# Experimental Investigation of Physical Properties of Homogenous and Functionally Graded Glass Fiber Reinforced Vinyl-Ester Composites

**Vishvamohan Sharma, Manoj Kumar Sain, Praveen Saraswat**
Department of Mechanical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
***Email:*** **praveen.saraswat@skit.ac.in**
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**Abstract- Nowadays, the industrial requirement of new materials continually evolving the innovation in the composite materials field. Functionally graded materials (FGMs) are specialized engineering materials with varying properties due to a geographic gradient in structure and composition. Numerous composites are being manufactured for specific purposes other than general features that are highly significant and valuable. This paper presents the findings on the physical characteristics of glass fiber reinforced vinyl-ester-based homogenous and functionally graded polymer composites followed by the fabrication of both types of composites. The findings showed that the void fraction and water absorption are found to be enhanced in the case of homogenous polymer composite than functionally graded polymer composite, and these characteristics were found to be increased with fiber loading.**

**Keywords–** Composite materials; FGMs; Void fraction; Centrifugal casting

## 1. INTRODUCTION

Composite materials are formed by combining two or more two dissimilar materials having significantly different properties. Composite consists of two types of materials; one is matrix material, and another is reinforcement. Materials like metals or alloys, ceramics, polymers and resins used as a continuous base material for composites are known as matrices. Based on the material of the matrix, composites can be categorized as metal-matrix, ceramic-matrix and polymer-matrix composites as shown in Figure 1. Polymer-matrix composites contain polymer as a matrix and other additives which are used to improve the strength and other properties as reinforcement. The tensile, compressive, shear and impact strength, wear-resistance and elasticity are comparatively enhanced by the use of reinforcement. Different kinds of polymers are available for the matrix as per the requirement. The most commonly used polymer matrix materials are polyester, vinyl-ester, epoxy, phenolic-ester, polystyrene, polyamide, polypropylene, poly-ether, etc. Glass fiber, basalt fiber, kevlar fiber, graphite powder, wood fiber, carbon fiber, etc. are the commonly used reinforcement materials. These materials are used to fabricate polymer matrix reinforced composites [1].

In that time various polymer composites are available. Polymer composites are broadly categorized into two types. First on the basis of sources and second on the basis of the matrix. Source-based polymer composites are divided into three types such as fiber composite, natural fiber composites and bio-composites. Matrix-based polymer composites are of three types such as thermoplastics, thermoset and rubber.

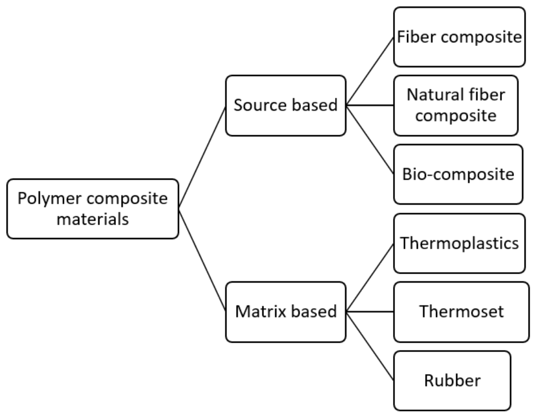


**Figure 1**: Types of polymer composite materials

In functionally graded materials (FGM) the properties (i.e., mechanical, thermal, chemical, etc.) varies gradually and continuously in a particular direction. To achieve this, composite is molded by gradually varying the percentage of its constituents. FGMs are very useful when mechanical properties like Young’s modulus of elasticity, Poisson ratio, and mass density are required to be varied.

The use of FGMs is increasing day by day in different sectors including power electronics, mining, aerospace and medical. These types of composites are very useful in spacecraft parts, heat insulation, condenser components, facings for nuclear reactors, engine parts and high-power electrical connectors, etc. [2].

FGM manufacturing processes generally build spatially non-uniform structures that is "gradient" and then this structure is transformed into a bulk material by "integration". Various FGM manufacturing processes are depicted in Figure 2.

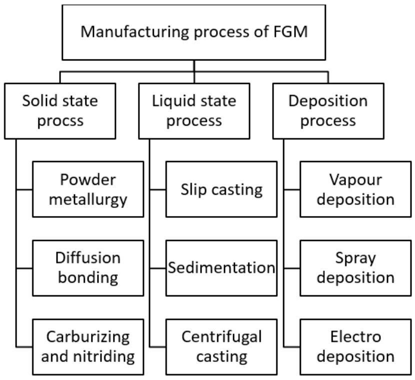


**Figure 2**: Classification of the fabrication process of functionally graded materials

Centrifugal casting or putrefaction casting technology is used to cast hollow parts of metals, glass and concrete. Most typical axisymmetric parts manufactured by this process are pipes, flywheels, cylinder liners, etc. This process provides very sound casting used for various applications in ramjet engines, compressor cases, petrochemical furnace parts, many military weapons and other high-reliability applications. Tilt function metal matrix composite made of pure aluminum enhanced with SiC can be fabricated by horizontal centrifugal casting technology [3].

Functionally graded composites are also used in manufacturing gears, heat exchange plates, reflectors, solar photovoltaics, camera bunks, turbine blades, the front edge of the missiles, and space vehicles where varying properties are required [4].

Many automotive components like, cylinder liner, piston, combustion chamber, racing car brakes, shafts, leaf spring and flywheels, need varying or graded properties. FGMs with varying properties are very suitable for such automotive components. However, the use of FGM with gradual varying properties in the body coating of automobiles is very limited and is generally used only in important parts [5].

The functionally graded structure exhibits varying bond strength, corrosion and wears resistance that is not possible with a uniform structure. Therefore, it is now widely used in dentures, denture parts and other biomedical applications also.

The objective of the present study is to fabricate homogenous and functionally graded glass fiber vinyl ester-based reinforced polymer composites and perform a comparative analysis of the physical characterization of fabricated composites.

## 2. LITERATURE REVIEW

Uses of homogeneous polymer matrix-based composite materials are gradually increasing in the world over the last few years. Homogeneous polymer matrix composite materials formed for different reinforcements and fillers have been motor vehicle parts, micro-electro-mechanical systems, marine, defense, biomedical, optics and small gear assemblies used in domestic appliances. The summary of the literature review with key findings is given in Table 1.

**Table 1**: Key findings of the literature review

| Reference | Type of composite fabricated | Key findings |
|---|---|---|
| Dhinakaran et al, 2021 [6] | Palm fiber and glass fiber polymer composite | Flexural and tensile strength improves with the increase in fiber loading |
| Elbakhshwan et al, 2021 [7] | Polymer cement composites | Compressive strength was doubled when polymer cement exposed to $CO_2$ |
| Thiagarajan et al, 2021 [8] | Chopped glass fibre/ epoxy polymer composite | Flexural and tensile strength composites increase pistachio shell micro particle loading |
| Tiwari et al, 2020 [9] | Sulphur co polymer LCNT composite cathode | The sulfur- Co polymer LCNT cathode leads to a high electrical conductivity which results in a good rate capability |
| Liang et al, 2020 [10] | Multi-color AIE polymeric nanoparticles | AIE polymer nanoparticles in various colors had good compatibility |
| Eben et al, 2020 [11] | Stretchable IPN polymers | Mechanical strength andslipelasticity of IPN polymers was enhanced |
| Shi et al, 2021 [12] | Carbon fiber HBM epoxy composites | Impact and tensile strength were improved compared to untreated CF composites |
| Prasad et al, 2021 [13] | Crab shell powder and glass fiber reinforced polymer composite | Impact, tensile and flexural strength of the composites are found to be maximum with 5 % of crab shell powder |
| Tang et al, 2021 [14] | Chitosan reduced graphene oxide (CS-RGO) polymer composite. | CS-RGO/PDMS composite exhibits better performance compared to RGO/PDMS composite |
| Wu et al, 2020[15] | Polymer composite reinforced with carbon nanotubes | CNT alignment in the composite was achieved and tensile strength was improved |

| | | |
|---|---|---|
| Mishra et al, 2018 [16] | Epoxy alumina functionally graded polymer nanocomposites. | Flexural strength of FGPNC was improved up to 11% |
| Kumar and chandrappa, 2014 [17] | Al-SiC functionally graded composite materials. | Impact strength and hardness of composite material improve with an increase in SiC % |
| Chung and das, 2006 [18] | Functionally graded nylon-11 composites | Tensile and compressive strength were found to be increased while strain at break and yield were found to be decreased with an increase in glass bead volume % |
| Put et al, 2002 [19] | Functionally graded $ZrO_2$-WC composites | The density of $ZrO_2$-WC composite increase with the increment of WC volume percentage. |
| Lucignano and Quadrini, 2009 [20] | Glass and silica functionally graded composite | Macro indentation hardness test used to estimate the complex mechanical properties on a plane surface of FGM composites |
| Stabik et al, 2010 [21] | Graphite powder copper powder and ferrite powder functionally graded composites | Wear and magnetic properties were found to be dependent on reinforcement concentration |
| Fadhil et al, 2017 [22] | Barium ferrite and lithium ferrite functionally graded composites | Magnetic and dielectric constant improves with the increase in the number of a layer as a result of improved average grain size |

## 3. MATERIALS AND METHODS

In this research work, vinyl ester is selected as a matrix material and glass fiber is selected as a reinforcement material for the fabrication of homogenous and FGM composites. Vinyl-ester is a thermoset type engineer having good mechanical properties with exceptional chemical and corrosion resistance even at a wide temperature range. The hand mixing technique was used for the fabrication of homogenous polymer composite materials. The hand mixing technique is very simple and cost-effective, and no special skill is required for fabrication by this technique.

For the fabrication of functionally graded materials (FGMs), a vertical centrifugal casting technique was used. This method is suitable to generate a continuous gradient of fiber loading at a low cost compared to other methods. The samples prepared are shown in Figure 3.

The weighed percentage of glass wool powder selected as 2.5, 5.0, 7.5, 10 and 12.5 weight percentage for both the types of composite materials.

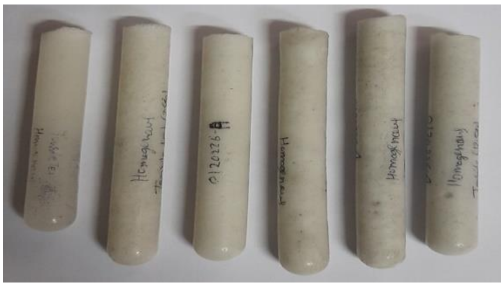

**Figure 3**: Sample of glass fiber homogenous polymer composite

### *3.1 Density and voids*

The calculated mass density ($P_{ct}$) in terms of weight fraction can easily be obtained using the following equation

$$\mathrm{Pct} = 1/(\frac{\mathrm{Wf}}{\mathrm{Pf}} + \frac{\mathrm{Wm}}{\mathrm{Pm}})$$

Where, W is weight fraction; P is density; Suffix f is for fiber, m is for matrix and ct is for composites.

The void content of composite sample has been calculated by following formula [23].

$$\mathrm{Vv} = \frac{\mathrm{Pct}-\mathrm{Pce}}{\mathrm{Pct}}$$

### *3.2 Moisture absorption test*

Moisture or water absorption has been conducted to study the water absorption tendency of the glass fiber reinforced polymer composite. In this test, firstly we dried all the composite samples and we take the weight of all samples from the weighing scale. Then the composite samples were immersed in a water tub at room temperature for a time period of 24 hours until saturation was reached. After one day we take samples from the water tub and dry them with a cotton cloth. We take the weight of all composite samples from the weighing scale. Then we calculated the percentage of weight gain of all composite samples.

Percentage of weight gain = $(\mathrm{W2} - \mathrm{W1})/\mathrm{W1} * 100$ [89]

Where $W_2$= weight of composite sample when immersed in the water tub

$W_1$ = Weight of dry composite sample

## 4. RESULT AND DISCUSSION

### 4.1. Void fraction

The void fraction with the experimental and theoretical density of the homogenous and graded glass fiber reinforced vinyl ester polymer composite has been listed in Table 2. In this work density of both homogenous and graded composites increased gradually. It shows that the particle breakdown has no significant effect on composites and the relationship between fiber and matrix will improve. We have also calculated the void fraction of homogenous and graded composites by the given formula. While increasing the filler material, a void fraction may be gradually increased. From table 2, it can be seen that the homogenous composite has more void content as compared to functionally-graded composites. Hence, void fraction increases with fiber loading in both homogenous and graded composites as shown in Figures 4 & 5.

**Table 2:** Density and void fraction

| Composition | Fabrication technique | Density(g/cm$^3$) Theoretical | Density(g/cm$^3$) Experimental | Void fraction (%) |
|---|---|---|---|---|
| VER+0% GF | Homogenous | 4.32 | 4.27 | 1.15 |
| VER+2.5% GF | Homogenous | 4.33 | 4.22 | 2.54 |
| VER+5%GF | Homogenous | 4.35 | 4.22 | 2.98 |
| VER+7.5% GF | Homogenous | 4.37 | 4.23 | 3.20 |
| VER+10% GF | Homogenous | 4.39 | 4.24 | 3.41 |
| VER+12.5%GF | Homogenous | 4.40 | 4.24 | 3.63 |
| VER+2.5% GF | Graded | 4.33 | 4.26 | 1.61 |
| VER+5%GF | Graded | 4.35 | 4.26 | 2.06 |
| VER+7.5% GF | Graded | 4.37 | 4.27 | 2.28 |
| VER+10% GF | Graded | 4.39 | 4.28 | 2.50 |
| VER+12.5%GF | Graded | 4.40 | 4.28 | 2.72 |

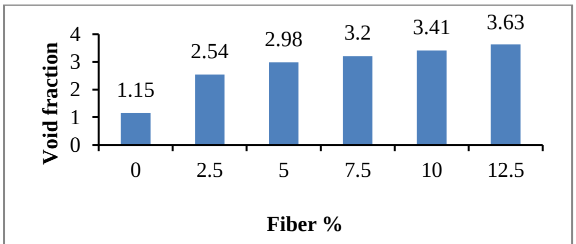


**Figure 4:** Void fraction in homogenous glass fiber reinforced composite

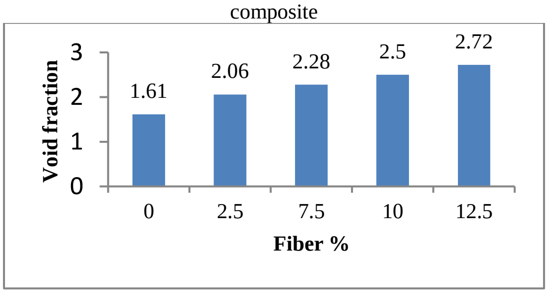


**Figure 5:** Void fraction in functionally graded glass fiber reinforced composite

### *4.2 Water absorption*

Water absorption of homogenous and graded glass fiber reinforced vinyl ester polymer composite has been shown in Table 3. In this test water absorption of homogenous samples was found to be more than the graded sample. Water absorption increases and decreases with fiber loading of both homogenous and graded composite samples as shown in Figures 6 & 7.

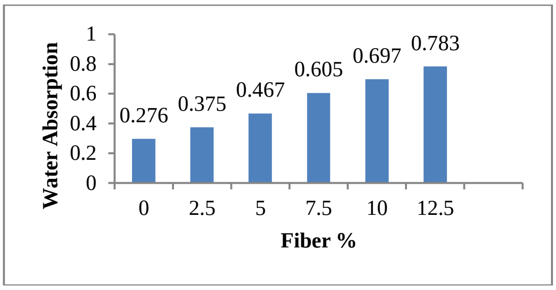


**Figure 6:** Water absorption in homogenous glass fiber reinforced composite

**Table 3:** Water absorption test

| Composition | Fabrication technique | Weight of dry sample in (g) | Weight of sample after immersed in water in (g) | Water absorption (%) |
|---|---|---|---|---|
| VER+0% GF | homogenous | 7.23 | 7.25 | 0.276 |
| VER+2.5%GF | homogenous | 5.33 | 5.35 | 0.375 |
| VER+5%GF | homogenous | 6.12 | 6.15 | 0.467 |
| VER+7.5%GF | homogenous | 5.10 | 5.13 | 0.588 |
| VER+10%GF | homogenous | 5.19 | 5.23 | 0.697 |
| VER+12.5% GF | homogenous | 5.77 | 5.82 | 0.783 |
| VER+2.5%GF | graded | 7.86 | 7.88 | 0.312 |
| VER+5%GF | graded | 7.18 | 7.21 | 0.398 |
| VER+7.5%GF | graded | 8.11 | 8.15 | 0.487 |
| VER+10%GF | graded | 7.68 | 7.72 | 0.576 |
| VER+12.5% GF | graded | 8.10 | 8.15 | 0.665 |

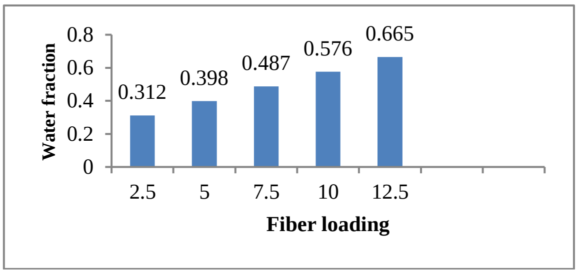


**Figure 7**: Water absorption in functionally graded glass fiber reinforced composite

## 5. CONCLUSION

The experimental comparative study of homogenous and functionally graded glass fiber reinforced polymer composite in physical characterization have drawn the following specific conclusions as reported in this study.

Fabrication of the glass fiber reinforced vinyl ester-based homogenous and functionally graded composite with varying percentages of glass fiber wt. % (0, 2.5, 5, 7.5, 10 and 12.5) have been fabricated through the hand lay-up method and vertical centrifugal casting technique respectively.

The density of homogenous glass fiber reinforced composite is increased with an increment of glass fiber weight percentage and in functionally graded glass fiber reinforced composite density is also increased with an increment of glass fiber weight percentage. The void content of the homogenous composite is higher than the functionally graded composite and both show an increasing trend with fiber loading.

It has been investigated that the water absorption percentage of both homogenous and functionally graded glass fiber reinforced composite shows an increasing trend with fiber loading. From 0 wt., % to 7.5 wt.% fiber loading, water absorption of homogenous composite is higher than functionally graded composite. From 10% to 12.5% fiber loading, water absorption of functionally graded composite is higher than homogenous composite.

Analysis of mechanical properties such as hardness and tensile strength etc. will be analyzed for further investigation in the next step of the study.

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