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EVALUATION OF MECHANICAL PROPERTIES OF POLYMER COMPOSITE MATERIALS

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ABSTRACT

Composite material are engineering materials made from two or more constituent materials, which are distinct in physical or chemical properties, which remain, separate and distinct on a macroscopic level within the finished structure.

The present experimental work deals with the study of mechanical properties of glass fiber reinforced polymer with vinyl ester resin and silicon dioxide filler particles. Glass fiber mat of 360 gsm and silicon dioxide of size 40 to 150 mesh is used. Laminates are prepared by using Hand lay-up method. Laminates are cured in hot air oven at 80^0C about one hour for better curing. Specimens for tensile, flexural and impact test were cut from the fabricated laminate according to the ASTM standards and are tested. The result showed that the Ultimate tensile strength of the laminate with 5, 10, wt% silicon dioxide filler exhibit lower tensile strength till 5% as compared to unfilled composites and then increases. For bending test, the laminate with 5, 10% silicon dioxide filler exhibit higher flexural strength than unfilled composite at constant position and load condition and in impact test the laminate with 5, 10% silicon dioxide filler exhibit higher impact strength than unfilled composite.

I. INTRODUCTION

1.1 Composite Materials

A composite material is defined as a combination of two or more materials that results in better properties than when the individual components are used alone. Composite materials are consisting of one or more discontinuous phases embedded in a continuous phase. The discontinuous phases are usually harder and stronger than the continuous phases and are called the ‘reinforcements‘ or ‘reinforcing materials’ whereas the continuous phase is termed as the ‘ matrix’ which is more ductile and less hard. The reinforcements serve to strengthen the composites and improve the overall mechanical properties of the matrix. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them.

II. MATERIALS

2.2 Reinforcement materials

- Glass fibers in the form of woven mat – 360 gsm
- Filler – Silicon dioxide

2.2.1 Glass fiber

Glass fiber is a material consisting of numerous extremely fine fibers of glass. It is used as a reinforcing agent for many polymer products, to form a very strong and light fiber reinforced polymer (FRP) composite material called glass reinforced plastic (GRP), popularly known as "fiber glass". Glass fiber mat of 360 gsm is as shown in figure 2.1 and also specification of glass fiber mat is as shown in table 2.1.

- **Specification of glass fiber mat**

Figure 2.1: Glass fiber mat of 360 gsm

Product	E-glass fabric
Product family	Plain woven
Manufacturer	Owens Corning (OCV) Technical Fabrics, India
Total weight (g/m^2)	360
Fabric width (m)	1

Table 2.1: Specification of glass fiber mat

2.2.2 Filler material

In this study, silicon dioxide (figure 2.2) with an particle size of 40 to 150 mesh were used as filler in 5%wt, 10%wt, with respect to weight of vinyl ester resin.

Silicon dioxide, also known as silica (from the Latin silex), is a chemical compound that is a dioxide of silicon with the chemical formula SiO_2. Silica is most commonly found in nature as quartz. Silica is one of the most complex and most abundant families of materials, existing both as several minerals and being produced synthetically. Notable examples include fused quartz, crystal, fumed silica, silica gel, and aero gels. Applications range from structural materials to microelectronics to components used in the food industry.

- **Specification of silicon dioxide filler**

➢

Figure 2.2: Silicon dioxide

Product	Silicon dioxide (extra pure)
Manufacturer	Loba Chemie Pvt. Ltd., Mumbai, India
Molecular formula	SiO_2
Molecular weight	60.08
Physical state	Crystalline powder
Colour/odour	White/odourless
Particle size	40-150 mesh
Boiling point	2230^oC
Melting point	1710^oC
Specific gravity/density	2.20 g/cm^3
Chemical stability	Stable under normal temperatures and pressures
Conditions to avoid	Dust, moisture

Table 2.2: Specification of silicon dioxide filler

2.3 Resin System

The resin system consists of vinyl ester (figure 2.3) with its 2% of catalyst, promoter, accelerator. Vinyl ester resins are unsaturated resins prepared by the reaction of a monofunctional unsaturated acid, such as methacrylic or acrylic, with a bisphenol diepoxide. The resulting polymer is mixed with an unsaturated monomer, such as styrene. The handling and performance characteristics of vinyl esters are similar to polyesters. Some advantages of the vinyl esters, which may justify their higher cost, include superior corrosion resistance, hydrolytic stability, and excellent physical properties, such as impact and fatigue resistance. It has been shown that a 20 to 60 mil layer with a vinyl ester resin matrix can provide an excellent permeation barrier to resist blistering in marine laminates. Specification is as shown in below table 2.3.

➢ **Specification of vinyl ester resin**

Figure 2.3: vinyl ester resin

Product		Vinyl ester resin (general-purpose)
Manufacturer		Naptha Resins and Chemicals Pvt. Ltd., Bangalore, India
Product family		Polyflex GR 200-60
Appearance		Clear liquid
Density (g/cm^3)		1.06
Brookfield viscosity @ 25^{o}C	**cP**	440
	Pa-s	10^{-3}
Acid value (mg KOH/g)		9.65
Volatile content (2 g/150^{o}C/1 h) (%)		42.45
Heat distortion temperature (^{o}C)		102

➢ **Features of vinyl ester resin**

- Vinyl ester combines inherent toughness with outstanding heat and chemical resistance.
- Corrosion-resistance.
- Possesses low ester content and low unsaturation resulting in greater resistance to hydrolysis and less shrinkage during cure.
- High resistance to micro fracturing and shrinkage.

III. SPECIMEN PREPARATION

3.1. Fabrication process

Figure 3.1: Basic procedure of hand lay- up technique

Fabrication is defined as the process of converting raw materials into finished products. Fabrication process is done by using *Hand lay-up method*. *Hand lay-up molding* is the method of laying down fabrics made of reinforcement and painting with the matrix resin layer by layer until the desired thickness is obtained.

The glass fiber mat of size 250×250mm is used for fabrication of laminates. Release film was laid on the surface of the mold and release spray is sprayed to facilitate easy removal of the laminate after curing. The glass fiber mats are laid on the surface of the mold. Figure 3.2 shows the step by step fabrication process.

a) Mold

b) Applying release spray to the release film

c) Applying resin on the mat

d) Applying load

e) Curing in oven

f) Cured plate

Figure 3.2: Fabrication Process

The resin, catalyst, promoter and accelerator mixture is applied on both surface of the glass fiber mat using brush, the same mixture is uniformly distributed throughout the glass fiber mat and the procedure is continued for all next layers of glass fiber mat and the mold is then closed and load is applied for about 24hrs for curing. Plates are prepared with 0%, 5% and 10% of silicon dioxide filler materials using *By-mass* method. Plates are again cured at 80^0C using oven.

For the preparation of particle filled glass fiber reinforced vinyl ester composites, silicon dioxide filler particles are added to the above mixture, the composite specimen with two different filler proportions are prepared. The weight fractions of the filler in the matrix were 5%, 10% with respect to the weight fraction of the vinyl ester resin.

66.67 gram of resin is added for each 100 gram of glass fibre. Resin system consists of vinyl ester resin with its 2% of catalyst, promoter and accelerator.

The weight fraction of fiber and filler in the finished laminate is calculated using the equation

$$\mathbf{W = W_t / W_{fl}}$$

Where, W_{fiber}= Weight fraction of fiber, %

W_t= Total weight of mats, grams

W_{fl}= Total weight of mats + epoxy resin

3.2 Preparation of samples

All samples are prepared according to American Standard for Test Methods (ASTM)

3.2.1. Tensile Test Specimen

According to ASTM D 638, the specimen is cut into required dimension (175× 20×5) using jig saw and is finished to size using emery paper. Aluminum end tabs are mounted at both ends of the specimen for the purpose of gripping. The geometry of the test specimen is shown in figure 3.1

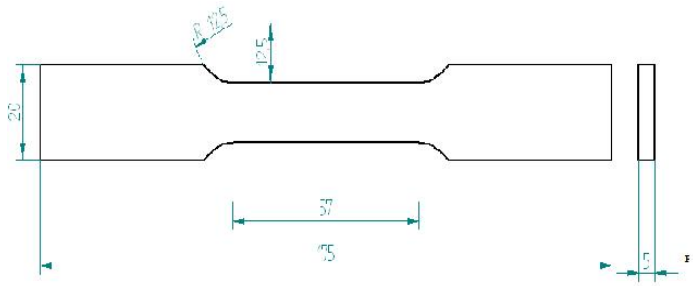


Figure 3.9: Geometry of the tensile test specimen

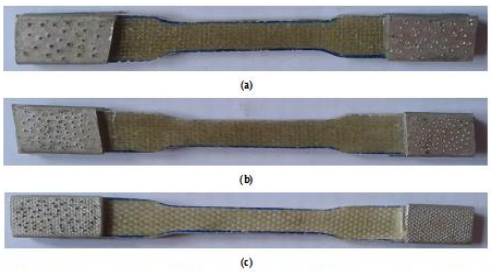


Figure 3.10: Tensile test specimen for (a) Unfilled test specimen (b) 5% filled test specimen (c) 10% filled test specimen

3.2.2. Flexural Test Specimen

According to ASTM D790, the specimen is cut into required dimension (150×12.7×10) using jig saw and is finished to size using emery paper. The geometry of the test specimen is shown in figure 3.2

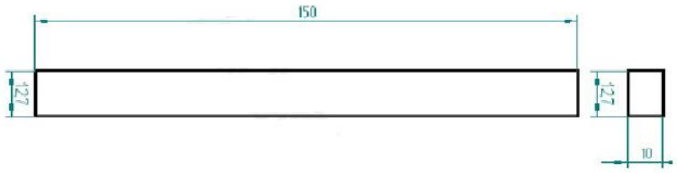


Figure 3.11: Geometry of Flexural test specimen

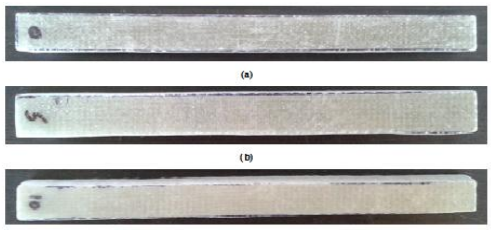


Figure 3.12: Flexural test specimen for (a) Unfilled test specimen (b) 5% filled test specimen (c) 10% filled test specimen

3.2.3. Impact Test Specimen

- **Izod Test Specimen**

According to ASTM D 256, the Izod specimen is cut into required dimension (64×12×3.2) using jig saw and is finished to size using emery paper. The geometry of the test specimen is shown in figure 3.3.

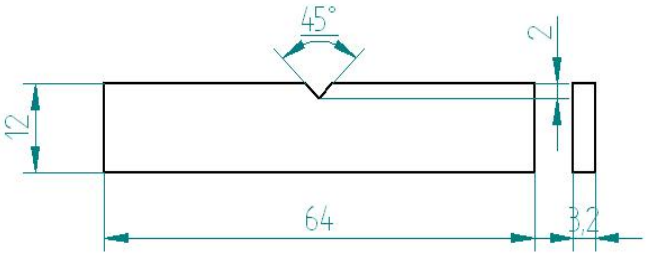


Figure 3.13: Geometry of the Izod test specimen

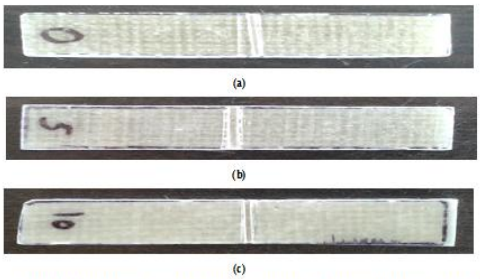


Figure 3.14: Izod test specimen for (a) Unfilled test specimen (b) 5% filled test specimen (c) 10% filled test specimen

IV. EXPERIMENTATION

4.1 Tension Test

Figure 4.1 shows tensile specimen of GFRP composite whose ends are gripped into universal testing machine with a capacity of 100 KN. Extensometer is fitted to test specimen which measures extension over the length of the specimen. The sample is loaded along the fiber direction gradually and at regular intervals of loads extension is measured. After certain load extension increases at faster rate and the capacity of extensometer to measure extension comes to an end and hence, it is removed before this stage is reached and extension is measured from scale on the UTM. Load is increased gradually till the specimen breaks. For each composition, three identical specimens are tested and average results are reported. The load v/s deflection values are noted and stress v/s strain graphs are plotted.

Figure 4.1: Tensile test setup

4.2 Flexural Test

The flexural test measures the force required to bend a beam under three point loading conditions. The specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test.

The 3- point bend test is conducted as per ASTM standard D790 using UTM. The data recorded during the test is used to evaluate the flexural strength.

Figure 4.2: Flexural testing unit showing the positioning of sample

4.3 Impact Test

➢ **Izod Test**

The impact properties of the material are directly related to the overall toughness which is defined as the ability to absorb applied energy. Impact strength is a measure of toughness. In this research, pendulum impact test – Notched Izod Impact Test is utilized. Figure 4.3 shows Izod testing machine.

Figure 4.3: Impact testing machine (Izod test)

4.4 Results And Discussions

In this section the experimental results obtained for the tensile, bending and impact tests were discussed.

4.4.1. Tensile strength

Since composites are brittle materials they manifest only macroscopic elastic deformation up to the stress at which they fails. These materials follow linear elastic stress-strain relations up to their fracture. The stress-strain diagram and load v/s displacement diagram for these composites are as shown in figure 4.4(a) to figure 4.4(h), all curves indicate non-linear behavior. The point of deviation from linearity is the indication of failure initiation due to development of crack on the tension side. Young's modulus is determined from the slope of the stress-strain curve within the elastic limit.

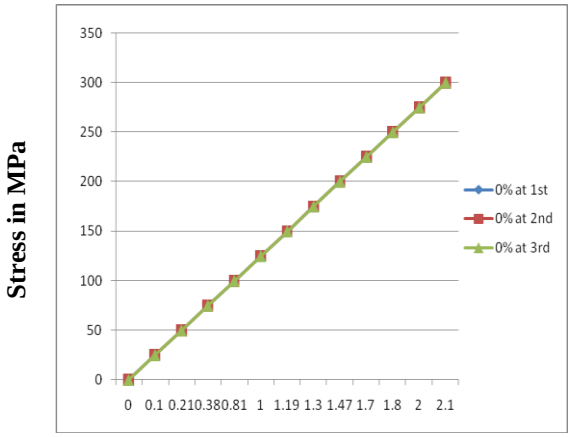


Figure 4.4(a): Stress v/s Strain graph for unfilled specimens

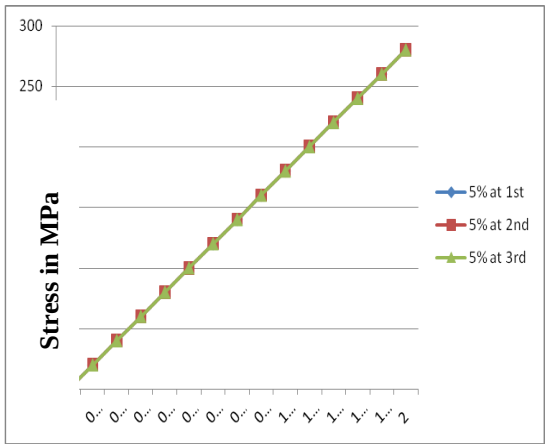


Figure 4.4(b): Stress v/s Strain graph for 5% filled specimens

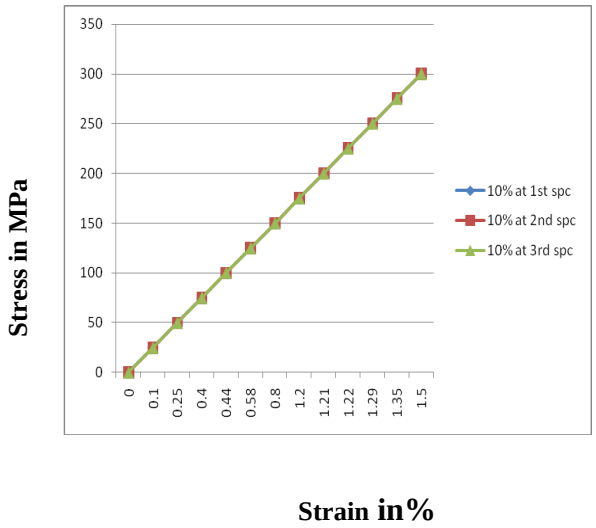


Figure 4.4(c): Stress v/s Strain graph for 10% filled specimens

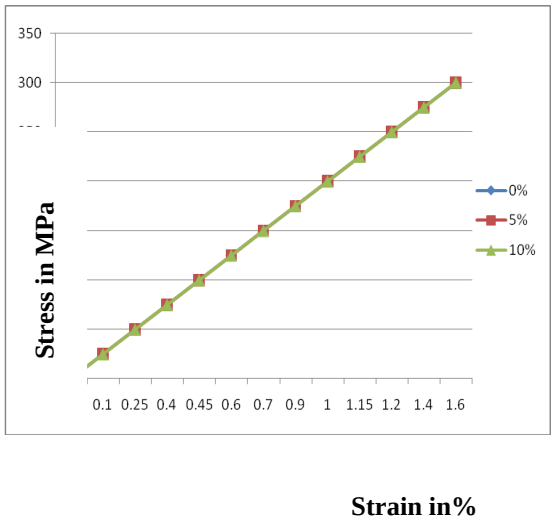


Figure 4.4(d): Stress v/s Strain graph for different combinations

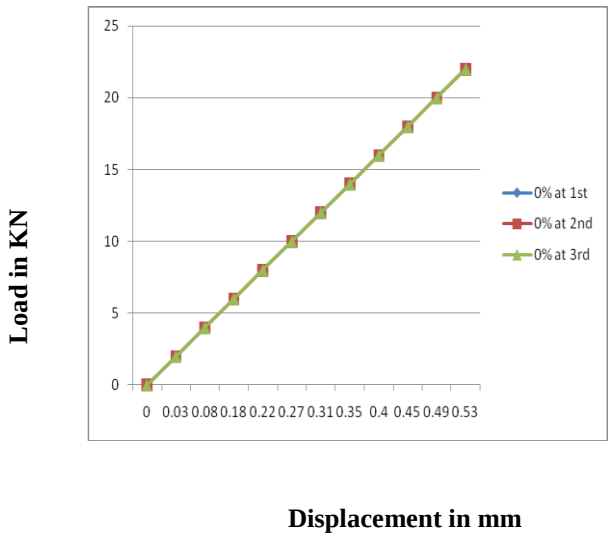


Figure 4.4(e): Load v/s displacement graph for unfilled filled specimens

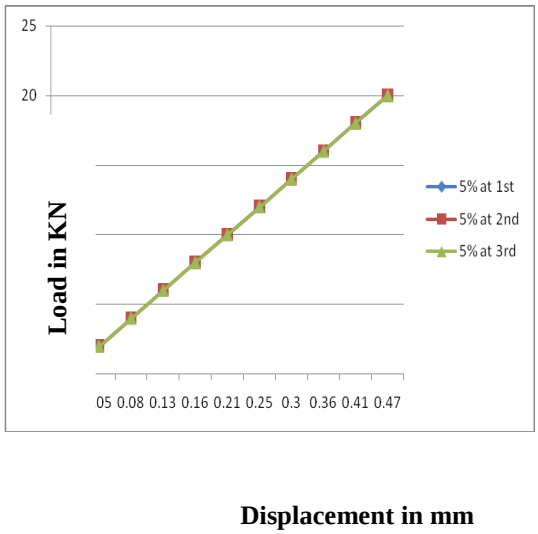
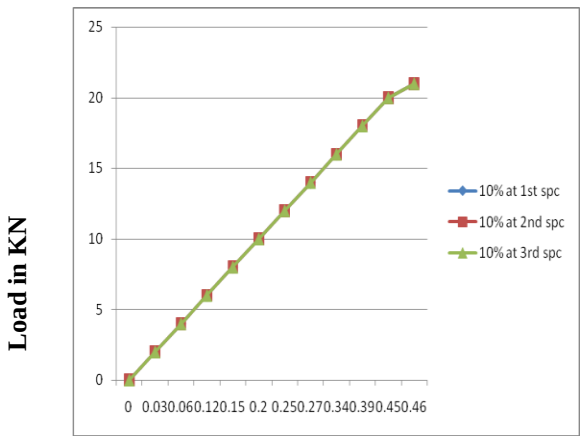


Figure 4.4(f): Load v/s displacement graph for 5% specimens



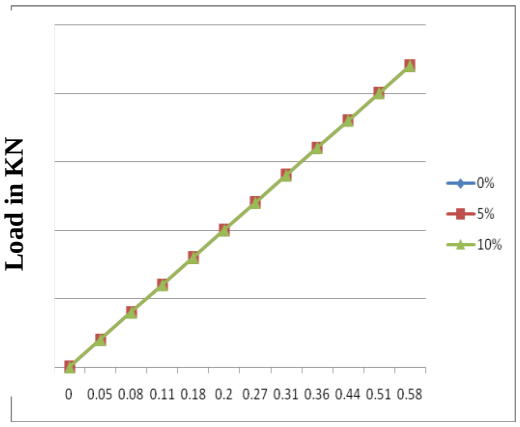


Figure 4.4 (g): Load v/s displacement graph for 10% filled for different specimens

Figure 4.4(h): Load v/s displacement graph combinations

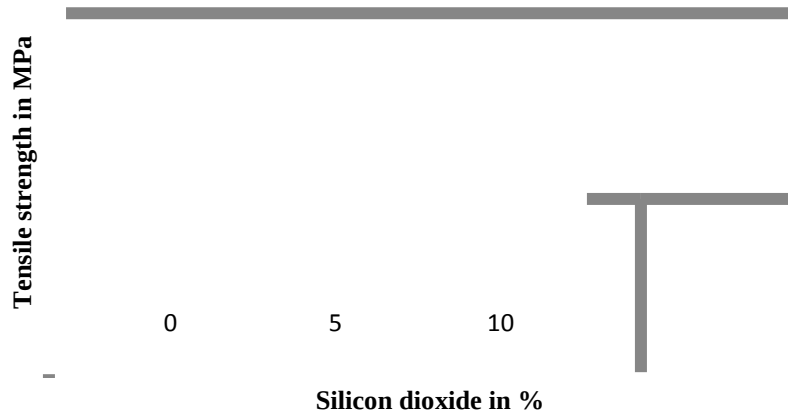


Figure 4.4 (i): Tensile strength v/s wt% of silicon dioxide

Figure 4.4(i) shows the variation of ultimate tensile strength v/s wt% of silicon dioxide filler. The Ultimate tensile strength of the laminate with 5, 10, wt% silicon dioxide filler exhibit lower tensile strength till 5% and then increases.

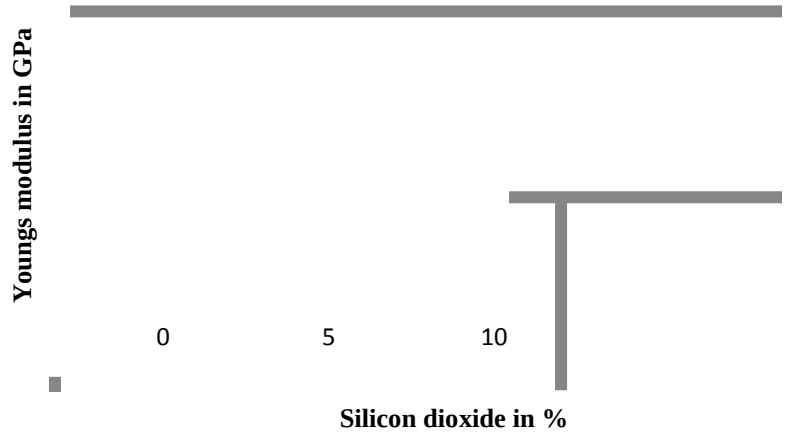


Figure 4.4(j): Young's modulus v/s wt% of silicon dioxide

The variations of tensile properties (Young's modulus, total percentage elongation) of the Glass-fiber reinforced vinyl ester composites with silicon dioxide filler are shown in Figures 4.4(e)–4.4(f). It is clearly seen that weight fractions of the silicon dioxide filler in the vinyl ester matrix appear to influence tensile properties. The Young's modulus of the glass fiber reinforced vinyl ester composite was decreases with filler content upto 5% and then increases.

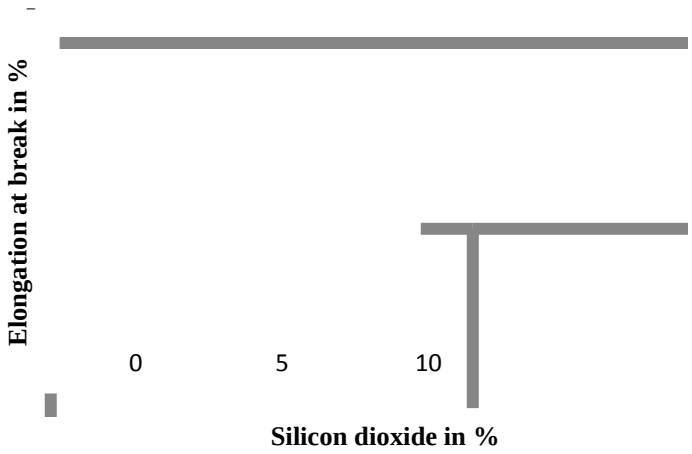


Figure 4.4(k): Elongation at Failure v/s wt% of silicon dioxide

Higher the filler percentage, higher is the agglomeration of SiO2 particles, thus reducing the tensile strength. Young's modulus is mainly dependent on the matrix deformation of the composite and increases as the slope of load-deformation curve at the initial stage and is practically not much influenced by the interfacial strength between fiber and the matrix.

The tensile modulus of SiO2 filled composites increases as the wt. fraction of the filler increases. Again there is a reduction in the elongation at break of the composites with increase in the wt. fraction of the filler. This is due to the fact that the SiO2 filler is hard and also highly brittle. As the wt. fraction of SiO2 filler increase, the tensile modulus of the filled composites increases, but at the same time the system becomes more brittle. The increase in the tensile strength with wt. fraction of filler is attributed to the high modulus of ceramic filler which are dispersed uniformly in the fabric layers of filled composites.

Percentage elongation at failure increases with increasing the silicon dioxide filler up to 5% and then decreases. Since after certain limit the specimen becomes more brittle with the addition of silicon dioxide.

4.4.2 Flexural strength

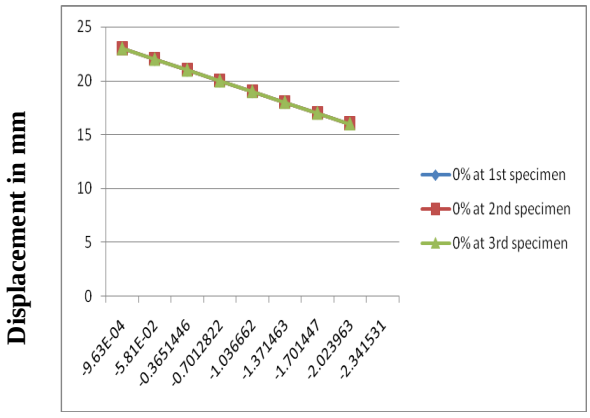


Figure 4.5(a): Displacement v/s Load for unfilled specimens

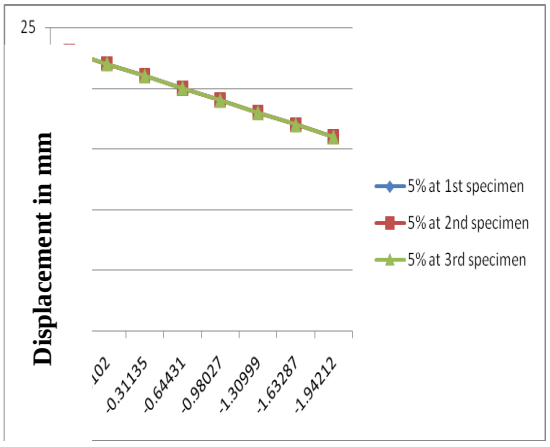


Figure 4.5(b): Displacement v/s Load for 5% filled specimens

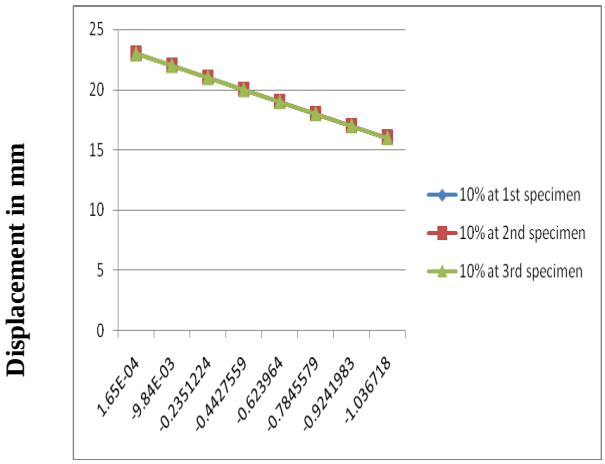


Figure 4.5(c): Displacement v/s Load for 10% filled specimens

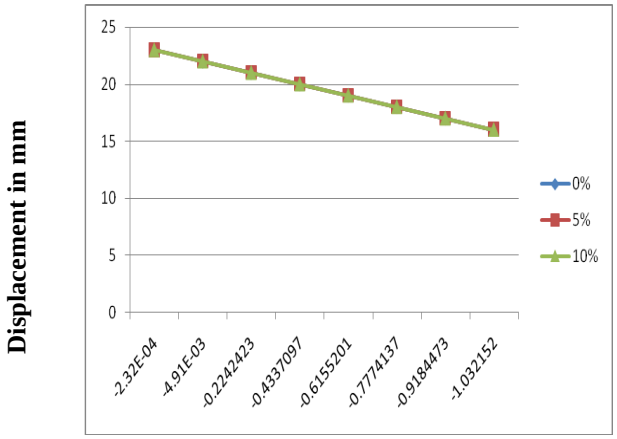


Figure 4.5(d): Displacement v/s Load for different combinations

Figure 4.5 shows the variation of flexural strength v/s wt% of silicon dioxide filler. By observing above graphs, the laminate with 5, 10 wt% silicon dioxide filler exhibit higher flexural strength than unfilled composite at constant position and load condition. The flexural strength is found to increase with the increase in filler content.

5.3. Impact strength

The izod impact strength v/s wt% of silicon dioxide diagram for these composites are shown in figure.

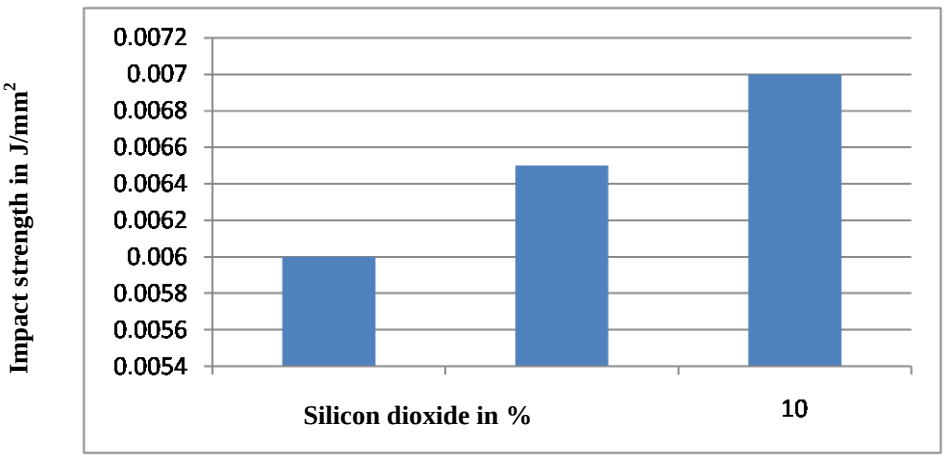


Figure 5.3(a) :Impact strength v/s wt% of silicon dioxide

Figure 5.3(a) shows the variation of impact strength v/s wt% of silicon dioxide filler. The laminate with 5, 10 wt% silicon dioxide filler exhibit higher impact strength than unfilled composite. The impact strength is found to increase with the increase in filler content.

VI. CONCLUSION

Effect of inclusion of silicon dioxide as filler material in glass/vinyl ester composites on tensile and impact test has been investigated experimentally. Based on the results of investigation, following conclusions are made.

- The Ultimate tensile strength of the laminate with 5, 10, wt% silicon dioxide filler exhibit lower tensile strength till 5% and then increases.
- By observing flexural strength graphs, the laminate with 5, 10 wt% silicon dioxide filler exhibit higher flexural strength than unfilled composite at constant position and load condition. The flexural strength is found to increase with the increase in filler content.
- In Izod test, the laminate with 5, 10 wt% silicon dioxide filler exhibit higher impact strength than unfilled composite. The impact strength is found to increase with the increase in filler content.

There may be reasons for this decline in strength of these particulate filled composites compared to the unfilled one. One possibility is that the bonding at the interface between the filler particles and the matrix may be too weak to transfer the load from matrix to fiber. This poor interfacial bonding causes partially separated micro spaces between the filler and epoxy matrix, which obstructs stress propagation when stress is applied and induces decreased strength and increased brittleness.

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