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Fabrication of Continuous GFRP Composites using Vacuum Bag Moulding Process

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Abstract

Fiber Reinforced Polymer (FRP) composites are being promoted as the materials of 21st century because of their superior corrosion resistance, excellent thermo-mechanical properties, and high strength-to-weight ratio. Out of those, Glass Fiber Reinforced Polymer (GFRP) composite materials are replaced by many traditional engineering materials owing to their outstanding material properties. According to the application or need sophisticated fabrications of composites has increased enormously. This increase in the development of such materials will become more economical and reliable when manufacturing process is more efficient and durable. Here we used continuous Glass fiber of 430 GSM (Grams per Square Meter) as the reinforcement material and Epofine 230 (CY230) a class of Epoxy polymer as the matrix material. This paper discusses about the fabrication of continuous (uni-directional) SIKA E-Glass Fiber Reinforced Polymeric (GFRP) composites using Vacuum Bag moulding process.

Keywords: *Fiber Reinforced Polymer (FRP composites), Glass Fiber Reinforced Polymer (GFRP) composites, 430 GSM (Grams per Square Meter), reinforcement material, Epofine 230 (CY230), matrix material, continuous (uni-directional), SIKA E-Glass Fiber Reinforced Polymeric (GFRP) composites, Vacuum bag moulding*

1. Introduction

Invention of composite materials satisfying various design requirements has revolutionized the fields of research and development in material world. All most all the applications where high strength, high stiffness and light weight is required, the composites are preferred. These have very high strength to weight ratio. This property justifies there usage in many domains. A material system composed of two or more components with distinct properties and distinct boundaries is termed as a Composite material or Composite [1]. Composites have long lasting applications in the fields of aerospace, military, marine, wind turbine, sports equipment, automobile, civil structures etc. [2]. Glass fibers are first commercially produced in USA in 1937 and the first GFRP was produced in 1942 [3]. The percentage of FRP composites usage in aircrafts was about 10% in 1990's and now a days it was around 40%-50% [4]. The tensile and compressive behaviour of composite laminates is studied over the past decades. But fatigue in composite structures is a very complex phenomenon and is completely new area which is still under development [5]. For such testing it is very important to know the material characterisation of the required composite laminate.

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In this paper, the step by step procedure for fabrication of continuous (unidirectional) SIKA E-Glass Fiber Reinforced Polymeric (GFRP) composite specimens using Vacuum Bagging (VB) technique is explained. This entire fabrication work was carried out at Indian Institute of Technology (IIT), Hyderabad. Vacuum Bagging or Vacuum Bag Laminating is a clamping method that uses atmospheric pressure to hold the adhesive or resin coated components [6]. An ideal composite layup minimises the amount of resin because the resin itself adds the weight rather than strength [7]. Each and every layer produced is termed as *ply*. Vacuum bagging is a refinement of hand lay-up process which uses the concept of creating vacuum to eliminate entrapped air and excess resin such that the voids created will be eliminated from the laminate. It is an effective, cost-efficient technique which uses vacuum pressure to provide optimised fiber to resin ratio which is a very important phenomena in strength aspect. The bag reduces the amount of volatiles emitted during cure. The best vacuum bag systems will be produced just under 14 Psi (0.9652bar) or 2000 Psf (Psi- pounds per square inch, Psf – pounds per square foot). Most FRP constructions will not require a full 14 Psi but rather 5-10 Psi [8]. The use of vacuum reduces the void content in the composite and improves the quality as well [9]. The present work was done under a vacuum pressure of 13.77 Psi (0.949 bar) and curing is done at room temperature. The key advantages of vacuum bagging are it provides equal pressure to all the surface of the part (whether the part is made up of vertical, horizontal, curved, compound curved or any combination of these), optimised fiber-to-resin ratio, less resin wastage, very consistent resin usage etc. The degree of vacuum in vacuum bagging determines the amounts of air trapped in the composite laminate. This residual air results in the formation of dry spots and micro voids and these defects are in turn responsible for the degradation of mechanical properties of the laminate [10-16]. M.K. Kang [17] developed an analytical model to analyse the resin flow in vacuum bag moulding process. Manufacturing of the qualitative parts using vacuum bagging is dependent on various parameters like viscosity of the resin, defined pressure, air check, nature of reinforcement, quality of sheets used *etc.* [18].

2. Materials

The specimens are being manufactured using the following equipment : Vacuum pump, Matrix material (Resin and Hardener), Reinforcement material (SIKA Wrap uni-directional glass fiber – 430 GSM), Mylar sheet, Peel ply fabric, Perforated sheet, Breather sheet, Bagging sheet, Tacky tape, flow tube, flange *etc*.

2.1. Specimen Geometry and Mounting of Vacuum Pump

The details of specimens [19] to be manufactured are listed in Table 1. Two Vacuum pumps (ALUE) of 1 HP capacity are adopted to carry out the fabrication work simultaneously. These are positive displacement oil lubricating pumps that can run at higher vacuum pressures, most efficient and long lasting than oil-less pumps. It maintains constant pressure throughout the cure cycle of the composite. One vacuum pump is connected with a pressure gauge of capacity -0 Kpa to -100 Kpa and the other is connected to a pressure gauge of capacity -0 inHg to -30 inHg (where Kpa: Kilo Pascal's and inHg: Inches of Hg). The total fabrication of 0deg tensile test specimens is connected to one vacuum pump, 90deg tensile test specimens including compression test specimens is connected to another vacuum pump. Shear test specimens are done separately in the next day.

Table 1. Material Characterisation Specimen Dimensions for Continuous GFRP Composites

Material Characterisation Specimen	Orientation (deg)	ASTM Designation	Specimen Dimensions (mm)			No.of Layers required (t=0.3mm)	Aluminium Tab dimensions (mm)	
			L	W	T		L	T
Tensile test	0	D3039	250	15	1	3	56	1.5
Tensile test	90	D3039	175	25	2	6	25	1.5
Compression test	0 or 90	D3410	139.7	6.35	2	6	63.5	2
Shear test	±45	D3518	250	25	2	6	50	1.5

ASTM – American Society for Testing and Materials **D**- Designation
L- Length **W**- Width **T**- Thickness **t**- Thickness of Weave

2.2 Matrix Material (EPOFINE - 230 and FINEHARD – 951)

The main functions of Matrix material are it binds up the fibers, transfers load to the reinforcement, provides rigidity and shape to the structure, isolates the fibers for slow crack propagation, protects fibers from wear and corrosion and also maintains surface quality [20]. Epoxy resins are widely used in industrial applications because of their good mechanical properties, adhesive property, solubility, chemical resistance, low shrinkage, excellent water resistance, excellent resistance to heat and electrical insulation etc. [21]. EPOFINE 230 is an electrical grade liquid epoxy casting resin and FINEHARD 951 is a polyamine hardener purchased from Fine Finish Organics Pvt. Ltd [22] the properties of resin and hardener are enclosed in Table 2. The mixing ratio of resin to hardener is 10:1 by weight. The advantage of using this resin hardener mixture is the low viscosity of resin. This property helps in infusion of resin smoothly.

Table 2. Properties of EPOFINE - 230 and FINEHARD – 951

	Characteristic	Test Method	Specification
EPOFINE – 230 (CY 230)	Viscosity at 25^0c	ASTM- D 445	1,200 – 1,900 mPas
	Epoxy content	ISO – 3001	4 – 4.5 Eq/kg
	Density at at 25^0c	ASTM- D 4052	1.12 – 1.16 g/cc
	Flash point	ASTM- D 93	190 – 200^0c
FINEHARD – 951 (HY 951)	Viscosity at 25^0c	ASTM- D 445	< 20 mPas
	Flash point	ASTM- D 93	110 – 120^0c
	Density at at 25^0c	ASTM- D 4052	0.97 – 0.99 g/cc

ISO - International Organisation for Standardisation.

2.3. Reinforcement Element

The main functions of reinforcement material are they carry 70% to 90% of load, provides structural properties like strength, stiffness and thermal stability etc [23]. Packing roll of 24 in.x 150 ft. unidirectional woven high strength E-glass SIKA wrap of 430 GSM (430 Grams per Square Metre) along with related Product Data Sheets (PDS) were imported from SIKA fabric systems, USA. These are generally used for structural applications [24]. According to the product data sheet the fiber construction has Wrap: White glass fibers (99% of total area weight) and Weft: White thermoplastic heat-set fibers (1% of total area weight) and weave thickness is about 0.3mm [25]. The key advantages are it has increased loading capacity, Flexibility of surface geometry, strengthening of substrates with low strength possible, good seismic strength and excellent cost performance. The technical data [26] was listed in Table 3.

Table 3. Material Properties of SIKA Unidirectional Glass Fiber Fabric

Fiber Type	High strength E- Glass fibers
Fiber orientation	0^0 deg
Weight per square yard	440 g/m^2
Fiber Density	2.56 g/cm^3
Fiber Design thickness	0.3 mm
Tensile strength of fibers	2,300 N/mm^2 (nominal)
Tensile E-modulus of fibers	76,000 N/mm^2 (nominal)
Strain at break of fibers	2.8 % (nominal)

2.4. Sheets

2.4.1. Mylar Sheet

Mylar sheet of 100 microns (1 micron= 10^{-6} m) is used for fabrication. It is a good electric insulator, transparent, chemically stable and reflective in nature. It is used to get mirror finish on the specimen.

2.4.2. Release fabric/ Peel ply fabric / Release Film

It is a smooth woven fabric which will not bond with epoxy. It is used to separate the breather and the laminate. Excess epoxy can wick through the release fabric and can be peeled off from the laminate after the laminate cures. High performance fluropolymer [27] release film- WL5200 (WRIGHTLON) is used in this fabrication. It is capable of cure temperatures up to 500^0F (260^0c). This has an ability to provide glossy finish when used directly on the laminate. It has elongation at break 350% and Tensile strength 7000 psi (48 Mpa) as per ASTMD882, yield 22.8 m2/kg/25.4 µm.

2.4.3. Perforated release sheet/ Perforated Film

A solid release film that has been perforated with a uniform hole pattern is taken. It can be used in conjugation with release fabric. It helps to hold the resin in the laminate

2.4.4. Breather sheet/ Bleeder/ Absorption Fabric

Breather cloth is a thin, stretchable, high fill non weave polyester material. It allows air from all parts of the envelope to be drawn to a port or manifold by providing a slight air space between the bag and laminate and also it absorbs excess resin seeping through the porous release film. Econoweave 22 (Economical Breather) [28] is used. It is the lightest polyester breather used for low pressure cures.

2.4.5. Bagging Sheet

Bagging sheet forms an air tight envelope around the laminate. It is transparent in nature to allow easy inspection of the laminate as it cures. Low temperature nylon vacuum bagging film is used in the fabrication. Econolon [29] is an inexpensive nylon bagging film for low temperature cures, compaction and debulking. The thickness of the sheet is 0.0015 inch (37.5 mm). It has elongation at break 375% and Tensile strength 7000 psi (48 Mpa) as per ASTM D882, Maximum use temperature is 300^0F (149^0c), Melting point is 380^0F (193^0c) as per ASTM D 789-94, Yeild 34.8 m2/kg/25.4µm.

2.5. Resin Infusion Tube and Tacky Tape

One resin infusion tube of 10mm diameter with appropriate length is taken to connect between flange and catch pot. Tacky tape is a sealant tape used to provide continuous seal between bagging film and mould around the perimeter of the mould. They are very pliable and similar to the structure of chewing gum and these have sealing properties on both sides. Most sealant tapes are generally butyl-based materials.

2.7. Flange

Flange is placed on the top side of the fabrication setup. The top side of the flange is made with brass and the bottom side is made up of Aluminium. It consists of an infusion tube is connected to flange top on one side and to catch pot of vacuum pump on the other side. It is used to flow the excess resin towards the catch pot.

Figure 1. Flange and Flange Clamp

3. Method

3.1. Mould Surface Cleaning

Two flat scratch less glass moulds of area 65 X 65 cm^2 and thickness 4 cms are taken as the base of fabrication. They were cleaned neatly with a cotton ball, because even existence of single hair on it will cause air leakage. Paste the Tacky tape on four sides of the mould such that the laminate should have sufficient space to fabricate. Now a Mylar sheet of 100 microns is placed on the mould such that it acts as a mould release agent and also obtains mirror finish of specimen (in the absence of Mylar sheet we can just apply any mould release agent like Marbocote 220) for taking out the laminate easily from the mould after drying of laminate completes.

3.2. Cut and Position the Reinforcement

From the Table 1 it is clear that specimens of Tensile test (0 deg and 90 deg) and compression test (0 deg or 90 deg) require only linear Glass fiber fabric and shear test specimens need $+45^0$ and -45^0 oriented fabrics. The 0 deg tensile test specimens are fabricated on one mould because it needs only 3 layers of fabric. As we need three specimens we cut three layers of fabric having area of 270 X 70 mm^2. Another mould is used to fabricate 90 deg tensile specimens and 0 deg specimens because they need 6 layers of fabric, as we need three specimens we cut three layers of fabric having an area of 300 X 250 mm^2 using special fabric scissors. The next day a bevel protractor is used to find 45 deg inclination and cutting was followed maintaining the area of 300 X 100 mm^2. Sequence of ± 45 deg orientation is preferred in laminate preparation.

3.3. Resin Preparation

EPOFINE 230 and FINE HARD 951 [22] are mixed in the ratio 10: 1 by weight. For example if we take three 270 X 70 mm^2 fabric sheets it weighed exactly 136.82 gms i.e.

approximately 137 gms. So for this application we need to add 137 gms of CY 230 and 13.7 gms of HY 951. But there exists a practical problem that if we use exactly this resin-hardener mixture it is not sufficient to wet all the fabric sheets because some of it will be wasted during spreading, at infusion tube, flange and catch pot *etc*. So it is better to have 150 gms of CY230 and 15 gms of HY951. This mixture is finely mixed for about 1-2 min using a mixing scoop to release the dissolved gasses. If the mixing time increases it starts solidifying.

3.4. Fabrication

A small spreader sheet is used to spread the resin hardener mixture uniformly on the Mylar sheet so that the adjacent fabric wets out completely. We add one by one fabric sheet and also spread the mixture uniformly between the glass fabrics. Always spreading should be done in the direction of fiber if not it disturbs the fibers of fabric shown in Figure 2.a. Now place a peel ply fabric to peel out the laminate easily after it is completely dried out and also place a perforated sheet to absorb excess resin from perforates and this is followed by 2 layers of breather sheets (shown in Figure 2.b and 2.c to absorb the air lying between the mold and bagging sheet (shown in Figure 2.d) and also it eradicates the formation of flange impression observed after the casting completely dries out.

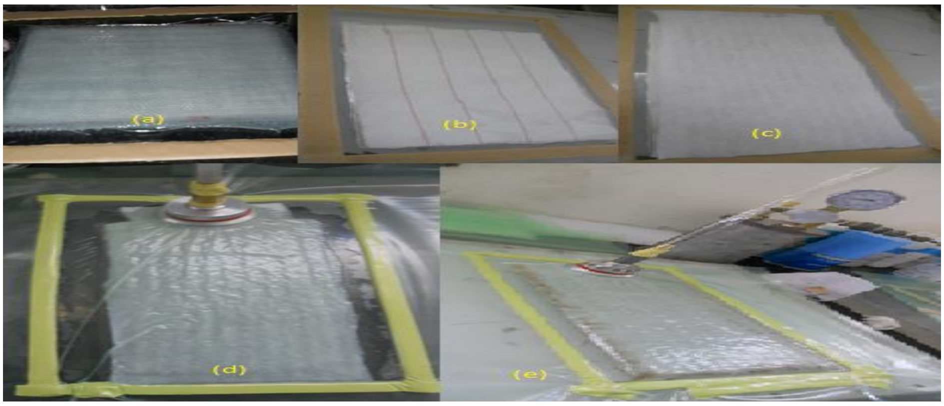

Figure 2. Fabrication of Glass Fiber Reinforced Plastic composites using Vacuum Bagging Process

(a) Wetting the fabrics using spreader sheet (b) Placing Peel ply fabric and Perforated sheet
(c) Placing two layers of Breather sheet (d) Bagging sheet with flange
(e) Fabrication unit connected with catch pot of vacuum pump

Flange is placed on the top side of this setup to have the property of weight and to send the excess reisn to the catch pot. Place the bagging sheet over this setup in such a way that it should pass through topside opening of flange. Check the sealing of bagging sheet with tacky tape throughout the periphery. Mount the flange with a clamp and connect the infusion tube in between flange and catch pot and seal it as shown in Figure 2.e. A unified model to describe the combined mass and momentum balance between the resin and fibers is given by [30, 31].

$$-\frac{1}{vf}\frac{\partial V_f}{\partial t}-\frac{1}{V_f}\frac{\partial V_f}{\partial x_1}V_i^f=\frac{\partial}{\partial x_i}\left(\frac{K_{ij}}{\mu_r}\frac{\partial p}{\partial x_j}\right)$$

Where V_f is the fiber volume fraction, Vi^f is the velocity of fibers, p is the resin pressure, μr is resin viscosity and *Kij* is the permeability tensor of the anisotropic fiber perform. When high permeability layers are used over the fiber perform, an effective permeability tensor is used for *Kij*. Subscripts of *i* and *j* are the direction indices. A collecting cup is placed inside the catch pot so that the excess resin will be collected. The top surface of the catch pot is fixed with a Poly Tec pressure gauge connected to the ALUE vacuum pump using a quick return valve. Turn ON the pump it starts sucking air and excess resin. Carefully check the air leakage by hearing the small sound coming from the fabrication setup. Spread the bagging sheet uniformly such that sucking will be done smoothly. Wait for a while until the pressure reaches -95 Kpa in -100 Kpa pressure gauge or -28 inHg in -30 inHg gauge. Shut down the vacuum pump and observe whether the pressure is maintained constant or not. Finally more the constancy in pressure greater the quality of the product because it indicates that the air has not sucked back i.e. no voids occur inside the laminate.

4. De-moulding the Laminate

The vacuum pump should stay on until the part is fully cured. Generally it takes 24-28 hours to cure and is completely done at atmospheric temperature. After that cut the bagging film around the edge and remove. Remove the bagging tape, pull out the peel-ply (this will take a little bit of force) and finally remove the part from the mould.

5. Cut the Specimen

The final laminate obtained has improper edges and also to prepare required specimens a BOSCH wood cutting machine (230 V, 50Hz, 8amps) was used. The cutting blade made up of stainless steel having outer diameter of 254 mm and inner diameter of 30 mm. At first the FRP laminate is made to pass across the blade such it trims the laminate and now based on the width of the specimen to be cut keeping an allowance of 3-5mm on each side, the distance between horizontal column and cutting blade is measured with steel rule and fixed.

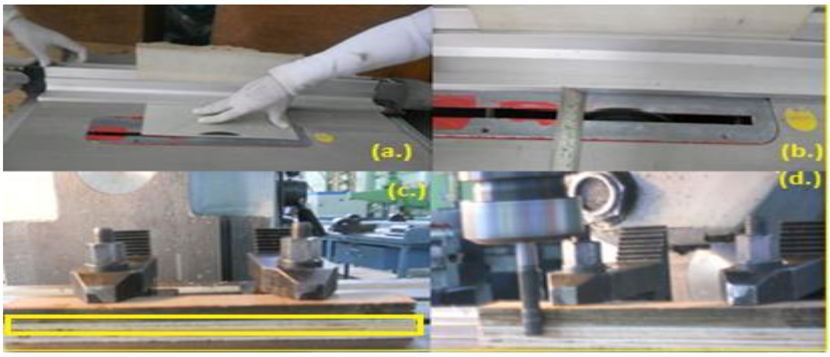

Figure 3. a.) Trimming the Edges of FRP Laminate b.) Measure the Distance between Cutting Wheel and Column according to Specimen Width c.) FRP Laminate is Protected by Wood Pieces of same Size on Top and Bottom Side d.) Final Trimming on Universal Milling Machine with Diamond Coated Carbide Tool

After cutting the specimen the edges will have small sharp fibers so this will be removed on universal milling machine that can be operated horizontally and vertically. If we directly use the laminate due to brittleness it may get damaged so the top and bottom side is protected by placing wood pieces of same dimensions as that of laminate. A diamond coated carbide cutting tool rotating at 2000 rpm is used to trim the laminate finally by moving it around the laminate. Finally the laminate is removed from the fixtures and used for testing.

6. Conclusion

Vacuum Bagging provides uniform pressure and eliminates putti pooling or putties starved areas as a result of unequal clamping pressure. It produces the total attachment of core to facings allowing the sandwich to develop the maximum mechanical properties. It improves quality of composite i.e. fiber to volume ratio, excellent surface finish, usage of multiple layers of fiber, improved strength and stifness etc. These properties made to implement Vacuum Bagging fabrication process in most of the sophisticated industrial applications to attain better material performance even under reasonable cost.

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