Experimental Investigation of Mechanical and Thermal properties of sisal fibre reinforced composite and effect of SiC filler material

Malla Surya Teja$^1$, M V Ramana$^2$, D Sriramulu$^3$ and C J Rao$^4$

$^1$ M.Tech Student, Aditya Institute of Technology and Management, Tekkali
$^2$ Associate Professor, Aditya Institute of Technology and Management, Tekkali
$^3$ Professor, Aditya Institute of Technology and Management, Tekkali
$^4$ Professor & HOD, Aditya Institute of Technology and Management, Tekkali

E mail: mallasuryateja@gmail.com, myramana6028@gmail.com, sreeram_india9@yahoo.com, raoj_chintu@yahoo.com.

Abstract

With a view of exploring the potential use of natural resources, we made an attempt to fabricate sisal fibre polymer composites by hand lay-up method. Natural fiber composites are renewable, cheap and biodegradable. Their easy availability, lower density, higher specific properties, lower cost, satisfactory mechanical and thermal properties, non-corrosive nature, makes them an attractive ecological alternative to glass, carbon or other man-made synthetic fibers. In this work, the effect of SiC on mechanical and thermal properties of natural sisal fiber composites are investigated. The composite has been made with and without SiC incorporating natural sisal fiber with polyester as bonding material. The experimental outcomes exhibited that the tensile strength of composite with 10%SiC 2.53 times greater than that of composite without SiC. The impact strength of composite with 10% SiC is 1.73 times greater than that of composite without SiC plain polyester. Thermal properties studied include thermal conductivity, specific heat capacity, thermal diffusivity, thermal degradation and stability. Three different samples with 0%, 5%, 10% SiC powder are considered. With the addition of SiC filler powder, thermal conductivity increases, specific heat capacity gradually increases then decreases, thermal diffusivity increases and thermal stability improves with Sic powder.

Keywords – Silicon carbide filler, Chemical treatment, Natural fiber composites, Sisal fiber, Mechanical and Thermal properties

1. Introduction:

Natural fibers have played a significant role in human civilization since prehistoric times. The human beings depend on them for garments and other simple domestic uses as well as complex applications such as land dwellings and reed-built sailing craft etc. The natural fibers – reinforced composite had the advantage of being light, strong, cheap, nonabrasive, high specific mechanical and thermal properties and are more environmental friendly. However these have some drawbacks such as brittleness, moisture absorption and low processing temperatures. Thermoplastic polymers especially polypropylene are produced and used today in vast quantities. However, they are seldom used as pure polymers and are usually combined with mineral fillers like fly ash, graphite, silicon carbide etc. Fillers find application in the polymer industry almost exclusively to improve thermal and mechanical properties. The properties of composites mainly depend on the matrix, fibers, and other interfacial bonding. Several investigators have used natural fibers as reinforcement in the
development of green composites. The adhesion between the reinforcing fibers and the matrix in composite material plays an important role in final thermal properties of the composites. Material characteristics play an important role in manufacturing and design engineering. Knowledge of the response of the work material during manufacturing is essential for adopting more efficient, effective and economical processing methods. Proper understanding of the response of the work material under different situations is possible only if the characteristics of a material are known. Composites with natural fibers are gaining increasing attention for a variety of applications. Available natural fibers such as jute, coir, sisal, and Palmyra belong to this category [1]. Glass, carbon, boron and Kevlar fibers are being used as reinforcing materials in Fiber Reinforced Plastics [FRP] which have been widely accepted as materials for structural and non-structural applications. Synthetic fibers are not eco-friendly. Hence attention has been focused on the utilization of natural fibers for the production of fiber-reinforced materials. One of the natural fiber-polymer composites are investigated by Paramasivan and Abdulkalam, A.P.J. [2] using sisal fibers and epoxy matrix. The fabrication process followed by winding and laminating technique, that which is of easy and low cost technique. According to this technique, to improve the tensile strength of sisal epoxy composites is up to 250-350 MPa which is near to strength of glass-epoxy composite with same volume fraction.

As sisal fiber is of low density, that the specific strength of glass fiber composites can be compared with specific strength of sisal fiber composites. This work denotes the easiness of developing new composites by reinforcing easily available natural fibers, to be used in areas like construction and consumer goods. It also reports the use of electron probe microanalysis for calculating the filler scattering in sisal-polymer composites. Chopped sisal fibre polyester composites are prepared by the press mold technique. Mechanical properties of the composites are evaluated through accelerated weathering tests conducted pertaining to ASTM D-520 specification. It is found that the specific modulus of the composite is 1.90 compared with 2.71 for glass fibre reinforced plastics, while the specific strength is of the same order as that of polyester and 30% less than glass fiber reinforced plastics. Accelerated testing revealed little change in initial modulus, reductions of 5% in ultimate tensile strength, 16% in flexural strength and 5.4% in water absorption. Lakkad.S.C. et al [6] in this work, evaluate the mechanical properties like tensile, compressive strength and young’s modules of elasticity of bamboo specimens and these results are compared with same properties of mild steel and glass fiber reinforced plastics. Jindal.U.C. [7] compared the ultimate tensile strength of dendrocalamus strictus specie of bamboos with mild steel. The bamboo composites have nearly six times more than that of mild steel. Also compared the properties of different orientations of fiber placing in composite like parallel and transverse orientations of bamboo fibers. Fiber incorporated plastics have been very popular due to their flexibility, their lightness and the ease of fabrication of complicated shapes with economic savings in contrast to fiber reinforced metals/alloys. In addition, these composites can be easily substituted for conventional materials in several areas such as the building industry, transportation and consumer goods. Some of these attempts made in recent times for the utilization of natural fibers through composite material technology have indicated their potential as substitute for the conventional materials such as wood and glass fibre reinforced plastics (GFRP) in many applications. There are, however, a number of limitations, including cost factor and their performance over a long time duration, which need further research. Extensive literature is available on the production and mechanical behavior of composites obtained by reinforcing epoxy with fibre of glass, boron, carbon silicon carbide etc. Many researchers in the past have developed composites with natural fibres such as sisal hene, quen, jute, banana, cotton, etc. [3, 4, 5, 8].Many researchers reports about the enhancement of thermal conductivity of polymer by thermal conduction.
mechanisms and other techniques [9,10,11]. Progelhof et al. [15] have predicted the thermal conductivity of composites and demonstrated various theoretical and empirical models with brief description that focusing the relative merits. Maewal et al. [16] evaluated the heat transfer in fibrous composites by using binary mixture with a periodic hexagonal micro structure primarily in fiber direction. Chamis [17] summarized the expressions for the thermal conductivity of different orientations of composites like longitudinal and transverse isotropic composites.

2. Sample Preparation:

2.1 Materials
Polyester resin ECMALON 4411, cobalt naphthanate as accelerator in which speed up chemical process, and methyl ethyl ketone peroxide as catalyst which speed up the chemical reaction. SiC powder is purchased from local industry and sisal fiber is collected from sisal plant.

2.2 Fiber Extraction and Processing
Sisal leaves are separated from sisal plant, these are grouped in bundles. These bundles are soaked in water for 15 days. These soaked leaves were cleaned in running water and dried under sunlight for 24 hours and chopped into desired length. The fibers are undergone for chemical treatment, that the collected fibers are soaked in 2% NaOH solution for one full day. These soaked fibers cleaned and dried in room temperature.

2.3 Polyester Bonding Material
Polyester resin is durable, comparatively inexpensive, has superior corrosion resistance, has good range of mechanical properties, 4413, which is a general purpose polyester resin is used as matrix material. Resin ECMALON 4413 is of pale yellow Colour of 500-600 CPS Viscosity (Brokfield Viscometer) 1.13 grams/c.c. of Specific Gravity.

2.4 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.

2.5 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.
Hand lay-up technique was adopted in the preparation of unidirectional composites. 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. Fill the mold with required mass of fibers by spreading them as homogenously as possible. Take the required mass of silicon carbide powder in a measuring jar. Pour small amounts of liquid polyester in the silicon carbide powder jar and stir it thoroughly. Add catalyst to this paste using a syringe and stir it fast. 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 direct contact with each other. Else they both react chemically extremely rapidly with issuing out fire. 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. To ensure that no air bubbles are trapped inside, take a transparency sheet and cover it over the mold immediately by using rolling operation. 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. The specimens were also post cured at 70 °C for 8 h after removing from the mold. In the same above process composites are also prepared by adding SiC (5%, 10%) to resin and proper mixing were done before poured on fibers.

| Sample code | Polyester | Sisal fiber | silicon carbide (SiC) |
|-------------|-----------|-------------|----------------------|
| A           | 70        | 30          | 0                    |
| B           | 65        | 30          | 5                    |
| C           | 60        | 30          | 10                   |

3. Mechanical & Thermal test results:

3.1 Tensile strength
The ASTM D638-89, standard test method adopted for measured the tensile properties of composite. The specifications of specimen is 160 mm long, 3 mm thick and 12.5 mm wide were prepared. Three identical specimens were tested for each type of composite. Aluminum tabs were glued to the ends of the specimen resin filling the space at the tab overlap to prevent compression of the sample and also
for effective gripping in the jaws of the chuck. The specimens were tested at a cross head speed of 2 mm/min, using an electronic tensometer.

Tensile strength is one of the important mechanical properties in engineering materials. It has been observed that the tensile strength of composite with SiC is better compared to without SiC composite. The average values of tensile strength for neat, silicon carbide (SiC) filled composite samples respectively.

| Table 2. Tensile strength of samples |
|-------------------------------------|
| Sample | Tensile strength(M Pa) |
|--------|------------------------|
| A      | 28.6                   |
| B      | 45.7                   |
| C      | 72.5                   |

Figure 2. variation of tensile strength of 0%, 5%, 10% SiC in sisal fiber composite

3.2 Impact strength

Izod impact test notched specimens were prepared in accordance with ASTM D256-88 to measure impact strength. The specimens were 63.5 mm long, 12.7 mm deep and 10 mm wide. A sharp file with included angle of 45° was drawn across the center of the saw cut at 90° to the sample axis to obtain a consistent starter crack. The samples were fractured in a plastic impact testing machine.

The impact behavior of sisal fiber reinforced composite with and without SiC samples was studied based on impact strength. The average values of impact strength for composite samples are plotted. It can be observed that the impact properties were improved for all composite samples of silicon carbide (SiC) compared to neat composite. This behavior is attributed to the reduction in toughness of polyester after incorporation of SiC particle.
### Table 3. Impact strength of samples

| Sample | Impact strength |
|--------|-----------------|
| A      | 7.6             |
| B      | 10.23           |
| C      | 14.25           |

![Impact Strength (J/m²)](image)

**Figure 3.** Variation of impact strength of 0%, 5%, 10% SiC in sisal fiber composite

### 3.3 Thermal conductivity measurement

Thermal conductivity is the property of a material to conduct heat. It can be defined as ‘the quantity of heat transmitted through a unit thickness in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions’. Thermal conductivity of the samples is measured at 500°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.

### Table 4. Thermal conductivity of samples

| Sample | Thermal conductivity |
|--------|----------------------|
| A      | 0.25                 |
| B      | 0.31                 |
| C      | 0.38                 |
Figure 4. variation of thermal conductivity of 0%, 5%, 10% SiC in sisal fiber composite

The above graph shows that as the volume fraction of SiC increases, thermal conductivity also increases, and it is seen that composites containing 10% Sic exhibits the highest thermal conductivity.

3.4 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.

For temperature range (30°C-80°C), specific heat values of all samples are gradually increased i.e. good storage of heat is possible. In this particular range of temperature 16.6% of specific heat of sisal fiber increased. The specific heat of composite with 5%, 10% silicon carbide over composite is 22.52% and 37.56%, increased respectively. This may be due to higher values of specific heat of silicon carbide than sisal fibre. It is observed that all three sample specific heat values are decreased for temperature range of 800-1200, which causes thermal instability of sisal fiber composite.

Figure 5. variation of specific heat of 0%, 5%, 10% SiC in sisal fiber composite with temperature
3.5 Thermal Degradation
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 weight loss for temperature range gives the denotes of the sample composition and thermal stability, including filler materials and volatiles.
All the measurements were performed as per ASTM E1131 standard using high resolution Perkin Elmer TGA7 Thermo-gravimetric Analyzer. The TGA test is performed in the temperature range of 20°c-800°c for the 5 to 10 g weighted samples at a heating rate of 5°c/min under nitrogen atmosphere. Three distinct temperature regions phase-I (0°c-300°c), phase-II(300°c-500°c) and phase-III(500°c-800°c), where samples undergoes the weight loss. At low temperature region i.e. for phase-I, It is found that small weight loss occurred due to evaporation of moisture. For medium temperature region i.e. for phase-II, it is found that actual degradation occurs which accounts for the thermal degradation of the cellulose and lignin with polymeric matrix and then the degradation is very slow and less. From TGA the onset of thermal degradation is taken at a weight loss of 10% 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.

![Thermal degradation graph](image)

**Figure 6.** variation of thermal degradation of 0%, 5%, 10% SiC in sisal fiber composite with temperature

3.6 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. The results of temperature dependence of thermal diffusivity for A,B,C are presented. Thermal diffusivity of samples A,B,C decreases with increase of temperature, which is compared to thermal conductivity in opposite manner from 150K to 260K. it is due to the reduction of mean free path phonons.
4. Conclusions
In this work, mechanical and thermal properties of Sisal fibre polyester resin composites have been discussed. The tensile strength is increases with the increase of SiC, that it obtains maximum tensile strength at 10% SiC. The composite with 10% SiC has the maximum impact strength and it reaches 14.25 J/m². Thermal conductivity of the composite increases with increase in the SiC filler content. For a given temperature, specific heat capacity decreases as SiC filler content increases. Specific heat capacity increases with increase in temperature at any SiC filler content. Further as SiC filler content increases, rate of increase of specific heat capacity with temperature reduces. Thermal diffusivity of composite decreases with increase of temperature. 10% SiC filler content has highest degradation at onset temperature and also least amount of weight loss. Thus, it has highest thermal stability. Temperature at maximum weight loss is nearly constant (350°C-380°C) for all SiC content.

5. References
[1] A.R. Prasad 2003, XIII Nat. conf. ISME2003.
[2] Parmasivam, T and Abdulkalam, A.P.J., 1974, Fi. Sci. Tech; I; 8588.
[3] Satyanarayana, K. G., Sukumaran, K., Kulkarni, A. G., Pillai, S. G. K. and Rohatgi, P. K., 1986:17; 329-33.
[4] Madhava, M. R., Suha Raman, Pavithran, C., Prasad, S.V. and Rohatgi, P. K., 1982. 2nd Nat. Symp. on Ultrasonics, (New Delhi. U.S.I.)
[5] Fardons Mubark and Han Augustin, 1954. R &I;29; 108-113.
[6] Sefain, M. Z., Fedl, M. A. and Rakha, M. 1984; R &I;29; 269-272.
[7] Pakotiprapha, B., Pama, R. P. and Lee, S. I. 1979, Int. J. Hous. Sci. Appl; 3; 167-190.
[8] Jindal, U. C. 1986, J. of comp. mat.;20;19-29.
[9] de Aranjo FFT, Rozenberg HM. 1976 J Phys D Appl Phys;19;665.
[10] Sundastorm DW, Lee YD. 1972 J Appl Polym Sci;16;3159.
[11] Agari Y, Uno T. 1986 J Appl Polym Sci;32;5705.
[12] Agari Y, Velu A, Naga S. 1993 J Appl Polym Sci;49;1625.
[13] Katz SH, Milewak JV. 1978 , Handbook of fillers and reinforcements.New York: Van Nostrand, Reinhold, 1978.
[14] Fricke H. 1978 Phys Rev;24;575.
[15] Progelhof C, Thorne JL, Reutsch RR. 1975 SPE Conf., Akron, OH, p. 221±57.
[16] Maewal A, Gurtman GA, Hegemier GA. 1978 Trans ASME, Ser CJHeat Trans; 100: 128.
[17] Chamis CC. NASA Tech. Memo 83320. Presented at the 38th Annual Conference of the Society of Plastic Industry (SPI), Houston, TX, 1983.