ISSN No:-2456-216

Thermal Response of Long Jute and Banana Hybrid Epoxy Fibrous Natural Composites

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Abstract:- The thermal response of long Jute and Banana reinforced epoxy natural composites has been investigated. The materials systems used for the investigation are : Epoxy (EP), Epoxy/4 wt.% Banana fiber (BF)/4 wt.% Jute fiber (JF) (EP8), Epoxy/8 wt.% BF/8 wt.% JF (EP16), Epoxy/12 wt.% BF/12 wt.% JF (EP24), and Epoxy/16 wt.% BF/16 wt.% JF (EP32). These composites were processed and fabricated using hand – lay-up technique. The thermal response of the aforesaid material systems were studied using thermogravimetric analysis (TGA). The % weight loss of these composites at defined temperature has been recorded from the thermograms. The hybridization effect of long jute and banana fibers on the thermal stability of epoxy fibrous composites were investigated. It is revealed from the experimentation that higher loading of natural fibers has enhanced the thermal stability of composites. The percentage weight loss of these composites has been controlled at higher thermal load using the combined effect of natural fibers.

Keywords:- *Thermal; Jute Fiber; Banana Fiber; Epoxy; Natural Composites.*

I. INTRODUCTION

Polymer composites are the materials which are the best substitution for metallic components in industries. They played the vital role in the design and applications of structural components. Polymers are multifunctional materials which are used for the structural applications because of self lubrication, high strength to weight ratio, aesthetic appearance, light weight and structural stability under the influence of thermal load [1]. The performance of these composites must be considered under the influence of thermal load. Polymer and their thermal stability can be improved by the polymer modification. There are three methods of polymer modification : Polymer blending, co-polymerization and reinforcing the polymer by filler and fibers [2]. The synthetic fibers such as carbon fibers, glass fibers and Kevlar fibers have already exhibited their strength in improving structural and thermal stability of polymer composites. Most of the polymer composite fail due to the severe effect of thermal load during interaction with hard surfaces. This has to be controlled in order to prevent the loss of material at severe thermal environmental conditions. The governing of material loss due to the effect of thermal load has been explored by the concept of polymer modification using the reinforcing the synthetic fibers. Further, the usage of thermoplastic matrix as the base material has proved the worth of their usage in the filed of polymer composites during wear and frictional analysis [3]. But the effect of using thermoset matrix as the base material is very limited in supply. Further, the potential of natural fibers such as jute, banana, ramie and sisal fibers are in forefront to show their strength as the reinforcing agents in developing the polymer composites for thermal applications. Many researchers have contributed their work to the field of fibrous polymer composites partcularly for thermal applications. The thermal behaviour of natural fibre reinforced polymer composites requires critical discussion to exhibit to the research bench the thermal strength behaviour of these polymer composites which are develop eco-friendly polymer composites. Further, the degradation of polymers at particular thermal load along with their associate fillers must be accountable in order to enhance their reinforcement composition.

The investigation in to the hybrid effect of Glass - Basalt fiber on the thermal response of PA66/PTFE thermoplastic composites has been reported by Rudresh et al [4]. They reported these thermal responses through TGA and DSC. Study showed that the addition of these fibers has enhanced the thermal stability of polymer composites. Further, the weight loss of these composites has been controlled by the addition of these hybrid fibers. The effect maize fiber and polyester coated maize fiber on the thermal behaviour of polymer composites has been reported by Saravana Bavan et al [5]. They developed these composite using vacuum assisted resin transfer molding technique. They fund that these composites were degraded at a temperature of 200 ^{0}C. Also they reported that the maximum temperature for raw fiber was around 330°C and polyester coated maize fiber, 410°C. They shwoed that the addition of these fibers has enhanced the thermal stability of composites. The effect of jute and carbon fibers on the thermal behaviour of HDPE composites has been explored by singh et al [6]. The temperatures of highest rate of degradation of 10/90, 20/80 and 30/70 Jute fiber/ carbon fiber -HDPE composites were 483°C, 485°C and 488°C respectively and at 550°C the composite compositions show the residual mass of 4.3%, 5.8% and 7% respectively. The thermal behaviour of natural fiber reinforced epoxy composites using TGA and DSC techniques has been investigated by Fouzi et al [7]. The natural fibers used for the processing of composites were pineapple leaf fibre, kenaf fibre and mengkuang fibres. The samples for both analysis were subjected to maximum temperature of 600°C at a

ISSN No:-2456-216

heating rate of 10°C/min. The results showed that treated fibres show higher maximum peak temperature as compared to the untreated fibres. The thermal response of treated and untreated sisal fiber reinforced polyester composite shave been explored by Sreekumar et al [8]. It is found that the chemical treatment of these fibers could enhanced the thermal stability due to the structural changes on the surface fibers. The investigation on the thermal behaviour of raw jute and banana fiber reinforced epoxy hybrid composites. The jute and banana fibers were used in the ratio of 100/0, 75/25, 50/50, 25/75 and 0/100 to develop the composites. The effect of thermal stability has been maintained in the epoxy based composite up to 50 wt.% of banana fiber.

The effect of jute fiber and banana fiber on the thermal conductivity of epoxy based fibrous composites has been reported by sathish pujari et al [9]. It is observed from the investigation that the thermal conductivity of the natural composites decreases with increase in loading of fibers. Thermal conductivity of Banana fiber composite was better when compared to jute fibers.They showed that banana fiber is a good insulator and can be used to develop insulating materials. The physical and thermal properties of jute and banana fiber reinforced hybrid epoxy composites has been investigated by Devi Reddy and Biswas [10]. these composites were varied up to 0 to 40 wt.%. It is found that the weight loss of composites has been declined due to higher loading of fibers in epoxy composites. The investigation on the thermal properties of jute fiber loaded oil palm - epoxy composites has been reported by Jawaid et al [11]. TGA technique has been carried out on these composites. They reported that the addition jute fibers has improved the thermal stability of oil palm - epoxy composites. The thermal properties of hybrid jute and sisal reinforced epoxy composites has been reported by Gupta et al [12]. They developed these composites using hand lay up technique. The 30 wt.% of fibers were used in composites in varying ratios of fibers. It is found from the investigation that the higher percentage of jute fiber in composites has enhanced the thermal behaviour of epoxy based composites. The effect of coir fiber reinforcement on the thermal behaviour of Jute / Bamboo epoxy hybrid composites has been reported by sathish et al [13]. these composites were processed using casting method. It is well documented that the higher percentage of coir in the hybrid epoxy composites exhibits the good thermal stability than the lower ones. Margabandu Sathiyamoorthy and Subramaniam Senthilkumar [14] has reported the hybrid effect of jute - Carbon fibers on the thermal behaviour of epoxy composites. They developed these composite using the concept of hand lay up. The fibers of different varying weight fraction percentage has been utilized in developing the composites. It is proved that the stability of these composites has been obtained at higher temperature due to higher loading of fibers. TGA suggested that the weight loss of these epoxy composites has been controlled at higher temperature due to the reinforcement effect of hybrid fibers.

From the literature review, it is observed that the effect of short natural fibers such as jute, banana, sisal, Ramie and cotton and others were available in plenty. The effect of individual fibers on the thermal behaviour of different thermoset plastics have been reported in large scale. But the hybrid effect long fibers were very limited in supply. Further, the hybridization effect of long banana and jute fibers on the thermal behaviour of epoxy fibrous natural composites is not reported. Therefore, the hybrid effect of long banana and jute fibers on the thermal behaviour of epoxy based natural composites have been investigated.

II. MATAERIALS, FORMULATIONS, PROCESSING AND POLYMER TESTING

A. Materials

The physical data of materials used for the production of composites is shown in Table 1. The physical information provided by the supplier for the epoxy, hardener, long banana, and jute fibers are listed in table 1. Table 2 lists the designation and formulations of material systems in weight fraction percentage used in the processing of composites.

Table 1 Materials used in the Processing of Epoxy Composites

Materials	**Suppliers Name**	**Form and size**	**Density (gr/cc)**
Epoxy LY556	Zenith industrial supplies, Bangalore, India	Liquid	1.15
Hardener (HY951)	Zenith industrial supplies, Bangalore, India	Liquid	0.98
Jute fiber	Fiber Region, Valasaravakalam, Tamil Nadu, India	15 to 25 mm, Diameter : 5 to 30µm	1.5
Banana fiber	Fiber Region, Valasaravakalam, Tamil Nadu, India	15 to 30 mm, Diameter: 5 to 30µm	1.35

Table 2 Formulations of Materials System in Weight Fraction Percentage

Materials`	**Designation**	**Weight fraction and percentage**		
		Epoxy	**JF**	**BF**
Epoxy	EP	100	--	--
Epoxy / 4 wt.% Jute / 4 wt.% Banana Fiber	EP8	92	4	4
Epoxy / 8 wt.% Jute / 8 wt.% Banana Fiber	EP16	84	8	8
Epoxy / 12 wt.% Jute / 12 wt.% Banana Fiber	EP24	76	12	12
Epoxy /16 wt.% Jute / 16 wt.% Banana Fiber	EP32	68	16	16

ISSN No:-2456-216

B. Processing of Epoxy Fibrous Composites

The epoxy based natural composites were processed using hand lay-up technique. The composite plates were fabricated using dimension controlled mold box made of a wooden block of 100 mm x 100 mm x 6 mm. The material formulations systems with fiber wt. % of 8, 16, 24 and 32 having equal volume of long banana and jute fibers were used for the development of these composite plates. The Epoxy LY556 with hardener HY951 was used as the base matrix to process epoxy-based composites. To remove any residues of air bubbles that might have been present due to variations in the volume fraction of fibers, the designed proportion of resin – hardener of 10:1 was chosen and filled in the glass jar under the effect of a vacuum chamber. The mold plate can be released using a releasing agent applied over the release plate. A release agent spray has been applied to the inner surface of the mould in order to make it easier for the plate to release. The composite mixture was put in the form of a smooth layer with a thickness of 2 mm once the mould was positioned over the glass plate. On the top of the composite layer, the fibers with designed volume proportion were also applied. The compaction pressure was applied to for a period of around 72 hours. In order to prepare specimens for various tests, the laminated composites produced by the aforementioned procedure were cut in accordance with ASTM requirements. The production lay out along with the processing mold with specimens for testing is shown in the fig. 1.

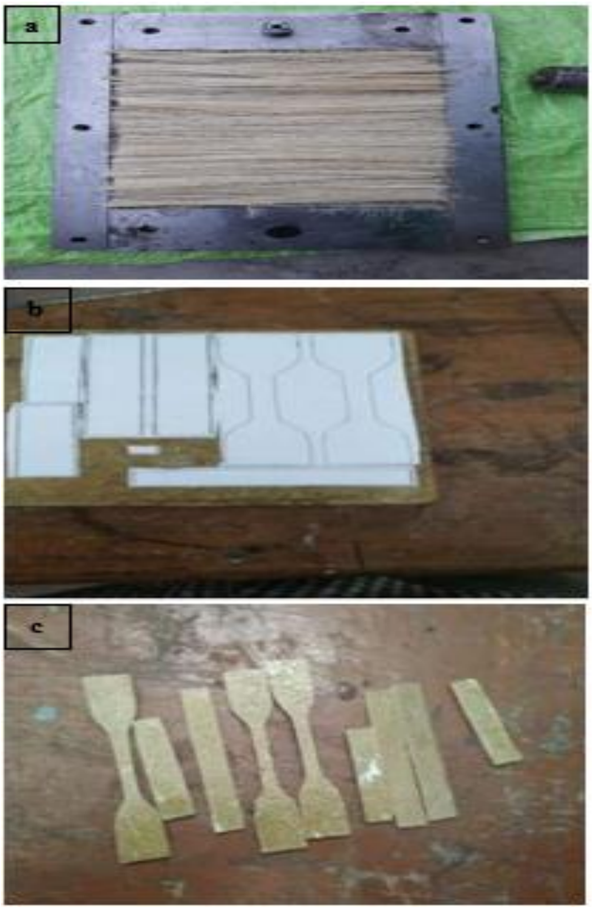

Fig 1 Experimental Set Up used for Processing Composites: A) Resin Block with Fibers, B) Marking Pattern as Per Astm Dimensions on the Fabricated Plate and C) Astm Specimens for Different Tests

C. Testing of Composites

The thermal response of the epoxy based natural composites has been tested using Thermogravimetric Analysis (TGA).

Fig 2 Experimental Set Up used for Thermogravimetric Analysis (Universal V 4.7 TA Instrument)

The weight loss under the influence of thermal conditions of polymer composites was evaluated using the concept of thermogravimetric analysis (TGA). The thermal range used for the study was 30 – 800 ^{0}C under the controlled nitrogen atmosphere at a heating rate of 20 ^{0}C / min (Universal Instruments, TGA Q50 V 20.13) (Fig. 2). The percentage weight loss at different temperatures was recorded using thermograms. The derivative weight loss and other related temperatures were documented and analyzed using derivative TGA thermograms.

III. RESULTS AND DISCUSSION

The effect of long jute and banana fibers on the thermal response of epoxy based natural composites has been investigated using the concept of TGA. The stages of different temperatures required to define the performance of the polymer composites has been reported. TGA theromgrams reports percentage weight loss at different temperatures and their relation with the composition of the fibrous composites . Following section details the thermal response of these natural composites under the impact of hybrid effect of long natural fibers.

Table 3 Thermal Stages of Epoxy Natural Composites

Composites	**Temperature (± 2 ^{0}C)**		
	T_o	**T_m**	**T_c**
EP Composites	201.23	381.22	559.67
EP8 Composites	204.21	389.38	606.94
EP16 Composites	202.16	390.04	628.30
EP24 Composites	205.26	397.44	609.46
EP32 Composites	209.29	398.24	610.88

The thermal response of banana and jute fiber reinforced epoxy natural composites has been evaluated using thermo gravimetric analysis (Fig. 3(a - c)) and Fig. 3(d and e). The weight loss of these composites under different operating temperatures and also the different stages of the temperature such as onset temperature (To), Melting temperature (Tm) and crystallization temperature (Tc) has been recorded in table 3 and table 4 respectively.

ISSN No:-2456-216

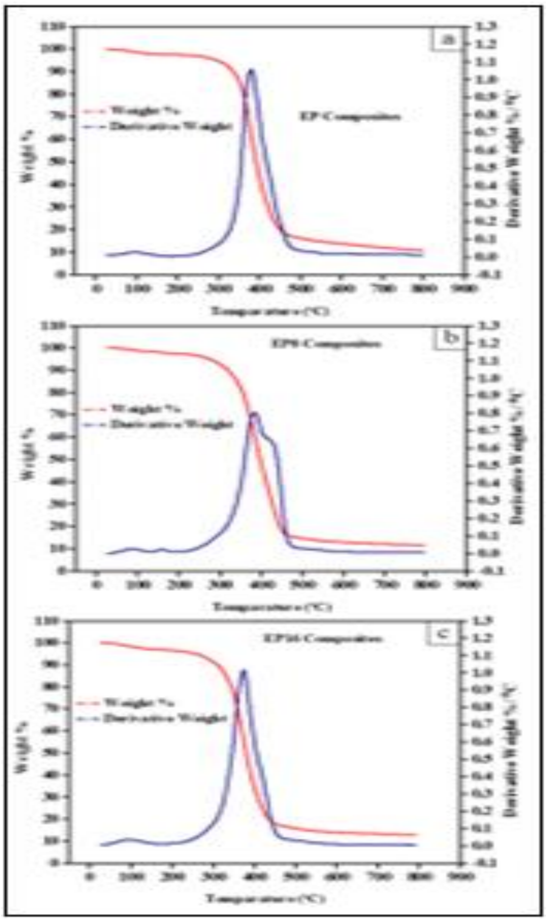

Fig 3 TGA Thermograms of Epoxy Based Natural Composites: a) EP Composites, b) EP8 Composites, c) EP16 Composites

From the results of the experimentation that the effect of hybridization of these natural fibers has appreciable effect on the thermal stability of epoxy based composites. The hybrid effect of natural fibers has controlled the weight loss due to the thermal effect at severe situations.

The thermal response in terms of different stages of temperature of neat epoxy (EP) is demonstrated in fig. 3(a). It is observed from the thermograms that the on set temperature of EP composites begins at 201.23 ^{0}C. This is the temperature at which the composites are free from moisture. With the loading of temperature, the EP has received the heat at which the softening state which is the melting temperature of EP has been attained (381.22 ^{0}C). Further thermal loading tends to move from softer zone to crystallization zone and reached the final value of 559.67 ^{0}C as their crystallization temperature (Table 1). But further loading the system leads to ass stage which may be 10 % from the total weight of the system. This is in good agreement with the work of others [2, 12, 13].

The thermal response of EP8 and EP16 fibrous epoxy composites is exhibited in fig. 3(b and c). It is observed from the thermograms that the on set temperature of EP8 and EP32 composites starts at 204.21 ^{0}C and 202.23 ^{0}C respectively. It is observed that all composites starts eliminating the water contents at almost a common temperature,. Here the presence of fibers do not have any effect on the on set temperature because at this stage thermal response was totally governed by neat epoxy [1, 2, 14, 16]. The absorption of heat starts continuing after further loading of temperature. But EP8 and EP16 composites exhibits the melting temperature of 38.38 ^{0}C and 390.04 ^{0}C against the melting temperature of neat epoxy which is 381.22 ^{0}C. This shows that the effect of adding fibers in to epoxy has enhanced the softening state of the polymer composites. Therefore, the thermal stability of epoxy based composites has been improved by the hybridization effect of natural fibers. The total amount of heat supplied after softening state has moved composites to the crystallization stage exhibiting the temperature of 606 ^{0}C and 628 ^{0}C. The increase in softening point of epoxy filled composites was due to the increased volume fraction of fibers [2, 8].

Similar observations were made from EP24 and EP32 composites. But from the previous response of EP8 and EP16 composites, the volume fraction of fibers has played the significant role in defining the thermal behaviour of EP based fibrous composites.The thermal behaviour of EP24 and EP32 composites is demonstrated in fig. 4(d and e). The onset temperature has been defined based on the thermal strength of the epoxy. With increases in thermal load, the softening point of fibrous composites has been attained. Here the melting point of 397 ^{0}C and 398 ^{0}C have been exhibited by EP24 and EP32 composites. Higher volume fraction of fibers in composites has exhibited the highest melting point because of restriction in molecular momentum of these composites. Further, the hard phase of fibers with the soft matrix has raised the softening point of polymer due to heterogeneous phase of composites [14, 16]. Further heating has led to the crystallization stage with a temperature of 609 ^{0}C and 610 ^{0}C respectively.

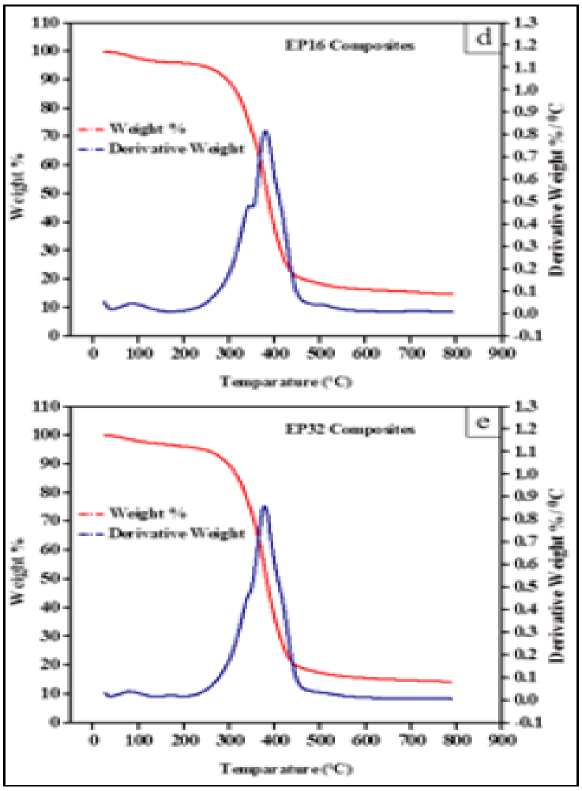

Fig 4 TGA Thermograms of Epoxy Based Natural Composites: d) EP24 and e) EP32 Composites

Table 4 Percentage Weight Loss at Different Temperatures of Epoxy Natural Composites

Composites	**Percentage weight loss (± 2 ^{0}C)**				
	10%	**20%**	**30%**	**50%**	**Maximum**
EP Composites	336.54	362.78	373.68	393.23	459.28
EP8 Composites	325.45	360.37	376.98	402.57	470.28
EP16 Composites	320.38	353.83	368.79	389.84	501.23
EP24 Composites	304.44	341.06	362.43	391.38	518.45
EP32 Composites	308.94	344.75	365.61	392.05	604.88

From the thermograms of TGA, the weight loss of epoxy based composites has been documented in the table 4. It is observed from the table that the higher volume fraction of fibers leads to reduce the weight loss of composites at higher temperature. It was seen that neat epoxy composites will lose 10% at 337.53 ^{0}C and will be maximum at 458.28^{0}C. But the weight loss of all EP based composites (up to 20%) increases at lower temperature than neat epoxy. Further loading of the same fibers could control the loss of weight even at higher temperature.

From the table 4 is it is observed that the weight loss of the Epoxy based composites has been impaired at higher temperature due to the addition of fibers. The 50% weight loss of composites has been considered appreciable by all the composites. It is observed that neat epoxy had lost 50 % of its weight at about 393.23 ^{0}C. Similarly EP8 (402.57 ^{0}C), EP16 (389.84 ^{0}C), EP24 (391.38 ^{0}C) and EP32 (392.05 ^{0}C). It is observed that weight loss of composites has been impaired with peak temperature. Further, the maximum weight loss of all EP based composites exhibits the defined weight loss at higher temperatures. EP32 composites has exhibited the maximum weight loss at peak temperature of 604.88 ^{0}C compared to all the composites. Similarly EP8 (470.28 ^{0}C), EP16 (501.23 ^{0}C), EP24 (518.45 ^{0}C) and EP32 (604.88 ^{0}C). This showed that higher volume fraction of fibers leads to enhance the structural stability which restrict the flow heat from one location to other, This has lead to the development of thermal resistance against the weight loss of composites [2, 8, 10]. Among all the epoxy based fibrous composites studied, EP32 composites has the superior thermal response compared to all other EP based composites. This is in good agreement with the work of others [8, 11, 12, 14].

IV. CONCLUSION

The hybridization effect of long jute and banana fiber reinforced epoxy natural composites has been investigated for the thermal behaviour using Thermogravimetric Analysis (TGA). It is observed that the thermal stability of composites was improved by the increase in volume fraction of fibers in composites. The weight loss of composites at higher temperature has been controlled due to the reinforcement effect of hard fibers. Among the composites studied, EP32 composites has exhibited the superior thermal behaviour compared to all the composites. But the natural fibers were hydrophobic in nature. This has minor effect on the weight loss of composites.

ACKNOWLEDGMENT

Author extends heartfelt thanks to Dr. Madhu D, Professor, Government Engineering College Ramanagara. Karnataka for their support to complete this research work.

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