ISSN (e): 2250 – 3005 || Volume, 07 || Issue, 4|| April – 2017 ||
International Journal of Computational Engineering Research (IJCER)

Design and fabrication of a novel polymer matrix composite for industrial applications

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Abstract: *Polymer matrix composites have found considerable applications in automotive industries, sports equipment's, ship manufacturing industries etc. The demand for novel material with mapped characteristic corresponding to the desired functionality is a reality today. Fiber-reinforced composite material was found to be one of the most promising and effective types of composites, as it claim dominance over the majority of applications from topmost fields.*
Keywords: Polymer matrix composites, , hot pressing, layered structures, Ready.

I. INTRODUCTION

The phrase "**composite**" broadly refers to a material system which is composed of a discrete **reinforcements** dispersed in a continuous phase (**matrix**). A polymer matrix composite (PMC) is a composite material composed of a variety of short or continuous fibers bound together by an organic polymer matrix. PMCs are designed to transfer loads between fibers through the matrix. Some of the advantages with PMCs include their lightweight, high stiffness and their high strength along the direction of their reinforcements. Other advantages are good abrasion resistance and good corrosion resistance. The properties of composite structures depend not only on the fiber reinforcements, but also on the polymer matrix, the characteristics of the interface between the fiber and the matrix, and the manufacturing process used to form the finished structure.

Fig-1-Some examples of the things where composites are used

Reinforcement of polymers by strong fibrous network permits fabrication of Polymer Matrix Composites (PMC) characterized by the following properties:

a) High tensile strength;
b) High stiffness;
c) High Fracture Toughness;
d) Good abrasion resistance;
e) Good puncture resistance;
f) Good corrosion resistance;
g) Low cost.

The main disadvantages of Polymer Matrix Composites (PMC) are:

I. Low thermal resistance;
II. High coefficient of thermal expansion.

Types of polymers used as matrix materials for fabrication composites:

a) Thermosets (epoxies, phenolics),
b) Thermoplastics (LDPE),
c) High Density Polyethylene (HDPE),
d) Polypropylene,
e) Nylon,
f) Acrylics

According to the reinforcement material the following groups of Polymer Matrix Composites (PMC) are used:

I. Fiber glasses – Glass Fiber Reinforced Polymers;
II. Carbon Fiber Reinforced Polymer Composites;
III. Kevlar (Aramid) fiber reinforced polymers.

Reinforcing fibers may be arranged in different forms:

- Unidirectional fibers;
- Roving;
- Veil mat: thin pile of randomly orientated and looped continuous fibers;
- Chopped strands: thin pile of randomly orientated and looped short (3-4 inches) fibers;
- Woven fabric.

Properties of PMC are determined by:

- Orientation of the fibers
- Concentration of the fibers, properties of matrix

II. LITERATURE REVIEW

Polyester resin with glass fiber reinforced fillers have been employed to analyze the mechanical properties such as tensile strength, flexural strength and Young's Modulus for single and multiple fibers [1]. Sang-Young Kim have generated a numerical model from the trial information generated which in the future could be utilized for accessing the mechanical properties of laminates delivered utilizing distinctive types of fibers without additionally tries[2]. Mouritz have used vinyl ester epoxy resin and glass fiber reinforced fillers to analyse mechanical properties such as tensile strength, compressive strength and in-plane shear properties using the vacuum infusion process and hand layup process samples and found the vacuum infusion processed GFRP samples showed better mechanical properties than the hand layup technique due to hand layup's technique increased porosity [3]. Selvaraju et al analyzed the development of fiber-reinforced polymer composites in naval ships and submarines [4]. Vallbo analyzed the application of Aramid fiber reinforced polymer (CFRP) and glass fiber reinforced Polymer (GFRP) in marine applications such as naval patrol boats, submarine diesel storage tanks, lube tanks, utility tanks, low pressure pipes, cable ladders and trays with the intention of reducing weight, improving corrosion resistance and increasing the strength to weight ratio[5]. Chalmers has analyzed the effects of the mechanical properties with manufactured transport containing vinyl ester matrix and polyvinyl chloride (PVC) as a core material with carbon fiber reinforcement [6]. Nagalingam et al studied the different types of resins such as polyester resins, vinyl ester and epoxy resin with different combinations of reinforcements such as E-glass, carbon and aramid fiber to reduce the stiffness, reduced maintenance load and manufacturing costs [7]. Analysis of different combinations of polyester resin, fiber and nano-clay (MMT) with varying percentages of combinations and observed the ultimate tensile strength decreased with an increase in the percentage of nano-clay and at the same time impact strength increased with the increase in the percentage of nano-clay [8]. Suresh et al explored the mechanical and erosion wear of E-glass fiber reinforced 50 % by weight in epoxy resin[9]. Jawad Kadhim Uleiwi et al carried out a study using epoxy resin with reinforced EGlass and graphite filled epoxy composites[10]. P.N.B. Reis et al studied and investigated the effect of fibre volume fraction on the flexural properties of the laminated composite[11]. M. Davallo et al studied the flexural behaviour of hand manufactured hybrid laminated composites with a hemp natural fibre/polypropylene core and two glass fibres/polypropylene surface layers at each side of the specimen[12]. S. Benjamin et al investigated the Mechanical behaviour of unidirectional glass polyester composites to identify performance differences of composites with different glass lay-ups and laminate thicknesses during flexure and tensile testing formed by hand lay-up moulding (HLU) [13]. Jane Maria et al studied about flexural properties of continuous random glass-polyester composites formed by resin transfer moulding (RTM) and hand-lay up (HLU) moulding to determine the effects of glass content, composite thickness, reinforcement geometry and type of fabrication on damage developed during flexure tests [14]. Hence, both types of composite series appeared to fail at a critical strain value. The damage developed during the test was monitored on the side of each polished beam using an optical microscope [15]. Mallick et al proposed Polymer matrix composites (PMCs) used in automotive and road transportation applications [16].

III. METHODOLOGY

- ➢ Thermoset composites are fabricated either using "wet forming" processes, or processes which used premixes or prepregs.
- ➢ In wet forming process resin in fluid state is used, while forming the final product. The resin gets cured in the product while the resin is "wet". This curing may be aided by application of external heat and pressure. Typical wet forming processes include, (Hand layup, Pultrusion, Vacuum bagging).
- ➢ In alternative processes, which rely on premix or prepregs forms (and not wet forms), pre-fabricated material in semi-cured form is used to provide shape to the final product.
- ➢ We have employed HLU process considering our resources and constraints and hence confining our discussions to that process here.

3.1. Hand layup process

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mold size and placed at the surface of mold. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed. The schematic of hand lay-up is shown in fig. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperature is 24-48 hours. This method is mainly suitable for thermosetting polymer based composites. Capital and infrastructural requirement is less as compared to other methods. Production rate is less and high volume fraction of reinforcement is difficult to achieve in the processed composites.

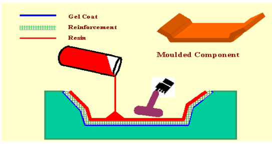

Fig-2 Hand lay out process

Hand lay-up method finds application in many areas like aircraft components, automotive parts, boat hulls, diase board, deck etc.

3.2 Procedure:

- ➢ The matrix production is done by hand layup process. The materials we require are glass fiber, polypropylene sheet, a base for support, wax, polyester resin, hardener, catalysts(accelerator), weighing machine, brush, gloves, beakers, dropper and scissor.
- ➢ First the glass fiber is cut into specific dimensions i.e. 200x100 into 6 pieces .then it is weighed it came out to be 70gms. After that we made a specific liquid by mixing polyester resin, hardener, catalysts in proper ratio i.e. with 30 liter resin 300ml of hardener and with 1litre of both resin and hardener there must be 10ml of catalysts. So we took 67gms of resin and mixed 2ml of hardener and 2ml of catalysts which is approx value of the previous ratio. it is then steered for 3mins and then this liquid solution is rubbed properly on the 6 pieces of glass fiber sheet.
- ➢ We could also use the hardener directly but for easy and proper working we have to go for this solution.

- The whole thing is again covered by the polypropylene sheet after that a roller is rolled over the prepared stuff so that all the extra amount of hardener that is present inside the pack should get overflow and then it is being pressed and kept for 24hrs to harden properly.
- After 24 hours it is taken out with proper precaution and now we are leading towards testing of this material.

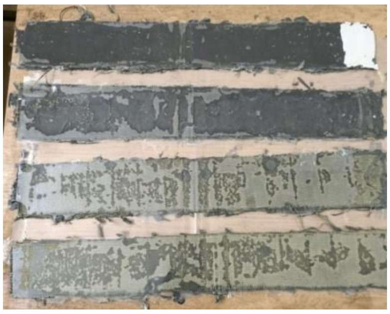

Fig. 3. Samples fabricated at our Laboratory.

Fig. 4. Samples fabricated at our Laboratory

Fig.5. Representation of Functionally Graded Material

IV. RESULTS AND DISCUSSIONS :

Experiments on fabrication of Alumina-Graphite polymer matrix composite.
The samples were cut to ASTM standard (D3039) for tensile test as shown below:

Fig -6 Composites with their composition

The samples were tested for density at AMT Lab, CSIR-IMMT as shown below:

10% Al2O3 with Graphite

10% Al2O3 with Graphite				
Sl No	wt. in Air(g)	wt in liquid(gm)	Density(g/cc)	Remarks
1	0.5589	0.0025	1	Average of best of three readings 1.014
2	0.5763	0.012	1.017	
3	0.5975	0.0185	1.027	
A. 20% Al2O3 with Graphite				
Sl No	wt. in Air(g)	wt in liquid(g)	Density(g/cc)	Remarks
1	0.6395	0.584	1	
2	0.6549	0.586	1.093	
3	0.6559	0.0194	1.026	1.0396
B. 30% Al2O3 with Graphite				
Sl No	wt. in Air(g)	wt in liquid(g)	Density(g/cc)	Remarks
1	0.7858	0.0177	1.019	
2	0.7939	0.0068	1.004	
3	0.798	0.013	1.012	1.0116
C. 40% Al2O3 with Graphite				
Sl No	wt. in Air(g)	wt in liquid(g)	Density(g/cc)	Remarks
1	0.7015	0.0132	1.015	
2	0.7175	0.0142	1.016	
3	0.7165	0.0138	1.017	1.016
D. 6 layered Aramid with-Epoxy resin				
Sl No	wt. in Air(g)	wt in liquid(g)	Density(g/cc)	Remarks
1	1.1816	0.0958	1.083	
2	1.2001	0.1318	1.118	
3	1.2043	0.1239	1.1109	
	Average		1.10396	
E. Plain GF with Al2O3 -Epoxy resin				
Sl No	wt. in Air(g)	wt in liquid(g)	Density(g/cc)	Remarks
1	1.3726	0.2049	1.171	Average of best of three readings 1.1786
2	1.3742	0.2141	1.179	
3	1.3526	0.2177	1.186	

Table-1-density test report

Fig-4.2-testing images

Tensile Test for Sample E & F was conducted using UTM machine:

a) Sample E (Aramid Fiber (6 Layers) with Epoxy resin-failed at 22.2KN

b) Sample F (Plain Glass fiber with Al2O3 and Epoxy resin-failed at 7.86KN

% of Al2O3 & Hardness test	10%	20%	30%	40%
	61.93	74.43	77.49	82.92
	69.96	46.38	79.84	81.95
	64.56	89.21	73.80	80.58
	65.12	70.01	75.69	79.98
Average Hardness Reading	65.39	70.01	76.71	81.36

Table-4.2-hardness report

Output Data								
Load At Yield(KN)	Elongation at Yield (mm)	Yield Stress(N/mm2)	Tensile Strength (N/mm2)	Load at Break (KN)	Elongation at break (mm)	Breaking Strength(N/mm2)	Percentage Reduction in Area(%)	Percentage Elongation (%)
58.25	6.46	438.854	294.69	61.35	27.66	462.209	1.98	1.24
21.95	10.11	209.048	261.43	27.25	19.96	259.524	2.86	1.71
20.17	12.24	172.56	223.34	25.33	15.32	221.15	4.11	3.25
18.6	14.34	141.762	185.72	22.05	17.6	175	5.71	4.05

Hardnessest Test Results:

Sl No.	Al-Gr (in Percentage)	Hardness (HRRW)
1	10	65.39
2	20	70.01
3	30	76.71
4	40	81.36

Tensile Strength Test:

Tensile Strength	
% Al-Gr	Load(N)
10%	294.69
20%	261.43
30%	223.34
40%	185.72

Density Test

Sl No	AL-Gr(%)	Density (g/cc)
1	10	1.014
2	20	1.016
3	30	1.017
4	40	1.018

V. CONCLUSIONS

Reinforcements of fibers or particles in the matrix structure of composite materials have revealed outstanding remarks, making them a popular choice for topmost applications.

There are numerous types of fibers available for fabrication of fiber-reinforced composites; those are categorized as natural and synthetic fibers. Synthetic fiber provide more stiffness, while natural fibers are cheap and biodegradable, making them environmentally friendly. Though both types of fibers have their efficacy in significant applications, latest research has revealed the exceptional performance of hybrid fiber-reinforced composite materials, as they gain the advantageous properties of both.

Composite materials are fabricated with a number of different techniques, among which every technique is applicable for certain material. Effectiveness of manufacturing technique is dependent on the combination of type and volume of matrix or fiber material used, as each material possesses different physical properties, such as melting point, stiffness, tensile strength, etc. Therefore, manufacturing techniques are defined as per the choice of material.

For distinct applications in a variety of fields, certain solitary materials might be replaced with composite materials, depending on the enhancement in its required property. Composite structures have shown improvement in strength and stiffness of material, while the reduction in weight is magnificent. Composites have also revealed some remarkable features such as resistance to impact, wear, corrosion, and chemicals, but these properties are dependent upon the composition of the material, type of fiber, and type of manufacturing technique employed to create it. In accordance with the properties required, composite materials find their applications in many desired fields.

More future research is intended to discover new composite structures with a combination of different variants and adopting new manufacturing techniques. In this work Al2O3 and Graphite reinforced composite using epoxy and polyester resin is produced with hand lay off method. Their mechanical properties like tensile strength, shear strength, impact, hardness and are investigated fixture and results are obtained.

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