Comparative Analysis of Glass and Steel Fiber Reinforced Concrete Using ANSYS: Stress Response and Deformation Characteristics

[1]Rachita Garg, [2]Madhulika Malviya

[1]Research scholar, Department of Civil Engineering, Jhada Sirha Government Engineering College, Jagdalpur

[2]Assistant Professor, Department of Civil Engineering, Jhada Sirha Government Engineering College, Jagdalpur

***Abstract**: Most of the existing researches are based in reinforcement of concrete using steel and glass fibers only. The reinforced concrete was tested using compression test, tensile test. The self-compacting concrete lacks adequate compaction which deteriorates its compressive strength. It is therefore essential to augment its strength which could be achieved by addition of high strength fibers. The current research is intended to enhance the strength of concrete using high strength fibers. The structural characteristic of reinforced concrete would then be evaluated using compressive test and tensile test. From the FEA analysis, both 3% glass FRC and 3% steel FRC exhibit a linear increase in normal stress with increasing applied load, indicating elastic behavior within the tested load range. At each load level, the normal stress in 3% glass FRC is slightly higher than in 3% steel FRC. For 3% glass FRC, the stress increases from 12.13 MPa at 300 kN to 19.903 MPa at 492 kN. This indicates a stress increase of approximately 7.773 MPa over a load increase of 192 kN. For 3% steel FRC, the stress increases from 12.028 MPa at 300 kN to 19.725 MPa at 492 kN. This indicates a stress increase of approximately 7.697 MPa over a load increase of 192 kN. The slightly higher stress values in 3% glass FRC suggest that for the same load, glass FRC experiences more stress compared to steel FRC. This could be due to the inherent properties of glass fibers, such as lower modulus of elasticity compared to steel fibers. For applications requiring slightly higher stress resistance and where weight reduction is crucial, 3% glass FRC might be preferred. For applications where durability and higher toughness are critical, 3% steel FRC might be the better option.*

Keywords: **Self compacting concrete, FEA, compressive test**

1. INTRODUCTION

Concrete occupies a distinguished position among the building materials and it has been used in construction for more than a century as a main construction material. In the reinforced concrete structures, the formworks and reinforcement are becoming more complex and extremely dense; therefore, many problems can occur due to insufficient compaction of concrete and of the inappropriate filling of the formworks. As a consequence of this, the durability and performance of mature concrete can be lower. Improved durability of concrete and working conditions have had high preference in the development of concrete construction. Therefore, attention has been directed towards the use of concrete independent of the need for compaction, known as self-compacting concrete (SCC) which offers a better quality of concrete and improved durability. It brought a new insight into concrete technology by increasing productivity and making casting homogeneous concrete in congested structures possible. SCC was first developed in Japan in 1986; it was designed to fill the formwork completely and to flow through complex geometrical configurations and heavily reinforced areas, which are otherwise difficult to access, without any need for external compaction during the pouring process. Along with these advantages, SCC offers many benefits to construction practice: improvement of the efficiency and effectiveness on site by reducing the labour cost and construction time, elimination of the noise pollution and the health problems related to the use of vibration equipment and improvement of the surface finishes with less defects.

2. LITERATURE REVIEW

Lopez et. al. [1] As stated earlier, flowability is the main property of SCC that distinguishes it from conventional vibrated concrete. The flowability of SCC is measured in different tests, the most important of which are the slump flow, J-ring, L-box, V-funnel and sieve segregation tests. Studied in very specific cases, direct rheological parameters are a potential field of study for future investigations.
Campos et al. [2] designed a concrete mixture with coarse RCA and/or fine RCA in three different combinations (0%e20%, 20%e0% and 20%e20%). The amount of superplasticizer increased with the amount of RCA. The results showed that a suitable SCC can be achieved using these quantities of coarse RCA and fine RCA, if around 9% more water is added. Their results also corroborated previous observations that fine RCA water absorption is greater than the water absorption of coarse RCA.

Carro-Lopez et al. [3] considered a substitution of only the fine fraction of NA in proportions of 20%, 50%, and 100%, maintaining the superplasticizer constant. When examining the flowability of the mixes, which as is well known will decrease over time, they reached the conclusion that the greater the fine RCA content, then the faster the decrease in flowability. Different humidity conditions of the RCA have been also analyzed [4].

Gonzalez-Taboada et al. [5] designed SCC with coarse RCA (substitution percentages of 20%, 50%, and 100%) and three different situations were considered: dry aggregate and extra water (labelled M1), pre-soaked aggregate (labelled M2), and aggregate with 3% of natural moisture and extra water in the concrete mix (labelled M3). The main conclusion was that the coarse RCA was indeed suitable for the manufacture of SCC and that the best method to guarantee flowability over time was by pre soaking (M2) the aggregates. In contrast, control over flowability with methods M1 and M3 presented serious difficulties. Although, in conclusion, M2 was the best method, the authors claimed that aggregate pre-soaking as an industrial procedure would require excessive amounts of time and may not be profitable, which explained why M3 was the most widely used option [6]. However, in the case of SCC as a high-performance product, pre-saturation should be considered as an alternative to enhance behavior, besides profitability considerations. However, in the perspective of industrializing RCA-based SCC, the authors of this review considered it more efficient to use RCA with natural moisture and to modify the total water content of the mix, rather than by presoaking the aggregates.

3. OBJECTIVES

The current research is intended to enhance the strength of concrete using high strength fibers and test it using techniques of Finite Element Method. The 3D design of test unit is developed in ANSYS design modeler followed by static structural analysis. The static structural analysis of test unit is conducted using glass fiber reinforced concrete and steel fiber reinforced concrete. From the FEA simulation, the normal stress and deformation values are determined.

4. METHODOLOGY

The methodology process of structural analysis involves different stages of analysis i.e. preprocessing, solution stage and post processing. In pro-processing stage, the 3D model of test unit is developed using sketch and extrude tool. The test unit has dimensions of 150cm * 150cm *150cm. The developed 3D model of test unit is shown in figure 1. The model developed is discretized using hexahedral element type. The model possess topological consistency which makes it suitable to be meshed using hexahedral element type. The hexahedral element comprises of 8 nodes with 3DOF/node.

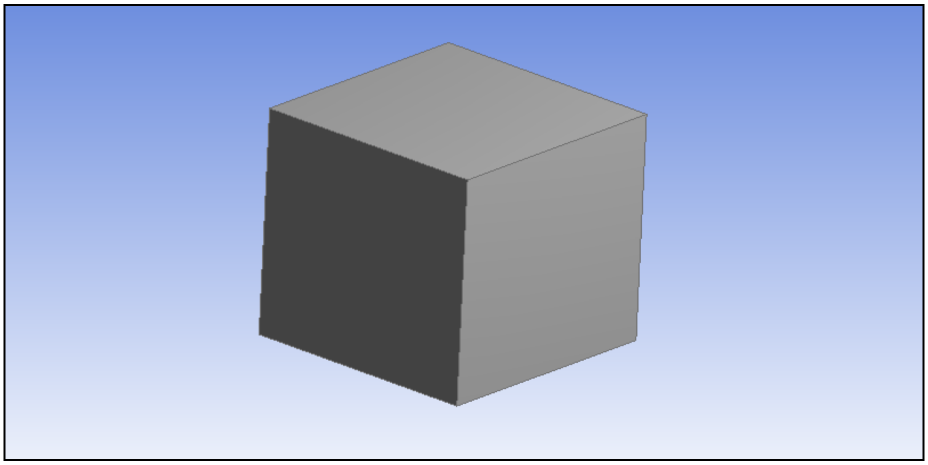

Figure 1: 3D model of test unit

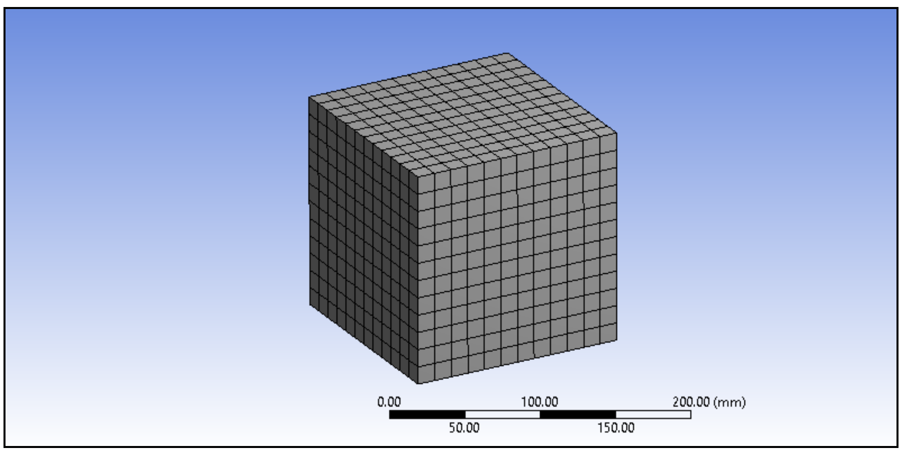

Figure 2: Meshed model of test unit

The mesh settings include fine meshing relevance with normal inflation and growth rate of 1.2. The mesh relevance setting is set to adaptive type. From meshing, the number of element generated is 1728 and number of nodes generated is 8281. The meshed model of test unit is shown in figure 2 above. After meshing, the model is applied with structural loads and boundary conditions. The structural boundary condition includes fixed support at the bottom of unit and top face is applied with 300kN load.

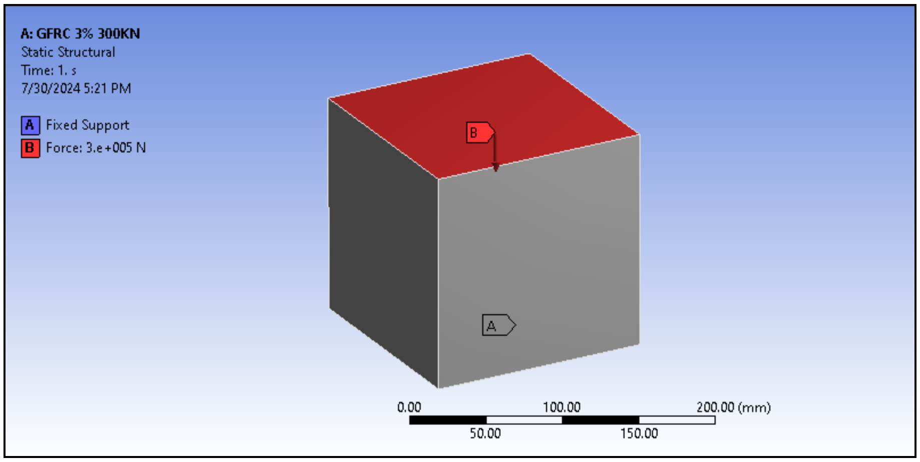

Figure 3: Structural loads and boundary conditions

After application of boundary conditions, the simulation process is run. The solver settings are defined in the process which includes solver type, update interval duration, display points and line thickness type. In the solution stage, the simulation solver is run which involves formulation of element stiffness matrix associated with each element of test unit. The subsequent step in solution stage is formulation of global stiffness matrix and nodal calculations for determining deformation, stresses.

5. RESULTS AND DISCUSSION

From the FEA simulation, the normal stress and deformation values are obtained for glass fiber reinforced concrete and steel fiber reinforced concrete. The induced normal stress on normal stress steel reinforced concrete is nearly 52.28 MPa as obtained at the bottom of the test unit.

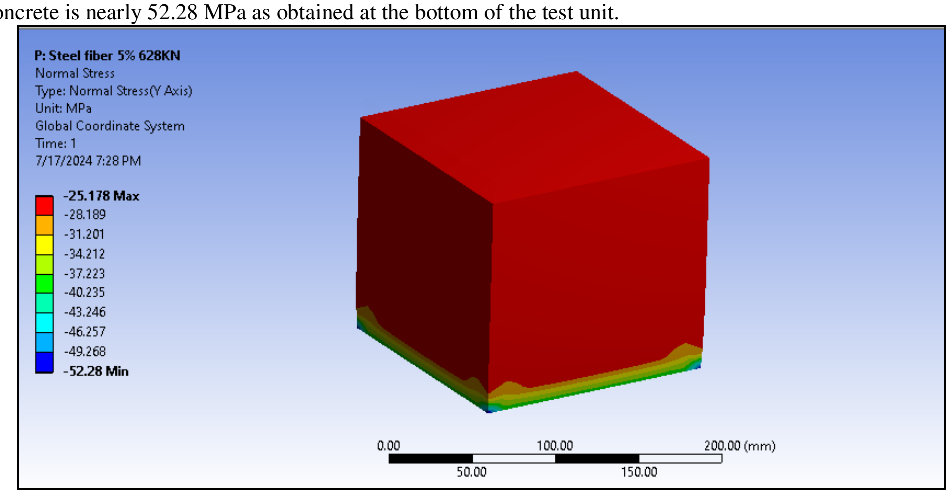

Figure 5: Normal stress on 5% steel fiber reinforced concrete at 628kN load

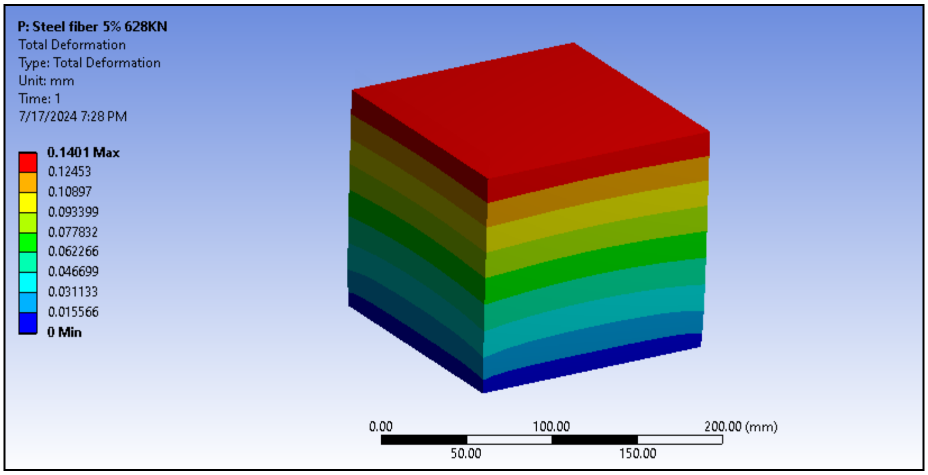

Figure 6: Total deformation on 5% steel fiber reinforced concrete at 628kN load

The deformation plot obtained from the simulation shows maximum value of deformation as represented by red colored zone. The deformation reduces on moving towards the base of the test unit. The deformation at the mid-section of test unit is .09399mm.

Table 3: Comparison Chart for normal stress (minimum)

Material	300kN	350kN	400kN	450kN	492kN
3% glass FRC	12.13	14.15	16.18	18.204	19.903
3% steel FRC	12.028	14.032	16.037	18.042	19.725

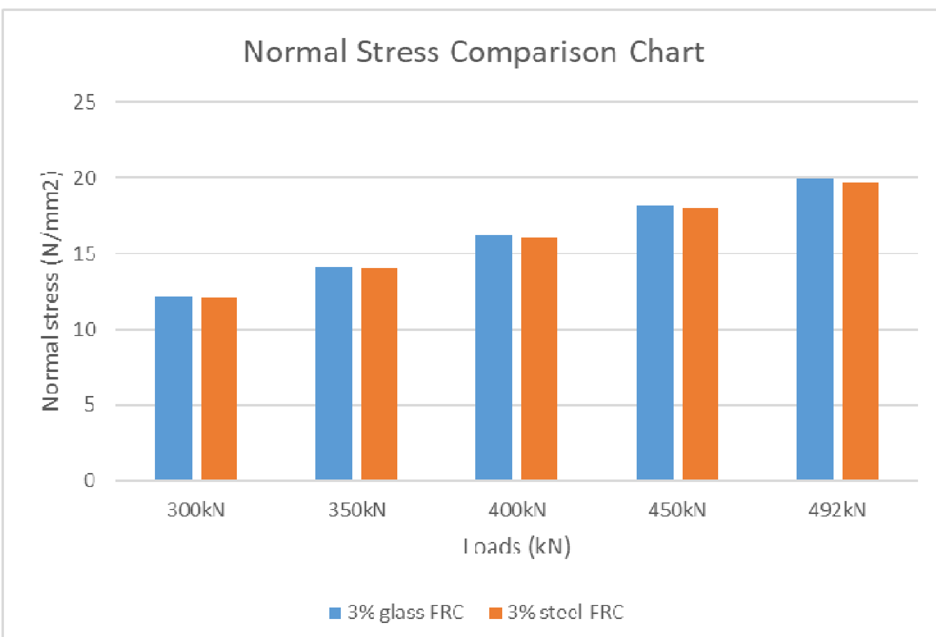

Figure 7: Normal stress comparison chart

Both 3% glass FRC and 3% steel FRC exhibit a linear increase in normal stress with increasing applied load, indicating elastic behavior within the tested load range. At each load level, the normal stress in 3% glass FRC is slightly higher than in 3% steel FRC. For 3% glass FRC, the stress increases from 12.13 MPa at 300 kN to 19.903 MPa at 492 kN. This indicates a stress increase of approximately 7.773 MPa over a load increase of 192 kN. For 3% steel FRC, the stress increases from 12.028 MPa at 300 kN to 19.725 MPa at 492 kN. This indicates a stress increase of approximately 7.697 MPa over a load increase of 192 kN. The slightly higher stress values in 3% glass FRC suggest that for the same load, glass FRC experiences more stress compared to steel FRC. This could be due to the inherent properties of glass fibers, such as lower modulus of elasticity compared to steel fibers. Despite the small differences, both materials perform similarly under the tested conditions, indicating that both types of fiber reinforcement provide comparable benefits in terms of stress distribution and load-bearing capacity. The difference in normal stress between the two materials is minor, ranging from 0.102 MPa at 300 kN to 0.178 MPa at 492 kN. These small differentials indicate that the choice between glass and steel fibers might be influenced more by other factors such as cost, weight, corrosion resistance, and specific application requirements rather than by the stress response alone. For applications requiring slightly higher stress resistance and where weight reduction is crucial, 3% glass FRC might be preferred. For applications where durability and higher toughness are critical, 3% steel FRC might be the better option.

Table 4: Comparison Chart for normal stress (minimum)

Material	550kN	600kN	628kN
5% glass FRC (MPa)	22.24	24.27	25.404
5% steel FRC (MPa)	22.05	24.05	25.178

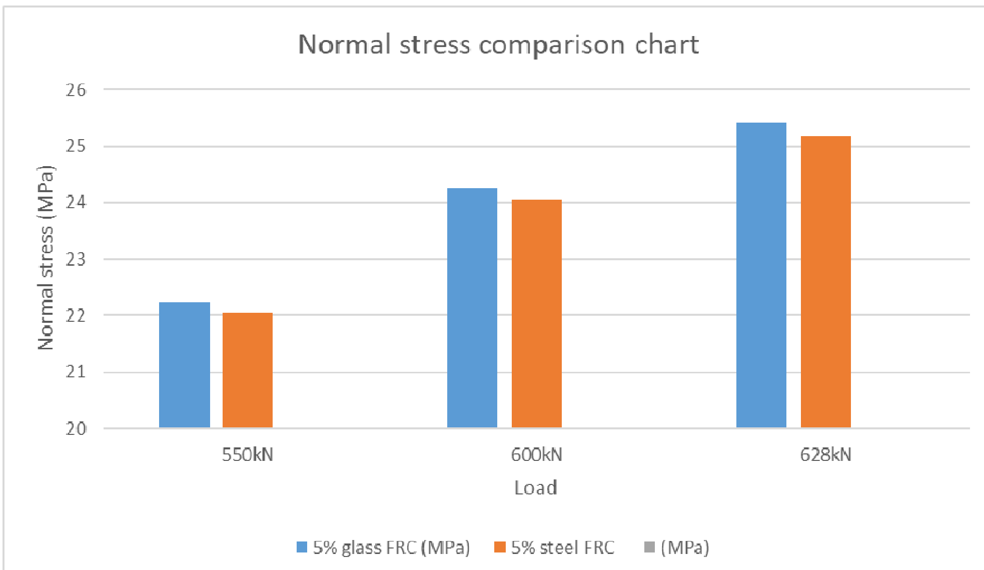

Figure 8: Normal stress comparison chart

At all load levels, the deformation in 5% glass FRC is consistently higher than in 5% steel FRC. The percentage difference in deformation between the two materials is approximately 20% across all load levels. This indicates that 5% steel FRC exhibits better resistance to deformation compared to 5% glass FRC under the given loads. In terms of deformation, 5% steel FRC performs better than 5% glass FRC, with around 20% less deformation at each load level.

Table 5: Comparison Chart for deformation

Material	550kN	600kN	628kN
5% glass FRC (mm)	0.1472	0.16062	0.16811
5% steel FRC (mm)	0.1227	0.13385	0.1401

Figure 9: Deformation comparison chart

This suggests that steel fibers contribute more effectively to reducing deformation in the concrete matrix under loading conditions. Therefore, for applications where minimizing deformation is critical, 5% steel FRC would be a better choice compared to 5% glass FRC.

6. CONCLUSION

The FEA simulation is conducted to determine the normal stresses and deformation of glass fiber specimen at different loads. From the FEA analysis on glass fiber specimen, the maximum normal stress obtained at 492kN is 19.903MPa. This is obtained for glass fiber percentage of 0.3%. The similar simulation was conducted for glass fiber reinforced concrete at different loads i.e. 550kN, 600kN and 628kN. The normal stress is obtained for concrete with 628kN load with magnitude of 25.404MPa. Both 3% glass FRC and 3% steel FRC exhibit a linear increase in normal stress with increasing applied load, indicating elastic behavior within the tested load range. At each load level, the normal stress in 3% glass FRC is slightly higher than in 3% steel FRC. For 3% glass FRC, the stress increases from 12.13 MPa at 300 kN to 19.903 MPa at 492 kN. This indicates a stress increase of approximately 7.773 MPa over a load increase of 192 kN. For 3% steel FRC, the stress increases from 12.028 MPa at 300 kN to 19.725 MPa at 492 kN. This indicates a stress increase of approximately 7.697 MPa over a load increase of 192 kN. The slightly higher stress values in 3% glass FRC suggest that for the same load, glass FRC experiences more stress compared to steel FRC. This could be due to the inherent properties of glass fibers, such as lower modulus of elasticity compared to steel fibers. Despite the small differences, both materials perform similarly under the tested conditions, indicating that both types of fiber reinforcement provide comparable benefits in terms of stress distribution and load-bearing capacity. The difference in normal stress between the two materials is minor, ranging from 0.102 MPa at 300 kN to 0.178 MPa at 492 kN. These small differentials indicate that the choice between glass and steel fibers might be influenced more by other factors such as cost, weight, corrosion resistance, and specific application requirements rather than by the stress response alone. For applications requiring slightly higher stress resistance and where weight reduction is crucial, 3% glass FRC might be preferred. For applications where durability and higher toughness are critical, 3% steel FRC might be the better option.

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