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STUDY OF THERMAL PROPERTIES BY INFLUENCE OF FILLER MATERIAL ON CARBON-EPOXY COMPOSITES

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Abstract - *The objective of the present study is to determine the thermal properties like thermal* ***diffusivity (α), thermal conductivity (K), specific heat*** *(Cp) and Co-efficient of thermal expansion (CTE) by the influence of filler materials like silicon carbide (SiC), zirconium oxide (ZrO2) in the carbon fiber reinforced epoxy composites. The composites are fabricated by filling varying concentrations of the filler content 10% and 20% by the weight fraction method. The hand layup technique is adopted for the process of fabrication of the composites. In this study determination of thermal conductivity, thermal diffusivity, specific heat is done by laser flash method (LFA) carried out on NETZSCH LFA 427 equipment and Co-efficient of thermal expansion is determined by using Thermo Mechanical Analyzer TMA Q400 equipment. The study concludes that the thermal diffusivity increases with increase in concentration of silicon carbide (SiC) at low temperature services, the thermal conductivity and specific heat is high with silicon carbide (SiC)+(ZrO2) zirconium oxide filled composites at lower temperature, the study also reveals that Co-efficient of thermal expansion is low for composites with zirconium oxide (ZrO2) as a filler material at high temperature, where in at higher temperature thermal diffusivity and conductivity are high for composites with no filler materials.*

Key words: Carbon fiber reinforced composites with epoxy resin, silicon carbide, Zirconium oxide, Thermal conductivity, Thermal diffusivity, specific heat, coefficient of thermal expansion, Laser flash method etc.

1. INTRODUCTION

Composites are one of the adaptable and most refined engineering materials known to the mankind from the time immemorial. Progresses/Innovation in the field of materials science and technology has given birth to these fascinating and wonderful materials. Their tremendous strength-to- weight ratio and design flexibility make them ideal in structural components for many of the industries. Since all materials are self-possessed of different materials in it if they were examined under microscopic level/at close enough point. At the present time composites can be seen all over the place from the airplanes to the automobiles and to the sports gadgets. They become a fundamental part of our day-to-day life. The term composite generally refers to a "matrix" material that is reinforced with "fibers".

Composites are made by the two or more materials which are having dissimilar properties, if we use these material individually some of the properties may miss in it, so by combining those two or more material into one we can overcome the missing property in the individuals. Due to this reason the composite materials are having the advantage over the conventional material and also by specific properties like strength-to-weight ratio, light weight and combined properties of the two or more materials in one composite only which make the structural design more stronger and be more versatile.

Carbon and graphite are superior high temperature materials with strength and stiffness properties and Maintainable at temperature up to 2500°C. Carbon fiber composites are used in the aeronautical, bio-medical, industrial and space application. Originally these are manufactured and used for very higher temperature requiring high performance standards. But in today's life they were used in commercial as well as in the defense applications. Now a variety of inorganic fillers have been used to change the properties of the composites.

The objective of this study is to investigate the effect of fillers on thermal properties of the carbon fiber reinforced epoxy composites and the comparison of the results with the untreated (without filler) carbon fiber reinforced epoxy composites.

2. MATERIALS USED AND FABRICATION METHOD

2.1 Materials used are:

Raw materials used in the study are

1) Woven carbon fabric (460 GSM)
2) Epoxy resin (Lapox T-22)
3) Hardener (K-6)
4) Fillers used are
   i. Silicon carbide (SiC)
   ii. Zirconium oxide (ZrO2)

2.2 Fabrication Method:

There are many techniques are available to fabricate the composite materials like automated, semi-automated depends on the die moulding, open moulding, closed moulding etc... to have the control over the thickness, surface finish and many more parameters. In this study we adopted hand lay-up technique which is an open mould method of fabrication of the composite products. The carbon fiber/epoxy based composites filled with varying concentration (0%, 10% and 20%) of fillers were prepared by considering the weight fraction method.

Steps involved in fabrication are,

- Cut the carbon fiber mat to the required shape, dimensions & orientations (angle) with consideration of the wastage allowance.
- Apply the wax coat on the surface & and allow it to dry.
- Pour the resin into the bowl & add 2% of hardener to it and mix well.
- Apply the mixed matrix on the wax coated surface & place the carbon fiber mat on that.
- Repeat the procedure obtain the required thickness of the composite by placing the mat one above the other and simultaneously applying the matrix.
- Meanwhile weigh the bowl of resin before and after the fabrication to know the amount of matrix used for the fabrication of the composite.
- Add the filler material to the matrix on basis of the weight fraction & follow the same steps.
- Allow the composites to cure for 48 hours.
- Remove the composite from the surface of fabrication.
- Cut the composite to the required sizes based upon the testing standards.

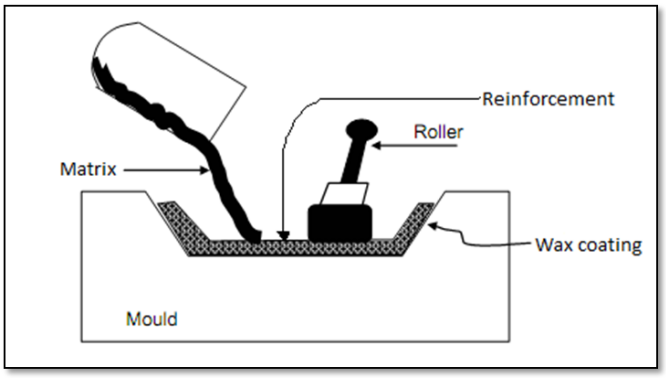

Fig -1: Hand layup method

2.3 Specimen preparation:

The fabricated slab/laminate was taken from the mould and the specimens are cut to the required sizes as requirement of the thermal testing standards of the equipment with the help of the cutting tools.

2.4 Composition of the samples:

Compositions are as follows,

- Sample 1. (Untreated): 50% of Carbon fiber + 50% of matrix (resin & hardener).
- Sample 2. (10% SiC): 50% of Carbon fiber + 40% of matrix + 10% SiC.
- Sample 3. (20% SiC): 50% of Carbon fiber + 30% of matrix + 20% of SiC.
- Sample 4. (10% ZrO2): 50% of Carbon fiber + 40% of matrix + 10% ZrO2.
- Sample 5. (20% ZrO2): 50% of Carbon fiber + 30% of matrix + 20% of ZrO2.
- Sample 6. (10% SiC&10% ZrO2): 50% of Carbon fiber + 30% of matrix + 10% of SiC + 10% of ZrO2

2.5 Dimensions of the samples:

Test specimen sizes

- Thermal conductivity, diffusivity, specific heat:- Specimen sizes for these tests are 10×10×4 mm
- Co-efficient of thermal expansion:- Specimen size for this test is 10×10×4 mm

2.6 Orientations of lamina in the sample are:

The fabricated composite product is the 5 layered composites and we taken the 0° and 45° as the orientation in consideration. The laminas are layered up as shown in below.

Layer (5) 0 degree
Layer (4) 45 degree
Layer (3) 0 degree
Layer (2) 45 degree
Layer (1) 0 degree

Fig -2: Orientations of laminas in composites

3. EXPERIMENTAL SETUP

Thermal tests carried out are

- Thermal conductivity.
- Thermal diffusivity.
- Specific heat.
- Co-efficient of thermal expansion.

Experiments Thermal conductivity, Thermal diffusivity and Specific heat are conducted in the same equipment with the same testing procedure without disturbing the sample once mounted on testing ramp.

Thermal conductivity:

Thermal conductivity measurement is carried out according to the testing standards of the equipment NETZSCH LFA 427 the samples prepared are having the dimensions 10x10x4mm. Thermal conductivity tests are conducted with the laser flash methodology. In which the sample is mounted on the carrier system in the furnace, after the sample reaches the predetermined temperature the laser beam is absorbed on the one surface of the sample results in the homogeneous heating, relatively temperature increases on the other surface of the sample which is measured with the IR detector with respect to the time. Thermal diffusivity is computed by the software using time/increase in temperature.

Thermal diffusivity is determined by the eqn.

$$\propto = 0.1388 \frac{l^2}{t_{0.5}}$$

Where

l^2 is Sample thickness.

$t_{0.5}$ is time at 50% of the temperature increase.

α is thermal diffusivity.

Then the thermal conductivity it is the measure of thermal diffusivity (α), Specific heat (Cp) and density (ρ) as a function of temp and then to compute the thermal conductivity (K) from these data by the eqn.

$$K = \alpha \times \rho \times Cp$$

Where

α is thermal diffusivity.

ρ is density.

Cp is specific heat.

K is thermal conductivity.

Fig -3: NETZSCH LFA 427 equipment

Co-efficient of thermal expansion:

Co-efficient of thermal expansion is the measure of the dimensional change of the samples after subjected to the temperature. The test is carried out in the thermo-mechanical analyzer TMA Q400 equipment. The specimens are prepared according to the testing standards of the equipment TMA Q400. The dimension of the sample is 10x10x4mm. The specimen is placed on the platform in the furnace and then the zero measure i.e. initial measurement of the sample is measured then set the final temperature value and range. The test is goes on until the final temperature is reached. After reaching the final temperature the equipment stops and the values are noted by the software. Then repeat the procedure for further samples.

The Co-efficient of thermal expansion is given by eqn.

$$CTE = \frac{\Delta L}{L \Delta T}$$

Where

L= Original length of the sample

ΔL= Change in length of the sample

ΔT= Temperature change

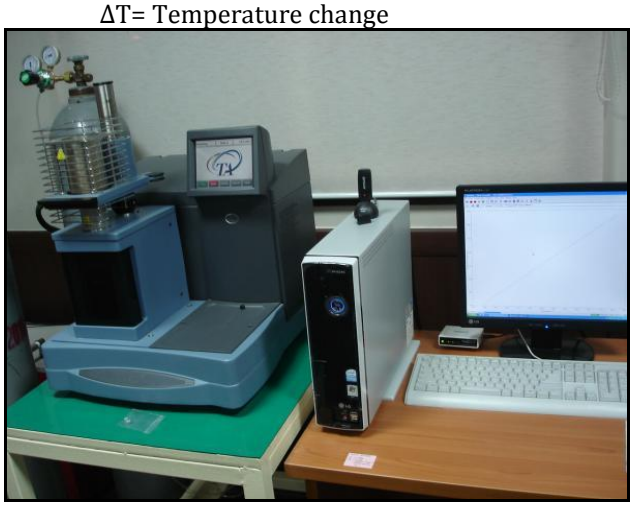

Fig -4: TMA Q400 equipment

4. RESULTS AND DISCUSSINS

4.1 Thermal Diffusivity:

Table -1: Results of thermal diffusivity w.r.to temperature

Samples	Density (gm/cc)	40 °C	80 °C	120 °C
Untreated	1.38	0.221	0.218	0.216
10% Sic	1.30	0.233	0.228	0.106
20% Sic	1.53	0.412	0.293	0.107
10% ZrO_2	1.50	0.249	0.231	0.102
20% ZrO_2	1.30	0.272	0.203	0.103
10% Sic + 10% ZrO_2	1.30	0.358	0.245	0.159

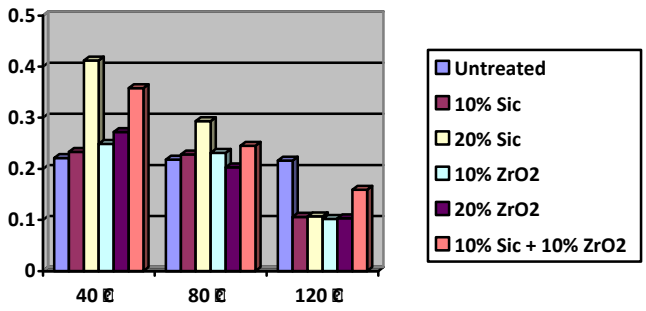

Chart – 1: Thermal diffusivity v/s Temperature

From the plotted graph it can be observed that the thermal diffusivity of the carbon-epoxy composites increases with increase in the concentration of the filler material, but the thermal diffusivity consequently decreases with increasing temperature.

From the results it is clear that the carbon-epoxy composites influenced with the 20% Sic is having higher value (0.412mm/sec, 0.293mm/sec) of thermal diffusivity at 40°C and 80°C, then carbon-epoxy composites without any filler shows the higher value (0.216 mm/sec) for the thermal diffusivity at 120°C. Hence at the higher temperature the thermal diffusivity of carbon-epoxy composites without any filler material shows the higher value of thermal diffusivity.

4.2 Thermal conductivity:

Table-2: Results of thermal conductivity w.r.to temp

Samples	Density (gm/cc)	40 °C	80 °C	120 °C
Untreated	1.38	0.332	0.358	0.378
10% Sic	1.30	0.339	0.362	0.185
20% Sic	1.53	0.605	0.473	0.189
10% ZrO_2	1.50	0.366	0.372	0.178
20% ZrO_2	1.30	0.548	0.327	0.165
10% Sic + 10% ZrO_2	1.30	0.659	0.441	0.3434

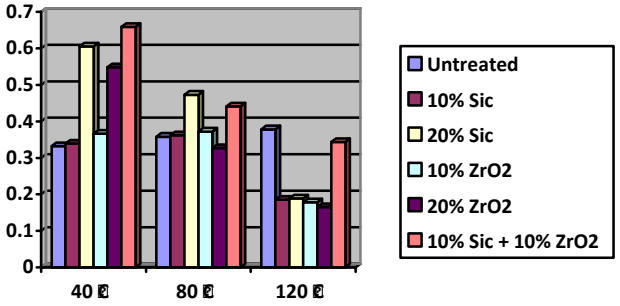

Chart – 2: Thermal conductivity v/s Temperature

From the graph we can observe that the thermal conductivity increases with the increase in the concentration of the filler materials Sic and ZrO2 respectively and also thermal conductivity decreases as the increase in the temperature it is due to the presence of the phonon vibrations which creates the resistance to the flow of heat energy from the low temperature area to high temperature area and it is also the nature of the graphite material that thermal diffusivity and thermal conductivity of the materials goes on decreasing as the temperature goes on increasing [3].

In the composite materials the heat conduction is mainly with the vibrations of the crystal lattice. This phenomenon of vibrations is described by phonon interaction. The optic phonon energy increases with increase in temperature. Hence, creates more resistance to

the flow of heat energy. Thus this results in decrease of thermal conductivity as increase in the temperature. In this present work graph explains that the carbon-epoxy composites filled with the 10%Sic+10%ZrO2 is having the higher value for thermal conductivity (0.659 W/m/K) at 40°C and the carbon-epoxy composites filled with 20% Sic is having higher value for thermal conductivity (0.473 W/m/K) at 80°C. This is because of presence of Sic i.e. thermal conductivity of Sic is higher than that of ZrO2.

4.3 Specific heat:

Table-3: Results of specific heat w.r.to temp

Samples	Density (gm/cc)	40 °C	80 °C	120 °C
Untreated	1.38	1.118	1.24	1.346
10% Sic	1.30	1.12	1.24	1.349
20% Sic	1.53	1.131	1.244	1.364
10% ZrO_2	1.50	1.133	1.241	1.348
20% ZrO_2	1.30	1.126	1.243	1.349
10% Sic + 10% ZrO_2	1.30	1.14	1.125	1.35

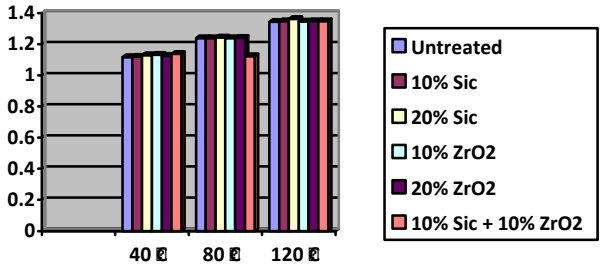

Chart – 3: Specific heat v/s Temperature

From the graph we can observe that the specific heat values are almost same in different temperature ranges i.e. because of as long as the density of composite does not change their specific heat will not make the high difference [3].

From the graph it is clear that the carbon-epoxy composites with 10%Sic+ 10%ZrO2 is having higher value (1.14 J/g/K) for specific heat at 40°C. And 20% Sic filled carbon-epoxy composites has higher specific heat (1.244 J/g/K & 1.364 J/g/K) at 80°C and 120°C respectively.

4.4 Coefficient of thermal expansion:

Table-4: Results of Co-efficient of thermal expansion w.r.to temp

Temperature	Untreated (µm/m.°C)	10% Sic (µm/m.°C)	20% Sic (µm/m.°C)	10% ZrO2 (µm/m.°C)	20%ZrO2 (µm/m.°C)	10%Sic+10%ZrO2 (µm/m.°C)
30	86.57	100.7	81.42	118.4	91.48	81.77
50	97.57	175.7	108.6	-105.6	150.8	4.688
70	57.54	47.43	-52.75	-9.439	40.62	132.6
90	177.9	219.6	149	199.3	175.5	175.9
110	159.1	172.2	137.7	201.9	161.6	150.9
130	75.22	140.6	130.2	156.8	104.3	94.95
150	77.37	70.62	188.9	817.6	30.07	60.84
157	180.7	44.87	283.8	1919	22.01	55.5

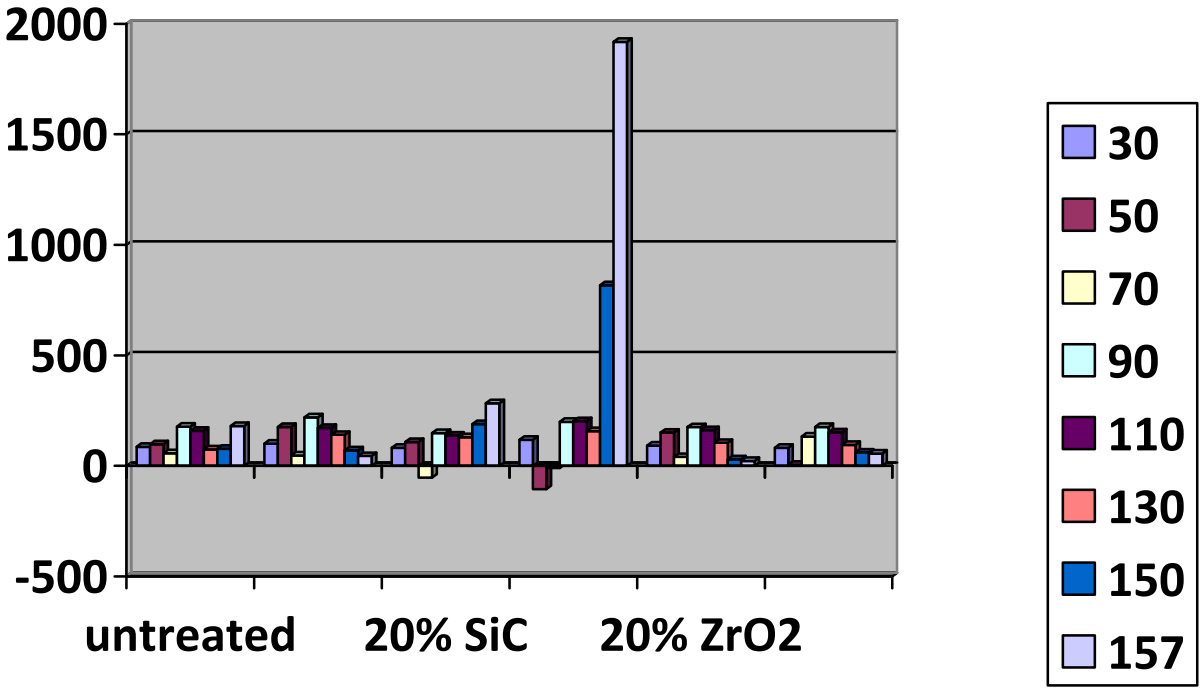

Chart – 4: Co-efficient of thermal expansion v/s Temperature

From the graph it has been noticed that the co-efficient of thermal expansion is varies with the variation of concentration of different fillers, this may be due to the addition of higher concentration of the filler in composite material which provides the better filler matrix interactions in the composites, the filler material toughens the matrix and hence preventing the composites from the expansion [9].

From the results it has been noticed that the carbon-epoxy composites filled with the 20% ZrO_2 shows the less co-efficient of thermal expansion value (22.01 µm/m.°C) at the temperature 157°C

5. CONCLUSIONS

The study concludes that the thermal diffusivity increases with increase in concentration of silicon carbide (SiC) at low temperature services, the thermal conductivity and specific heat is high with silicon carbide (SiC)+(ZrO2) zirconium oxide filled composites at lower temperature, the study also reveals that Co-efficient of thermal expansion is low for composites with zirconium oxide (ZrO2) as a filler material at high temperature, where in at higher temperature thermal diffusivity and conductivity are high for composites with no filler materials.

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