Thermal Properties of Maize Fiber Reinforced Unsaturated Polyester Resin Composites

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Abstract—**Increase in demand for natural fiber composites are raising today because of more advantage when compared to traditional fiber composites. In the present work, natural fiber composite material is processed by vacuum assisted resin transfer molding technique and the fibers are maize stalk fibers with matrix of unsaturated polyester resin. With suitable catalyst and accelerator composite material is fabricated and thermal properties for the material is examined by thermal gravimetric analyzer, differential scanning calorimeter and the results are also compared with finite element method.**

Index Terms— **composites, finite element method, natural fibers, thermal analysis**

I. INTRODUCTION

There is an increase demand for environmental friendly materials such as natural fiber composites to replace the traditional fiber (i.e. carbon, glass, and aramid fiber) composites. The reasons are: biodegradability, less emissions to the atmosphere, abundant, renewable, availability and can be produced at low cost in many parts of the developing world [1]. These materials are strong, stiff, and due to their low densities, they have the potential to produce composites with similar specific properties to those of E-glass materials [2] as shown in table 1. Natural fibers are generally ligno cellulosic in nature, consisting of helically wound cellulose micro fibrils in a matrix of lignin and hemi cellulose. Uses of natural-fibers as reinforcement have proven viable in a number of automotive parts. Flax, sisal, and hemp are processed to door cladding, seatback linings, and floor panels. Coconut fiber is used to make seat bottoms, back cushions, and head restraints, while cotton is used to provide sound proofing, and wood fiber is used in seatback cushions [3].

A better understanding of their physical properties such as mechanical and thermal behaviours will enable engineers to produce an optimum design for a structure [4]-[6]. The thermal conductivity of a composite depends upon the thermal conductive nature of the fiber, matrix, properties of constituents as well as on their volume fractions, sizes, shapes, orientations and perfect bonding between the constituents.

Polymer matrices are most commonly used because of cost efficiency, ease of fabricating complex parts with less tooling cost and also have excellent room temperature properties when compared to other matrices [7], [8]. Thermoset matrices are formed due to an irreversible chemical transformation of a resin into an amorphous cross-linked polymer matrix.

The present work is concentrated in processing a composite material from natural fibers of maize stalk with thermoset polymer through vacuum assisted resin transfer molding. The prepared material is subjected to thermal analysis with the help of thermal gravimetric analyzer and differential scanning calorimeter. The material is also compared with the input values of finite element analysis software commercial tool ANSYS. The predicted results were appreciable. Thermal characteristics of maize stalk fibers and maize fibers reinforced with unsaturated polyester resin for different fiber volume fractions and conductivity was also determined.

A. *Requirement of Natural fiber Composites*

Generally natural fibers are classified into three categories; vegetable, animal and mineral fibers, among which mineral fibers are no longer or very rarely used due to their carcinogenic effect. All vegetable fibers such as, cotton, flax, jute, hemp etc contains mainly cellulose and proteins. Animal fibers consist of fibers with animal origin such as hair, silk and wool. According to their origin vegetable fibers are further classified into bast, leaf, or seed fibers [9]-[11]. The bast and leaf fibers lend mechanical support to the plants stem or leaf respectively; examples for these kinds of fibers include flax, hemp, jute, and ramie. The surfaces of natural fibers are uneven and rough which provides good adhesion to the matrix in a composite material [12]. The specific mechanical properties of natural fibers have high significance for their utilization in composites as shown in table 1. In natural fibre reinforced composites/bio composites, fibre acts as reinforcement and show high tensile strength and stiffness. Polymer/bio polymer acts as a matrix that holds the fibre and transmits the forces.

In recent day’s natural fiber composites materials are widely used in automotives such as car door panels, car roofs, covers, [13] and structural panels, sandwiched beams for roofs in housing and structural applications [14]. These materials are also familiar in interior applications such as furniture and packaging for electrical appliances. Bio

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composites are now used in interior cladding of railway carriages and air craft bodies [15].

Table1. Comparison of mechanical properties of natural fibers to synthetic fibers[9], [10]

Fibers	Density (g/cm$^{3)}$	Tensile strength (MPa)	E-modulus (GPa)	Elongation (%)
Flax	1.5	500-1500	60-80	2.7-3.2
Coir	1.2	590	6	15-25
Jute	1.3	390-800	10-30	1.5-1.8
Sisal	1.5	500-700	38	2-3
E-glass	2.5	2400	73	3

B. *Thermal Conductivity of Composites*

Fiber is the reinforcing phase of a composite material. Thermal conductivity of a composite depends upon the thermal conductive nature of the fiber and matrix. Commonly used fibers for composites include glass, carbon, and aramid etc [16]. As the thermal conductivity of a polymer composite is based upon the conductivity of fiber and resin, resins are usually insulating and the conductivity is dominated by fiber material. The compactness of fibers per unit area influences the conductivity of the composite. Fiber packing in a composite depends on the method of manufacturing [17]. Thermal conductivity of composites is anisotropic in nature. The knowledge of thermal conductivity of composites is needed for accurate design. Data about thermal conductivity of resin facilitates to reduce stresses related to shrinkage of composites during cure and mismatch in thermal expansion coefficients.

Heat transfer process within epoxy matrix composites filled with solid glass beads was investigated [18] and numerical simulation was made by using commercial finite element analysis software ANSYS. Numerical simulation and heat transfer process of polyester matrix composites filled with rice husk particles was determined [19] and the analysis was carried out by ANSYS software. The results pointed that the effective thermal conductivity of the composite decreased with increase of volume fraction of filler particles. Thermal conductivity of micro encapsulated phase change materials with matrix of epoxy composites was evaluated [20] and modeling analysis of relative thermal conductivity was performed.

Modeling of polymer fiber composites and thermal properties of composites was investigated [21] and finite element method was used to calculate the effective thermal conductivity [22]. Hollow cores from natural fiber composites were manufactured and macro analysis of sisal fiber sandwiched panels was analyzed [23]. Micro mechanical models were used to predict the properties and the analysis was done by using finite element method software ANSYS to determine the flexural properties of the sandwiched panels.

II. EXPERIMENTAL WORK

Vacuum bags are used along with molds and hence this method is called as Vacuum Assisted Resin Transfer Molding (VARTM) as shown in figure1. VARTM process enhances resin flow and reduces void fraction. It consists of two important mechanisms: flow of the resin through the preform, compaction and relaxation of the preform under the vacuum pressure. In addition, the resin cure kinetics and viscosity are ensured for complete resin infiltration of the preform before resin gelation [24]. The benefits of VARTM when compared to non-vacuum bag curing of composite laminates include: better fibre to resin ratio, stronger laminate, low void content, reduces operator exposure to harmful emissions, reduced resin usage due to pre-compacted fabric, faster ply lay-up.

The main steps of the process are:

1. A dry fabric or preform and accompanying materials such as release films, peel plies are laid on tool surface.
2. The preform is sealed with a vacuum bag and the air is evacuated by a vacuum pump.
3. Liquid resin with hardener from an external reservoir is drawn into the component by vacuum.
4. The liquid resin with hardener is infused to the preform until complete impregnation occurs.
5. Curing and de-molding steps follow the impregnation to finish the product.

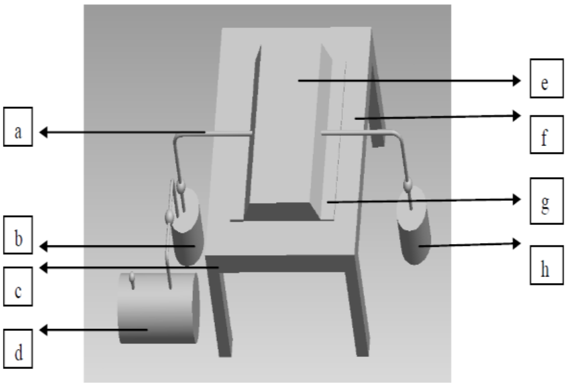

Fig. 1. Vacuum assisted resin transfer molding (a)- resin distribution pipe, (b) – resin trap, (c) – working table , (d) - compressor (e) – mold, (f) – working table, (g) – vacuum bag, (h) – polymer container

Maize stalk fibers were collected from a local farm in Karnataka and thermoset polymer of unsaturated polymeric resin were purchased from M/s Vinayaka chemicals, Bangalore, India. Methyl ketone peroxide and cobalt octoate were choosed as a catalyst and acccelerator and mixed in proper proportions. The maize stalk fibers were cleaned thoroghly in running water and sun dried. Later these fibers were kept in oven to remove the moisture content and alkali chemical treatment was carried out. The processing of composites were performed through vacuum assisted resin transfer molding technique as shown in figure1.The processed material is studied for thermal analysis through thermal gravimetric analyzer and differential scanning calorimeter and the results were compared with commercial available finite element analysis software package tool ANSYS.

III. RESULTS AND DISCUSSIONS

A. *Surface Morphology of the Composites*

Morphological analysis of raw maize stalk fiber and alkali treated maize fiber with polymeric resin was carried out by scanning electron microscope (SEM) micrographs. Natural fiber samples were coated with gold using a vacuum sputter coater and placed in for analyzing. The morphology changes were analyzed and observed using Jeol JSM-5600 LV electron microscopy with an accelerating voltage of 15 kV. These SEM micrographs of the resin and composites show a clear cut difference in the morphology of the resin and composite as shown in figure 2.

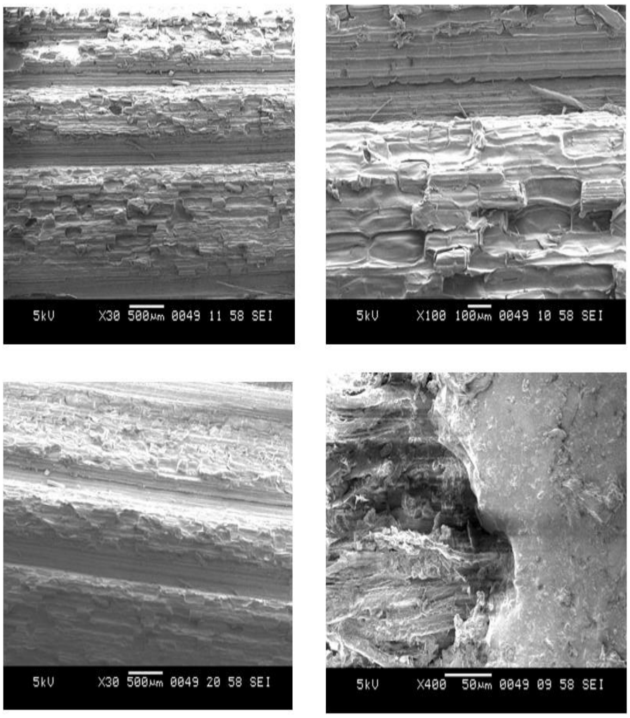

Fig.2. SEM Images of maize fiber reinforced with polyester resin Indicating the Orientation of Fibers and its morphology

Figure 2 shows the orientation of fibers in polyester resin and its surface morphology, the surface of the fiber is not smooth indicating that the compatibility between fibers and resin matrices are poor. However this compatibility can be improved when fiber is treated with other chemical treatment methods that will improve interfacial bonding between them.

B. *Thermal Gravimetric Analysis (TGA)*

Thermo gravimetric analysis was performed under nitrogen atmosphere. The natural fiber sample was heated from room temperature to 400°C, while the polyester maize fiber composite sample was heated from room temperature to 505°C at a heating rate of 10°C/ min and a nitrogen gas flow rate of 60 mL/min. The thermal gravimetric and derivative thermo gravimetric curve was obtained using TA analysis software. The results of thermo gravimetric analyses for raw and polymer coated maize fibers are shown in figure 3 and figure 4.

It can be seen that the decomposition profiles of the fibers are characterized by three step degradation. The first one is attributed to the evaporation of moisture at 130°C. The second step, which corresponds to low molecular weight components at 230°C and final degradation temperature, starts around 330° C for raw fiber, and for the composite it starts at around 410°C. From the TGA profile, it can be viewed that the final residue and maximum degradation temperature T_{max} has significantly improved and the thermal stability of the composite has been improved.

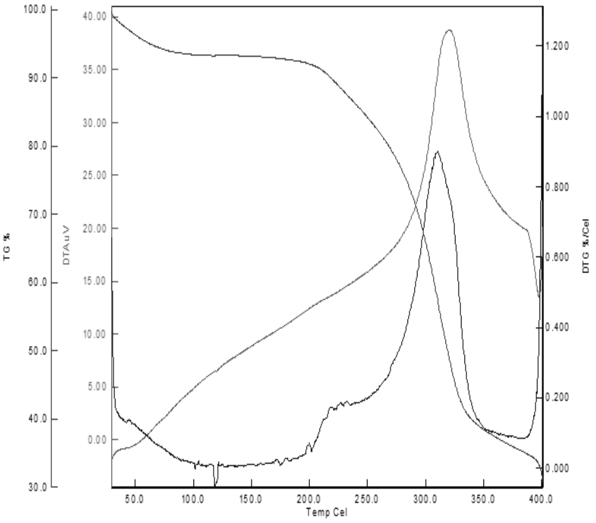

Fig.3. Thermo gravimetric analysis for maize fiber

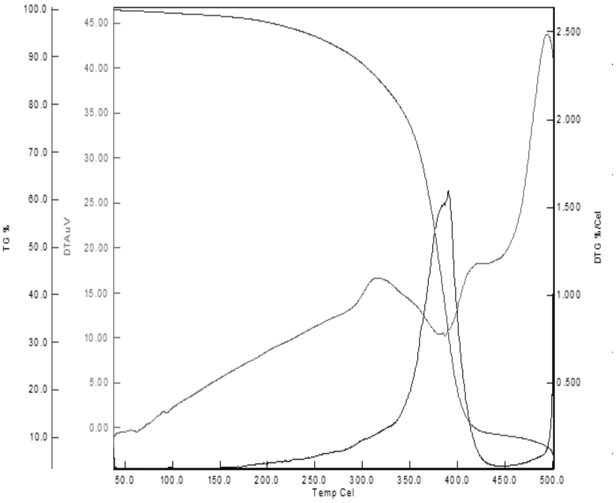

Fig.4. Thermo gravimetric analysis for unsaturated polyester maize composite

C. *Differential Scanning Calorimetry (DSC)*

Displayed in figure 5 and figure 6 is the differential scanning calorimetric results obtained by heating the specimen of raw maize fiber and fiber treated with unsaturated polyester resin at a constant heating rate of 10^{o} C/min. The plot shows the heat flow as a function of the sample temperature. The samples having size of 5±3 mg were heated at a constant rate of 10°C/min between temperature ranges of 20°C to 250°C and then cooled with nitrogen to 40 °C at a cooling rate of 10°C/ min with a flow rate of 30 ml/min. For raw fiber, the glass transition event T_g was observed at 80^oC as an endothermic stepwise decrease in the heat flow or heat capacity and a broad endothermic peak at 97^oC.

For polymer coated fiber, the glass transition temperature was observed at 67^oC.With a further increase in the sample temperature, the resin eventually undergoes curing and thus it can be observed as exothermic peak. The endothermic peak is mostly due to adsorbed moisture and the exothermic peaks are due to the degradation of the maize fiber.

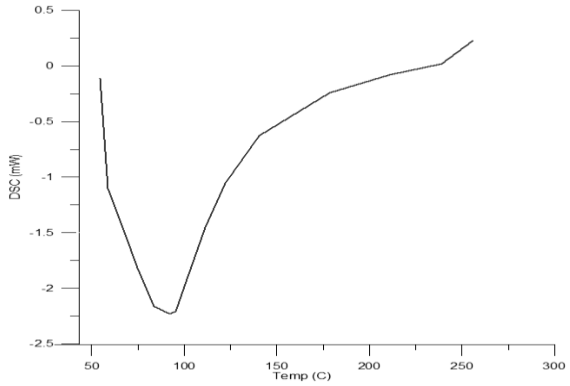

Fig.5. DSC for maize fiber

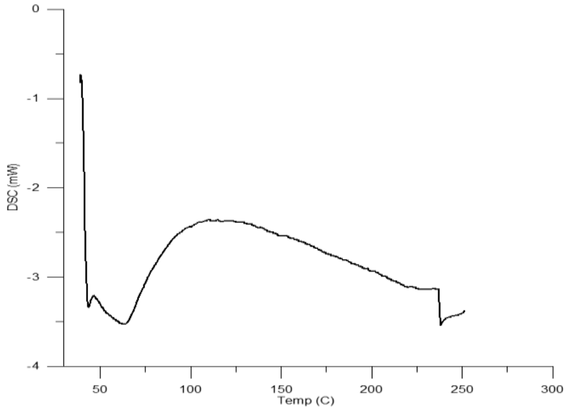

Fig.6. DSC for unsaturated polyester maize composite

D. Finite Element Method (Analysis)

Some of the assumptions are been carried out in achieving the result, they are as follows

- Locally both matrix and fiber are homogenous and isotropic.
- Thermal contact resistance between fiber and matrix interface is negligible.
- Composite laminate is free of voids
- Heat loss due to radiation and convection is neglected.
- Filaments are equal and uniform in shape, size and are symmetrical about x and y axes.

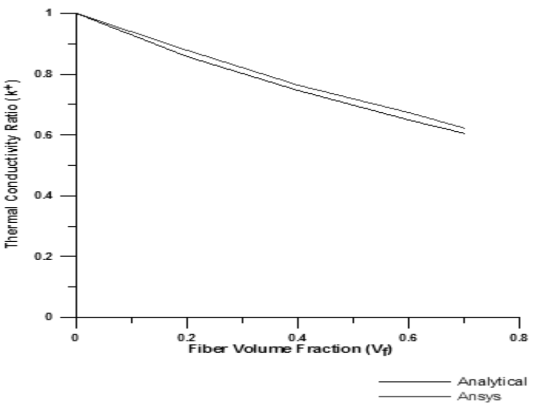

Fig.7a. Variation of k^+ (k_f/k_m=0.494) with fiber volume fraction

Figure 7a and 7b shows the variation in transverse thermal conductivity for different fiber volume fractions for maize fiber reinforced with polyester resin and thermal conductivity for maize fiber reinforced with unsaturated polyester resin. Figure 8a and 8b shows the heat flux along the composite and temperature distribution in the composite material. Figure 8c shows the contour plot for temperature distribution along the composite. Table 2 and 3 displays the value of k (thermal conductivity) of unsaturated polyester maize fiber reinforced composite.

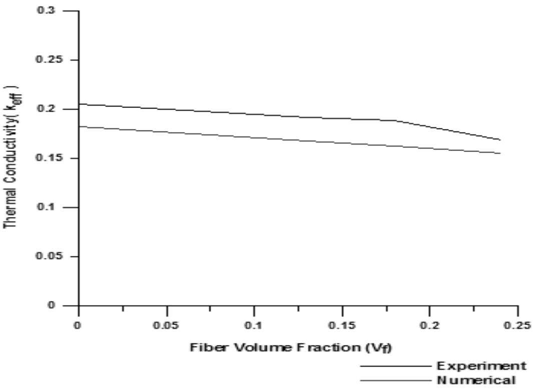

Fig. 7 b. Variation of thermal conductivity for maize fiber reinforced with unsaturated polyester resin

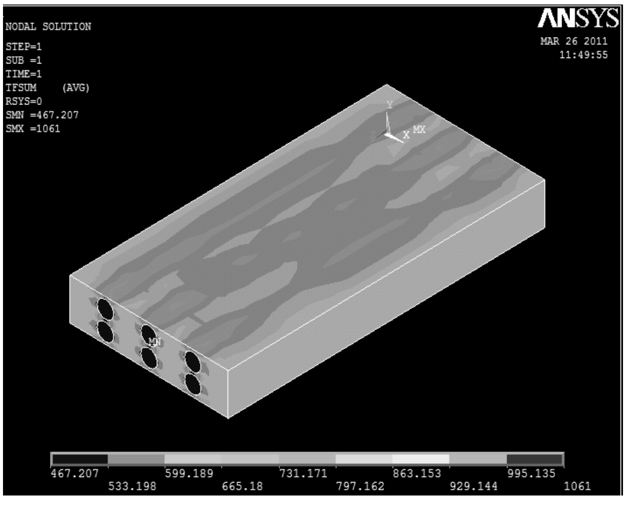

Fig. 8a. Heat flux along the composite (maize-unsaturated polyester resin)

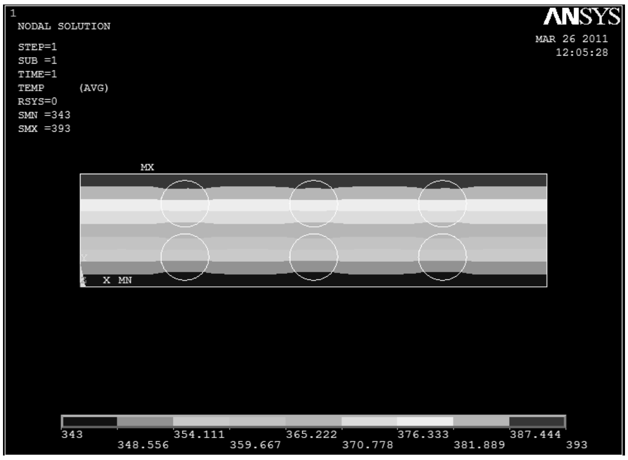

Fig.8b. Front view – Temperature Distribution (Maize-Unsaturated Polyester Resin)

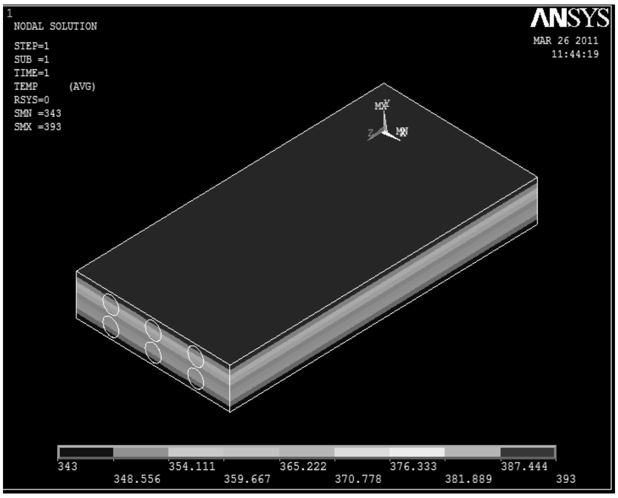

Fig. 8c. Contour plot for Temperature Distribution along the composite (Maize-Polyester Resin)

Table 2. Unsaturated polyester maize fiber reinforced composite

v_f	k_f / k_m	k_{eff} (FEM)	k_{eff} (Analy)	k_{eff} (Expt)	k^+ (Expt)	k^+ (Analy)
0	0.494	0.182	0.182	0.205	1	1
0.13	0.494	0.167	0.164	0.192	0.936	0.901
0.18	0.494	0.162	0.158	0.189	0.921	0.868
0.24	0.494	0.155	0.151	0.169	0.824	0.829

Table 3. Unsaturated polyester maize fiber reinforced composite

v_f	k_f / k_m	k_{eff} (FEM)	k^+ (FEM)	k_{eff} (Analy)	k^+ (Analy)
0	0.494	0.182	1	0.182	1
0.2	0.494	0.159	0.878	0.156	0.857
0.4	0.494	0.139	0.764	0.135	0.745
0.6	0.494	0.122	0.674	0.117	0.648
0.7	0.494	0.112	0.62	0.109	0.602

IV. CONCLUSIONS

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 fibres 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 T_{max} 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.

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