The Nucleus **51**, No. 1 (2014) 13-18

The Nucleus
A Quarterly Scientific Journal of Pakistan
Atomic Energy Commission
NCLEAM, ISSN 0029-5698

DENSITY VARIATION EFFECTS ON CROSS DIMENSION (CD) STRENGTH OF PHENOLIC MULTILAYERED COMPOSITES FABRICATED VIA VARTM

*M.A. NASIR, Z. KHAN[2], MUDASER ULLAH, R.A. PASHA, R.A. RAHMAN,
Q. ALI[1], S. ANAS, S. NAUMAN and S. AMIN[2]

Mechanical Engineering Department, University of Engineering and Technology, Taxila, Pakistan

[1]Mechanical Engineering Department, University of Engineering and Technology, Lahore, Pakistan

[2]Institute of Space & Technology, Islamabad, Pakistan

[3]Electrical Engineering Department, University of Engineering and Technology, Taxila, Pakistan

(Received October 31, 2013 and accepted in revised form March 11, 2014)

Different phenolic composites categorized on the basis of different reinforcing fibers, each fiber has a constant length of 50 mm in its respective composite grade, are investigated on the basis of varying number of piles per square area of tested zone. As the piles differ in interested zone then resultantly density is changed for each composite grade, although the resin and hardener are kept constant for each sample of tested composite type. Vacuum Assisted Resin Transfer Molding (VARTM) technique is used to synthesis all phenolic composites used in this research. During synthesis of each grade the same resin (Resole) and hardener (Rylex-30) are used in VARTM setup, however the fiber volume ratio is changed from 52-60% with respect to density range utilized in this work. Detail design description of VARTM is also discussed and optimized up to maximum scale to acquire compact, uniformly strengthen and porosity banned specimens. Cross Dimension (CD) Tensile and flexure strength variability with respect to density (changing fiber volume ratio) of each grade is viewed on experimental basis and tried to explain their behavior.

Keywords: Phenolic composites, VARTM, Reinforcing, Laminated plastics, Flexure strength, Cross Dimension (CD)

1. Introduction

Low weight to strength ratio made the composites more ideal than conventional materials. Recently researchers are striving to optimize composites; this effort is also in the same direction. As the plies of material increases, the per square density booms up however the increasing quantity is totally dependent on reinforcing fiber usage. Composite materials belong to a family of materials that are produced by engineering processes. These are produced by two or more constituent materials, having much varying chemical and physical properties and it remains distinct and isolated in the final structure. For designer it is compulsory to nominate best material for the design of electrical, chemical, mechanical, thermal, etc. applications [1]. The organized and logical selection of superlative material for a specified application always begins with distinct properties and cost of the considered material. It is explained by exemplifying that it is necessary for thermal blanket to have poor thermal conductivity so that the losses of heat are minimum. Composites are revolutionary materials which provide best and unique chemical, thermal physical and mechanical properties because these materials have the best properties of their constituent materials while their undesired properties are vanished away in the final product. In a plastic reinforced with glass fiber, the ultimate composite acquire high strength of glass fibers and chemical resistance and ductility comes from plastics while the undesired brittleness of glass fibers is totally depressed and not part of the composite [2]. The fibers, reinforcing part of composites, consist of slim and uninterrupted long fibers or tiny fibers segments. When reinforcement is done by short fibers then it is advised that the aspect ratio of the fibers should be high. Now-a-days most of the composite fibers contain synthetic fibers as a reinforcing component. These fibers are used with a matrix that is responsible for their tight bounding [3]. The composite material fulfilling the most of material demands recently is Polymer Matrix Composite (PMC). The constituent of PMC is plastic and reinforcing fibers made of ceramic material such as glass or carbon. To achieve the valuable properties of the end product the volume of the fibers is maintained nearly 60% in PMC. There are another species of composites also used in some applications named as Metal Matrix Composites (MMC) and Ceramic Matrix Composites (CMC) using metal and ceramics as a matrix respectively. For aerospace, automotive and recreational applications advanced composite materials are attracting the designers recently. Composites materials are actually redefining the materials world by

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* Corresponding author : ali.nasir@uettaxila.edu.pk

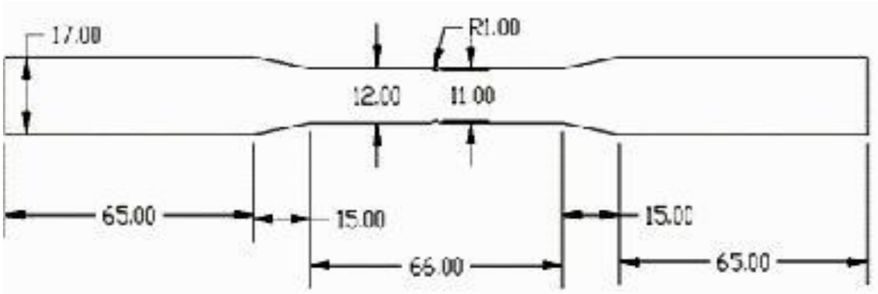

Figure 1. Dogbone specimen.

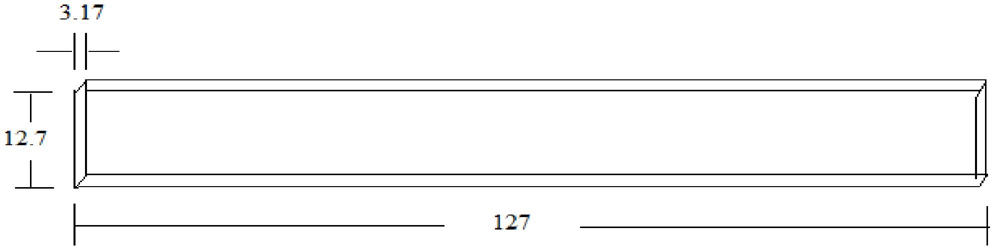

Figure 2. Bend test specimen.

encircling more and more applications fields such as civil engineering structures, biomedical articles such as prosthetic devices and many more. The most attractive property of composites, ultimate tensile strength, is enhanced by a process named reinforcement. Reinforcement increases rigidity and resists crack propagation. The pattern of the fibers decides the strengths of the reinforcement, If well attached with the matrix, thin fibers can have high strength and overall composite properties [4]. Short and long fibers are in the form of chips are used in operations like compression molding and sheet molding etc. Continuous reinforced materials have layered structure.

A newly developed technique, VARTM, is used to mold the fiber reinforced composites in this research. Apparent and flexible sheet such as Mylar or nylon is pasted on preform and sealed it on the mold. By a suction device vacuum is created between thin sheet and preform and then part is cured in an oven. Then pressure is applied and resultantly the concentration of the fibers is enhanced alongwith the best adhesion between the layers of sandwiched structure [5]. VARTM process has an advantage over conventional technique of Resin Transfer Molding (RTM) due to very minute tooling required of end product leading to reducing the total cost. This process is also superior due to the reason of less stringent surface requirement.

In this paper, the composites containing different reinforcing fibers are tested at varying layer stages and tried to show the effects of different density levels of different fibers with same resin and hardener at tensile and flexure stability. These different density levels are created by using VARTM technique. Multiple tension and bend test are done and results are demonstrated showing the validity of exact amount and type of fiber for a specific use. However, in the whole research it is considered that inter-layer compactness is upto optimum level and uniform in all specimens tested.

2. Experimental Work

2.1 Specimen Preparation

Two phases of material test are performed in this research. In phase I, tensile test for tensile strength and in phase II bend test for flexure strength are conducted. For tensile test, dogbone specimens are prepared according to ASTM Standard D638-03 as shown in Figure 1 while for bend test; specimens are fabricated according to ASTM Standard D790 shown in Figure 2.

Special types of molds are formed to fabricate these specimens of phenolic composites. The material test system used to examine the tensile validity of specimens is MTS 810 furnished with an advanced extensometer. Different metals are used as mold materials. Materials are important for better results and good experimentations. Majority of mold tool metal used lie in following categories; (a) 1 Ni-Cr Alloy Steel, (b) Mild Steel, (c) Aluminum. For this research mild steel was selected as a mold material and mold contain three parts, base plate, heart plate and nozzle catching plate. An electric discharge wire cut and die sinking machine is used to fabricate different parts of molds.

Figure 3. VARTM setup for dog bone mold.

Table 1. Mechanical properties of different phenolic composites grades

Material	ASTM Grade	Hardness (Rockwell)	Bond Strength (lbs.)	Dielectric Strength (kv)	Heat Resistance (^{0}F)	Moisture Absorption (%)
PP-116	XX	115	1500	50	250	0.25
CP-103	C	105	2000	55	225	1.70
CF-105	CEF	105	2000	55	250	1.22
SG-230	G-7	100	800	50	400	0.09
EG-403	G-10/FR-4	110	2500	65	250	0.10
EG-413	G-11	112	1700	75	300	0.11

The upper part of mold is used for resin entry while the lower part is the heart of mold because it has cavities according to specimen dimensions and the third part is supporting plate.

2.2. *Synthesis of Phenolic Composites*

2.2.1. *VARTM Setup*

A Typical VARTM setup is used to synthesis all phenolic composites grades used in this research. Basically it consists of four parts; (1) Resin chamber and degassing unit, (2) VARTM Mold, (3) Resin Trap and (4) Vacuum pump. Resin chamber & degassing unit was made from Galvanized steel. It consists of two nozzles one is attached to a valve and the other one on the upper portion of the chamber, a portion in which synthesis of composites materials are taken place. The nozzle which is attached below to the ball-valve is connected with the mold inlet port, from here resin flows to the mold with the help of vacuum pressure. Attaching the upper nozzle was necessary because degassing of resin was required to remove air trapped inside the resin solution. The nozzle is connected with vacuum pump and degassing is done for 30 minutes to completely remove the bubbles. Resin is poured into the chamber in premixed ratio with hardener. Capacity of chamber is 400ml approx. Resin trap is one of the essential parts of the setup. It saves the pump by preventing the excess to flow directly to vacuum pump which can cause damage the pump. So it traps the excess resin which can be reused. We designed resin trap by using a laboratory beaker. Excess resin flows through the mold outlet to the resin trap as illustrated in Figure 3.

It also helps to remove trapped bubbles inside the mold by removing the air from the mold. Clamp is used to stop the flow further to the resin trap when the mold is completely filled. Diaphragm pump was used as vacuum pressure provider to make the flow of resin smoothly.

3. Results and Discussion

In this research, six different species of phenolic composites are studied, these actually have varying strengthen materials (reinforcing fibers), and resultantly there are variations in their mechanical properties as mentioned in Table 1.

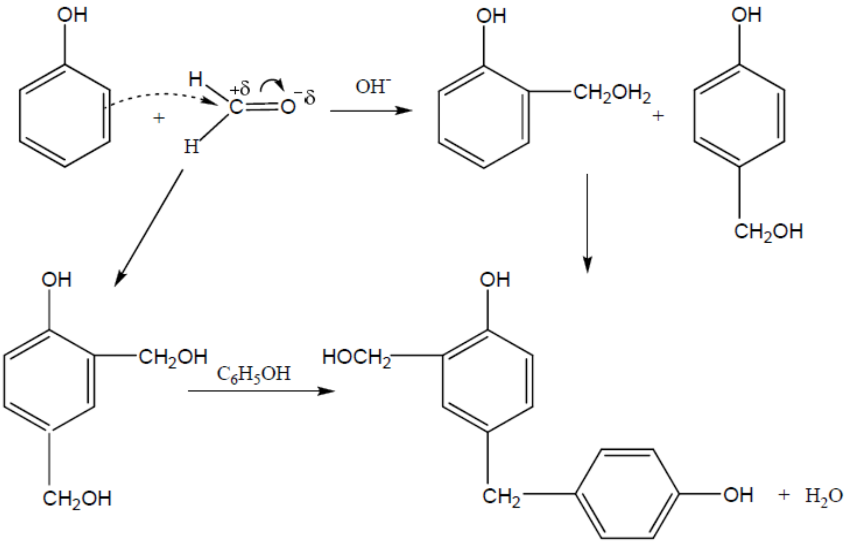

Figure 4. Chemical structure of resole resin.

Table 2. Reinforcing fibers used in their respective phenolic composites grades

Phenolic Grade	PP-116	CP-103	CF-105	SG-230	EG-403	EG-413
Reinforcing Fiber Type	Paper Phenolic	Canvas Phenolic	Canvas Fine	Silicon Glass	Epoxy Glass	Epoxy Glass

Resole are the resins which are produced when phenol reacts with access amount of formaldehyde in the presence of alkaline catalyst. The chemical structure formula is shown in Figure 4.

Resole resins are treated at low temperature by mixing of organic acid that speeds up polycondensation of the methyl-ol group which is already present in resin [6]. The reaction takes place rapidly in acidic environment, yields water, methylene and ether as byproduct. Due to thermally incompatible situations the ether decomposes and new product is formed named as formaldehyde, which is an aromatic structure containing chemical [7, 8]. It is highly thermally stable increasing the molecular weight of matrix. The low strength of phenolic matrix is tried to compensate by reinforcing materials. In this research different types of reinforcing materials are used as shown in Table 2 by fixing common matrix type.

3.1. Flexure Strength

It is viewed from Figure 5 that flexure strength depends largely on the type of reinforcing material. The stability of composites under tension is almost based on reinforcement [9], however, in flexure strength the involvement of resin effects are also considered. Actually the bending moment of dried matrix is not to be ignorable. To check flexure strength in bend tests the failure in all types of phenolic composite specimen at bottom surface of the fibers is exactly below the loading roller [10]. A theoretical valve of flexure strength at different matrix density levels is calculated by using Eq.1 [11].

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \qquad (1)$$

It is assumed that all failures take place at the upper side of fibers instead of lower side where σ_c is flexure strength and σ_m and σ_f are the tensile strength of phenolic matrix and reinforcing fiber respectively.

The differences in flexure strength to failure in Figure 5 in bend tests is due to different shear strength values of the fibers. However, the specimen geometry, dimensions, non-homogeneity in material and shear deflection which takes place at different degree in dried laminates along with pure bending also somehow contribute in varying flexure strength [12]. Although matrix density variation in inter fiber zone (IFZ) have a large effect on properties of laminates. If bend tests are held at two different spans to depth ratios then it is possible to separately estimate the flexure strength than shear. In Figure 5 the flexure strength behavior of all material grades show similarity while increasing the rigidity of material by adding more matrix in IFZ.

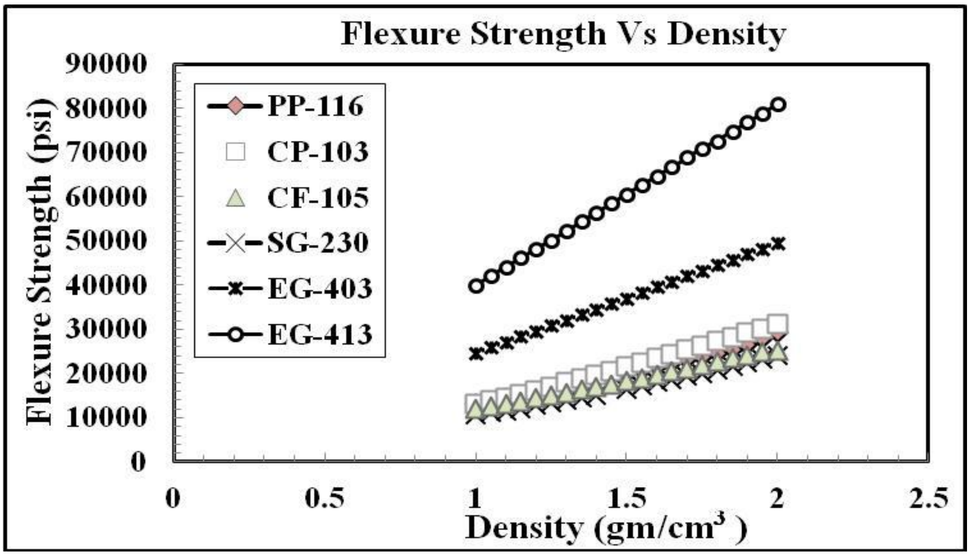

Figure 5. Flexure strength variations of different phenolic composites.

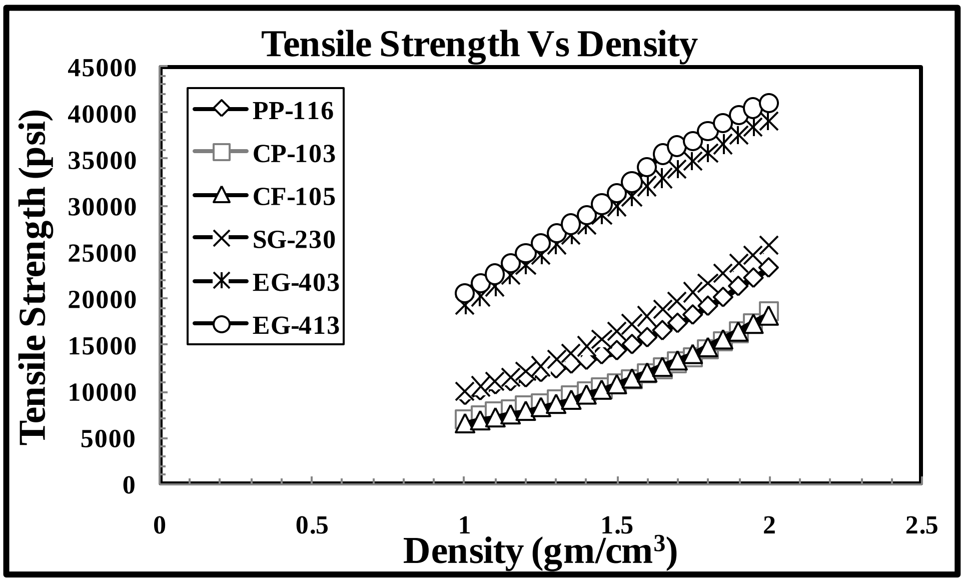

Figure 6. Tensile strength variations of different phenolic composites.

3.2. *Tensile Strength*

Tensile strength performance of different grades of phenolic composites almost shows similar behavior concerning the strains and modulus. Average strain at the point of ultimate tensile stress is examined nearly 2-4 % for most of studied composites. Most of dog bone specimens are broken in the center at notch location and it is observed there is shear mode of failure in all cases. This type of failure is evident that flexure modulus values are lower than the tensile modulus values as depicted in Figure 6. For homogenous materials, simple theory of bending states that modulus in bending is same as in tension [13]. But in our case the greater tensile modulus reveals that there is non-homogeneity in the matrix is present. Actually it supports the already mentioned statement of maximum matrix coagulation in IFZ. However it is also experienced that tensile rigidity is increased by increasing the coagulation although the tension modulus is less than the previous value having low coagulation.

When doing a comparison then it is stated that flexure modulus decreased more than tensile modulus by increasing material density.

4. Conclusion

The results specify that it is possible to gain an approachable degree of reproducibility in phenolic laminates by VARTM technique. However, the surface finishing attained by using phenolic laminates is poor with respect to commercial demands. The results also reveal degree of variations in compatibility between phenolic resin system and various reinforcements. Material packs between reinforcement affects linearly on flexure strength trends regardless of type of reinforcement. Tensile modulus behavior with increasing density for all tested specimens is same except those having epoxy glass as reinforcing fiber. In epoxy glass case the flexure modulus and tension modulus gain the same value when material coagulation takes place.

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