

FRACTURE TOUGHNESS EVALUATION OF PARTICLE FILLED COMPOSITE

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ABSTRACT-The main objective of the present work is to analyze the influence of solid glass microsphere (SGM) particle volume fraction and size of particle on fracture toughness of particle filled epoxies. The composite plates with different particle sizes (dia 100 μ m, 200 μ m) and with various proportions of solid glass microsphere (0, 3, 4, 5, 6, 7 & 10%) are fabricated by molding techniques. In molding process, the epoxy resin and hardener are mixed in the weight ratio of 10:1. Single edge crack plate specimen is preferred and cut from the fabricated plates. There are three failure modes available (ie., tensile, shear mode and tearing mode) to understand the fracture behavior of materials. In this work tensile mode is considered. The specimens prepared for seven different proportions of SGM are tested in a Universal testing machine under tension to determine the applied critical stress. Applied critical stress values are used to predict the critical stress intensity factor at the tip of the crack. The effect of solid glass microsphere particle volume fraction on fracture toughness of composite material is studied numerically and also experimentally. The fracture toughness values increases up to 6%, above which there is a decrease in the fracture toughness of composite material.

Keywords: Solid Glass Microsphere, Particle filled composite, Stress intensity factor

I. INTRODUCTION

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. It is also called a composition material or shortened to composite. Especially Polymer composites have emerged as important structural engineering materials in automotive, marine, aerospace, transportation, infrastructure applications and as well as in civil engineering applications, because of their high strength to weight ratio. The most common advanced composites are polymer matrix composites (PMCs) consisting of a polymer (e.g., epoxy, polyester, urethane) reinforced by thin diameter fibers (e.g., graphite, aramids, boron). For example, graphite/epoxy composites are approximately five times stronger than steel on a weight for-weight basis. The aim of the review paper is to present and discuss problems from the development of the test methods arising mainly from the specific properties of Polymer Matrix Composites.

II. PARTICULATE COMPOSITE

One form of composites is particulate reinforced composites with concrete being a good example. The aggregate of coarse rock or gravel is embedded in a matrix of cement. The aggregate provides stiffness and strength while the cement acts as the binder to hold the structure together. There are many different forms of particulate composites. The particulates can be very small particles (< 0.25 microns), chopped fibers (such as glass), platelets, hollow spheres, or new materials such as bucky balls or carbon nano-tubes. In each case, the particulates provide desirable material properties and the matrix acts as binding medium necessary for structural applications. Particulate composites offer several advantages. They provide reinforcement to the matrix material thereby strengthening the material. The combination of reinforcement and matrix can provide for very specific material properties. For example, the inclusion of conductive reinforcements in a plastic can produce plastics that are somewhat conductive. Particulate composites can often use more traditional manufacturing methods such as injection molding which reduces cost

III. FRACTURE MECHANICS

Fracture mechanics is the field of mechanics concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. In modern materials science, fracture mechanics is an important tool in improving the mechanical performance of mechanical components. It applies the physics of stress and strain, in particular the theories of elasticity and plasticity, to the microscopic crystallographic defects found in real materials in order to predict the macroscopic mechanical failure of bodies. Fractography is widely used with fracture mechanics to understand the causes of failures and also verify

the theoretical failure predictions with real life failures. The prediction of crack growth is at the heart of the damage tolerance discipline. There are three ways of applying a force to enable a crack to propagate that is called modes of fracture. Fracture mechanics plays an important role in material strength which can be classified into two types there are Linear Elastic Fracture Mechanics (LEFM),Elastic Plastic Fracture Mechanics (EPFM).

Modes of failure

In the context of fracture mechanics, test methods have evolved for measuring the interlaminar fracture toughness in terms of a critical value of strain energy release rate (SERR), G_c , associated with delamination onset and growth. A complete description of interlaminar fracture toughness requires characterization of pure three fracture mode.

- **Mode I fracture** – Opening mode (a tensile stress normal to the plane of the crack),
- **Mode II fracture** – Sliding mode (a shear stress acting parallel to the plane of the crack and perpendicular to the crack front), and
- **Mode III fracture** – Tearing mode (a shear stress acting parallel to the plane of the crack and parallel to the crack front)

Fracture mechanics concepts are essentially the same for each mode. However the great majority of all actual cracking and fractures cases in metals are mode I problems. A crack in the very early stage of development will turn into a direction in which it experiences only Mode I loading, unless it is prevented from doing so by geometrical confinement. For this reason fracture mechanics of metal is generally confined to Mode I.

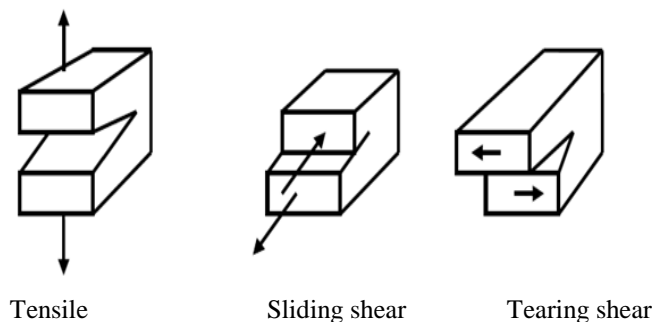


Figure 1.Modes of fracture

Fracture Toughness of Single Edge Crack Plate

Fracture toughness is an indication of the amount of stress required to propagate a pre existing flaw. It is a very important material property since the occurrence of flaw is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components.

This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture. A parameter called the stress intensity factor (K). The stress intensity factor is used in fracture mechanics to predict the stress state near the tip of a crack caused by a remote load or residual stresses. It is denoted by K. It is a theoretical construct usually applied to a homogeneous, linear elastic material and is useful for providing a failure criterion for brittle materials, and is a critical technique in the discipline of damage tolerances. Critical stress intensity factor is used to determine the fracture toughness of most materials. The geometry of a single edge crack plate is shown in Figure 2. The For a plate of dimensions $h \times b$ containing an edge crack of length a , if the dimensions of the plate are such that $(h/b) \geq 1$ and $(a/b) \leq 0.6$,

The stress intensity factor at the crack tip under an uniaxial stress σ is given in Equation (1).

$$K_I = \sigma \sqrt{\pi a} \left[1.12 - 0.23 \left(\frac{a}{b}\right) + 10.6 \left(\frac{a}{b}\right)^2 - 21.7 \left(\frac{a}{b}\right)^3 + 30.4 \left(\frac{a}{b}\right)^4 \right] \dots(1)$$

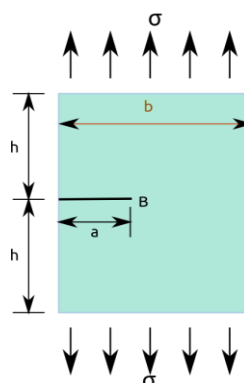


Figure 2.single edge crack plate

For the situation where $(h/b) \geq 1$ and $(a/b) \leq 0.6$ the stress intensity factor can be approximated by Equation (2).

$$K_I = \sigma \sqrt{\pi a} \left[\frac{1 + 3 \frac{a}{b}}{2 \sqrt{\pi \frac{a}{b} \left(1 - \frac{a}{b}\right)^{3/2}}} \right] \quad \dots(2)$$

In this case the stress intensity factor for mode I can be calculated by using the above equation 2. Here b and a values are known values that is specimen dimension and crack length σ (critical stress) is obtained from the experimental results.

IV. EXPERIMENTAL PROCEDURES

Raw materials

Glass particle having very small size (modulus 70GPa) are used as the reinforcement material supplied by Suriya Glass beads, Mumbai, India. The size of glass particle is 100 μ m solid spherical shape. The matrix material used is a general purpose epoxy resin (LY 556) and hardener (HY951) supplied by Ram Composites, Hyderabad, India. The plates with different particle proportion are fabricated by molding techniques.

Fabrication of composite materials

The composite materials are fabricated by using molding technique. Before resin transfer, prepare the mold to required dimensions. The inside of the mold is coated with releasing agent. Here wax is used as a releasing agent. The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as per recommendation and this mixture is kept for few minute. To prepare the composites, glass powder with average size (100 μ m and 200 μ m solid sphere) particle are reinforced in epoxy resin (density 1.2gm/cc). This mixture is kept in vacuum in order to remove trapped air bubbles. Finally the mixture is transfer to the mold which is allowed to cure at room temperature for 24 hours and then, the particulate filled composite plate is released form the mold. Single edge cracked plate specimen of suitable dimension are cut using a diamond cutter for fracture characterization. To measure the fracture toughness, of the single edge crack plate which is prepared in various proportion of glass particle (0% 3%, 4%, 5%, 6%, 7% 10%, 15%) and various size of glass particle, the stress intensity factor of the composite material is measured.

Testing

Tensile testing, also known as tension testing is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required. The single edge crack plate specimen have been fabricated in different composition. The specimens are tested. The test is carried out in Central Institute of Plastic and Technology Chennai. The most common universal testing machine is used for testing

The test process involves placing the test specimen in the testing machine and slowly extending it until it fractures. During this process, the elongation of the gauge section is recorded against the applied force

. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering strain, ϵ , using the Equation (3).

$$\epsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \quad \dots\dots(3)$$



Figure 3. Universal Testing Machine

Where, ΔL is the change in gauge length, L_0 is the initial gauge length, and L is the final length. The force measurement is used to calculate the engineering stress, σ , using the Equation (4).

$$\sigma = \frac{F}{A} \quad \dots\dots(4)$$

Where, F is the tensile force and A is the nominal cross-section of the specimen. Using tensile strength and calculate the fracture toughness of the specimen.

V. RESULT AND DISCUSSION

Effect of varying wt.% of SGM on void content of particle filled composite

The theoretical and experimental densities along with the corresponding values of voids fraction are presented in Table 1. The values differ from each other due to the inclusion of voids during composite fabrication. It is clear from Table 1 that the void fraction in the composites increases as the wt.% of the filler increases. This is due to the reason that the density of SGM is higher than the density of Resin and thus at higher wt.% the filler distribution becomes non uniform. However, in this study, the pressure immediately applied after the casting, has reduced the porosity in the composites. The pressure applied leads to the improvement in the bonding between the Epoxy and reinforcement and also enhances the wettability of the particles. Sajjadi et al.20 also reported an increase in the porosity content in the Epoxy resin with the increase in the wt.% of SGM. The reason for the increase in the void content was the poor wettability of SGM in Epoxy resin.

Table 1. Theoretical and experimental density of SGM-filled Epoxy composites

S.No	Composite	Theoretical Density (gm/cc)	Experimental Density (gm/cc)	Void fraction (%)
1.	Epoxy Resin + 0% SGM	1.2	1.1879	1.015
2.	Epoxy Resin + 5% SGM	1.2317	1.20936	1.847
3.	Epoxy Resin + 10% SGM	1.2658	1.24077	2.019
4.	Epoxy Resin + 15% SGM	1.2705	1.24255	2.247

Effect of SGM content and size on fracture toughness of particle filled composites

The experimental and finite element method (FEM) results for fracture toughness of composite in various proportion and size are shown in Figure 4. It is observed that the experimental values of fracture toughness of particle-filled composite increases with the increase in wt.% of the filler up to the percentage of 6, further increment in the filler leads to decrement in the fracture toughness (details in Table 2). Numerical values of fracture toughness also increase with the increase in the wt.% up to 6% of SGM further increment in the filler leads to decrement in the fracture toughness of particle filled composites. Similar observations were found when size of the SGM filler is varied. Compare the both results (dia 100µm, 200µm), fracture toughness values decreases when increase the particle size as shown in the table 2. Similar results were also observed between experimental/FEM results, i.e. error 13.45%, 12.94%, 24.5%, 17.82, 19.37, 30.19% and 37%, respectively for 3, 4, 5, 6, 7, 10, and 15wt.% filled composites.

Table 2. Numerical and experimental stress intensity factor of SGM-filled Epoxy composite

S.No	Composite	Applied critical stress (σ) MPa	Dia (100µm)		Dia (200µm)
			Experimental SIF (MPa√m)	Numerical SIF (MPa√m)	Numerical SIF (MPa√m)
1.	Epoxy Resin + 0% SGM	1.6325	0.6325	0.4681	0.4681
2.	Epoxy Resin + 3% SGM	1.8435	0.7143	0.6182	0.5401
3.	Epoxy Resin + 4% SGM	2.3420	0.9074	0.7899	0.5989
4.	Epoxy Resin + 5% SGM	3.9603	1.4835	1.8475	0.9787
5.	Epoxy Resin + 6% SGM	4.0728	1.5779	1.9201	1.5208
6.	Epoxy Resin + 7% SGM	3.7421	1.4498	1.7981	1.3414
7.	Epoxy Resin + 10% SGM	3.4704	1.3240	1.7238	1.1354

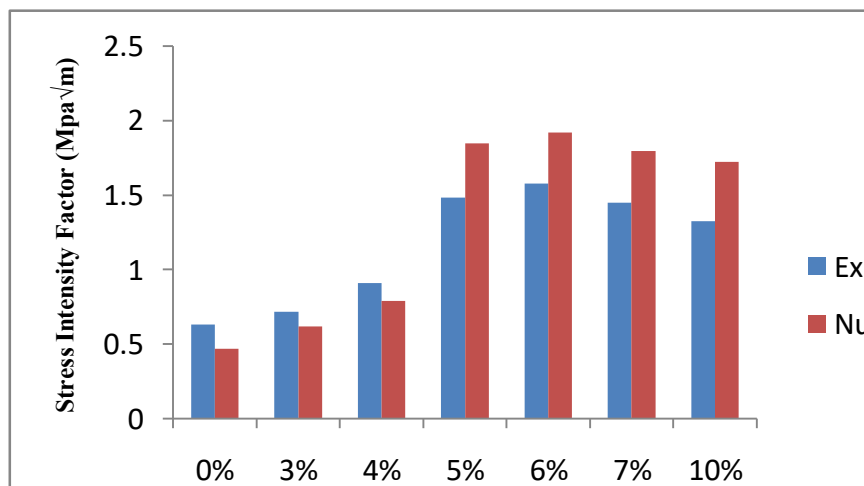


Figure 4. Stress intensity factor of SGM filled polymer composite

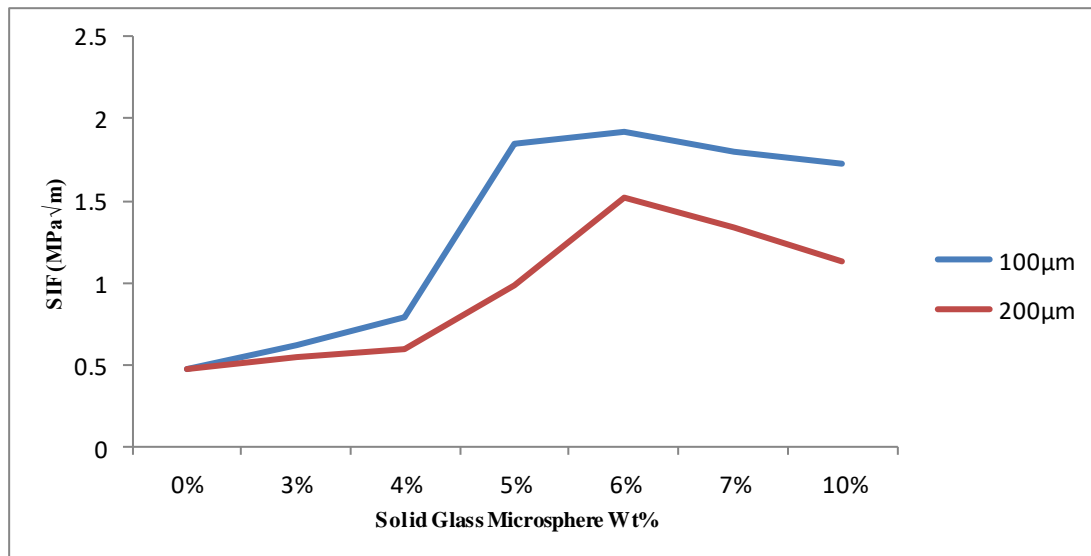


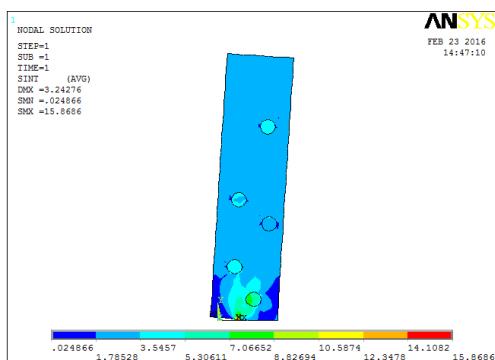
Figure 5. Comparison of SIF in both diameter of SGM particle

Effect of SGM content and size on Deflection of particle filled composites

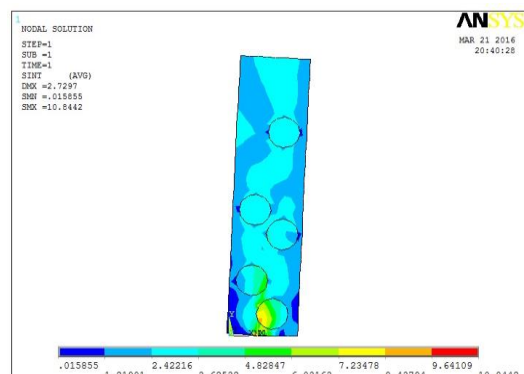
The experimental and finite element method (FEM) results for Deflection are shown in Figure 7. It is observed that the Deflection of particle-filled composite increases with increase in the wt.% of the filler up to 6% above which decrease the Deflection (details in Table 3). Similar observations were observed in varying the size of the SGM. Compare the both results (100µm,200µm),deflection values decreases when increase the particle size as shown in the table 3. Similar observations were also observed between experimental/FEM results, i.e. error 13.45%, 12.94%, 24.5%, 17.82, 19.37, 30.19% and 37%, respectively for 3, 4, 5, 6, 7 and 10wt.% SGM filled composites.

Table 3. Theoretical and experimental deflection of SGM-filled Epoxy composites

S.No	Composite	Applied critical stress (σ) MPa	Dia (100µm)		Dia (200µm)
			Experimental Deflection (mm)	Numerical Deflection (mm)	Numerical Deflection (mm)
1.	Epoxy Resin + 0% SGM	1.6325	0.74679	0.92367	0.9236
2.	Epoxy Resin + 3% SGM	1.8435	1.98542	2.17180	1.9960
3.	Epoxy Resin + 4% SGM	2.3420	2.20918	2.82052	2.0746
4.	Epoxy Resin + 5% SGM	3.9603	3.01967	3.24276	2.7297
5.	Epoxy Resin + 6% SGM	4.0728	4.98889	5.13085	3.8024
6.	Epoxy Resin + 7% SGM	3.7421	4.56892	4.62844	3.0629
7.	Epoxy Resin + 10% SGM	3.4704	2.19220	2.50949	1.6817



Epoxy Resin + 5% SGM(100µm)



Epoxy Resin + 5% SGM(200µm)

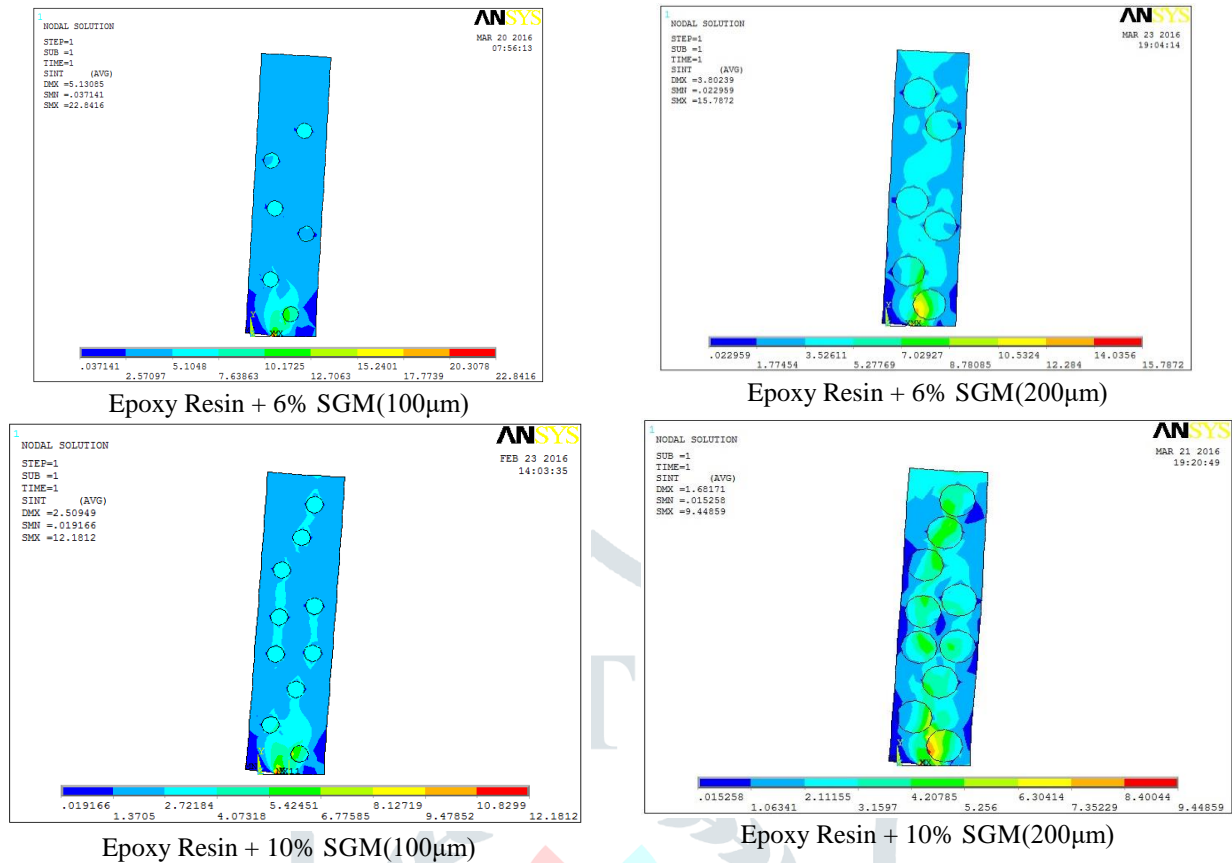


Figure 6. Numerical results for Deflection in varying the size of SGM particle

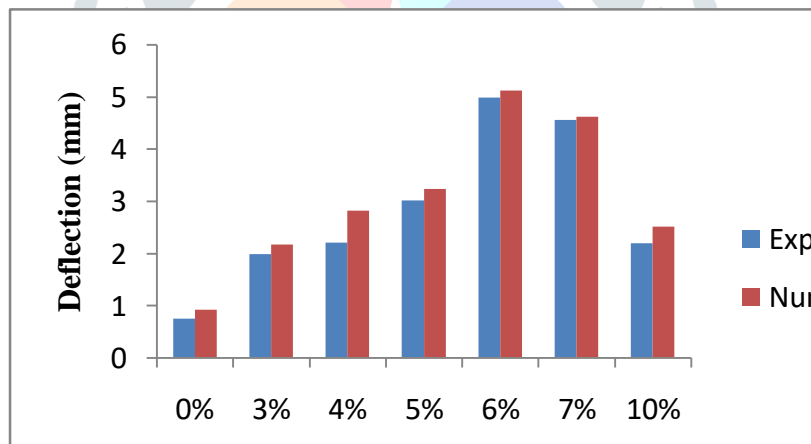


Figure 7. Deflection of SGM filled polymer composite

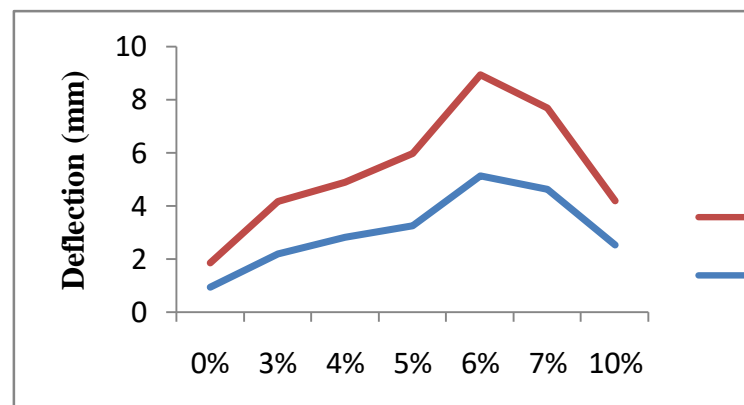


Figure 8. Comparison of deflection in both diameter of SGM particle

VI. CONCLUSION

In the current research, SGM particulate-filled Epoxy polymer composites were fabricated using casting process and the effects of SGM content and size on physical, mechanical and fracture behavior of Epoxy polymer composite were investigated. The experimental results obtained for mechanical properties and fracture toughness were compared with the finite element results. The following conclusions were drawn from the study.

- The void content of the fabricated composites was found to increase with increased SGM content. The void content of Epoxy polymer composites increased from 1.01% to 2.24% from 0 to 15wt.% SGM. This increase in the void content may be due to the inadequate wettability of SGM in Epoxy polymer composite.
- The stress intensity factor for unfilled and SGM-filled Epoxy polymer composites is found to increase with the increase in the wt% of SGM up to 6% above which decrease the stress intensity factor.
- The Deflection for unfilled and SGM-filled Epoxy polymer composites is found to increase with the increase in the wt% of SGM up to 6% above which decrease the deflection
- The fracture toughness and deflection of particle filled composite decreases with increase the SGM particle size.

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