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# Experimental investigations and finite element analysis of debonding behaviour of steel fibre reinforced epoxy

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**ABSTRACT**

The mechanical advantage of using composite is high strength to weight ratios which increases their capabilities for aerospace, structural and automobile applications. The epoxy-coated reinforcement (ECR) has gained mainstream acceptance to extend the useful life of highway structures. The volume fraction of reinforcement affects the overall strength a composite and the orientation of fibers in matrix plays a significant role in determining the debonding behavior. The present work focuses on the determination of compressive strength and debonding behavior of steel reinforced epoxy composite with different orientation angles of fibers. The results revealed that among different orientations of fibers, reinforcement at 0° angles shows maximum compressive strength and least debonding than 45° and 90° angle of reinforcement.



## Introduction

For years, FRP (fiber reinforced plastic composites) have growing applications in different industries. Composite is a mixture of two or more constituents/materials (or phases) with different physical/chemical properties at the macroscopic or microscopic scale [1]. In general they have two or more constituents, fiber and matrix. They are classified by the geometry of the reinforcement: particulate, flake, and fibers or by the type of matrix: polymer, metal, ceramic, and carbon. The basic idea of the composite is to optimize material properties of the composite, i.e., the properties of the matrix are to be improved by incorporating the reinforcement phase. Fibers are the principal load-carrying constituents while the surrounding matrix helps to keep them in desired location and orientation and also act as a load transfer medium between them. Fiber-reinforced composites are often characterized by their high specific strength and specific modulus parameters (i.e., strength to weight ratios), and are widely used for applications in low-weight components [2]. The composite reinforced with carbon fibers are used for making bridges and structural members [3]. The high strength and damage resistance of the composites are very important for a number of practical applications. The aim of this paper is to study the debonding behavior of steel fiber reinforced epoxy composite with different angles of orientation under compressive loading. Testing of pressure loading is one of the most commonly used mechanical testing [4]. These tests determine the influence of reinforcement on pressure strength and modulus of elasticity and also provide the knowledge about the mechanisms of cracks which are unavoidable factor duration the testing of composite structure [5]. In determining the strength of composite, a dominant role is played by initiation and propagation of crack which is studied experimentally and numerically in this work. Further this study can be used to determine strength and debonding behavior of composites at other angles of reinforcement.

## Experimental

### Test Materials

The composite material used in this research was manufactured by using steel fibers of diameter 3.25 mm as reinforcement and matrix material was epoxy resin (R 101) and standard hardener (H 101) supplied by Fevitite, manufactured by Padmaja Laboratories, Navi Mumbai, India. The composite materials were fabricated by reinforcing steel fibers in epoxy resin at 10% volume fraction of reinforcement as shown in Fig. 1. The volume fraction is calculated by using equation 1 [6]. The specimens were prepared with different fiber orientation angles of 0°, 45° and 90° in epoxy by hand molding process using wooden die. The test specimens were molded into cubic pieces of dimensions 30 x 30 x 30 mm. Fig. 2 shows the square array of fiber packing geometry in 3D for single fiber which is used for calculation of volume fraction of reinforcement.

$$V_f = \frac{\pi l d^2}{4LS^2} \quad (1)$$

**Where**
l = length of fiber
L = longitudinal fiber spacing (length of matrix)
d = diameter of fiber
S = Fiber spacing (Refer fig. 2)

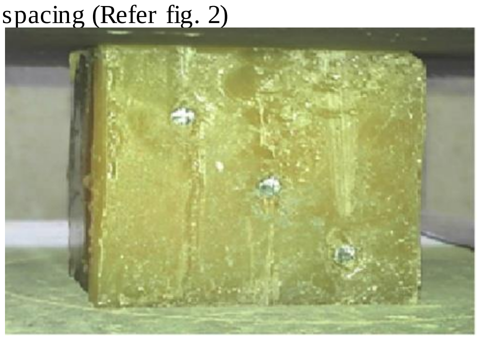

**Fig. 1. Figure showing steel fiber reinforced epoxy composite**

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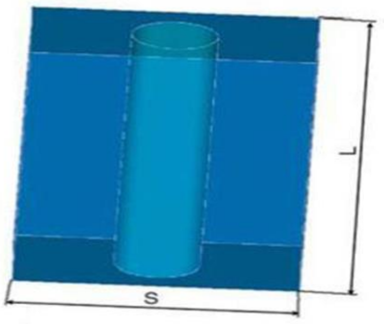


**Fig. 2. Unit cell of square array of fiber packing geometry in 3D for single fiber**

**Test apparatus and procedure**

All experimental tests were carried out at civil engineering lab of Maharishi Markandeshwar University, Mullana, Ambala, India.

The compression tests were carried out on servo hydraulic testing machine (with loading capacity of 20000 KN), shown in Fig. 3. The test specimens of unreinforced epoxy and reinforced composite with different orientation angles of fibers (0°, 45°and 90 were placed between the movable and fixed plates. The compressive load was applied and readings were obtained. The displacements corresponding to applied load were measured by displacement dial gauge and load v/s displacement graphs were plotted for each specimen.

**Fig. 3. Compression test rig**

**Finite element analysis scheme**

The composite specimens with different orientation angles were modeled using finite element analysis software ANSYS 12 (non commercial). The element type considered for the analysis was solid 8 node 45 and cohesive zone modeling approach was used which was similar to V. Kushch [7]. The properties of materials [8] used for FEM are shown in Table 1.

**Table 1 Materials properties for finite element modeling**

| **Material** | **Modulus of elasticity(GPa)** | **Poisson's ratio** |
|---|---|---|
| Epoxy (Matrix) | 2.4 | 0.36 |
| Steel fibers | 200 | 0.25 |

The compressive displacements were given to the models to study the stresses and their location where debonding of fibers will occur. The finite element analysis and experimental results were compared to validate the debonding behavior during compression testing.

**Results**

**Experimental results**

The force v/s displacement graphs were plotted for unreinforced epoxy, steel reinforced (10% volume fraction) at 0°, 45° and 90° orientation angles which are shown in Fig. 4 - Fig. 7. The comparison between the debonding load and displacement is shown in Fig. 8. The results revealed that when epoxy is reinforced with steel fibers, the compressive load bearing capacity increases by 32% to 50% depending upon orientation angles of fibers. Debonding of fibers in matrix is also affected by the orientation angles. Breaking force is maximum for 0° angle i.e. when fibers are arranged along X-axis, then 45° and 90° orientation. For 45 degree orientation the strength is more than 90 degree orientation due to the shielding effect [8] which suppresses the debonding at inner edges and outer edges gets debonded first.

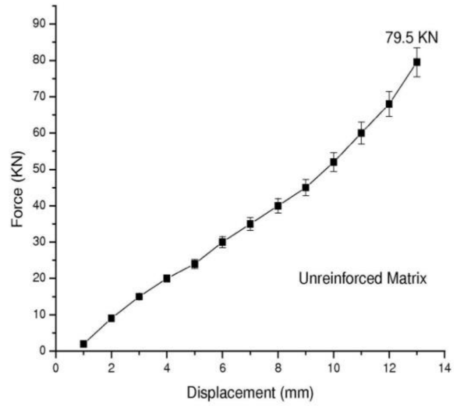


**Fig. 4: Force v/s Displacement plot for unreinforced matrix**

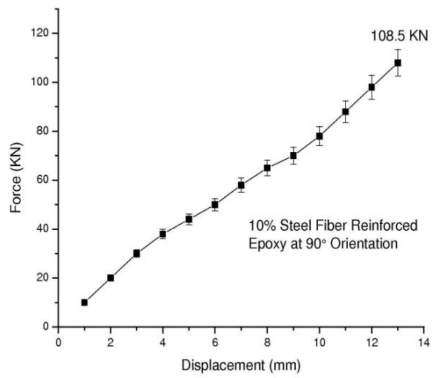


**Fig. 5: Force v/s Displacement plot for steel reinforced epoxy at 90°**

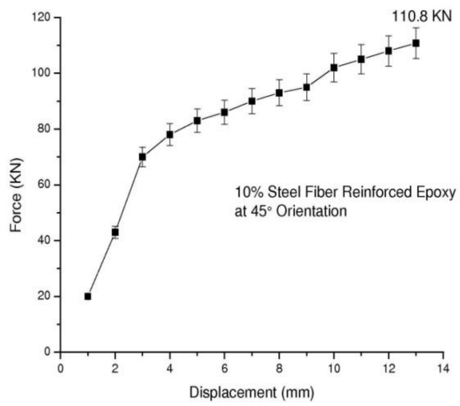


**Fig. 6: Force v/s Displacement plot for steel reinforced epoxy at 45°**

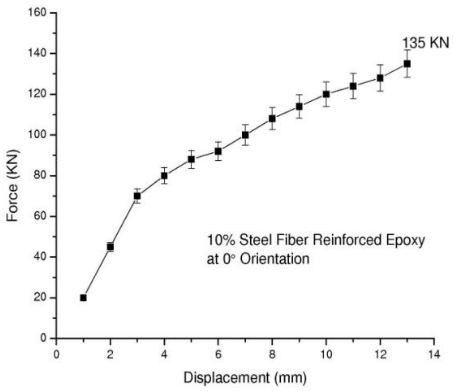


**Fig. 7: Force v/s Displacement plot for steel reinforced epoxy at 0°**

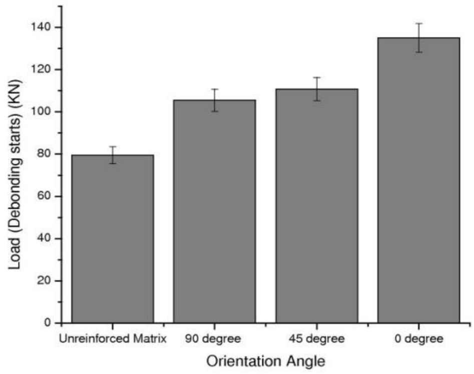


**Fig. 8: Comparison of force v/s displacement plots**

**Finite element results**

The composite specimens were modeled and compressive loads were applied to study the debonding phenomenon of fibers in matrix. Results revealed that debonding will start at the outer edges of fibers and when compared with the experimental debonding behavior, the results of finite element method reproduced in the similar manner which is shown in Fig.9 – Fig.11.

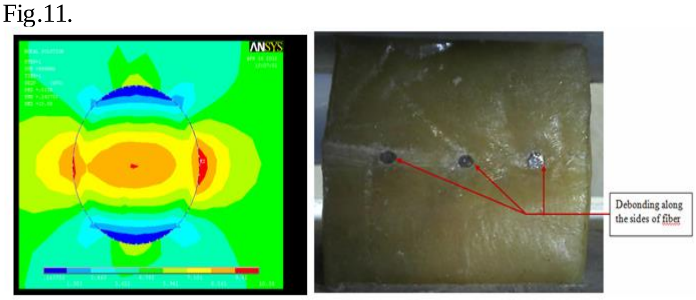


**Fig. 9: Numerical and experimental comparison of debonding behavior when fibers are at 0° orientation**

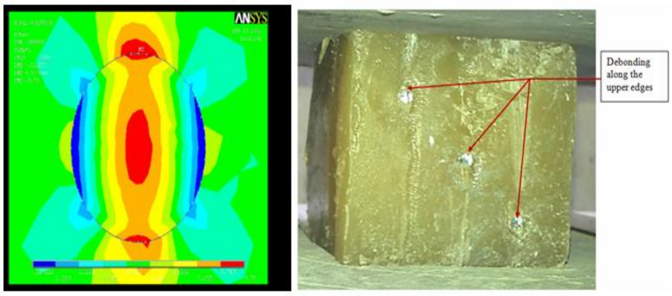


**Fig. 10: Numerical and experimental comparison of debonding behavior when fibers are at 45° orientation**

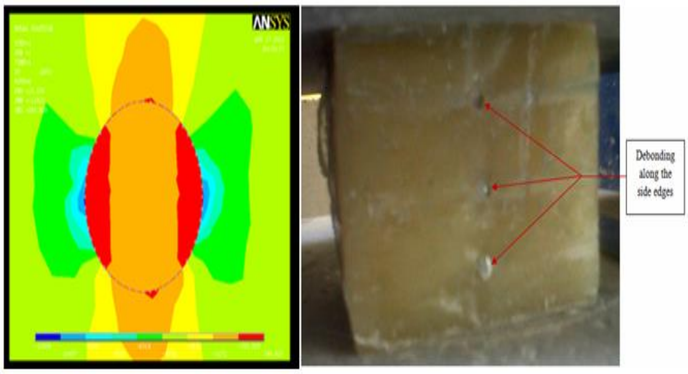


**Fig. 11: Numerical and experimental comparison of debonding behavior when fibers are at 90° orientation**

**Conclusions**

The aim of this paper was to analysis the compressive strength of steel reinforced epoxy composite at different orientation angle of fibers. F.E. Analysis of steel fiber reinforced epoxy composite has generated detailed quantitative data about the debonding behavior of composite. Compression tests result shows that failure/breaking of composites will start at the fiber/matrix interface and debonding behavior depends upon the orientation of fibers. Breaking load for the given composite increases with increase in reinforcement in percentage because fibers are the main load carrying members. Results shows that with 10% reinforcement of steel fibers the breaking load increased by 32.5% to 50%, depending upon the orientation of fibers. Load v/s displacement graph showed that for a particular load, maximum displacement is shown by unreinforced composites, followed by 90, 45, and 0 degree. For 0 degree orientation all fibers are under uniform stress distribution but for 90 degree orientation the stress distribution is not uniform as upper fiber is stressed maximum which will cause the premature failure.

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