

Finite Element Analysis of a Natural Fiber (Maize) Composite Beam

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Abstract: Natural fiber composite are termed as biocomposites or green composites. These fibers are green, biogradable, and recyclable and have good properties such as low density and low cost when compared to synthetic fibers. The present work is investigated on the finite element analysis of the natural fiber (maize) composite beam, processed by means of hand lay-up method. Composite beam material is composed of stalk-based fiber of maize and unsaturated polyester resin polymer resin polymer as matrix with methyl ethyl ketone peroxide (MEKP) as a catalyst and cobalt octoate as a promoter. The material was modeled and resembled as a structural beam using suitable assumption and analyzed by means of finite element method using ANSYS software for determining the deflection and stress properties. Morphological analysis and X-ray diffraction (XRD) analysis for the fiber were examined by means of scanning electron microscope (SEM) and X-ray diffractometer. From the results, it has been found that the finite element values are acceptable with proper assumptions, and the prepared natural fiber composite beam material can be used for structural engineering applications.

Keywords: Maize stalk beam, Morphology analysis, Biocomposites, X-ray diffraction, Finite element analysis, Heat transfer.

I. Introduction

Natural fibres are subdivided based on their origins, coming from plants, animals or minerals. All plant fibres are composed of cellulose while animal fibres consist of proteins (hair, silk, and wool). Plant fibres include bast (or stem or soft sclerenchyma) fibres, leaf or hard fibres, seed, fruit, wood, cereal straw, and other grass fibres. Over the last few years, a number of researchers have been involved in investigating the exploitation of natural fibres as load bearing constituents in composite materials.

The use of such materials in composites has increased due to their relative cheapness, their ability to recycle and for the fact that they can compete well in terms of strength per weight of material. Natural fibres can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. The cellulose fibrils are aligned along the length of the fibre, which render maximum tensile and flexural strengths, in addition to providing rigidity.

The reinforcing efficiency of natural fibre is related to the nature of cellulose and its crystallinity. The main components of natural fibres are cellulose (α-cellulose), hemicellulose, lignin, pectins, and waxes. Cellulose is a natural polymer consisting of D anhydroglucose (C₆H₁₀O₅) repeating units joined by 1,4-b-D-glycosidic linkages at C1 and C4 position (Nevell & Zeronian, 1985). The degree of polymerization (DP) is around 10,000.

Each repeating unit contains three hydroxyl groups. These hydroxyl groups and their ability to hydrogen bond play a major role in directing the crystalline packing and also govern the physical properties of cellulose. Solid cellulose forms a microcrystalline structure with regions of high order i.e. crystalline regions and regions of low order i.e. amorphous regions. Cellulose is also formed of slender rod like crystalline microfibrils. The crystal nature (monoclinic sphenodic) of naturally occurring cellulose is known as cellulose I. Cellulose is resistant to strong alkali (17.5 wt%) but is easily hydrolyzed by acid to water-soluble sugars. Cellulose is relatively resistant to oxidizing agents.

Reinforced concrete (RC) has become one of the most important building materials and is widely used in many types of engineering structures. The economy, the efficiency, the strength and the stiffness of reinforced concrete make it an attractive material for a wide range of structural applications. For its use as structural material, concrete must satisfy the following conditions:

(1) The structure must be strong and safe. The proper application of the fundamental principles of analysis, the laws of equilibrium and the consideration of the mechanical properties of the component materials should result in a sufficient margin of safety against collapse under accidental overloads.

(2) The structure must be stiff and appear unblemished. Care must be taken to control deflections under service loads and to limit the crack width to an acceptable level.

(3) The structure must be economical. Materials must be used efficiently, since the difference in unit cost between concrete and steel is relatively large.

The ultimate objective of design is the creation of a safe and economical structure. Advanced analytical tools can be an indispensable aid in the assessment of the safety and the serviceability of a proposed design.

II. Experimental Work

2.1 hand lay-up method

Hand lay-up technique was employed for the preparation of the natural fiber-reinforced polymer composite; mould made of steel was used with dimensions of 80 x 40 x 10 mm as shown in figure 2.1.

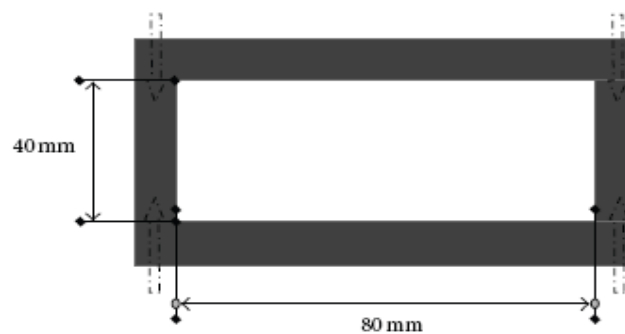


Figure 2.1 Schematic of hand lay up mold.

This method is the cheapest method of manufacturing, but it has some disadvantages such as long curing time and low production rate, and further the quality of the composite depends on the skill of the worker.

The stalk fibers were placed in the mold evenly, and thermosetting resin is mixed with promoter and catalyst. Mold release agent is applied all over the mold surface, and a brush or roller is used to wrap layering process of the fibers. Layers of the fibers impregnated with the resin are used to build up the require thickness.

2.2 Materials

Maize stalk fibers are collected from a local farm field, davangere, india, and general purpose unsaturated polyester resin , catalyst, and promoter were purchased from vinayaka chemicals, private limited, Bangalore, india. Unsaturated polyester resins are commercial thermoset polymers which contain a number of carbon, C=C double bonds.

Unsaturated means that the resin is capable of being cured from a liquid to a solid state. Typical unsaturated polyester may be prepared by reacting an unsaturated diacid, maleic anhydride, with a glycol and ethylene glycol. Matrix characteristics of unsaturated polyester resin are shown in table 2.1.

Sl No	Factors	Value
1	Appearance	Clear
2	Colour	Pale yellow
3	Viscosity @ 30°C	430 mPa-s (Brook field viscometer)
4	Gel time @ 30°C (minutes)	25

Table 2.1 Matrix characteristics of unsaturated polyester resin

2.3 Alkali treatment

Alkali treatment is the simplest method of chemical treatment of fibers; it leads to the increase in the amount of amorphous cellulose at the expense of crystalline cellulose. The important modification occurring

here is the removal of hydrogen bonding in the network structure. The following reaction takes place as a result of alkali treatment.



2.4 Preparation of maize stalk beam

Maize stalk fibers are cleaned thoroughly and later chopped in tiny sizes, and the chemical composition of maize stalk fibers are shown in table. These fibers are chemically treated by alkali method with 5% sodium hydroxide (NaOH) and are thoroughly rinsed with distilled water for 2 to 3 times and placed in oven for 70 minutes at 60° C. the polymer matrix is mixed with catalyst and promoter.

The resins are thoroughly mixed at appropriate proportions and processed by hand lay-up technique to produce a composite beam. The matrix must be liquid to ensure good wetting and impregnation of fibers during formation. A small beam mould is prepared and made to consist of maize stalks fibers of approximate length of 80mm and placed in a unidirectional manner as shown in figures 2.2 and 2.3.



Figure 2.2 Maize fibers with unsaturated polyester resin placed in the mould



Figure 2.3 Specimen of maize fiber composite beam

III. Finite Element Model And Analysis

Fiber composites consist of fiber and matrix phases, and the mechanical behavior of the composites is much determined by the fiber and matrix properties. Microstructures such as fiber shape, fiber array, and volume fraction of fibers are also more important in determining the mechanical properties. Micromechanical models have been used to predict the properties starting from the intrinsic properties and their constituents, and these models show that the fibre strength is not being completely employed as a result of poor fibre matrix interfacial adhesion and fiber length.

The material is modeled using certain assumptions and analyzed for mechanical properties with finite element method software (ANSYS). The composite material is assigned as unidirectional composite by assuming some properties that are given below.

Some of the assumptions used for the analysis work have been gathered by the literature.

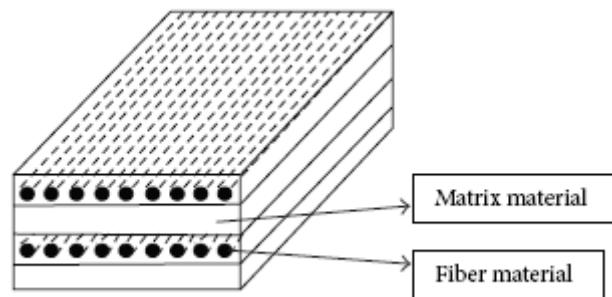
- 1) Fibers are not porous.
- 2) The material property for all the constituents are attributed as isotropic material for both volumes.
- 3) Fibers are uniform in properties with diameter.
- 4) Interphase bonding is maintained between fibers and matrix.

- 5) Perfect bond between fiber and matrix and no slip-page.
- 6) Fibers are arranged in unidirectional manner and perfectly aligned.
- 7) Composite material is free of voids.

The interface between fiber and matrix is also an interface that serves to transfer externally applied loads to the reinforcement via shear stress over the interface. Controlling the strength of the interface is imperative. Clearly good bonding is essential if stresses are to be adequately transferred to the reinforcement and hence provide a true reinforcing function. another important mechanical property is toughness or the ability of an engineering material to resist the propagation of cracks.

This occurs in composites by virtue of their heterogeneous structure. It is important that under certain circumstances interfacial adhesion breaks down so as to allow various toughening mechanisms to become operative. These mechanisms include crack blunting as proposed by and various energy absorption processes such as the frictional sliding of debonded fibre fragments within the matrix, fibre fracture, and the cration of new crack surfaces.

The finite element method was used to model the behavior of a material on the basis of micromechanical level. The model was assumed to be an isotropic material with a rectangular section of a beam. This section is then modeled in detailed using volume elements to represent the composite. Each element will have an isotropic property and will be positioned corresponding to the fibers, and the mesh regions are coarsely meshed (converged solution).



Composite material with fibre and matrix

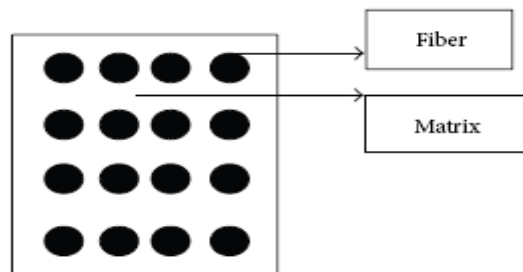


Figure3.1 Fibre and matrix region

The composite material consists of fibers aligned in unidirectional manner and modeled as a regular uniform arrangement, as shown in figure. This model assumed that the fiber is a perfect cylinder of length L (80 mm) and diameter d (1mm) in a matrix as shown in figure.3.1



Figure 3.2 Fem model of the composite with fiber and matrix

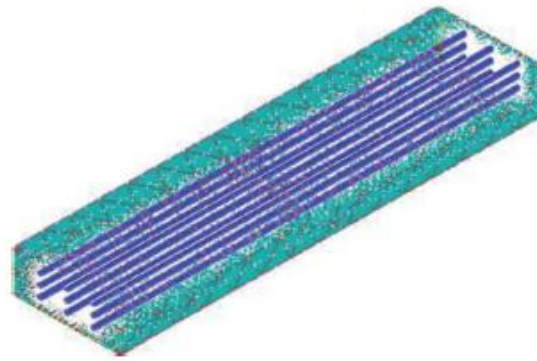


Figure 3. 3D model of the composite beam

The model is treated As a linear isotropic problem. The FEA model is constituted of SOLID 95 elements, used for fibre- matrix structure as shown in fig. the model included the fibre, matrix, and fibre- matrix interface. Nine fibres were modelled to the surrounding matrix . the fibers with surrounding matrix were selected for stress analysis in this model. These regions were modeled using the coarse mesh as shown in figure 3.2 and 3.3 and the load applied of I Kg at the top edge of the model.

3.1 Morphology analysis of maize fiber composites

Morphological analysis of raw maize stalk fiber and alkali- treated maize fiber with unsaturated polymeric resin was carried out by studying scanning electron microscope (SEM). Natural fiber samples were coated with gold using a vacuum sputter coater and analyzed. The morphology changes were observed using jeol JSM -5600LV electron microscopy with an accelerating voltage of 15 kV.

3.2 X-ray diffraction (XRD) analysis of maize fiber composites

The XRD analysis determined the crystallinity of the maize fiber and was used to indicate the dramatic change in the crystallinity of the maize fiber as shown in table. All the fiber samples were scanned in 2θ range varying from 10° to 50° . the spectrum corresponding to maize raw fibers shows the diffraction peaks of amorphous region and crystalline region at the following 2θ angles at 22.58° and a high peak nearly at 29.46° . For alkali-treated fibers, same peaks can be observed at 22.44° and 29.28° . similarly for the chemically treated fiber with unsaturated polymeric resin, the crystalline region peak at 28.12° and the amorphous region at 20.36° were observed. The position of the peak indicates an increase of interplanar distance in relation to fibre treated. This occurs due to generations of disorder when fibre is treated and the patterns for the above materials are similar.

IV. Ansys Analysis Results

The maize beam element is analysed using ANSYS and the ANSYS analysis results are shown from figure 4.1 to 4.7.

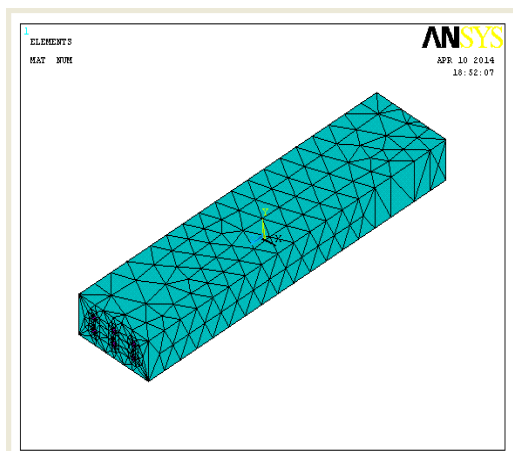


Figure 4.1 MESHED ELEMENT

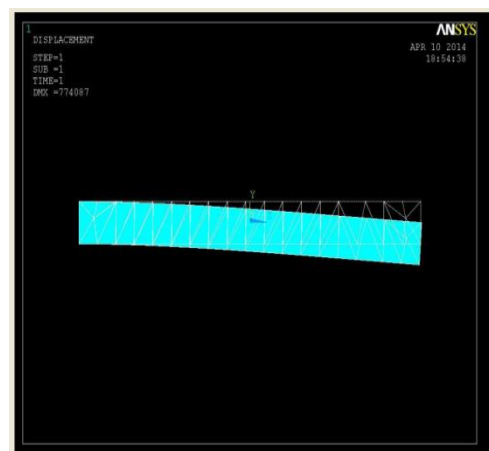


Figure 4.2 MAIZE BEAM DEFORM SHAPE

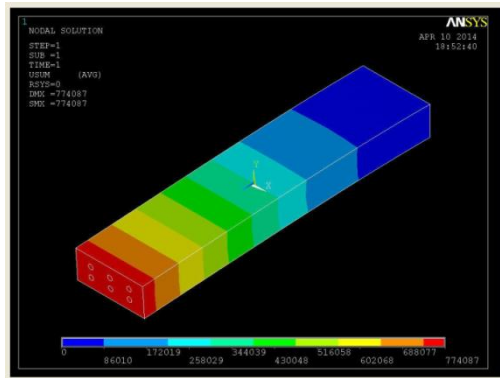


Figure 4.3 MAIZE BEAM DOF

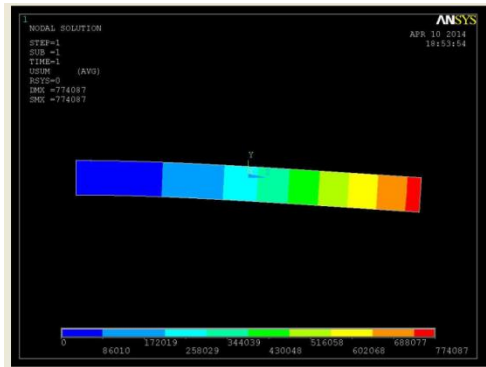


Figure 4.4 MAIZE BEAM DOF1

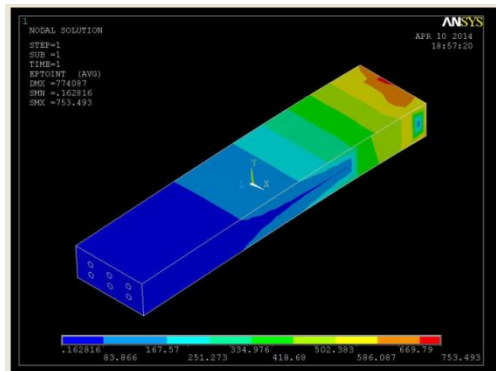


Figure 4.5 MAIZE BEAM STRAIN INTENSITY

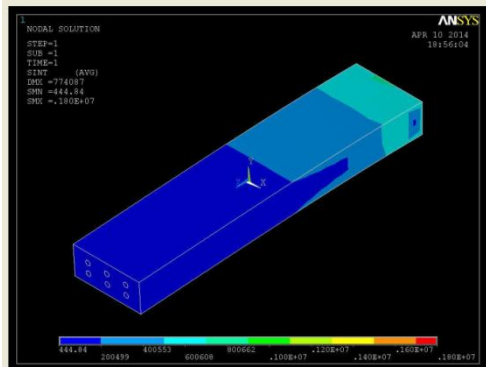


Figure 4.6 MAIZE BEAM STRAIN INTENSITY

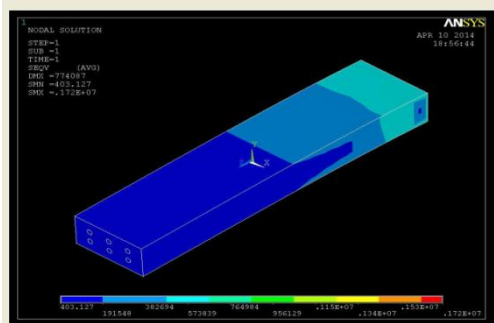


Figure 4.7 MAIZE BEAM VON MISSES STRESS

V. Conclusion

From the above morphological results, it can be concluded that it is necessary need to get good adhesion between fibers and the matrix; hence the fibers must undergo some additional chemical treatment. In order to get a good composite material, these fibers should change from hydrophilic to hydrophobic characters. From the finite element method analysis, it is confirmed that there is possibility of reducing the stress concentration in the matrix and at the fiber interface by increasing the fiber content to an optimum content.

More stress deviation in the fiber, matrix and interface regions of the composite leads to chances of fiber debonding. Vacuum infusion method used in this study offers more benefits than hand lay-up method due to better of fiber to resin ratio resulting in stronger and lighter laminates.

Thermo gravimetric analysis and differential scanning calorimetric tests were carried for maize fiber and polyester resin coated maize fiber samples, they provide useful information on thermal degradation values of composite. It is seen from thermal gravimetric analysis, the initial degradation temperature was around 200°C but Tmax for raw fiber is around 330°C and for the polyester coated maize fiber, it was around 410°C, and thus increase in thermal stability could be seen. Also it can be concluded from DSC profiles, the endothermic peak is noticed at around 97°C for raw fiber and 67°C for polyester coated fiber and are mostly due to adsorbed moisture.

The exothermic peaks are due to the degradation of the maize fiber noticeable above 300°C in case of raw fiber. Certain amount of variations in comparison of numerical and experimental results is shown. Limitations include a propensity to moisture uptake resulting in property degradation, and a large variation in fiber properties. The geometry and properties of natural fibers depend on the species, growing conditions, cambium age, harvesting, defibration and processing conditions. This variation makes it more difficult to analyze the effects of the fibers and their interfaces on the thermal properties of the composite material. These difficulties call for development of new strategies. From FEM analysis it is confirmed that there is a possibility of reducing the stress concentration in the matrix and at the fiber interface by increasing the fiber content to an optimum content. More stress deviation in the fiber, matrix, and interface regions of the composite leads to chances of fiber debonding. Finite element method software simulation (ANSYS) reveals that there is a need to have certain assumptions for the perfect bonding and also to define interface properties. In the present method the model is validated using some assumptions because natural fibers are anisotropy, porosity and the interphase, whose volume will vary with different conditions and fiber arrangements. Hence, the obtained values are predicted values.

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