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Polymer Matrix Composite Materials for Aerospace Applications

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Abstract---

High temperature resistant composites are widely used for thermal protection systems and as flame deflectors in aerospace industry. Advanced composite materials made of fiber reinforced polymer matrix composites because of their strength, stiffness, low weight and their excellent ablative properties made them to replace metallic components. In this paper, different aerospace composite materials, namely PAN- carbon and Rayon carbon fibers and glass fibers with phenolic and epoxy resins with some modifiers, laminates are made and characterized their properties as per the ASTM standards. The manufacturing of the laminates is done by the hand layup method and vacuum bagging and autoclave curing process. The characterization of the materials is for mechanical, material and thermal properties. Laminate with known defect was examined by Ultrasonic through transmission test method. Effect of modification of matrix system would be studied on laminate properties. Defects in the composite are analyzed by NDT methods.

Key Words--- Di-Amine, Ether, Rayon, E-Glass V9, Phenolic resin.

I. INTRODUCTION

Fiber reinforced polymer matrix composites has constituted a major breakthrough in the construction of low weight structures. In particular, significant benefits had been realized in the aerospace sector to meet the severe performance requirements with stern demands of reliability. Almost all aerospace components – airframes of fighter aircraft, helicopters, control surface and fins of civil aircraft, various planes in satellites, antennas, rocket motor casings and some complete airframes of small aircraft are witnessing an exponentially increasing use of the advanced composites. An important technological development that has contributed considerably to this growth of composite materials is the development of strong and stiff fibers such as Glass, Carbon along with concurrent developments in the polymer chemistry resulting in a various polymeric materials to serve as matrix materials. In particular the versatility of the technology of the carbon fibers having various properties has played a key role in this growth. With complimentary developments in computer hardware and software tools, and in computational methods of analysis rendering help to the analyze and understand the material behavior and to provide predictive as well as design tools, the complexity of the polymer – matrix composite materials has been overcome to facilitate the extensive applications. Composites have the applications in many fields. The creation of reliable heat resistant laminate composites for space application requires precision design and proper tests. Because composites are necessary to meet heat resistant requirements for the aerospace applications such as nose cones, flame deflectors, airframes etc.,

II. MATERIAL SELECTION

Composite materials are classified based on the matrix materials as well as the reinforcements. Here we used polymer thermo set matrix (i.e., Conventional Phenolic resin and modified Phenolic with Diamene and Ether) and fibre reinforcement material (i.e., E-Glass V9 and Rayon carbon).

A. Selection of reinforcement:

Since E-Glass V-9 is a conventional fibre for structural applications at high temperatures, it is also the insulating and since it is cheap in cost and easily available which is being used for many aerospace applications, hence it is selected.
Though the rayon carbon is very pricey, it is amorphous material for ablative purpose and is having vast applications in aerospace industry, hence it is selected.

B. Selection of Matrix:

Phenolic resin is the conventional matrix material which is used for aerospace applications to with stand high temperatures. In addition Di-amine and Ether modifiers are also considered to modify the properties of the conventional phenolic matrix.

III. FABRICATION AND TESTING OF THE MATERIAL

Manufacturing techniques for composites are not dependent on the type of matrix material. In fact, some metal forming techniques have been personalized to composites fabrication (e.g., matched-metal die molding). Nevertheless, processing conditions are completely dependent on the type of matrix material used. For instance, thermo sets necessitate long processing times, whereas thermoplastics entail relatively high pressures and temperatures.

A. Fabrication methods of Fibrous composites:

There are more than 50 processes depending upon fibre and matrix material type and nature, here we selected Wet/Hand lay -up process with Autoclave vacuum bagging.

B. Wet/Hand Lay-Up method:

Resins are impregnated by hand or brush into fibres which are in the form of woven, knitted, stitched or bonded fabrics. This is habitually accomplished by rollers or brushes, with ever-increasing use of nip-roller type impregnators intended for forcing resin or matrix into the fabrics or reinforcements by means of rotating rollers and a bath of resin. Laminates are gone to cure under standard atmospheric circumstances.

C. Preparation of Laminate

Despite the fact that the method has been replaced with mechanized techniques, the lay-up of pre impregnated material by hand is the oldest and most familiar fabrication method for advanced composite material structures. Furthermore, the basic skin tone of the method stays unchanged. Various steps are involved in the hand lay-up of a flat composite material laminate. Each step ought to follow in successive fashion in order to obtain a high-quality composite material laminate structure after final processing. Some steps in the hand lay-up of a flat composite material laminate is shown in Figures1-6. A narrative of these steps is as in the following.

Step 1.Keep the Phenolic resin with the modifiers and Glass and Rayon carbon fabrics ready. Clean the surface and put a polythene cover on the floor and put the fabric on it. Here the polythene cover acts as a releasing agent.

Step 2.Poured the resin onto the fabric and accomplish it by a brush for uniform distribution of the resin over the fabric. And wait for some time so as to be impregnated.

Step 3.Cut the fabric into the pieces as per the required dimensions.

Step 4.Cleaned the surface of the autoclave bed and applied a releasing agent on it.

Step 5.The prepreg ply is oriented and placed upon the bed of the autoclave.

Step 6.A porous release film is laid over the dam and the laminate

Step 7.A breeder cloth which can absorb the excess resin is applied over that.

Step 8.With the help of putty it is sealed.

Step 9.It is left for curing in the autoclave.

Step 10.After curing of the laminate it is removed from the autoclave.

Fig.1 Phenolic resin and E-Glass fibre

Fig.2 Application of resin over the fibre

Fig.3 Cutting the prepreg into piecess

Fig.4 cleaning the autoclave bed

Fig. 5 laying up of the plies one over the other

Fig.6 vacuum bagging

D. Sample making as per ASTM standards:

The samples are prepared as per the dimensions given in the following ASTM standard test procedures. And the laminate is cut by the diamond edge cutting machine shown in the fig.7 as the composite material requires the sophisticated cutting equipment in order to get fine cutting. Fig.8 shows few samples of the material cut by the diamond edge cutter.

Table 1

<table>
<tr><td>S.No.</td><td colspan="2">Test</td><td>ASTM standard</td></tr>
<tr><td>1</td><td colspan="2">Specific gravity</td><td>ASTM D-891</td></tr>
<tr><td>2</td><td colspan="2">Viscosity</td><td>ASTM D-2393</td></tr>
<tr><td>3</td><td colspan="2">Inter laminar shear strength</td><td>ASTM D-2344</td></tr>
<tr><td>4</td><td colspan="2">Flexural strength</td><td>ASTM D-790</td></tr>
<tr><td>5</td><td colspan="2">Impact strength</td><td>ASTM D-5941</td></tr>
<tr><td>6</td><td colspan="2">Oxyacetylene erosion</td><td>ASTM E-285</td></tr>
<tr><td>7</td><td colspan="2">Density</td><td>ASTM D-792</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">Resin content</td><td>Burn-off</td><td>ASTM D-2584</td></tr>
<tr><td>Nitric acid digestion</td><td>ASTM D-3171</td></tr>
</table>

Fig.7 cutting machine with diamond edge cutter

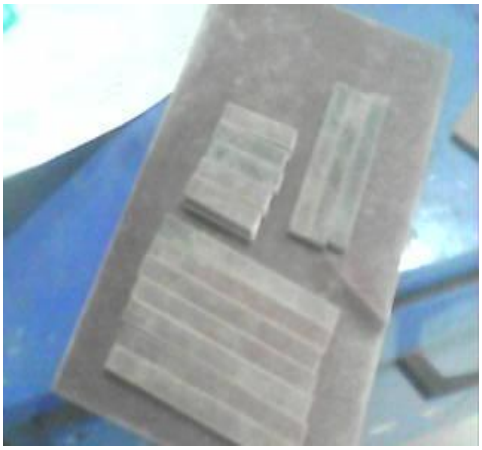

Fig.8 the cut samples

E. Destructive Tests:

The following equipments are used to do the tests mentioned above in the Table.1

1. Resin content test:

The resin content test is done in two procedures viz. a) Nitric acid digestion b) Burn-off method.

In the nitric acid digestion method the test samples are immersed in nitric acid until it is digested as it is shown in the following fig.9

In the burn off method a samples are kept in the furnace as shown in the fig.10

Fig.9 Nitric acid digestion

Fig.10 Burn-off method

2. Specific Gravity and Viscosity tests:

Specific gravity test is done with the distilled water and so is viscosity test. The following weighing machine in the fig.11 is used in the tests. And density is easy to find if we know the volume and weight of the sample.

Fig.11 a weighing machine

3. ILSS and Flexural strength tests:

The INSTRON Universal Testing Machine in the following fig.12 is used to do the three point bending test to find out the Inter laminar shear strength (ILSS) and the Flexural strength of the material.

Fig.12 three point bending test in UTM

4. Impact strength:

The IZOD impact test is done as given in the following fig.13

Fig.13 IZOD impact testing equipment

5. Oxyacetylene erosion test:

Oxyacetylene test is done to find out the erosion of the material. But because of some problem in the thermocouple we could not mention the temperature but we could find the erosion rate.

Fig.14 Oxyacetylene test

F. Test results:

The results of the tests are given in the following

Table 2

S.No.	Material	Density (gm/cc)	Resin content (% of wt)	Fiber content (% of wt)	Volume fraction of fiber V_f (% of Vol.)
1	E-GlassV-9/Ph(DA)	1.92	19.16	80.84	61.1
2	E-GlassV-9/Ph(E)	1.767	19.1	80.9	56.27
3	Rayon/Ph(DA)	1.3	28.49	71.51	53.12
4	Rayon/Ph(E)	1.29	29.13	70.87	52.24

In the results of table 2, when we compare the density it is very clear that for the rayon fiber with phenolic resin the both modifiers viz. Di-amine and ether show almost same. Though there is slight difference for glass fiber viz. E-glass v9 with phenolic resin modified by ether show less density. This is notable point here.

Table 3

S.No.	Material	ILSS (Mpa)	Flexural strength (Mpa)	Young's Moduls E (Gpa)	Impact Energy (KJ/sq.m)	Erosion rate (m/s)
1	E-GlassV-9/Ph(DA)	29.53	462.78	44.01	265.35	0.000374
2	E-GlassV-9/Ph(E)	14.45	220.92	26.74	121.83	0.000436
3	Rayon/Ph(DA)	16.32	205.69	23.43	48.74	0.000126
4	Rayon/Ph(E)	13.13	106.64	19.9	61.54	0.000133
5	E-GlassV-9/Ph	32.79	365.72	30.54	223.51	0.000294

In the results of table 3 and in the figures 15 and 16, when we compare the results Di-amine modifier is showing very good results in the flexural strength, Impact strength and erosion rate where as ether is showing poor results. Another notable point is that Di-amine modifier shows slightly less ILSS than the conventional material. So it can be assumed as error in the manufacturing process of the laminate. If we take care in the laminate making so as to get the best bonding between plies of the laminate it is suggestible material to use in the current industry of the Glass fiber and carbon fiber users. The Di-amine modifier modifies the flexural strength and Young's modulus to be high, Impact strength to be high and erosion rate to be low. This is more useful though the density is slightly high.

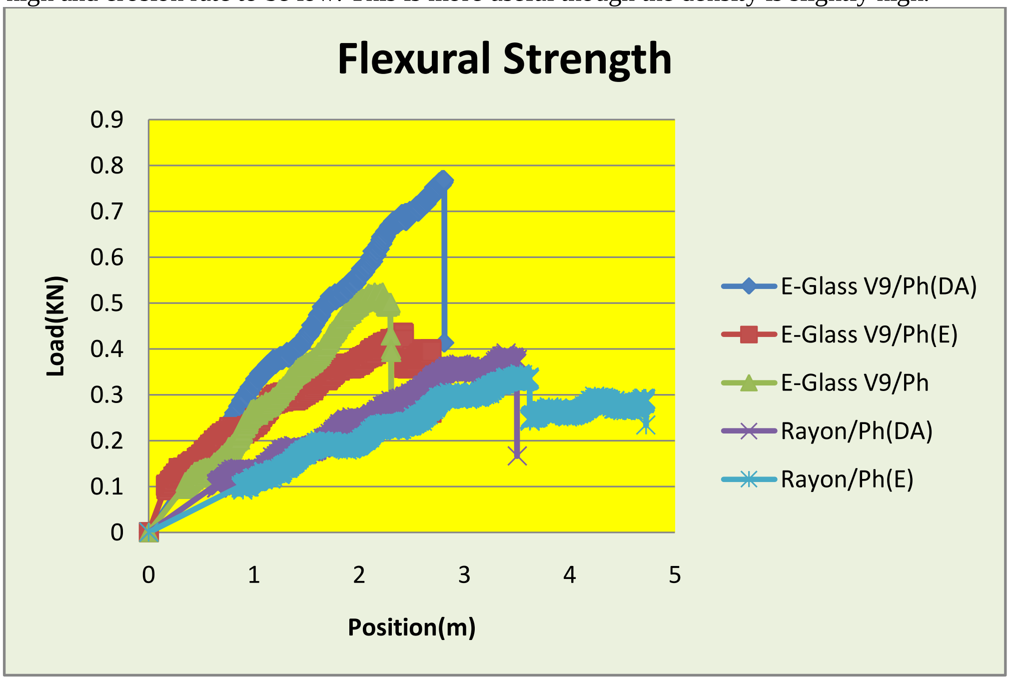

Fig.15 Comparison of Flexural strengths of materials

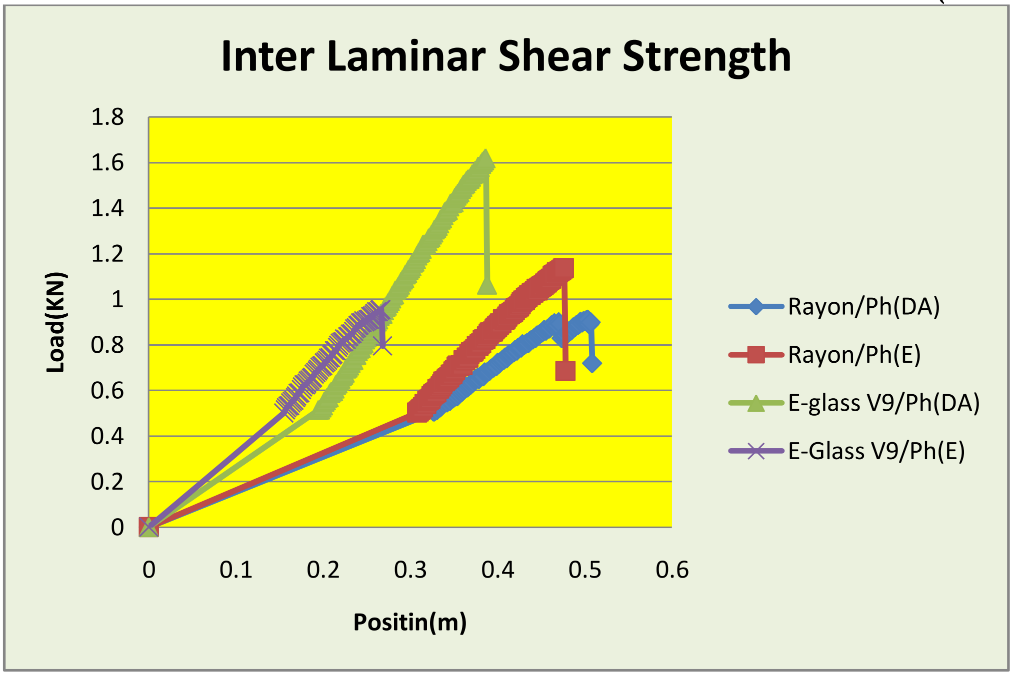

Fig.16 Comparison of ILSS of materials

IV. CONCLUSION

Conventional phenolic resin and modified phenolic resin were compared with E-glass V-9 and Rayon carbon fabrics. Phenolic resin is used as a matrix material because of its excellent thermal properties. Phenolic resin modified by Di-amine exhibited high flexural and impact strength. Composites made of E-glass V-9 and Rayon carbon is replaced by many metallic components because of their low density and high heat capacity. For high temperature applications in aerospace carbon phenolics are used as ablative materials because of their low erosion. E-glass composites because of their insulating character utilized for heat resistant composite.

In this paper we can finally conclude that the modifier Di-amine is an advisable modifier to use in the structural and thermal applications as it is showing the better Young's modulus, ILSS, flexural strength and low erosion rate and so is not the ether.

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