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Evaluation of Mechanical Properties of Polymer Composites Profiles for Marine Applications

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***Abstract*—Polymer matrix composites (PMC) are widely used in the fabrication of marine vehicles, because of its unique set of properties of high strength, light weight and corrosion resistance. Epoxy and vinyl ester are two widely used resin systems with glass reinforcement for naval applications. Post-curing of epoxy resins results in improving the glass transition temperature with a corresponding increase in tensile strength. Vinyl esters based composites are equally popular in marine applications due to comparable mechanical properties with superior moisture resistance compared to epoxy resins. The stiffness of PMCs used for structural applications for marine vehicles can be significantly improved by forming it into profiles with required sections such as L, C and I. Structures requiring a combination of vibration damping and stiffness can be provided by having sandwich structure, with foam or honeycomb interlayer. In this paper the mechanical properties of different sections of PMCs and sandwich structures have been compared and analyzed.**

***Index Terms*— Polymer Composites, Forming, Marine Vehicles, Post Curing, Flexural, Tensile, Stiffness, Sandwich.**

I. INTRODUCTION

Fiber reinforced composites have gained wide use in a variety of applications in defense and aerospace. They are used when high strength, light weight corrosion resistance and durability under severe environmental conditions, are required as is the case with many of the marine applications. The performance of these composites are tailored for a given applications. Structural skin or face sheet polymer matrix composites (PMC) require a combination of properties such as impact resistance, low moisture absorption, stiffness, vibration damping characteristics and strength. PMCs used for structural loads are designed for strength [1-5]. Epoxy and vinyl ester are two widely used resin systems for marine applications with glass, carbon and aramid fibers as reinforcement. Sandwich structures are used for skin and structural applications, while profiled PMCs are used for structural loads. Sandwich structures are made using (i) foam of different density and compositions (ii) metallic or polymer honeycomb. Profiled PMCs include, standard C, I L sections, hollow tubes with circular or rectangular shapes which offer high strength and stiffness. These profiles are manufactured using pultrusion, filament winding, RTM and hand layup techniques [6-9]. The properties exhibited by sandwich structures and profiled PMCs are a function of composition, shape and dimension.

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A. Materials and Methods

Materials

The studies in this paper are based on two resin systems (i)Epoxy resin Diglycidyl Ether of Bisphenol A (LY556) with triethylene tetra-amine hardner (HY951) in a stoichiometric ratio of 100:11(w/w) (ii) Vinyl ester with 2 % cobalt as accelerator, Methyl Ethyl Ketone Peroxide (MEKP) as catalyst, Di Methyl Acetamide as promoter in the ratio of resin: accelerator: catalyst: promoter 100:2:2:2. The resins were purchased from Huntsman Advanced Materials and Suntech Group. The E-glass fabrics 360 gsm, 0/90 plain weave, was purchased from Suntech Group, Bangalore, and was used as the reinforcement for the composites. The precursors for making foam (methyl di-isocynide and polyol) was procured from Sri Venkateshwara Enterprises, Bangalore.

Method of Manufacture of Laminates, Sandwich and L and C Profiles

The PMC laminates were fabricated using hand layup process. The number of fiber layers was derived based on the resin: fiber proportion 35: 65 wt % in all the cases. The glass-epoxy composites were cured at room temperature for 24 hours followed by post curing in a hot air oven with the following cure schedule (i) Increase the temperature from 25 to 50 ºC at 2ºC/min, followed by soaking at 50ºC for 30 min (ii) Ramp from 50ºC to 70ºC and soak for 1 hour (iii) Ramp from 70ºC to 85ºC and soak at 85ºC for 2 hours. The samples were allowed to cool to room temperature in the oven. The glass-vinyl ester composites were also prepared using similar procedure. The post curing schedule for glass-vinyl ester was 25 to 80 ºC at 2ºC/min, followed by soaking at 80ºC for 2 hours. Polyurethane foams were produced by mixing equal ratio of methyl di-isocynide and polyol. The liquid mixture was then poured into a mould and placed in a hydraulic press. After 30 minutes, the mould was removed from the hydraulic press. The density of the foam produced by this procedure was 300 kg/m^3.

B. Tests conducted as per ASTM standards

10 ton computer controlled UTM was used for conducting tensile and flexural tests. Computer interfaced pendulum type impact test machine was used for impact testing. The tensile, flexural and impact tests on the laminates were conducted as per ASTM D3039, D790 and D256 standards, respectively. Figure 1 shows the picture of the test specimens. The dimensions of the tensile test PMC laminates were 150 x 25 x 3 mm, the flexural test specimens were 127 x 12.7 x 3 mm and the impact test specimens were 64 x 12.7 x 3 mm.

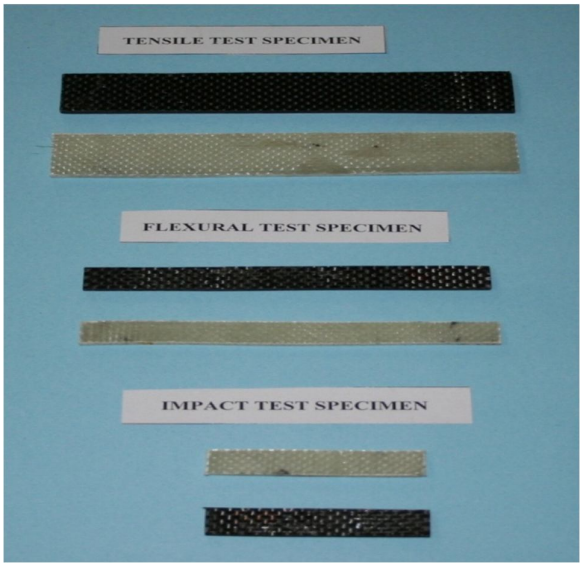

Figure 1 Polymer Composite Standard Test Specimens

Figure 2 shows the schematic of the three point bend test setup used to conduct the load versus deflection tests on sandwich, C and L profiles. The dimensions of the sandwich test specimen was 120 x 30 x 30 mm with 3 mm PMC face sheets on either side. The thickness of the C and L profile test specimens were 3 mm. The dimensions of the C section was 15 x 40 x 120 mm and L section was 35 x 35 mm.

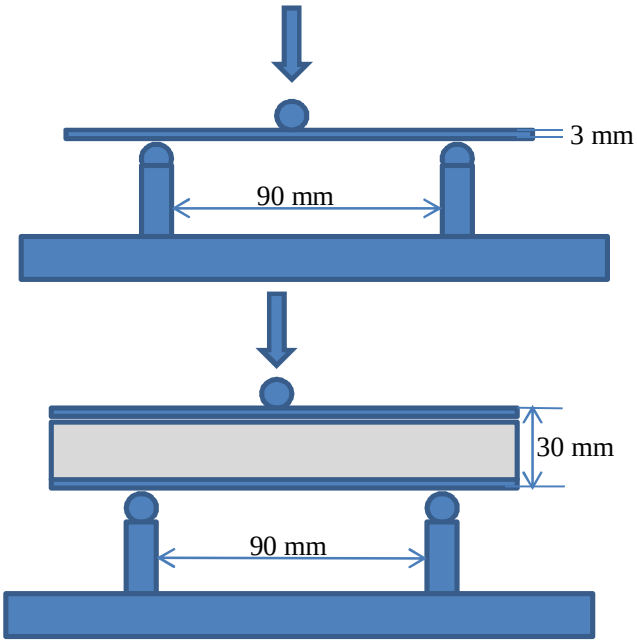

Figure 2 Flexural Test setup for Laminate, Sandwich, C and L profile Polymer Composite

II. Results & Analysis

Post curing of polymeric resins will enhance the degree of crystallinity due to higher degree of polymerization. The glass transition (Tg) temperature of epoxy resin increases from 80°C to 105°C due to post-curing, while that of vinyl ester increases from 72°C to 84°C. Higher Tg results in higher service temperatures of polymer composites. In addition, higher level of crystallinity of the polymer matrix will resist moisture absorption and degradation due to other environmental factors. Table 1 shows the effect of post curing on the mechanical properties of the polymer composites. The tensile and flexural strength increases, while the impact strength reduces. Table 1 shows that the tensile strength of glass-epoxy composite increases by 10%, but the flexural strength increases by 33%. Since, the tensile strength is a fiber dominated property, post curing has no effect on the fiber. The 10% increase in tensile strength can be attributed to improvement in the interfacial bond strength between fibers and resin. The 33% increase in flexural strength can be attributed to improvement in the inter-lamina bonding. The 8% decrease in impact strength is due to increase in crystallinity of the matrix phase, which makes it brittle.

TABLE I. EFFECT OF POST CURING ON GLASS TRANSITION TEMPERATURE & MECHANICAL PROPERTIES

Epoxy- Glass Composites				
Curing Temp.	**T_g (°C)**	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact Strength (MPa)**
Room Temp.	80	330	254	1885
50 °C FOR 30 min	85	343	276	1828
70 °C FOR 60 min	95	359	307	1785
85 °C FOR 120 min	105	369	379	1735
Percentage (%)	38.02	10.56	32.98	-7.80
Vinyl Ester – Glass Composites				
Curing Temp.	**T_g (°C)**	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact Strength (MPa)**
Room Temp.	72	271	314	1868
80 °C FOR 120 min	84	316	350	1839
Percentage (%)	14.28	14.24	10.28	-1.50

Structural applications of PMC demand higher stiffness to strength ratio and stiffness to weight ratio. The stiffness of PMCs can be significantly increased by forming it into different profiles and by incorporating

sandwich layer between the laminates. Figure 03 shows L profile, C profile and sandwich test specimens. Three point bend test setup, shown in Figure 02, was used to determine the load carrying capacity of different profiles and sandwich structure. Figure 0 show the load versus deflection plot of standard 3 mm epoxy glass laminate, 6 mm epoxy glass laminate and PUF sandwich with 3 mm epoxy–glass face sheet on either side. The PUF density is CC. The load carrying capacity of 6 mm laminates is 4 times that of 3 mm laminate, since the flexural load carrying capacity is inversely proportion to the square of the thickness. The flexural load carrying capacity can be further increased by 500 N by sandwiching PUF of 25 mm thickness between two 3 mm thick laminates. The density of the laminate is 2000 kg/cubic meter, while that of PUF sandwich is 3500 kg/cubic meter. The ratio of load carrying capacity to density for a given deflection of PUF sandwich structure is 3 times that of plain laminate.

(a)

(b)

(c)

Figure 3 (a) L profile, (b) C profile and (c) Sandwich Test Specimens

Figure 5 shows the load versus deflection plot of glass-epoxy laminate, Sandwich, L profile and C profile. The load carrying capacity of C profile, for a deflection of 4 mm, is 12 times that of plain laminate. The load carrying capacity of L angle is 10 times that of plain laminate for the same given surface area of 95 sq.cm.

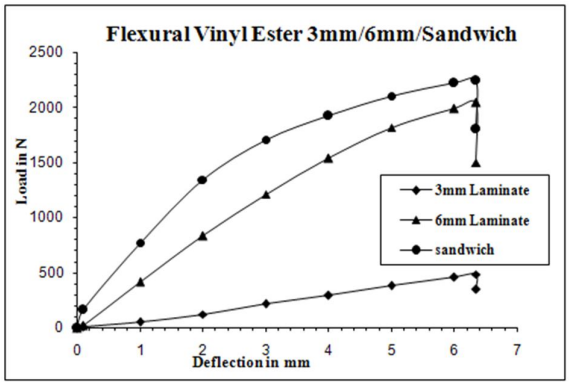

Figure 4 Load Vs Deflection Plot of PMC laminates and PMC-PUF Sandwich

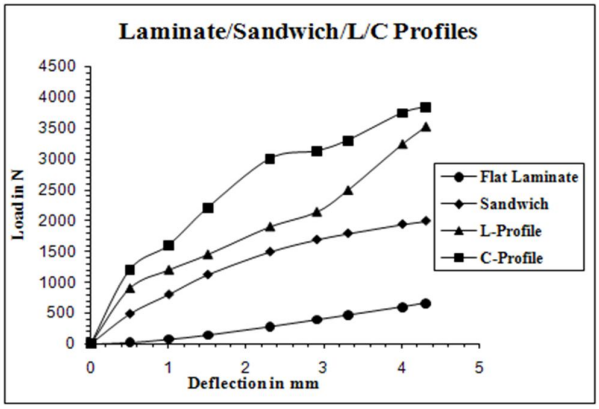

Figure 5 Load Vs Deflection Plot of PMC laminates, Sandwich, L profile and C profile

III. Conclusion

The mechanical properties of vinyl ester and epoxy glass composites are comparable. The glass transition temperature of epoxy composites is 20°C higher than that of vinyl ester composites. The vinyl ester – glass polymer composite PUF sandwich structures have nearly 12% higher load carrying capacity than equivalent laminates. L and C profile polymer composites have 71% and 81% times the load carrying capacity of equivalent plain composite laminate. Formed polymer composite products and sandwich structures have superior mechanical properties when compared to plain composite laminates.

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