International Journal of Mechanical Engineering and Robotics Research

*ISSN 2278 – 0149 www.ijmerr.com*
*Vol. 1, No. 3, October 2012*


*Research Paper*

# ANALYZATION OF FRP COMPOSITE'S MECHANICAL FAILURE AND INTERPHASE PROPERTIES THROUGH MECHANICAL CHARACTERIZATION AND FEA TECHNIQUES

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This paper is proposed to analyse the multi shaped reinforced elements like carbon fibre, glass fibre and highly dispersed nano sized alumina particles in the matrix of thermoset polymer's interphase properties. The thermoset epoxy resin was taken as the matrix materials. Fundamental tests like tensile, compressive and flexural were carried out for the different loading condition. The similar test was simulated through the FEA technique using ANSYS and the argument was established to explain the deviation among the results. A third phase material was introduced to represent the inter phase region and the mechanical properties as a function of inter phase strength was reported. In our analysis the different shape and size fiber inclusions were used, i.e., spherical, cylindrical, rectangular, cylindrical fibers with hemispherical ends. The volume fractions of fiber inclusions were varied from 0% to 40% and the FEA analysis was carried out to understand the behavior of material at the different loading conditions. The analysis also extended to calculate the behavior of the hybrid composite which contains glass fiber, carbon fiber and alumina particles in the matrix of epoxy. Detailed analyses of the enhancements of the mechanical properties due to the incorporation of the interphase material were studied.

***Keywords:*** Interphase, ANSYS, Fiber, Epoxy

## INTRODUCTION

Recent studies have indicated that mechanical performance of the short fiber-reinforced composites not only depends on matrix type, fiber type, fiber volume fraction, fiber orientation, etc., but fiber-matrix interface and geometrical shape are also of paramount importance. The strength of the composite material is enhanced by the incorporation of fibers and nano fillers. This is mainly due to

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increase of the surface areas of the nano filler materials and fiber-matrix interface region. The stress is absorbed at the interface region thus proving a better material for the advanced engineering application particularly in the aerospace industries. Shiqiang *et al.* (1999) showed the most important physical aspects is the geometry of reinforcing fibers, which influences adhesion between fiber and matrix, stress transfer and local mechanisms of failure. In addition to chemical bonding, the fiber/ matrix bond strength in shear is largely dependent on the roughness of the fiber surface and the fiber/matrix contact area. The three composite systems reinforced by glass fibers of different fiber cross-sectional aspect ratios. As a result, there are many fibers overlapped with each other with large contact areas where the matrix resin is too thin to play the role for stress transfer. The large fibers contact areas caused by fibers overlapping are weak places and can act as a path for crack propagation, a process of cumulative damage progression occurred during longitudinal tensile and flexural tests with increased Strains-to-failure, compared to that of the composites reinforced by the conventional round glass fibers. Xiao-Feng *et al.* (2007) showed the nanomechanical properties of CCNT reinforced epoxy composites were of the hardness, elastic modulus and tensile strength of the CCNT/ epoxy composite increase with increasing the weight percentage of the CCNTs. Observing from the cleavage surface and etched surface of the composite, it can be easily seen that the CCNTs dispersed well and inter-lock tightly with epoxy matrix, which governed their enhancement of mechanical and thermal properties. The macroscopic behavior of composites depends not only on the properties of their individual constituents but also on the elastic-plastic interaction between the erent phases and on the interface properties. In other work Kies reported similar observations that the brittleness of composites in the transverse direction is due to a strain concentration phenomenon in the polymer matrix. Indeed, it is well known that the embedded short borosilicate glass fibers used in this and in related works are of course much stiffer than the epoxy matrix. Therefore, it is understandable that local strain concentrations in the thin polymer layers between the neighboring fibers may occur. De Kok *et al.* (1993) displayed with finite element calculations that high local strains may occur in the matrix already at a low global strain level in the bulk composite. The application of the Von mises criterion pointed out that local strains are concentrated in thin bands near the fiber/matrix interface. The authors also showed that a thin rubbery interface facilitates the transfer of the plastic strain between the matrix and the fibers, hence facilitating the capability to increase the overall strain in the composite to a higher level. The test specimen shall conform to the dimensions of ASTM D638-10 The Type IV specimen is the preferred specimen and shall be used for tensile test. Calculate the compressive strength by dividing the maximum compressive load carried by the specimen during the test by the original minimum cross-sectional area of the specimen of ASTM D695-10. Componeschi, Hsiao, Daniel and Lee made an effort to develop a suitable compression test method for thick composites and investigated the effect of specimen thickness on the compressive strength. It was found that the failure strength decreases with increasing thickness of the unidirectional laminate, but most of the failures occurred near or at the specimen end where the load is introduced.

Johnson *et al.* (2012) made an effort to study the stress transfer behavior for an alumina fiber in epoxy resin using FEA. It was shown that the presence of a transverse crack significantly influenced the stress transfer mechanism. It was also shown that the stress transfer length increases with the length of the transverse matrix crack, therefore reducing the reinforcing efficiency of the fibre. The length of the transverse crack also had a significant influuence on the magnitude of the shear stress in the matrix at the fibre/matrix interface. Thus the matrix crack can delay or even prevent shear yielding of the matrix near the interface. Yang and Chen introduced the technique for Modeling and analytical methods to predict effective longitudinal Young's modulus of composites containing misoriented short fiber. The results showed that the Young's modulus of this kind of composites strongly depends on fiber volume fraction and the angle between fiber and load direction. The role of matrix volume fraction on stress distribution along fiber length was predicted using finite element method.

## OBJECTIVES

The objectives of the research study is:

- To study the influence of the reinforcing elements by neglecting the interface properties of the composite material;
- To study the influence of the reinforcing elements by considering the interface properties of the composite material;
- To study the influence of the geometrical shape of the fiber inclusion; and
- To study the influence of the volume fraction of the reinforcing elements.

## FINITE ELEMENT ANALYSES

All simulations in this work were carried out by the commercial finite element package ANSYS 12.0. The material properties for each constituent have been specified directly according to the supplier's data sheet. Tensile, compressive and flexure test are performed to investigate the mechanical failure and influence of interfacial properties of FRP composite. Tensile test is performed in compliance with standard ASTM D638-10 type IV specimen Compressive test is performed using the ASTM D695-10 standard specimen, and Flexural test also performed in compliance with standard ASTM D790 specimen.

The properties of discontinuous fiber composites mentioned in the Table 1.

**Table 1: Properties of Discontinuous Fiber Composites**

| Material | Elastic Modulus (GPa) | Poisson's Ratio | Density (gm/cm) |
|---|---|---|---|
| Carbon Fiber [55] | 242 | 0.33 | 1.81 |
| Glass Fiber [53] | 723 | 0.22 | 2.55 |
| Alumina Fiber [56] | 380 | 0.24 | 3.95 |
| Epoxy Matrix [54] | 3.35 | 0.35 | 1.2 |
| CFRP/Epoxy Interphase | 6.7 | 0.34 | ~ 1.2 |
| CFRP/Epoxy Interphase | 6.7 | 0.28 | ~ 1.2 |
| Alumina/Epoxy Interphase | 6.7 | 0.3 | ~ 1.2 |

## RESULTS AND DISCUSSION

### Tensile Test

When uniaxial tensile force is applied to a solid, the solid stretches in the direction of the applied force (axially), but it also contracts in both dimensions are perpendicular to the applied force. The value of the major principal stress of the CFRP gradually decreases with the increase of the addition of the fiber content for the cylindrical fiber, rectangular fiber and the cylindrical fibers with the hemispherical ends. The modulus increases in proportion to the filler the incorporation of a third material as interphase. This enhancement of properties may be due to the proper bonding property of the fiber and matrix. After 20% volume fraction of the fiber inclusion in Figure 1, the graph becomes almost linear and parallel to the horizontal axis.

The experimental result shows at 2 to 3% vol of CF has higher strength. And the CF increase the strength is decreasing up to 15% of CF content. From the Figure 1 the experimental values are near to the simulated values with Considered Interphase. It shows Interphase playes a major role to load transfer from fiber to matrix. As per ASTM D standard Specimen the tensile test simulated. The main aim of this work to ensure that the strength of the composite mainly depend on Strength of the Interphase. The below Figure 2 shows the strength was increased by considering Interphase then the Neglected Interphase. This is mainly because of the load was effectively transferred matrix to the fiber.

### Tensile Modulus of Short CFRP Composite

The Tensile modulus of the pure epoxy as well as of the composites containing the short Carbon Fiber (CF) and short Glass Fiber (GF) was analyzed. The modulus of pure epoxy is 3.38 GPa. The composite with 1.09% vol of CF shows a 3.6 GPa and improvement in tensile modulus is 4.47 GPa improved due to the incorporation of interphase properties

**Figure 1: Strength of the Composite Material Under Uni-Axial Tensile Test as a Function of the CFRP Volume Fraction**

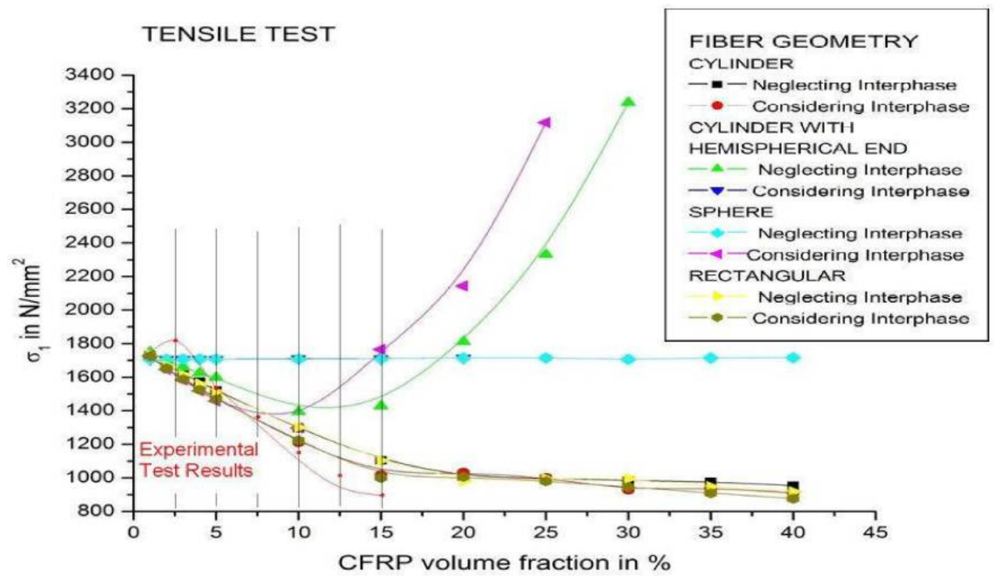


**Figure 2: Tensile Stress of 2.18% GF with 1% Alumina, Where Stress is Neglected, Interphase and Considered Interphase**

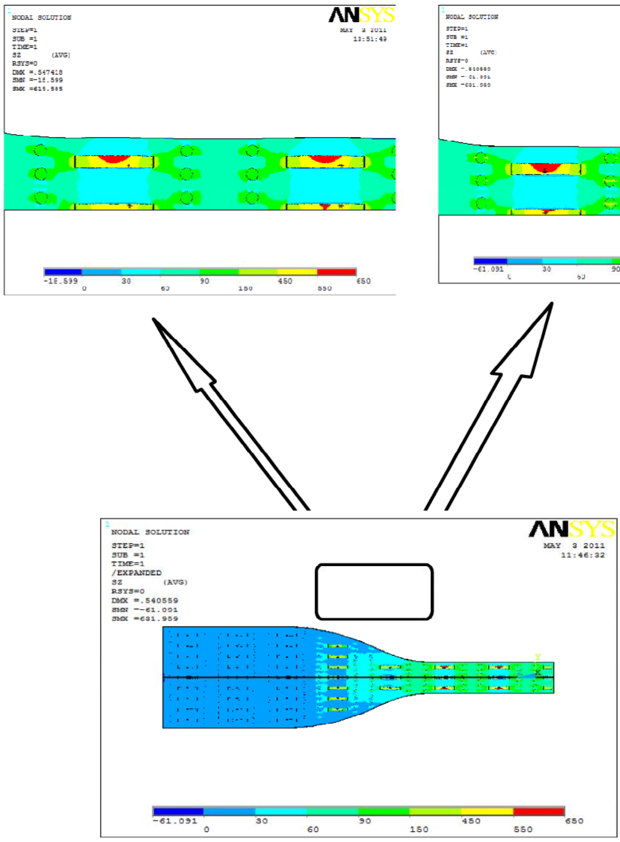



**Figure 3: Tensile Modulus of Short CFRP Composite**

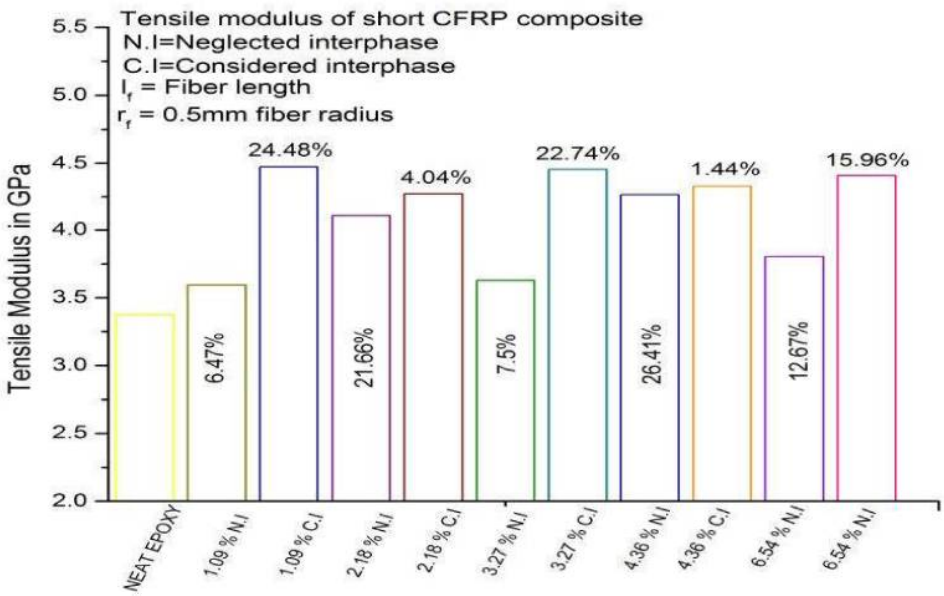
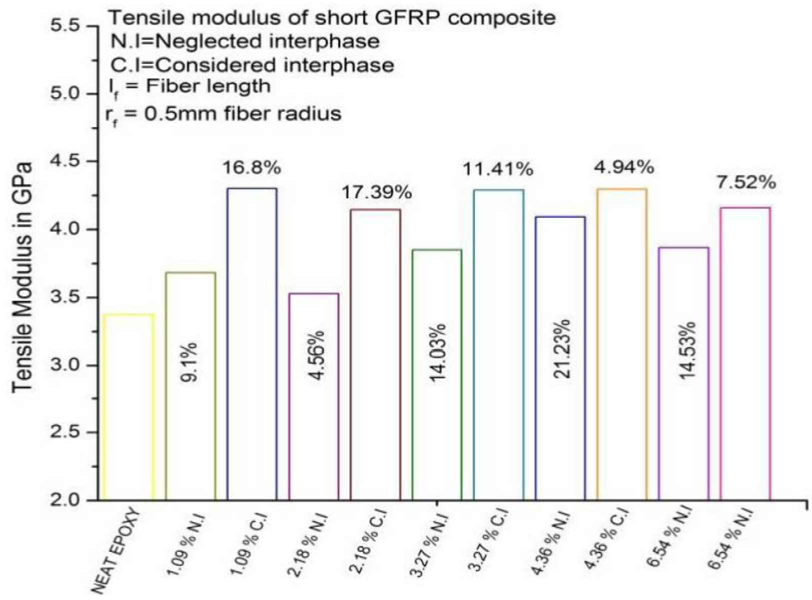


**Figure 4: Tensile Modulus of Short GFRP Composite**




using the tensile modulus formula. The above modulus has been calculated and plotted (Figures 3 and 4). The composite fiber radius of 0.25 mm with 1.09% to 6.54% vol of CF shows a 6.47% to 12.67% and GF fiber shows a 9% to 14.53% improvement in tensile modulus compare to neat epoxy. Tensile modulus of CF is 24.48%, 4.04%, 22.74%, 1.44% and 15.96% has improvement due to the incorporation of interphase properties.

The Tensile modulus of the pure epoxy as well as of the composites containing the short

**Figure 5: The Major Principal Strength of the Composite Material Under Uni-Axial Compression as a Function of the CFRP Volume Fraction**

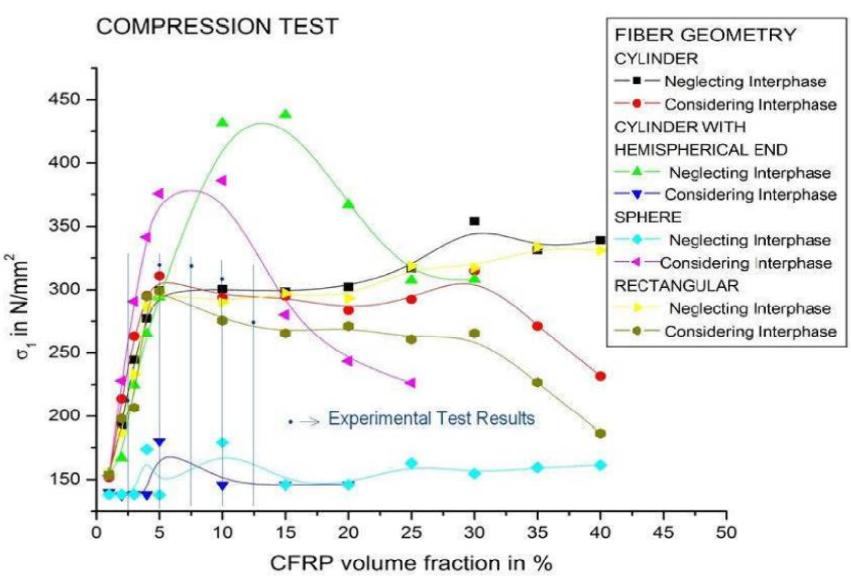
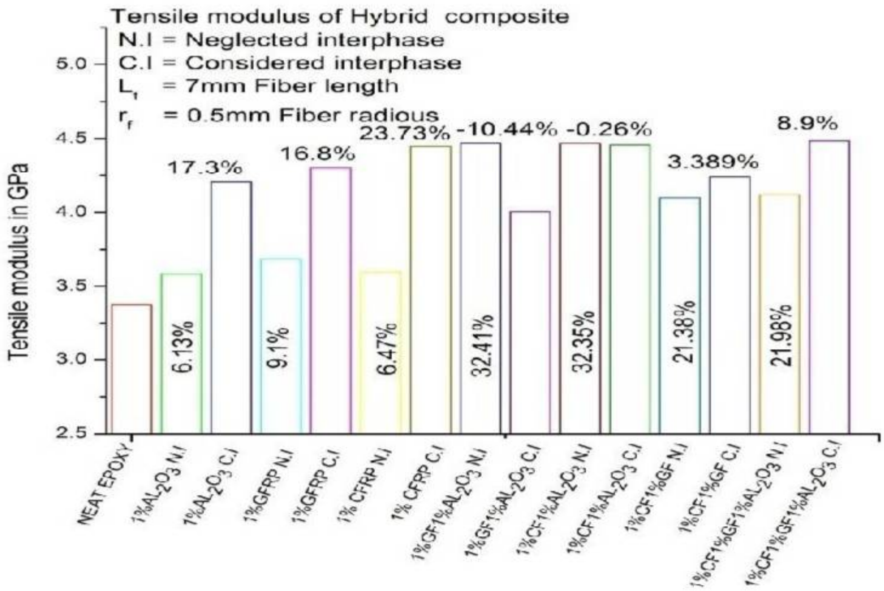


**Figure 6: Tensile Modulus vs. Hybrid Composites**




carbon fibers like CF and GF was analyzed with 97 to 291 no. of FRP with incorporation of 1% Alumina particle keeping constant. Tensile modulus of 1% vol of CF with 1% vol of GF has calculated as 21.38% improved compare to Neat epoxy. Figure 5 shows the improvement of tensile modulus with respect o the fiber content. Further improvement in the tensile modulus achieved due to the incorporation of interphase properties. Tensile modulus of 1% vol of CF with 1% vol of GF and 1% Alumina particle has calculated as 4.11GPa it means 21.38% improved compare to neat epoxy and further improvement in the tensile modulus achieved due to the incorporation of interphase properties.

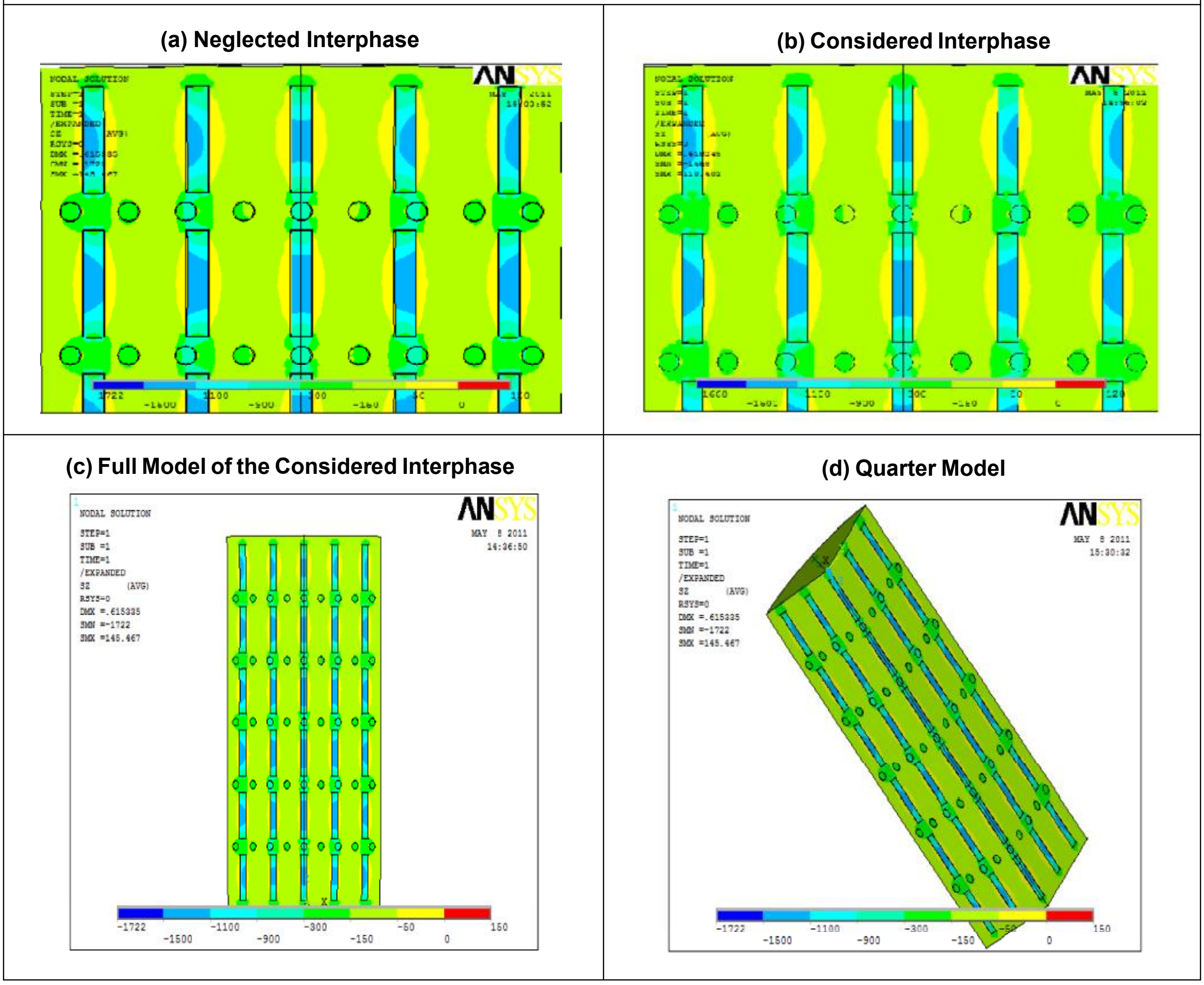
## COMPRESSION TEST

The compressive test for the composite material shows the improvement of the major principal stress at 7% and 12% of fiber inclusion for spherical and cylindrical fibers with hemispherical ends. Early increase of the major principal stress was observed for the rectangular and cylindrical fibers. Beyond the 15% of fiber inclusion, there was no improvement was observed for all type of fiber inclusion.

The experimental result shows at 5 to 12% vol of CF has higher strength. And increasing the CF the strength is decreasing up to 15% of CF content. From the graph the experimental values are near to the simulated values with considered Interphase (Figure 6). It shows Interphase plays a major role to load transfer from fiber to matrix. Due to the perfect bond between fibers to matrix the simulated test result showing higher values. But in practical matrix unable to transfer the load to fiber due to the fibers are not evenly distributed.

The compressive modulus of the pure epoxy as well as of the composites containing the short Carbon Fiber (CF) and short Glass Fiber (GF) was analyzed. The modulus of pure epoxy is 2.21 GPa. The composite with 0.98% vol of

**Figure 7: Stress Distribution of 1.98% Vol of CFRP with 1% Alumina Particle**




(a) Neglected Interphase

(b) Considered Interphase

(c) Full Model of the Considered Interphase

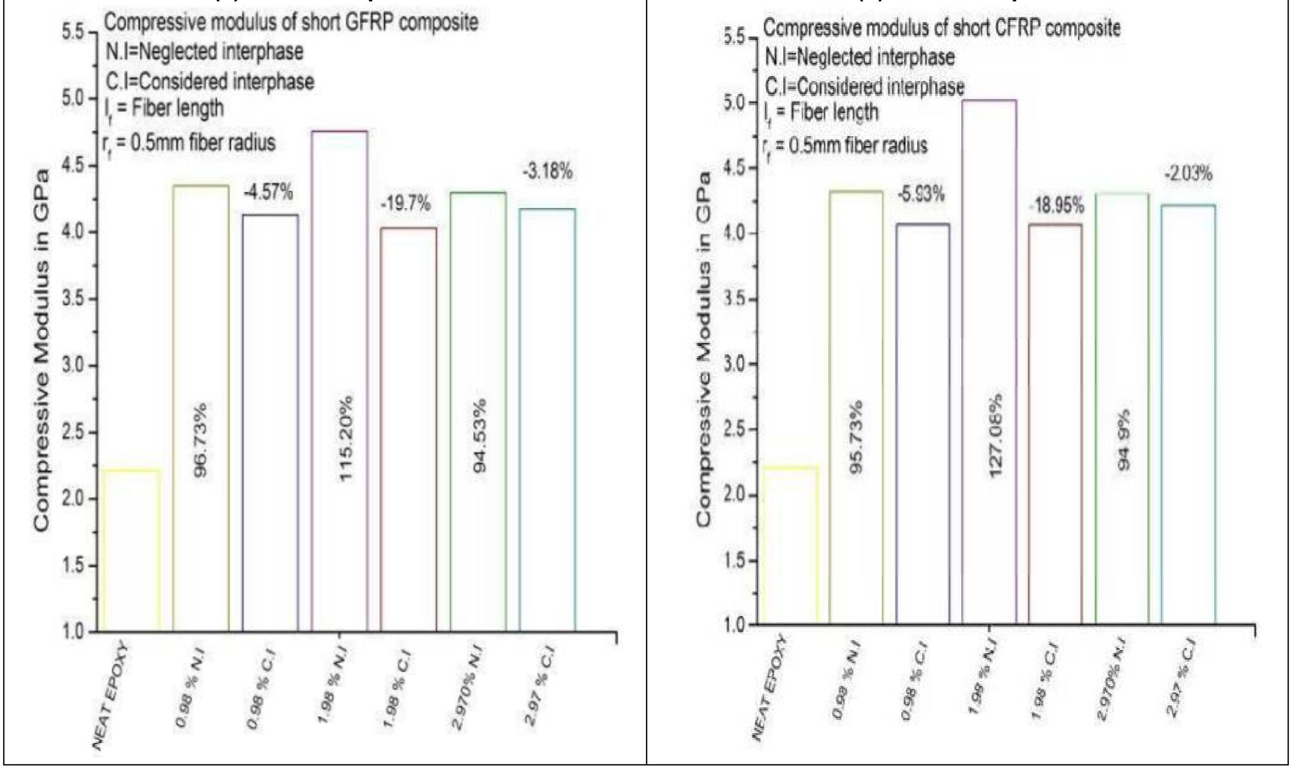
(d) Quarter Model

CF shows a 4.33 GPa and the modulus is 4.07 GPa reduced due to the incorporation of interphase properties. Using the compressive modulus formula (iv) the above modulus has been calculated and plotted (Figure 8). The composite fiber radius of 0.25 mm with mm fiber length are incorporated as 0.98%, 1.98% and 2.97% vol of CF shows a 95.73%, 127.08% and 94.9% improvement in compressive modulus compare to Neat epoxy. Tensile modulus of CF is predicted as 86.78%, 82.62%, and 88.39% due to the incorporation of interphase properties.

The compressive modulus of the pure epoxy as well as of the composites containing the short carbon fibers like CF and GF was analyzed with 54 to 162 no. of FRP with incorporation of 1% Alumina particle keeping constant. Compressive modulus of 1% vol of CF with 1% vol of GF has calculated as 79.86% improved compare to Neat epoxy. Further improvement in the compressive modulus achieved due to the incorporation of interphase properties. Compressive modulus of 1% vol of CF with 1% vol of GF and 1% Alumina particle has calculated as 3.96 6GPa

**Figure 8: Compressive Modulus vs. Volume Content of Fiber**

**(a) CFRP Composite** **(b) GFRP Composite**




it means 79.43% improved compare to Neat epoxy and 3.91GPa in the compressive modulus achieved due to the incorporation of interphase properties

## FLEXURAL TEST

A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports A support

**Figure 9: Flexural Stress Distributions**

**(a and b) Flexural Stress Distributions of 9% CFRP/Epoxy Composite Neglecting and Considering the Interphase Properties**

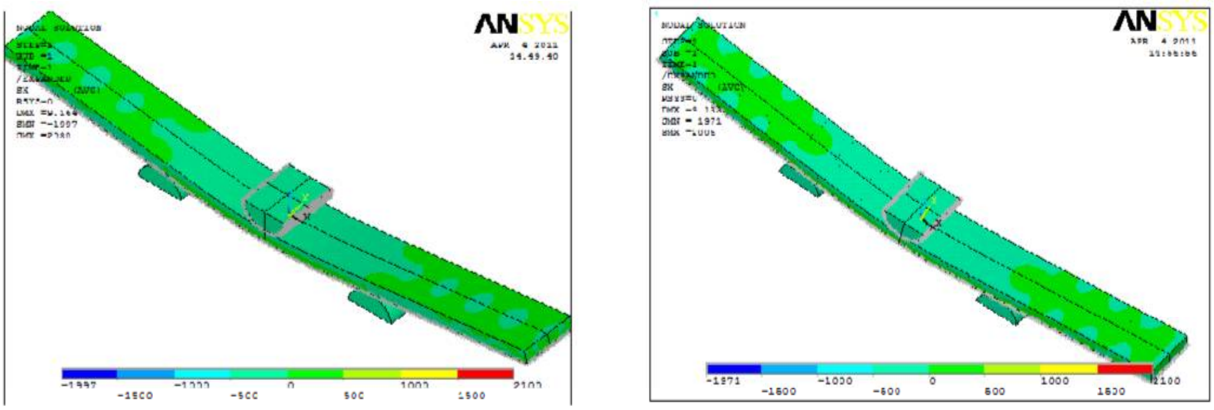


Figure 9 (Cont.)

**(c and d) Flexural Stress Distribution of 9% CFRP Neglecting and Considering the Interphase (Stresses in Fiber)**

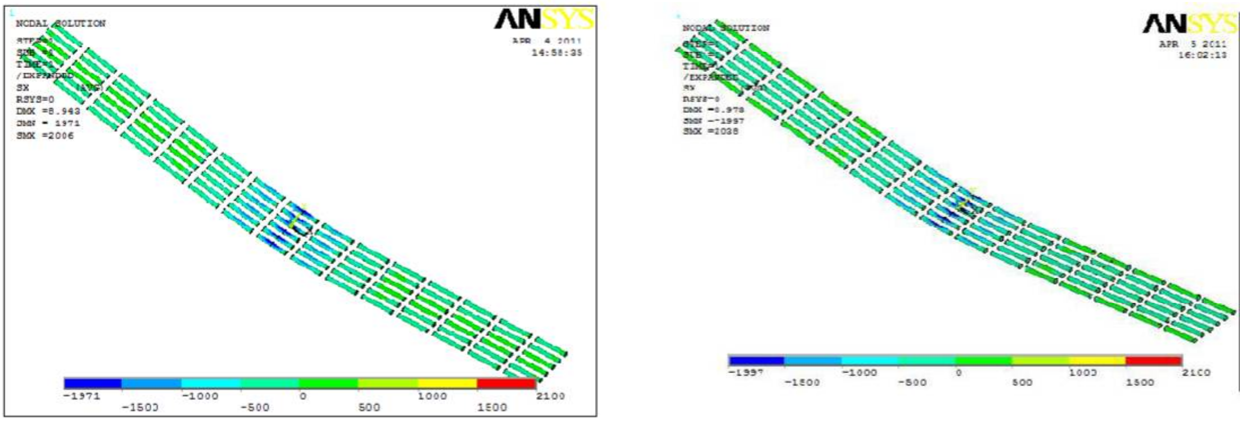
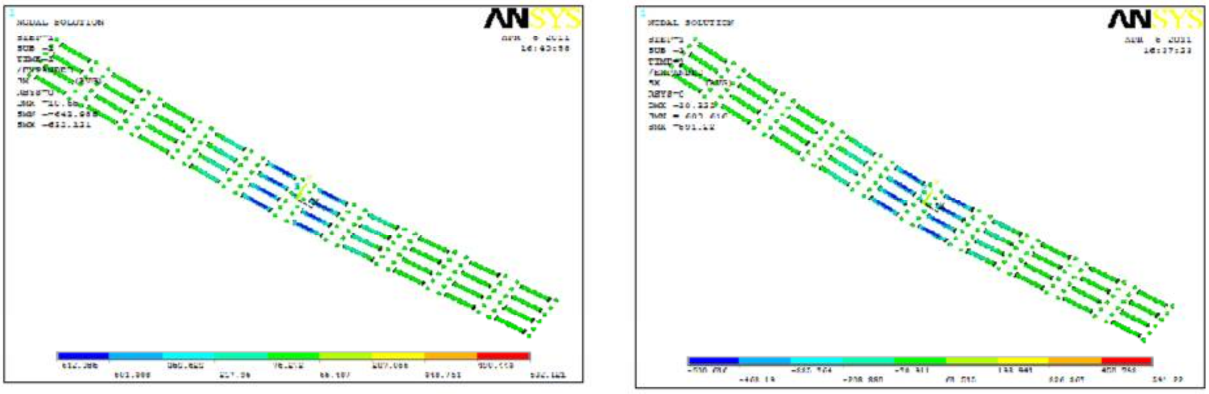
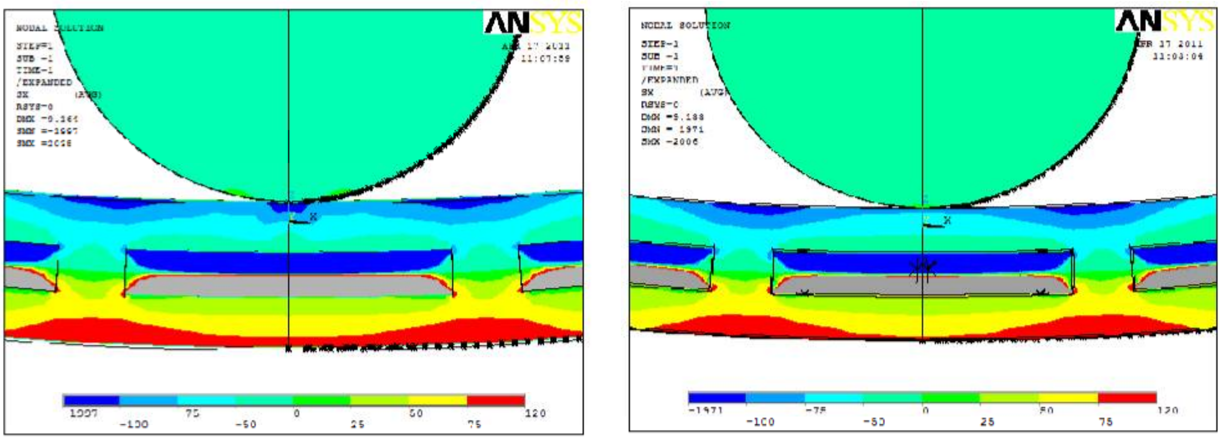



**Figure 10: Flexural Stress Distributions**

**(e and f) Flexural Stress Distribution of 4% GFRP with 1% Alumina Particles Neglecting and Considering the Inter Phase (Stresses in Fiber)**




**(g and h) Shows Flexural Stress Distributions of Matrix to Fiber on 9% CFRP/Epoxy Composite Neglecting and Considering the Interphase**



span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-death ratio may be required.

## CONCLUSION

The present study has shown that the ultimate tensile and compressive strength of the short carbon fiber and glass fiber reinforced composite was gradually decreases but the modulus increases with the increase of the filler content. The flexural modulus of the neat epoxy was increased by the addition of carbon fiber, glass fiber and further improvement of the flexural modulus is possible by adding a constant volume fraction of the Alumina particles in the epoxy matrix. In this study we have reported that the interface region plays a vital load not only to act for the mechanism of load transfer but also the as means to improve the mechanical properties of the material. The findings will help for the proper choice of the reinforcing material for the load bearing structures for critical application.

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