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Experimental Investigation of Effect of Aluminum Filler Material on Thermal Properties of Palmyra Fiber Reinforced Composite

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ABSTRACT
Natural fiber composites are renewable, cheap, completely or partially recyclable, carbon neutral and biodegradable. Their easy availability, lower density, higher specific properties, lower cost, satisfactory mechanical and thermal properties, non-corrosive nature, lesser abrasion to processing equipment, makes them an attractive ecological alternative to glass, carbon or other man-made synthetic fibers. Natural fiber composites are generally very good thermal insulators and thus cannot be used where thermal conduction is desirable. Increase in thermal conduction may be done by adding metal filler powders to the matrix. In this work, the effect of aluminum filler material on thermal properties of chemically treated palmyra fiber reinforced composites is investigated. Thermal properties studied include thermal conductivity, specific heat capacity, thermal diffusivity, thermal degradation and stability. Five different samples with 0%, 25%, 50%, 75%, 100% aluminum powder are considered. With the addition of aluminum filler powder, thermal conductivity increases, specific heat capacity decreases, thermal diffusivity increases and thermal stability improves with maximum at 50% aluminum powder.
Keywords **-** Aluminum filler, Chemical treatment, Natural fiber composites, Palmyra fiber, Thermal properties

I. Introduction

Fiber Reinforced Composite (FRC) materials consists of fibers of high strength and modulus, embedded in or bonded to a matrix with distinct boundaries between them. In this form both fiber and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents alone. In general, fibers are the principal load-carrying members, while the surrounding matrix keeps them in the desired location and orientation. The matrix serves to bind the fibers together, transfer loads to the fibers, and protect them against environmental attack and damage due to handling. The matrix is usually of much lower strength, stiffness and density and is tougher than the fibers.

A fiber reinforced resin system is a composite material consisting of a network of reinforcing fibers embedded in a matrix of thermosetting or thermoplastic resin. Other materials such as fillers and pigments may also be present, although they are not an essential part of the composite. In general, the resin used consists of a syrupy liquid which when combined with a suitable catalyst or hardener, can be cross-linked into a hard infusible solid.

Thermosetting resins change irreversibly under the influence of heat from a fusible and soluble material into one which is infusible and insoluble through the formation of a covalently cross-linked, thermally stable network. Thermo-setting resins are the most common types of matrix material for composites due to low melt viscosity, good fiber impregnation, and fairly low processing temperatures, lower cost. In this work, polyester a thermosetting resin is used as matrix material.

Fibrous composites are formed by embedding and binding together of fibers by a continuous matrix. a fiber is a material in an elongated form such that it has a minimum length to a maximum average transverse dimension of 10:1. A fiber is inherently much stiffer and stronger than the same material in bulk form because of its structure.

Fibers can be either synthetic which are manmade like glass, boron, kevlar etc., or natural like those obtained from plants, animals or minerals. Plants fibers from palm, flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, bagasse, rice husk, groundnut shell, banana etc., as well as wood which are used as a source of ligno-cellulosic fibers are often applied as the reinforcement of composites.

Synthetic fibers, because of their higher strength-weight ratio, modulus-weight ratio, fatigue strength-weight ratio, fatigue damage tolerance, and being lighter in weight, these composite materials are markedly superior to those of metallic materials. However, they pose critical environmental concerns as they are not easily degradable. For example, incineration of glass fiber based composites generates a lot of black smoke and bad odors and damages the incinerator by fusion of glass fibers. Many countries have imposed regulations to reduce pollution from manufacturing industries.

Natural fiber composites on the other hand are renewable, cheap, completely or partially recyclable, carbon neutral and 100% biodegradable because they absorb water, and decay through the action of fungi and bacteria. Their easy availability, lower density, higher specific properties, lower cost, satisfactory mechanical and thermal properties, non-corrosive nature, lesser abrasion to processing equipment, makes them an attractive ecological alternative to glass, carbon or other man-made synthetic fibers. Natural fiber products can be composted to improve soil structure, or incinerated with no emission of pollutants and release of no more carbon than the fibers absorbed during their lifetimes.

However, in general natural fiber composites are less strong and have lesser durability compared to synthetic fiber composites. Unlike synthetic fibers, natural fibers from hundreds of plants with their different natures, complicate the formulation of a unified approach. For natural fibers, investigation parameters should include thickness and characteristics of the bark, mainly the number, length and distribution of cells and fiber bundle structure, as well as the extraction methodology, fiber quality, fiber percentage and fiber-to-wood relationship of the product.

Palm tree is a widely cultivated, economically useful important tree of India with over 800 uses. Its leaves are used for thatching, mats, baskets, fans, hats, umbrellas and as writing material. Palmyra fiber extracted from palm tree is one of the commonly available, strong, natural fiber. In this work, palmyra fiber reinforced natural composites are considered.

Natural fiber composites are generally very good thermal insulators and thus cannot be used where thermal conduction is desirable. Increase in thermal conduction may be done by adding metal filler powders to the matrix. In this work, the effect of aluminum filler material on thermal properties of chemically treated palmyra fiber reinforced composites is investigated.

Apart from measuring the change in thermal conductivity due to addition of varying quantities of aluminum powder experimentally, variation in specific heat capacity and thermal degradation are also experimentally measured. Variation in thermal diffusivity is computed.

II. Preparation of Samples

Steps in preparation of palmyra fiber reinforced composite samples using Hand Lay technique.

2.1 Extraction of Palmyra Fibers from Palm Tree

Palmyra fiber is available in the form of bract on a Palmyra tree. First dried bracts are collected from Palm trees. Then the fibers inside the bract are segregated. They are soaked in water for 24 hours. Using a knife, the black layer on top of the fiber is scrapped off. These fibers are dried in sun for 2 days to remove the moisture. If necessary they should also be put in an oven for 2 hours at 70^{o}C to ensure that all the moisture is completely removed.

2.2 Chemical Treatment of Fibers

Mahesh et.al.[1] from their research observed that both mechanical and thermal properties of Palmyra fiber composites increased when the fibers are chemically treated. Hence in this work only chemically treated fibers are used. Cleaned fibers are kept in 4% (NaOH) solution for 4 hours for chemical treatment. The fibers are then removed and cleaned in water. They are kept in sunlight for 24 hours to remove moisture entirely. The fibers are then cut as per the required dimensions as per ASTM test sample specifications.

Fig.1: Chemically Treated Palmyra Fibers

2.3 Mold Preparation

Thermal conductivity test samples should be of circular shape with 50 mm diameter and 10mm thickness. To prepare the mold, a 50 mm diameter hole is cut in a 10 mm thick rubber sheet. This cut rubber sheet is affixed to a cleaned tile with mansion hygienic wax. The tile is cleaned thoroughly with shellac NC thinner solution.

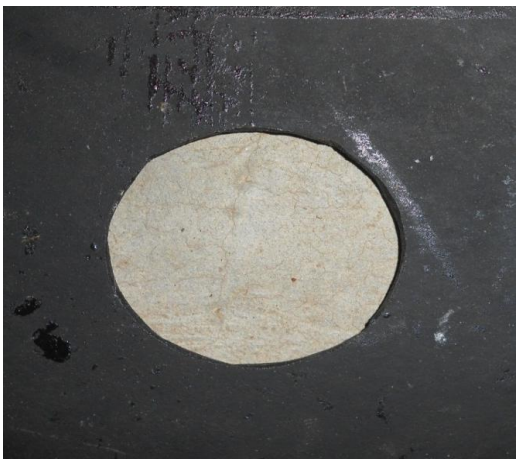

Fig.2: Mold for Sample Preparation

During preparation of the circular sample, it is observed that the fiber concentration is much higher

at the center than at the periphery. To get a nearly homogenous fiber distribution in the sample, in this research a large rectangular sample of 165 mm x 55 mm x 10 mm is prepared, out of which the required circular samples are cutout.

2.4 Preparation of Aluminum Powder

To create aluminum powder, an aluminum block is heated in a furnace and the top molten liquid layer is skimmed off. After this liquid cools off, it forms a coarse grain powder like semi-solid. The coarse powder is crushed and sieved to get finer powder.

Fig.3: Fine Aluminum Powder

2.5 Determining Quantities of Fiber and Aluminum

The maximum amount of fiber or aluminum powder that can fit in the mold is taken as 100%. To fit in maximum amount of fiber, fibers are spread layer upon layer very closely and ramming is done after each layer is spread. The weight of maximum fiber quantity in the circular mold is found to be 8 gm, which is taken as 100% (FB100). The weight of maximum aluminum powder quantity in the circular mold is found to be 15 gm, which is taken as 100% (AL100).

2.6 Polyester Bonding Material

Polyester resin is durable, comparatively inexpensive, has superior corrosion resistance, has good range of mechanical properties, and is light in weight. ECMALON 4413, which is a general purpose polyester resin is used as matrix material.

2.7 Catalyst and Accelerator

Curing or cross-linking of polyester is achieved by adding a catalyst (initiator) plus an accelerator (promoter) at room temperature. The function of catalyst is to speed up a chemical reaction by providing an alternate reaction pathway with lower activation energy. The function of accelerator is to alter chemical bonds and speed up the chemical process. In this work, cobalt accelerator along with Methyl Ethyl Ketone Peroxide (MEKP) catalyst is used.

Optimum quantity of catalyst and accelerator must be used. If more quantity is used, the specimen cures faster but will be of lesser strength and poor appearance. If lesser quantity is used, then the sample takes very long time (more than 8 hours) to cure. In this work approximately 2ml catalyst and 2 ml accelerator is used, which gave a curing time of around 4 hours.

2.8 Hand Lay Technique

2.8.1 Clean the mold with shellac NC thinner solution. Apply a thin coating of poly-vinyl alcohol on the interior tile surface and along the edges of the rubber sheet. Dry it for a day.

2.8.2 Fill the mold with required mass of fibers by spreading them as homogenously as possible.

2.8.3 Take the required mass of aluminum powder in a measuring jar.

2.8.4 Pour small amounts of liquid polyester in the aluminum powder jar and stir it thoroughly.

2.8.5 Add catalyst to this paste using a syringe and stir it fast.

2.8.6 Add accelerator to this mix and stir it fast. Extreme caution should be taken in ensuring that the catalyst and accelerator does not get into to direct contact with each other. Else they both react chemically extremely rapidly with issuing out fire.

2.8.7 Immediately apply this paste on top of the fibers which are filled in the mold, otherwise it would solidify rapidly in the measuring jar itself.

2.8.8 To ensure that no air bubbles are trapped inside, take a transparency sheet and cover it over the mold immediately by using rolling operation.

2.8.9 Place a tile on top covering the entire mold and its contents. Place sufficient weight (roughly 50 kg) on top of the mold and leave it undisturbed in a closed room for 1 day until the composite cures.

Fig.4: Palmyra Fiber Composite Sample

III. Thermal Testing Results

Thermal Tests conducted are:

1) Thermal Conductivity measurement
2) Specific Heat Capacity measurement
3) Thermal Diffusivity is computed.
4) Thermal Degradation measurement by Thermo-Gravimetric Analysis (TGA)

To investigate the effect of aluminum powder filler material on the thermal properties of the

chemically treated palmyra fiber composites, 5 samples are prepared.

Sample Name	Polyester gm	Fiber gm	Al gm	Relative Al %
AL0	13	8	0	0%
AL25	13.25	6	3.75	25%
AL50	13.5	4	7.5	50%
AL75	14.75	2	11.25	75%
AL100	15	0	15	100%

Table 1: Sample's Composition by Weight

Sample Name	Weight (kg)	Volume (m^3)	Density (kg/m^3)
AL0	0.020	1.79E-05	1117.8
AL25	0.022	2.50E-05	878.3
AL50	0.023	2.15E-05	1071.2
AL75	0.028	2.50E-05	1117.8
AL100	0.031	1.79E-05	1732.6

Table 2: Sample's Density

3.1 Thermal Conductivity

Thermal conductivity of the samples is measured at 50°C using guarded heat flow test method as per ASTM E1530 specifications. Unitherm Model 2022 manufactured by ANTER Corp., Pittsburgh, PA is used for this test.

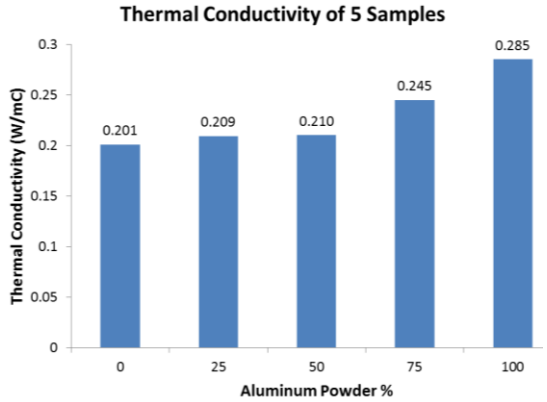

Fig.5: Sample's Thermal Conductivity

3.2 Specific Heat Capacity

Differential Scanning Calorimeter (DSC) technique using Double Furnace setup is used for measuring specific heat capacity. DSC is a thermo-analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Compared to Single Furnace setup, Double Furnace DSC gives more accurate readings over larger temperature range, with more rapid response time as it measures the heat flow change of the sample directly. Test equipment used is Netzsch Simultaneous Thermal Analyzer STA 449F5 Jupiter.

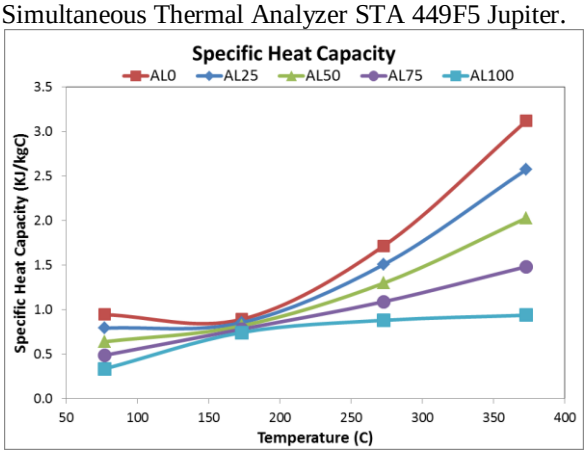

Fig.6: Sample's Specific Heat Capacity

3.3 Thermal Diffusivity

Although thermal diffusivity can be experimentally measured by flash method, in this work it is calculated after knowing thermal conductivity, specific heat capacity and density.

$$\alpha = \lambda/(\rho C_p)$$

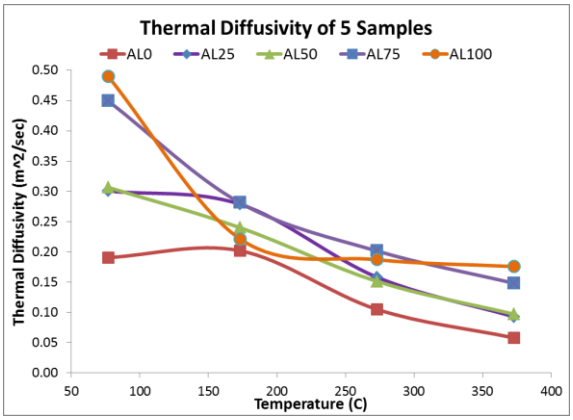

Fig.7: Sample's Thermal Diffusivity

3.4 Thermal Degradation by TGA

Thermo-Gravimetric Analysis (TGA) is a technique in which the mass of a substance is monitored as a function of temperature or time as the sample specimen is subjected to a controlled temperature program in a controlled atmosphere. TGA measures a sample's weight as it is heated or cooled in a furnace. The loss in weight over specific temperature ranges provides an indication of the composition of the sample, including volatiles and inert filler, as well as indications of thermal stability.

All the measurements were performed as per ASTM E1131 standard using high resolution Perkin Elmer TGA7 Thermo-gravimetric Analyzer. The samples weighing between 10 and 20mg are placed in a platinum pan and tests are performed within the temperature range of 20–700°C at a heating rate of 5°C/min under nitrogen atmosphere at flow rate of

50 ml/min. TG and DTG curves were analyzed to study the high temperature degradation behavior.

TGA curves [Fig.9] of specimens provide three distinct temperature regions, wherein the samples experience major weight loss. A small weight loss was observed during Phase-1 attributed to the evaporation of moisture. Actual degradation happens in second region attributed to the thermal degradation of hemicelluloses, cellulose and lignin together with polymeric matrix and thereafter the rate of decomposition was slow.From DTA curves [Fig.10] most decomposition also occurs at the temperature of 380-386°C (Phase-2).

Quantitative data in Phase-2 including onset thermal degradation temperature, end of degradation temperature, corresponding weight loss is given in Table 3, and are plotted in Fig.8.

From TGA [Fig.9] the onset of thermal degradation is taken at a weight loss of 12% from the initial weight. The end of degradation point is taken as the point where the steep drop of weight% finishes and the curve flattens out relatively Subtracting end of degradation weight% from onset weight% gives weight loss% during the Phase-2.

Sample Name	Onset Degradation		End Degradation		Wt Loss%
	Temp	Wt%	Temp	Wt%	
AL0	280.99	88.14	440.99	11.76	76.38
AL25	287.44	88.06	443.44	16.60	71.46
AL50	320.06	88.13	421.06	37.56	50.57
AL75	295.01	88.03	448.01	15.85	72.18
AL100	275.09	88.05	445.09	15.02	73.02

Table 3: Sample's Thermal Degradation by TGA

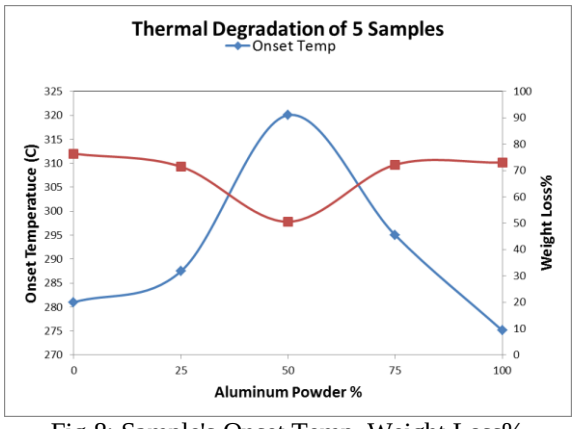

Fig.8: Sample's Onset Temp, Weight Loss%

From DTA curves [Fig.10] which is the first derivative of the weight % with respect to the time, the maximum value indicates the instant where the rate of weight loss% is maximum. These temperatures where maximum weight loss% rate occurs are listed in Table 4. In Phase-3, at the end of 900°C where the experiment is terminated, the residual weight left over is also given in Table 4.

Sample Name	Temp at Peak Wt Loss%	Residual Wt% at 900 C
AL0	380.9	7.91
AL25	385.4	12.68
AL50	382.0	25.73
AL75	383.5	11.91
AL100	381.7	11.35

Table 4: Sample's Peak Temperature, Residual Wt%

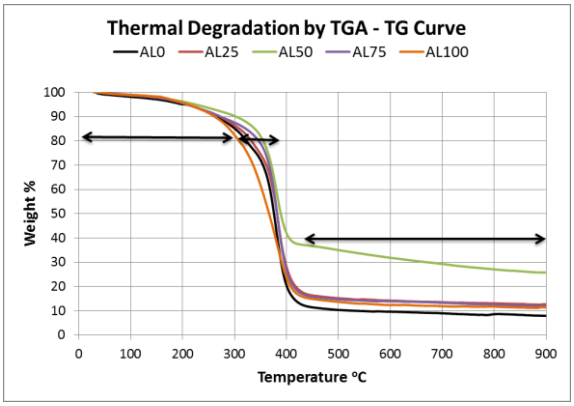

Fig.9: Sample's Weight Loss Curve

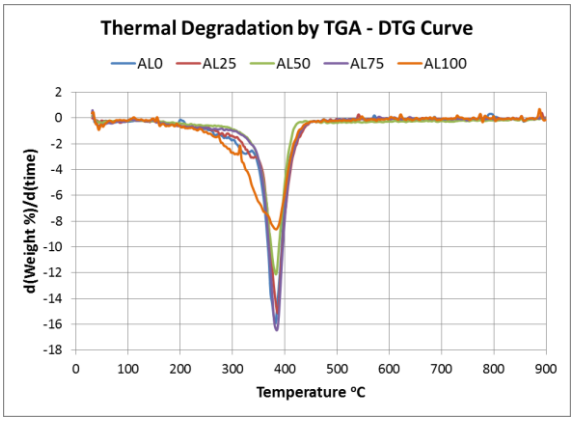

Fig.10: Sample's Weight Loss Derivative Curve

IV. Conclusions

1) Thermal conductivity of the composite increases with increase in the aluminum filler content.
2) For a given temperature specific heat capacity decreases as aluminum filler content increases. Specific heat capacity increases with increase in temperature at any aluminum filler content. Further as aluminum filler content increases, rate of increase of specific heat capacity with temperature reduces.
3) Thermal diffusivity of the composite decreases with increase in temperature.

4) 50% Aluminum filler composite has the highest thermal degradation onset temperature and also the least amount of weight loss. Thus it has the highest thermal stability
5) Temperature at maximum weight loss is nearly constant (380^oC-385^oC) for all aluminum content.

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