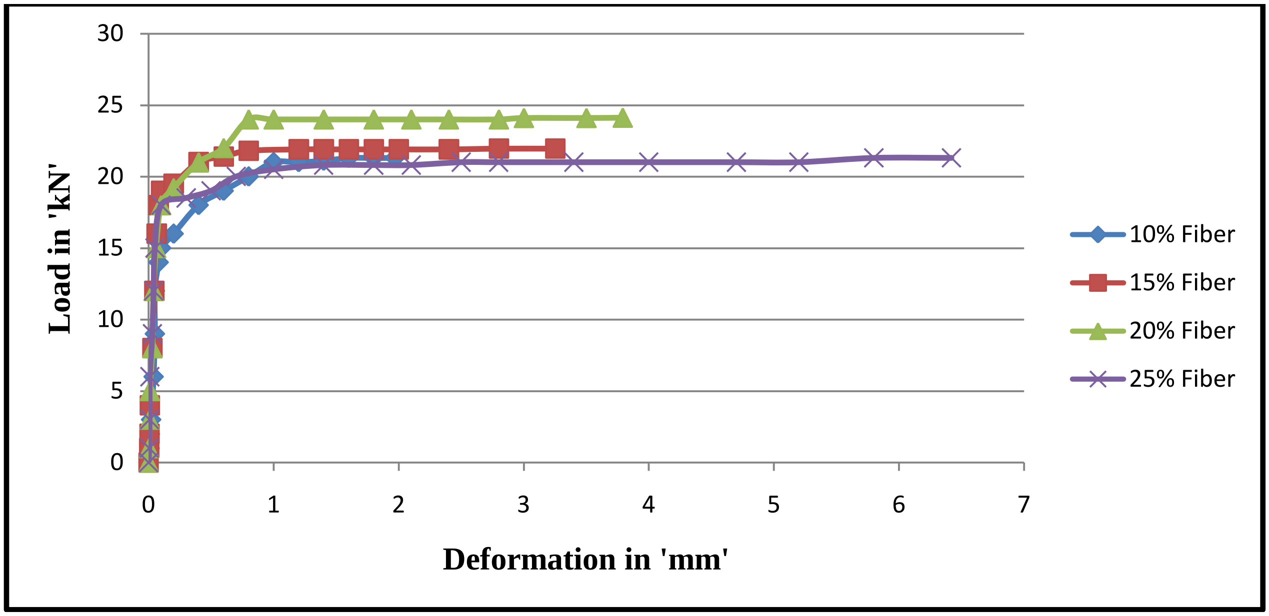

Figure. 9 Effect of fiber content on compression strength of eucalyptus fiber and epoxy

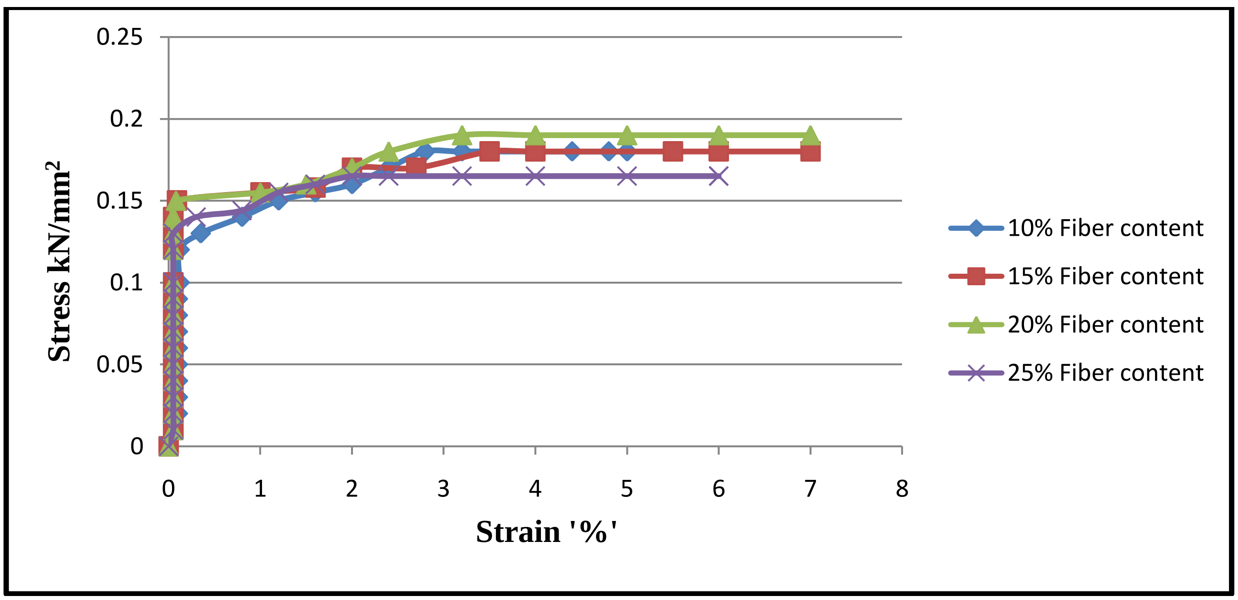

Figure.10 Stress versus Strain for compression test

4.4 Morphological Properties

The cross sectional view of the fabricated composite material consisting 10% eucalyptus fiber content specimens with X250, X500 and X1000 magnification are presented in Figures 8, 9 and 10 respectively.The surface features of the composite material used for the investigation is studied through micrographs taken from SEM. The images show high magnification SEM of the fracture surface of tensile 10% fiber content specimen, from the SEM images clearly identified that the failure mode of composite is due to the failure of fiber with matrix, it is observed that fiber pull out, this indicates to the poor fiber/matrix adhesion, it means the matrix plays a major role due to the maximum percentage of matrix. The load carrying capacity is less compared 25% fiber content specimen. Similarly, voids are more compared to 25% fiber content specimen, this may be due to more matrix content, or air entered into the specimen during composite preparation. From SEM images clearly identified that the failure mode of fiber in composite due to poor fiber/ matrix adhesion.

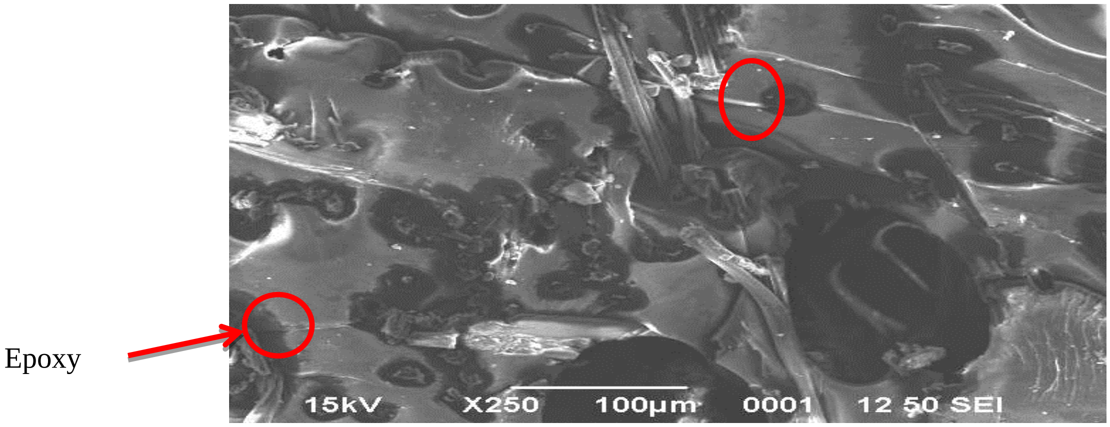

Figure. 8 X250 magnification SEM micrograph for 10% fiber content specimen

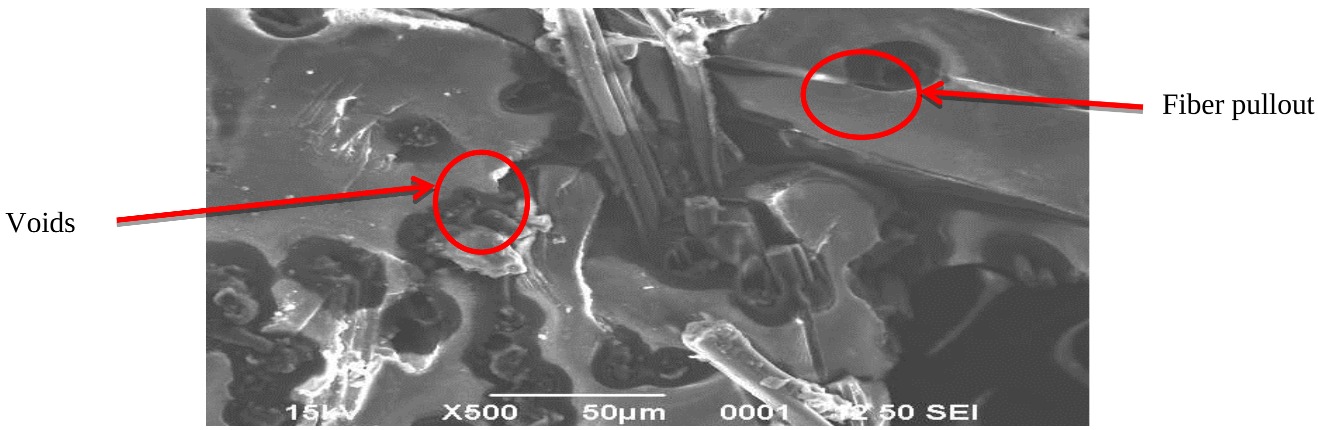

Figure. 9 X 500 magnification SEM micrograph of 10% fiber content specimen

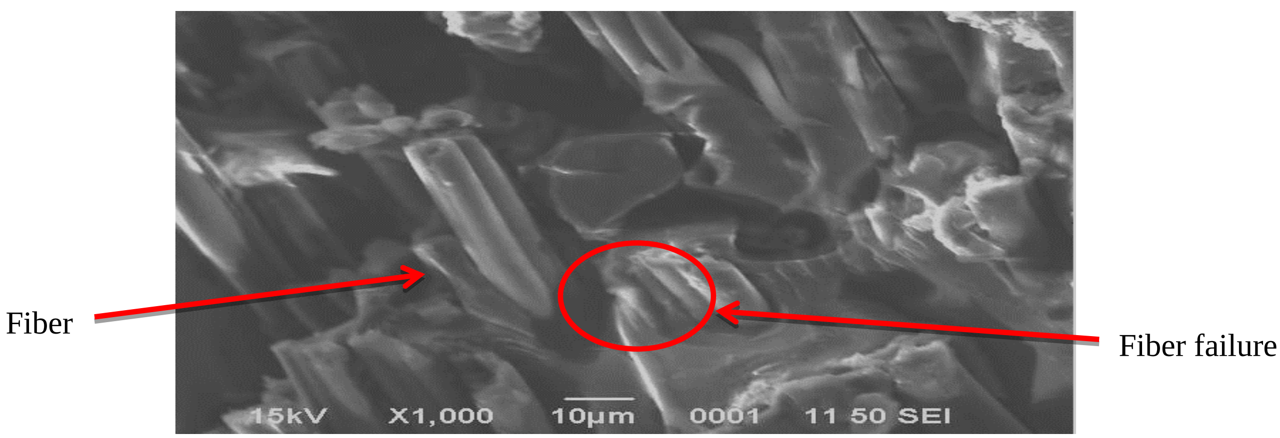

Figure. 10 X1000 magnification SEM micrograph of 10% fiber content specimen

The cross sectional perspective of the fabricated composite material consisting 25% eucalyptus fiber specimens with X250, X500 and X1000 magnification is presented in Figures 11, 12 and 13 respectively.

The Scanning Electron Microscope images are taken to study the interfacial properties and internal structure of a fractured surface of composite material [12]. The above images show high magnification SEM of the fracture surface of tensile 25% fiber content specimen.

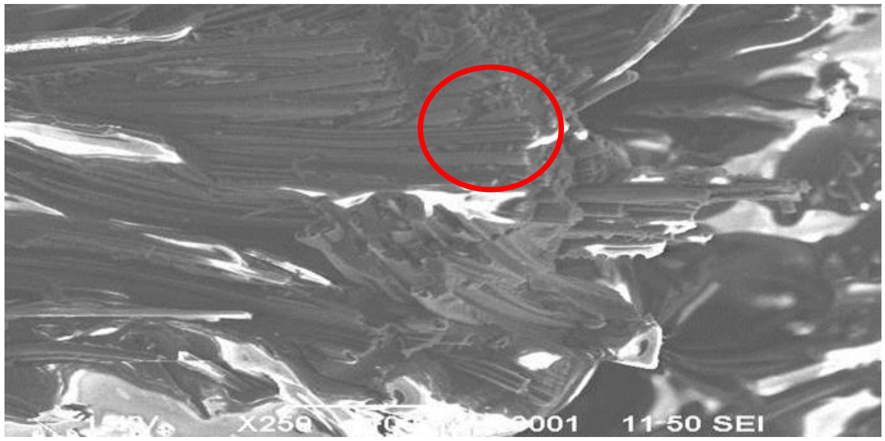

Figure. 11 X250 magnification SEM micrograph of 25% fiber content specimen

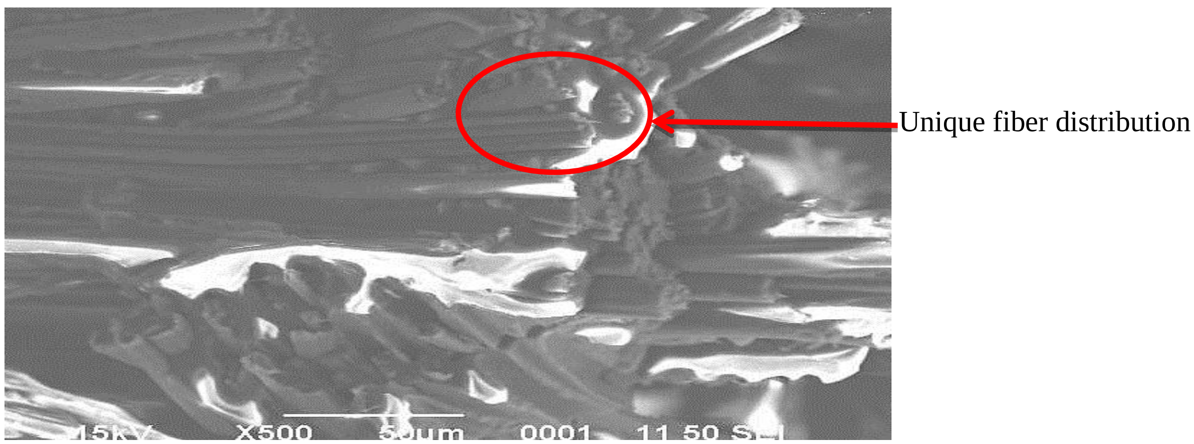

Figure. 12 X500 magnification SEM micrograph of 25% fiber content specimen

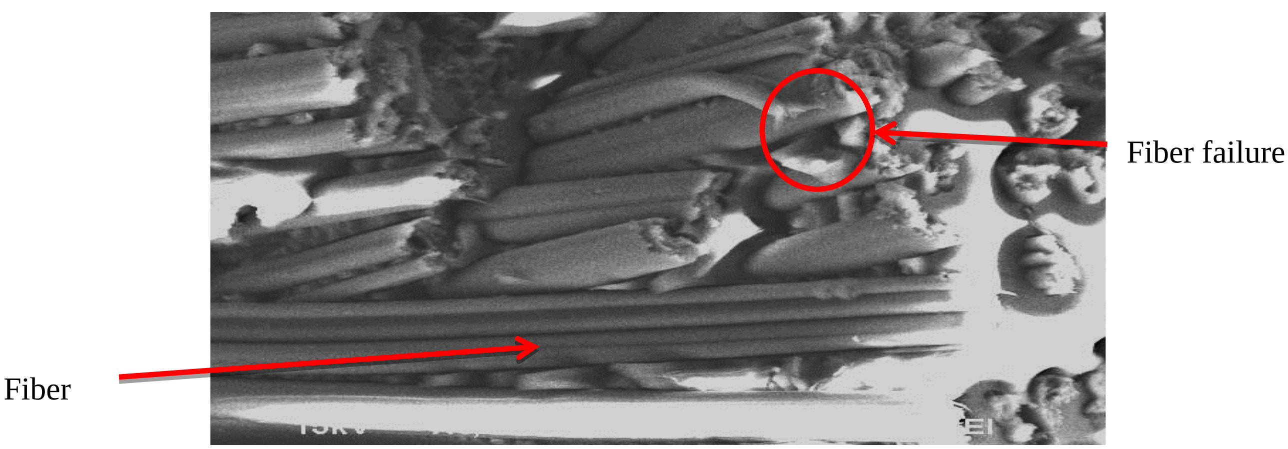

Figure. 13 X1000 magnification SEM micrograph of 25% fiber content specimen

SEM images clearly identify that the failure mode of composite is due to the failure of eucalyptus fiber, in general, the fiber pullouts are less, this indicates to the good fiber/matrix adhesion, hence the tensile strength and deformation of the 25% fiber content composite increases compared to the 10% fiber content composite. Which also contains numerous elongated fibers; this indicates the fiber is broken after attaining its ultimate load absorbing capacity. It is observed that there are less number of voids, because of the presence of more fibers. As the population of fibers is increasing, more stress failure points are contributing to decrease the tensile strength in higher fiber content [16]. The Comparison of tensile, flexural, compression, impact and hardness, strength with hard wood (poplar Balsam) and commercial Nuwood is shown in table 6.

Table 6 Comparison of Hard Wood (Oak) and Commercial Nuwood with Eucalyptus Reinforced Natural Composite [4]

Composite	Tensile strength (MPa)	Flexural strength (MPa)	Compression strength (MPa)
10% Fiber content	58.4	57.34	182.051
15% Fiber content	60.4	57.74	187.60
20% fiber content	66	58.67	191.42
25% Fiber content	70.08	60.00	182.05
Hardwood, poplarBalsam [4]	51.0	47.00	27.7
Commercial Nuwood	0.0977	1.0	17.09

Conclusions

- The eucalyptus fiber reinforced composites have higher tensile strength and strain rate with increasing in fiber content. The 25% fiber content specimen has greater tensile strength 70MPa.
- The eucalyptus fiber reinforced composites have higher Flexural strength strain rate with increasing in fiber content. The 25% fiber content specimen has greater flexural strength 60 MPa.
- The eucalyptus fiber reinforced composites have the higher compression strength and strain rate with increase in fiber content. The 20% fiber content specimen has greater compression strength 191.34 MPa.
- Morphological observation shows the fiber/matrix poor adhesion and more fiber pullouts in 10% fiber content specimen because of the presence of 90% epoxy.
- In compression molding technique, it possible to fabricate specimens with volume fraction up to 25% only. Above this volume fraction laminate method has to be followed for fabricating the specimens. This factor may be considered as one of the limitation of compression molding technique.

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