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Research Paper

THERMAL PROPERTIES OF BAMBOO FIBER REINFORCED POLYESTER COMPOSITE

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Natural fibers play a significant role in human civilization as they have the advantage of being light, strong, cheap and more environmental friendly. In addition, bamboo the natural fiber adopted for the present work is a renewable resource as it is one of the fastest growing plants and also prevents the transmission of UV light. The main focus of the study is on thermal properties such as specific heat, thermal degradation, flammability, limiting oxygen index and heat deflection, temperature of bamboo fiber reinforced polyester composite which is a partially biodegradable material.

Keywords: Bamboo, Thermal degradation, Flammability, Limiting oxygen index, Heat deflection temperature

INTRODUCTION

Composites have been usually mass-produced from a mixture of polymer matrix and a synthetic fiber as a reinforcing material (Bledzki and Gassan, 1999). Revival of interest in NFRC is observed during the last two decades, which has resulted in extensive research and newer industrial applications. Increased fiber-matrix compatibility and mechanical properties of composites, results in use of NFRC in areas such as boat hulls, buildings materials, automobile parts and aerospace applications (Chappale and Anandjiwala, 2010) .

In addition to the better mechanical properties the thermal properties of a particular resin with the addition of natural fiber, also showed application oriented properties. Heat deflection test results clearly showed that the HDT of the kenaf fiber reinforced PLA laminated composite was significantly higher that the HDT of PLA resin (Wanjun Liu *et al*., 2007). When hemp fiber is added (30% by weight) to Polylactic acid (PLA) and observed an increase in HDT by 30% (64^0C-84^0C). Compression molded samples had higher heat deflection temperature that is HDT is process dependent (Mohanty *et al*., 2004). HDT also increased due to increase in modulus, good dispersion and reinforcing (Masud *et al*., 2006).

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Knowledge of flammability of natural fiber-reinforced composites and the methods used to improve their fire resistance is necessary to ensure their use in the industries (Chappale and Anandjiwala, 2010). Fire resistance can be increased by using coatings and intumescent systems for thermosets and for reinforcing natural fibers, a flame-retardant treatment of the fibers prior to incorporation in the matrix (Sain *et al*., 2004). The flammability of a composite not only depends on the matrix polymer and the type of fiber, but also on the interactions between the two (Kandola and Kandare, 2008).

Limiting Oxygen Index can be used to express the flammability of natural fiber reinforced composite. If the Limiting Oxygen index is higher than the flammability is low and lower limiting Oxygen index results in higher flammability (Sain *et a*l., 2004).

Thermogravimetric analysis is a useful technique for the study of the thermal stability of composites and to evaluate basic characteristics of thermal degradation on the chemical kinetics of reactions at elevated temperatures. However thermal instability is the major limitation encountered in natural fiber reinforced polymer matrix (Mehdi Tajvidi and Akio Takemura, 2010). In this paper various thermal related properties like thermal degradation, HDT, LOI, flammability and specific heat are presented and studied.

MATERIALS AND METHODS

Materials

Unsaturated polyester resin of grade ECMALON 4411, methyl ethyl ketone peroxide and cobalt naphthanate were purchased from Ecmass resin (Pvt) Ltd., Hyderabad, India.

Fiber Extraction

A process called retting is employed to extract fiber from plants. This process involves the action of bacteria and moisture on dried bamboo strips to dissolve and rot away cellular tissues and gummy substances that surround the fiber bundles in the strips. And this soaking process loosens the fibers and can be extracted out easily. Finally, the fibers were washed again with water and dried at room temperature for about 5 days.

Preparation of Composite

Composites are prepared as per the ASTM standards. Firstly, the moulds are prepared as per the test specifications. The samples were prepared using Hand lay-up technique and the required amount of resin is poured into the mould by adding accelerator and catalyst to it which were 1.5% by volume of resin. The purpose of these additions at room temperature is for curing. First and last layers of sample were filled up with resin and in between layers are filled with appropriate amount of polyester resin and fibers. To yield good quality composites fiber deformation and movement should be constrained. Therefore at the time of curing, a compressive pressure of 0.05 MPa was applied on the mould and the composite specimens were cured for 24 h. The specimens were also post cured at 70^0C for 2 h after removing from the mould.

Specific Heat Measurement and Density of Composite

The specific heat capacity of samples was measured using a differential scanning calorimeter (TA Instrument, Model No. Q20) at a heating rate of 10^0C/min. The picnometric procedure was adopted for measuring the density of the composite.

Thermogravimetric Analysis

Thermogravimetric analysis is the determination of molecular deterioration that is the weight loss due to overheating. The sample was taken in powdered form and the samples were tested in a TGAtester supplied by Central Institute of Plastics Engineering & Technology, Chennai, India.

Flammability Test

Flammability test specimens were prepared in accordance with ASTM D-635 to determine how easily the specimens will burn. The specimens were 127 mm long, 3 mm deep and 12.7 mm wide. A set of 3 bars were tested with maximum fiber volume fraction and pure resin is noted and their average burning rate per minute calculated. The samples were tested in a Flammability tester supplied by Central Institute of Plastics Engineering & Technology, Chennai, India.

Heat Deflection Temperature Test

Heat Deflection Temperature test specimens were prepared in accordance with ASTM D-646 to determine the temperature at which the material deflects by a specified amount under the action of a specified stress. The specimens were 127 mm long, 3 mm deep and 12.7 mm wide. A set of 3 bars with maximum fiber volume fraction and another set of 3 bars of polyester resin were tested and their average heat deflection temperatures are noted. The samples were tested in a Heat Deflection Temperature tester supplied by Central Institute of Plastics Engineering & Technology, Chennai, India.

LOI Test

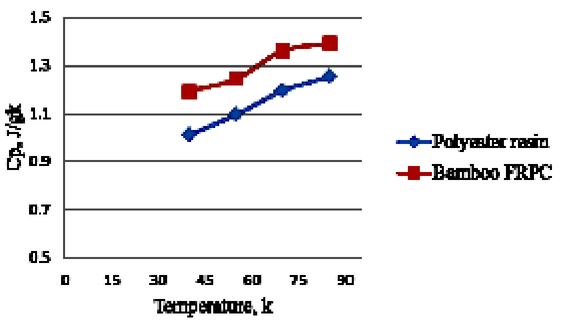
Limiting Oxygen Index test specimens were prepared in accordance with ASTM D-646 to determine the minimum concentration of oxygen, expressed as a percentage that will support combustion. The specimens were 100 mm long, 3 mm deep and 7 mm wide. A set of 5 bars were tested with maximum fiber volume fraction and their average limiting oxygen index is noted. Another set of 5 bars of polyester resin were tested and again their average is noted. The samples were tested in a Heat Deflection Temperature tester supplied by Central Institute of Plastics Engineering & Technology, Chennai, India.

RESULTS AND DISCUSSION

Specific Heat Measurement

The specific heat capacity values of polyester resin matrix and fiber reinforced composites measured in the range of 40^{0}C – 85^{0}C are shown in Figure 1. The results show that the specific heat of composite increases with increasing temperature. This behavior of composite is attributed to the lower specific heat capacity of the fibers.

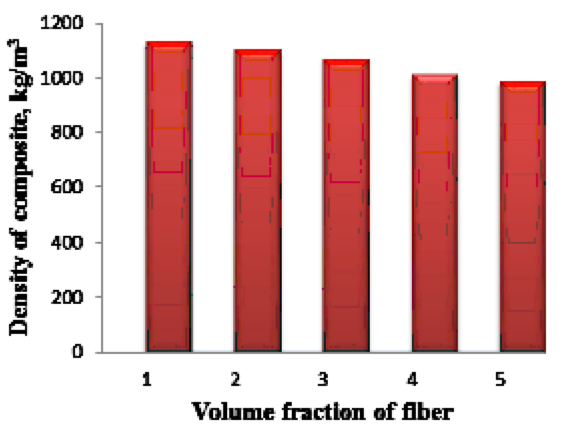
Figure 1: Variation of Specific Heat with Increase in Temperature



Density of Composite

The variation in density of composite with respect to volume fraction of fiber is presented in Figure 2. It is clearly evident that the density of the composite decreased with fiber content. The porous nature of the fibers may be responsible for decrease in the density of the composites under study. This means that with increase in fiber content, composites become light in weight. Hence, it is an attractive parameter for design of light weight structures.

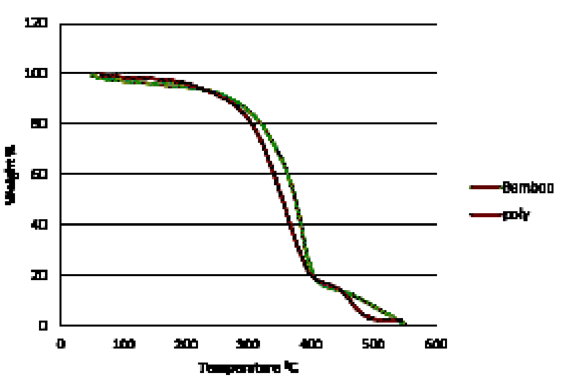
Figure 2: Variation of Density of Composite with Volume Fraction of Fiber



Measurement of Thermal Degradation

The TGA data for the biocomposite and resin are shown in Figure 3. In all the TGA curves, two main degradation regions can be observed. One is reportedly due to the thermal degradation of cellulose, hemicelluloses, and lignin in the bamboo fiber and the other higher temperature one is attributed to depolymerization of the polyester. A slight weight loss is observed below 100^{0}C which is attributed to the evaporation of absorbed moisture. The composite and resin showed almost same weight loss trend except that from 200^0 C to 400^0 C the weight loss of resin is a bit high.

Figure 3: TG Curves for Composite and Resin



The DTA curve gives better understanding of the behavior of the materials. The thermal decomposition initiation temperature and the peak temperatures can be recorded from the presented Figure 4 and 5. And these values are compared with sisal/phenolic composite and kenaf/pp composite (Mehdi, 2010) and observed a lowest initiation temperature for sisal/phenolic composite (Andressa, 2012) and highest peak temperature for bamboo/polyester composite (Table 1).

Figure 4: DGA Curve for Bamboo/Polyester Composite

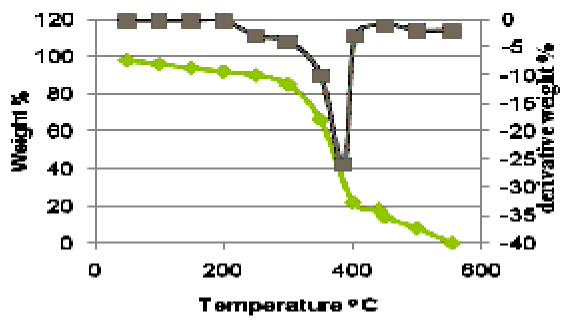


Figure 5: DGA Curve for Polyester Resin

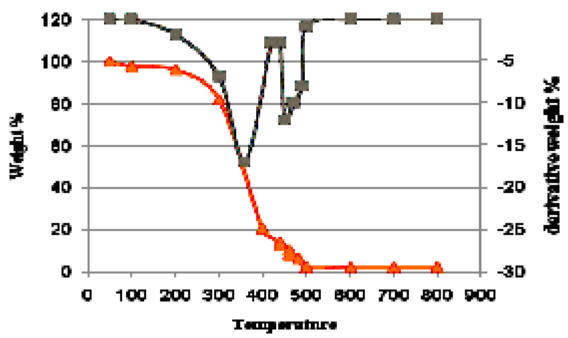


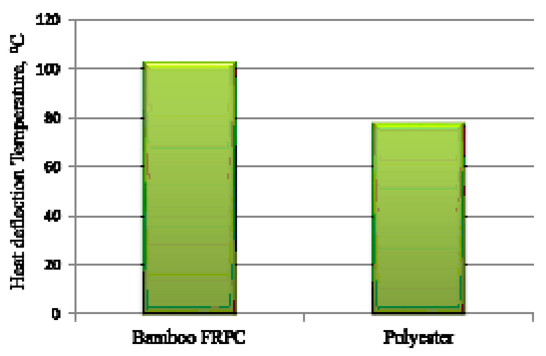
Table 1: TG/DGA Results for Various Materials

Formulations	T_{ini} (^{0} C)	$T_{hi\text{-}rate}$ (^{0}C)
Polyester	290	358.79
Polyester+bamboo fiber	250	385.63
PP+kenaf fiber [38]	243.6	356.9
Pheonolic + sisal fiber [19]	200	323

Measurement of Heat Deflection Temperature

The HDT or softening point of polymer-based materials is an important factor for designing industrial products. Figure 6 shows the HDT value for the bamboo FRPC and the resin. The HDT value of pure polyester resin is 78°C. Such a result is sensible given that the HDT value of the kenaf reinforcement is greater than that of the matrix (Jun *et al.,* 2012). This is attributable to the improved interfacial adhesion and higher crystallinity of the bio-composites, accordingly this must be considered in deciding on ultimate applications for this class of bio-composites.

Figure 6: Heat Deflection Temperature of Bamboo/polyester Bio-composite



The HDT of Bamboo FRPC is compared with the Kenaf/PLA composite and Banana/PLA composite in the Table 2. Kenaf/PLA composite showed a drastic increase in HDT value only with fiber volume fraction of 0.1 while the composites HDT values are not so remarkable.

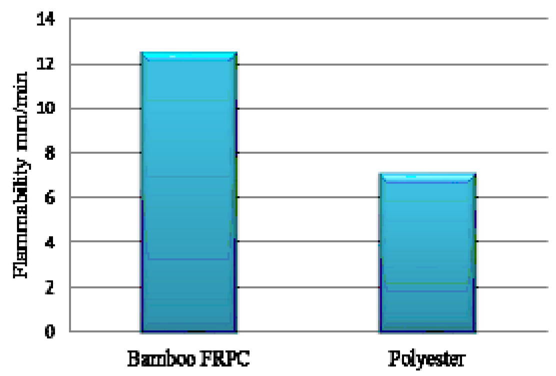
Table 2: HDT Values of Various Bio-composites

Composites	V_f	HDT
Polyester+bamboo fiber	0.3	103°C
PLA+kenaf fiber[39]	0.1	110°C
PLA+banana fiber [41]	0.3	139°C

Measurement of Flammability

Flammability of PP and PP composites was examined by a horizontal burning test according to ASTM D635. The specimen was held horizontally and a flame was applied to one end of the specimen. A burning time from the first reference mark, i.e., 25 mm from the end, to the second reference mark, i.e., 100 mm from the end, was recorded. Three specimens from the composite were tested. Then, burning rates of the composites were calculated. The composite showed higher burning rate than the neat polyester resin Figure 7. This indicated that bamboo fiber filled polyester composite had high sensitivity to flame.

Figure 7: Burning Rate of Resin and Composite



The burning rate of bamboo/polyester and sisal/pp composites is almost doubled while LDPE/AB wood composite is lowered to half (Table 3).

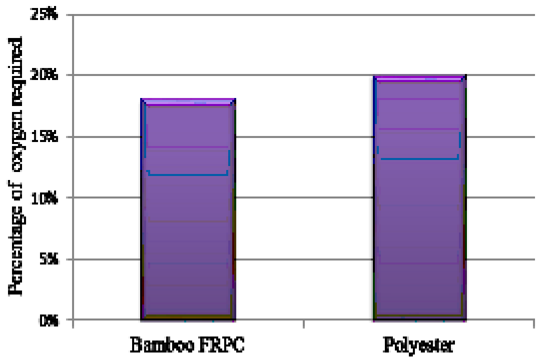
Table 3: Flammability of Different Composites

Composite	V_f	Flammability
Polyester+bamboo	0.3	14.53mm/min
LDPE +AB wood [22]	0.2	3.6mm/min
Pp+sisal[40]	0.3	54mm/min

Measurement of LOI

The amount of oxygen required for a specimen to burn is higher for polyester resin when compared with the composite and this means composite burns more easily than the resin (Figure 8).

Figure 8: LOI of Composite and Resin



The limiting oxygen index bamboo/polyester composite is compared with coconut/PLA and wood/PP and noticed that bamboo/polyester composite burns easy comparatively (Table 4).

Table 4: LOI Values of Various Composites

Composite	V_f	LOI
Polyester+bamboo fiber	0.3	18%
PLA+coconut fiber [20]	0.1	24%
PP+wood fiber [21]	0.3	21.40%

CONCLUSION

In this work, partially biodegradable green composites with bamboo fibers as reinforcement were successfully developed and their thermal properties were investigated.

From the results obtained, the following conclusions are drawn:

- The density of the natural fiber reinforced polyester composite decreases as fiber content increases.
- The influence of temperature on specific heat capacity of composite was similar as the thermal conductivity.
- Initial and peak temperatures of weight loss obtained from thermal degradation test of the composite are comparatively good when compared to resin and other composites.
- Flammability and LOI values indicate that the burning rate of composite is very high and it is required to lower the burning rate for use of composite for practical applications.
- Heat deflection temperature of the composite showed considerable increase in value when compared to the polyester resin.

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