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Performance of Fly-ash and GGBS-based Materials in High Strength Self-Compacting Concrete Reinforced Beams with Steel and Fiberglass Bars

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ABSTRACT

Construction of High Strength Self Compacting Concrete (HSSCC) can be done with inexpensive materials like ground granulated blast and furnace slag (GGBS). ash of the fly. A key element in determining the service life of concrete reinforced buildings is the resistance of the concrete and reinforcement to the corrosive effects of their surroundings. The presence of water in the structural building and structures with potentially damaged concrete covers can both exacerbate corrosion and deterioration of steel. This study aims to investigate the flexural behaviour of beams made of steel, glass fibre reinforced polymer (GFRP) rebars, and high strength self compacting concrete (HSSCC) made of fly ash and ground granulated blast furnace slag (GGBS). Different cement replacement percentages were used to create the beams, including 20% Fly-ash, 20% GGBS, 10% (5% Fly-ash + 5% GGBS), and 20% (10% Fly-ash + 10% GGBS).

Strengths in compression, flexural stiffness, and split tensile strength of high strength self-compacting concrete (HSSCC) made with various cement replacement combinations, including cementitious material like fly ash and ground granulated blast furnace slag GGBS, were investigated. To test the increase in mechanical strength, steel reinforcement was also added. The basic qualities of the self-compacting concrete (SCC), including filling capacity, flowability, and passing capacity, are tested first. The mixture with 20% GGBS and a 0.28 water-to-cement ratio had a compressive strength of 68.97 MPa, a tensile strength of 7.5 MPa, and a flexural strength of 8.9 MPa.

The goal of this study is to carry out the first study of its kind into the flexural behaviour of GGBS and SCC beams made of fly ash and reinforced with steel and GFRP. Investigating load-strain behaviour involved using ANSIS to perform a non-linear finite elements analysis. The results were then compared to experimental and numerical outcomes.

1. INTRODUCTION:

Concrete that self-compacts "(SCC) is a brand-new, specialised concrete mixture that, thanks to its incredible deformability and excellent segregation resistance, can be used to fill confined or strongly reinforced spaces without causing vibration. SCC [6] was developed in Japan. High-performance concrete is identified by a long cure time (HPC) and a small water-to-binder ratio (w/b). [7]. High-performance "Superior robustness, strength, and durability can be found in concrete (HPC). Either SCC or HPC can produce the desired concrete type when similar components are combined in the proper ratios [8].

Therefore, SCHPC is a concrete technological advancement that combines the best aspects of SCC and HPC. It combined the self-compacting qualities of the SCC with the superior strength and endurance of the HPC (good filling, passing, and segregation resistance). [9] Because of the SCHPC's noiseless compacting, construction time and costs were both significantly reduced. The composition of cement and the additives used in its manufacture account for the high cost of production. However, if mineral admixtures like FA and GGBS are used to cut labour costs, there might not be a change in overall costs. Additionally, the properties of the concrete were improved and SCHPC's economic and environmental advantages increased when FA and GGBS were combined in a trigonal mix.

The by-product of blast furnaces used to make iron is known as ground granulated blast-furnace slag (GGBS). The building industry has benefited technologically from its use in numerous countries around the world [17,18]. Enhancing the compactability and consistency of self-compacting concrete while protecting the cement from sulphate and chloride attack are just a few advantages of adding GGBS [19]. The flow-ability of the finished product is significantly enhanced when PC is substituted for the same amount of cement with GGBS.

According to Oner and Akyuz's research [20], the water to binder ratio falls for the same consistency as the GGBS concentration rises, indicating that GGBS has a beneficial impact on consistency. They added that as the GGBS replacement level rises, so does the compressive strength of concrete mixtures containing GGBS. Fly ash (FA), also referred to as pulverised fuel ash, is a byproduct of coal-fired power plants (PFA). Pozzolanic properties in SCC enable it to be used as a partial replacement for cement. Up to 30% of the bulk of PC may be replaced by FA, improving both the fresh and hardened properties of SCC. FA concretes take longer than conventional PC-based concretes to reach their maximum strength. FA can enhance the rheological characteristics of SCC while also using less water because of its compact spherical form [21].

II. EXPERIMENTAL STUDY

Material characteristics:

Fly-ash [8] class F (Type II), GGBS [9], and IS: 269 - 2015 OPC [43 Grade] were all used in this investigation. The chemical, physical, and mechanical characteristics of OPC, fly ash, and GGBS are listed in Table 1 [32]. River sand with a specific gravity of 2.85 and coarse aggregates with a specific gravity of 2.84 were combined to create fine aggregates. All mixtures contained HIFORZA864, a poly-carboxylate-based super plasticizer, to meet the workability requirements of ASTM C 494-13. The primary reinforcement was made up of 12 mm thermally mechanically treated (TMT) bars that complied with IS 1786:2000, and the stirrups were made of 8 mm mild steel rods. Steel's mechanical characteristics are listed in Table 2. You need potable, clean water for mixing. mixing previously consumed water.

Table 1 Physical Properties of Material

S. No.	**Material**	**Specific Gravity**
1	Cement	3.15
2	Fly-ash	2.4
3	GGBS	2.62
4	Fine Aggregate	2.56
5	Coarse Aggregate	2.66

Table 2 Mechanical Properties of Steel

S.No.	**Parameter**	**As Per 1786:2008Specifications**
1	Grade of Steel	Fe500
2	Ultimate Tensile Strength (Mpa.)	545
3	Yield Stress (Mpa.)	500
4	Elongation (%)	12

Geometrical details of test Beam:

The testing was a component of a larger investigation into the efficiency of GFRP bars in enhancing concrete beam functionality. For this study, 18 beams were cast and put through a two-point load test. Each beam had a cross-section that measured 150mm by 300mm and was 3000mm long. Figure 1 displays the cross-sectional characteristics of the beam. An HSSCC that also contained fly ash and reinforcement was used to cast 18 beams. Two 16 millimeter-diameter steel bars reinforce the tension and compression faces of Beams I, II, and III.

No matter how much cement is replaced by GGBS or Fly-ash, such as 20% Fly-ash, 20% GGBS, 10% (5% Fly-ash + 5% GGBS), or 20% (10% Fly-ash + 10% GGBS), the same GFRP-reinforced HSSCC beams are used. All of the beams have longitudinal reinforcements in the form of steel stirrups that are 150 mm apart and 8 mm in diameter. Table 1 contains the fundamentals of the beam.

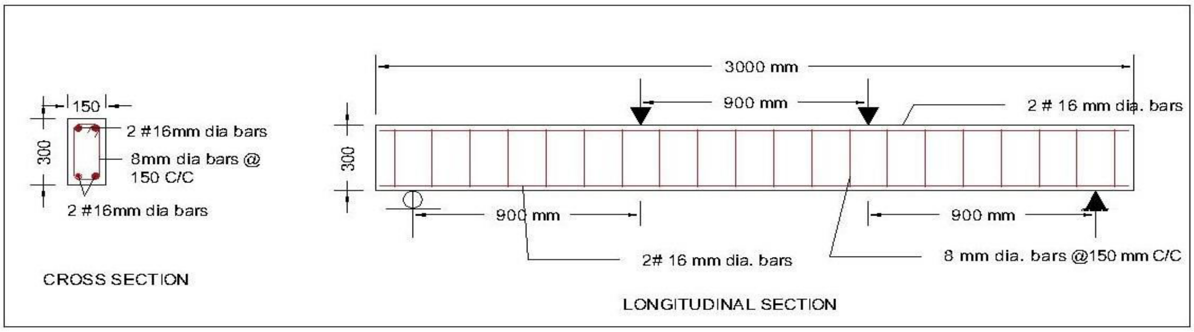


Fig 1. Geometrical details of test Beam

Fig 2. Tested instrumentation & installation

III. RESULTS AND DISCUSSIONS:

COMPRESSIVE STRENGTH:

Fig. 3 displays the compressive strengths of each HSSCC mixture. These graphs [16] compare concrete's compressive strength (CS) at various levels of admixture replacement. Concrete cubes with 0% replacement typically have a CS of 34.2 N/mm2, 56.4 N/mm2, and 65.9 N/mm2 after 3, 7, and 28 days, respectively. The typical CS of concrete cubes with 10% replacement of fly ash is 32.5 N/mm2, 56.4 N/mm2, and 63.73 N/mm2 after 3, 7, and 28 days, respectively. The typical CS of concrete cubes with 10% replacement of GGBS is 33.49 N/mm2, 56 N/mm2, and 65.38 N/mm2 after 3, 7, and 28 days, respectively. The typical CS of concrete cubes with 10% replacement of fly ash + GGBS is 31.29 N/mm2, 53.66 N/mm2, and 66.8 N/mm2 after 3, 7, and 28 days, respectively. At 3 days, the average concrete cube's compressive strength (CS) with 20% replacement of fly ash and GGBS is 36.3 N/mm2, at 7 days, 58.9 N/mm2, and at 28 days, 67.6 N/mm2. It demonstrates that the strength of admixtures at 20% replacement of fly ash + GGBS is marginally greater than 0% replacement at 3 days, 7 days, and 28 days.

However, the added strength from using fly ash + GGBS in place of 20% of the original quantity is acceptable.

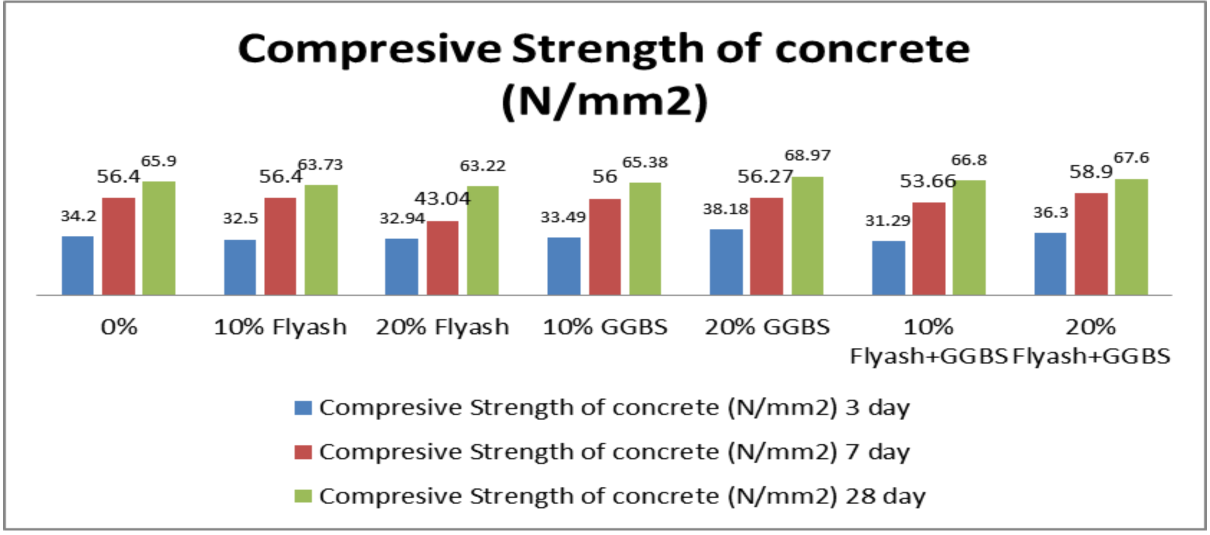


Fig 3: Compressive Strength

SPLIT TENSILE STRENGTH:

The split tensile strength (STS) values for HSSCC mixtures are shown in Fig. 4. This graph compares the STS of concrete at various percentages of cement replacement with admixtures. Concrete cubes with 0% replacement have an average STS of 3.87 N/mm2 after 3 days, 4.5 N/mm2 after 7 days, and 6.4 MPa after 28 days. The average STS of concrete cubes with 10% fly ash replacement is 3.32 MPa after three days, 4.4 N/mm2 after seven days, and 6.4 N/mm2 after 28 days. The STS of concrete cubes with 10% replacement of GGBS averages 3.47 N/mm2 after 3 days, 5.2 N/mm2 after 7 days, and 7.2 N/mm2 after 28 days. The average STS of concrete cubes with 10% fly ash replacement and GGBS is 3.31 N/mm2 at 3 days, 4.2 N/mm2 at 7 days, and 6.9 N/mm2 at 28 days. The average STS of concrete cubes with 20% fly ash replacement and GGBS is 4.05 N/mm2 after three days, 5.4 N/mm2 after seven days, and 7.4 N/mm2 after 28 days. First off, admixtures with a 0% replacement strength are weaker than those with a 20% replacement strength. Since the tensile strength of the 20% fly ash + GGBS concrete split was greater than the 0% replacement at the end of 28 days.

However, the added strength from using fly ash + GGBS in place of 20% of the original quantity is acceptable.

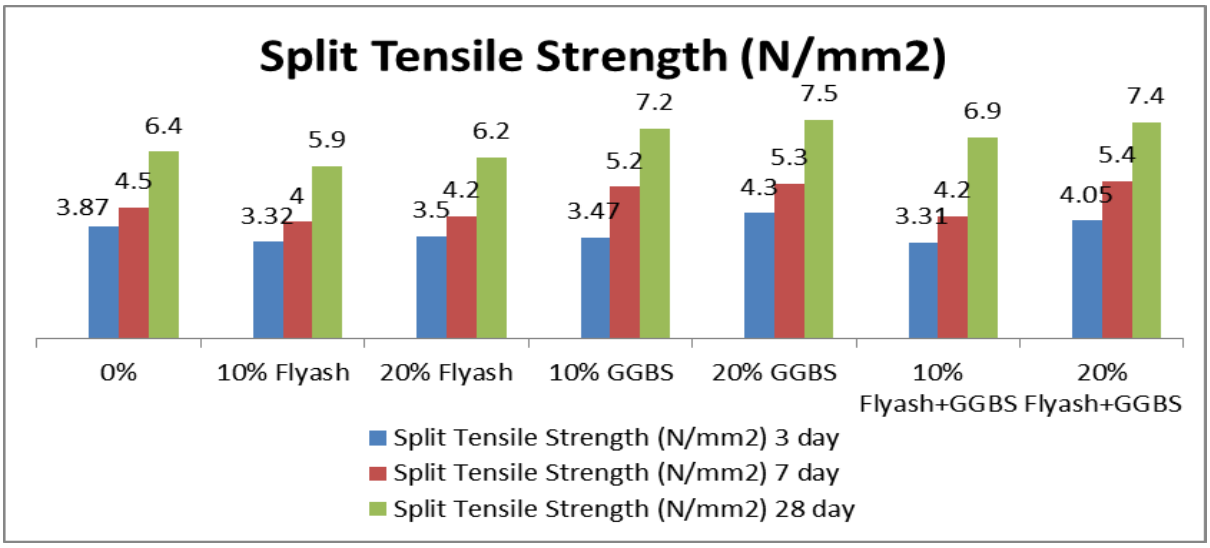


Fig 4: Split Tensile Strength

FLEXURAL STRENGTH:

The flexural strengths (FS) of HSSCC mixtures are shown in Figure 5. These graphs compare the FS of concrete at various admixture content levels. The average FS of concrete cubes with 0% replacement is 6.3 N/mm2, 7.2 N/mm2, and 8.44 N/mm2 after 3, 7, and 28 days, respectively. At three days, the average FS of concrete cubes with 10% fly ash replacement is 6.15 N/mm2, at seven days, it is 6.8 N/mm2, and at 28 days, it is 8.54 N/mm2. The typical FS of concrete cubes with 10% replacement of GGBS is 5.55 N/mm2 after three days, 7.15 N/mm2 after seven days, and 8.65 N/mm2 after 28 days. The average FS of concrete cubes with 10% fly ash replacement and GGBS is 5.85 N/mm2 after three days, 7.3 N/mm2 after seven days, and 8.76 N/mm2 after 28 days. The average FS of concrete cubes with 20% fly ash replacement and GGBS is 6.47 N/mm2 after three days, 7.36 N/mm2 after seven days, and 8.94 N/mm2 after 28 days. First off, admixtures with a 0% replacement strength are weaker than those with a 20% replacement strength.

However, the added strength from using Fly ash + GGBS in place of 20% of the original quantity is acceptable. The concrete's FS had surpassed that of a mix with 0% admixture replacement after 28 days.

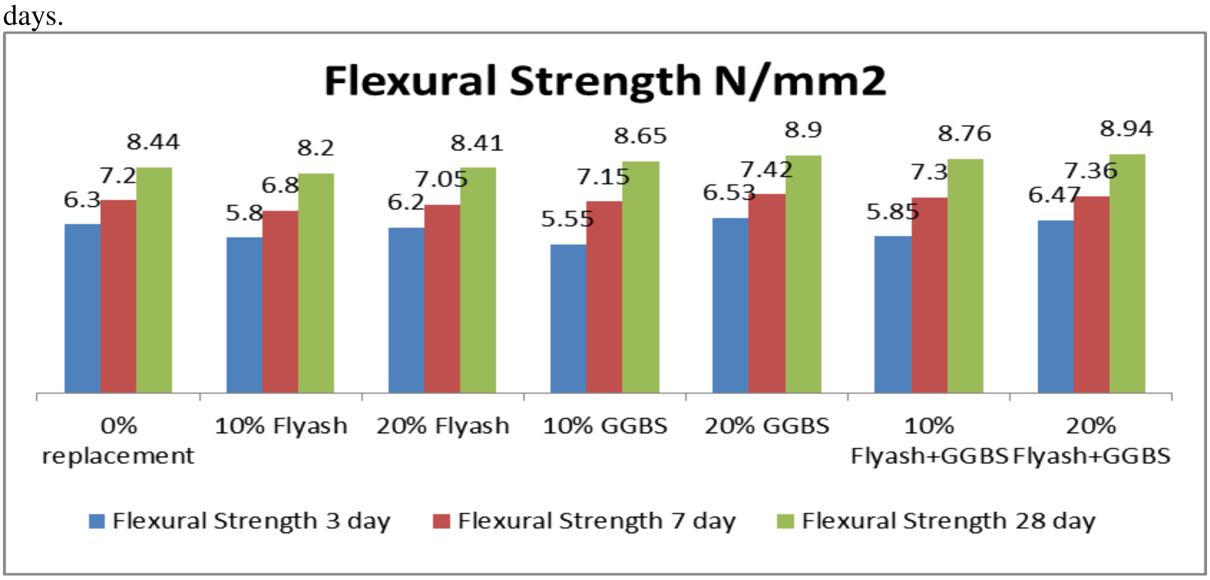


Fig 5: Flexural Strength

LOAD-STRAIN BEHAVIOUR:

The tensile strain in the GFRP reinforcement is not likely to change significantly before cracking starts. Moreover, when the load was brought closer to the fracture starting threshold, strain measurements taken on the bottom bar revealed a sharp increase. Strain measurements and the identification of first fractures agreed well.

Figure 6 displays the distributions of stress under various loads in GFRP reinforcement bars with the following specifications: X0-G, X20-G, X20-G-FA, X20-G-GGBS, X10-G-FA+GGBS, and X20-G-FA+GGBS. According to the results of the tensile test, the GFRP bars' estimated ultimate stresses ranged between 0.0069 and 0.0072, which is about the same as the bottom strains observed in GFRP beams that are close to failure.

Almost failing Top strain readings for GFRP beams ranged between 0.00018 and 0.00022. This suggests that GFRP bars were subjected to tests at high tensile strain, which would cause them to rupture.
Because of the low tensile strain measurements, we are certain that the GFRP bars inside the beam did not crack. Alternately, the steel bars were stressed beyond their breaking point, as shown by the control beam's strain measurement, which peaked at 0.0112 at beam failure from a yield value of roughly 0.004 prior to beam failure.

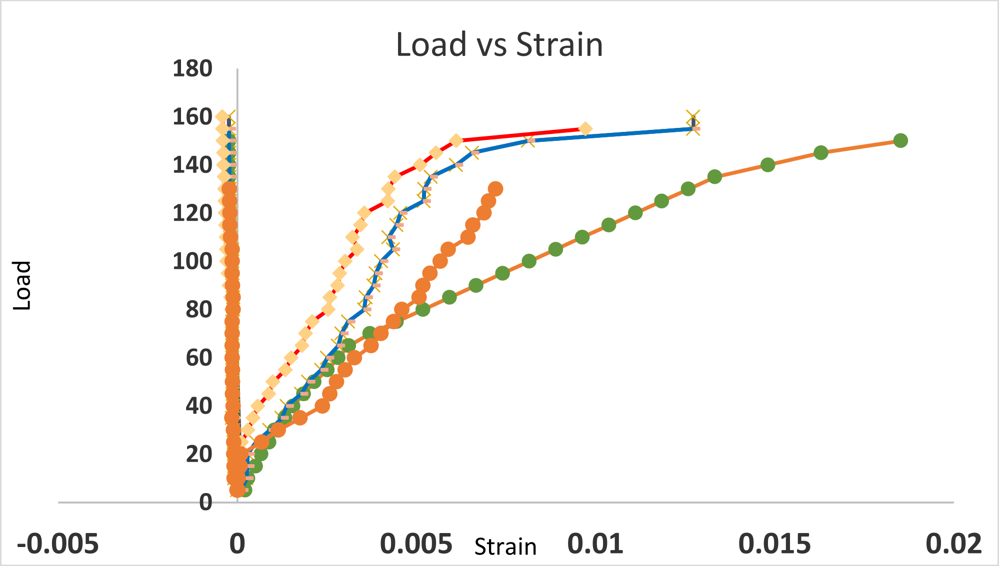


Fig 6: Load vs Strain Behavior

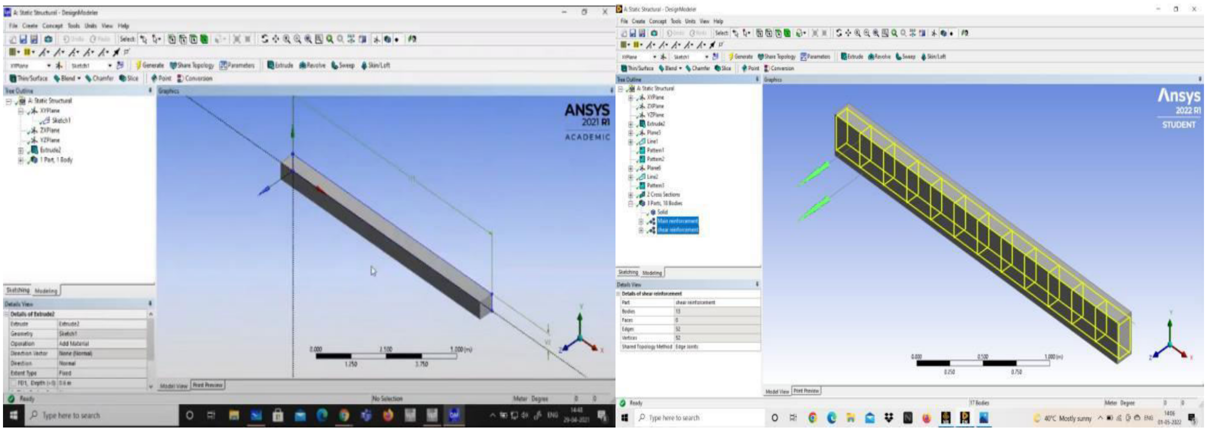
NON-LINEAR FINITE ELEMENTS ANALYSIS:

An NLFEA was used to model the flexural behaviour of GFRP-reinforced concrete beams. This procedure used the commercially available finite element analysis software tool ANSYS (ANSYS 2022 R1) Student version. The load-deflection curve, which may be the most important component of understanding the behaviour of the beams, accounts for response elements such as beam ultimate loads, initial breaking loads, and maximum deflection.

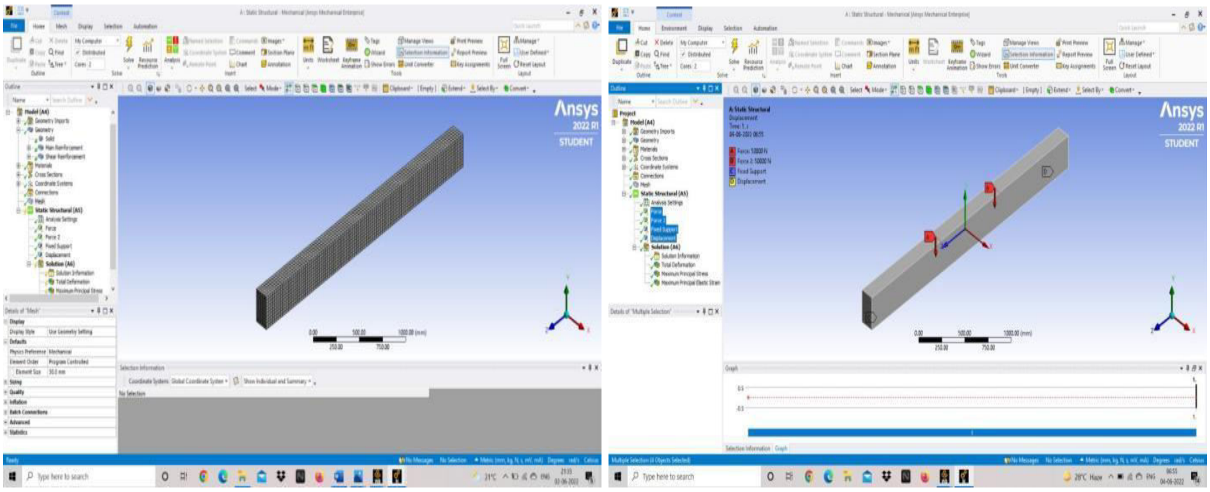
Therefore, it is thought that comparing the load-deflection relationships of the analytical findings with those of the experimental data is an appropriate method for validating the non-linear model.

The tested beams are symmetrical along the longitudinal axis midway between the supports in terms of shape, stress, and internal reinforcement. Finite element modelling was only used on half of the beams using symmetry. Each test beam was discretized using an average of 5000 3-D isoperimetric elements of Solid 65, as shown in Fig. 7.

The reinforcement along the length of the structure and the shear stirrups along the transverse axis are both simulated using the link 8 element.



(a) Concrete Element (b) Reinforcing bar element



(c) Meshing of beam element (d) Load pattern of beam element

Fig 7 : NLFEA Model of Test Beam using ANSYS

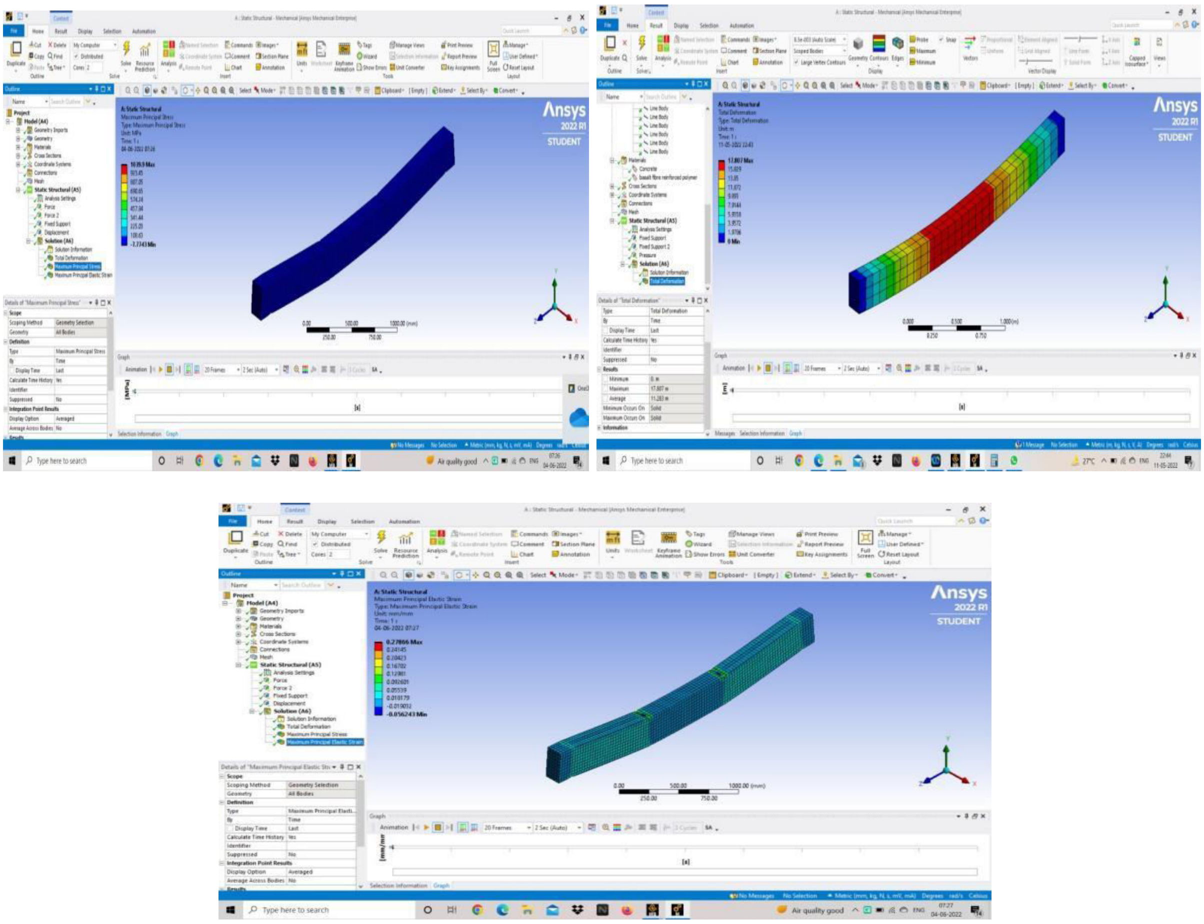


Fig 10: Analysis of Test Beam using ANSYS

EXPERIMENTAL AND ANALYTICAL RESULTS

Table 2 Experimental and Analytical Results

Beams	**Exp. results**		**Results of NLFEA**		**Numerical results / Exp.l results**	
	Load at cracking, P_{cf-exp} (kN)	Load at failure, P_{exp} (kN)	Load at Cracking, P_{cf-exp} (kN)	Load at Failure, P_{exp} (kN)	$(P_{cf-nu})/(P_{cf-exp})$	$(P_{u-nu})/(P_{u-exp})$
X0-ST	20	155	16.2	164	0.81	1.05
X0-G	15	132	13.4	146	0.89	1.1

Experimental testing of the beams is done, and the NLFEA results are contrasted with those. All of the beams cracked flexurally when the concrete's flexural strength was exceeded in the pure bending zone. The first area to display signs of breakdown was the tension zone inside and close to the constant moment area. Cracks began to appear along the shear span and spread vertically as the load, as shown in Fig. 10, was increased.

The RCC and GFRP test beams developed flexural cracks at 16.2 kN and 13.4 kN, as shown in Table 3. A mean Pc-nu/Pc-exp ratio of 0.81 and a coefficient of variation (C.O.V.) of 5.7% show that the predicted cracking loads, Pc-nu, and the experimental loads, Pc-exp, are in perfect agreement with one another. In Table 3, anticipated and experimental test specimen ultimate loads are contrasted.It was established that the analysis and experiment results were in good agreement. The RCC and GFRP test beams' ultimate flexural loads were 154 kN and 136 kN, respectively. The coefficient of variation was 16.13 percent. The analysis implicitly reflected the importance of the test parameters examined in relation to the load-carrying capability.

IV. CONCLUSION

- In this work, the flexural performance of HSSCC steel and GFRP reinforced beams under static loading was investigated. The results showed that all HSSCC beams showed a nonlinear connection up to failure. Steel-reinforced beams crack under flexure, in contrast to GFRP, which causes brittle failure in concrete. Causes of failure The steel beam that was being used as control reinforcement gave way, and it was immediately destroyed.
- In conclusion, the HSSCC performs better in both its fresh and hardened stages when 20% of the GGBS are replaced with cement and GFRP reinforcements.
- The initial strength is not changed by not replacing the concrete when compared to a 20% GGBS replacement.
- In comparison to control cube specimens, it was discovered that concrete cube specimens with 20% fly ash + GGBS replacement cement had a maximum compressive strength of 67.5 MPA.
- The split tensile results were superior to the control specimens when fly ash + GGBS was used as a 20% replacement for cement in concrete specimens.
- Flexural strength for the concrete specimens with 20% fly ash + GGBS in place of cement was 8.78 times greater than for the control specimens.
- Acceptable results were obtained for the specimens' split tensile strength, compressive strength, and flexural strength.
- The result of the beams was wider fracture widths developing as a result of the GFRP rebar's loss of stiffness. The GFRP bars, however, will not be affected by the early fracture stress because they are not corroded by their surroundings; as a result, the first crack load limitation may be slightly relaxed.
- However, when compared to steel reinforcements, non-corrosive quality GFRP produces good results for the life span of the structure, especially in worse environmental conditions. This is due to the use of GGBS and HSSCC based on fly ash as reinforcements. The beams' strength will be increased by additional tension reinforcements, which will also increase the construction's lifespan.
- Because they lacked rigidity, GFRP rebar-made beams started to crack. However, the restriction on crack width can be loosened because the environment around GFRP bars is not corrosive. Because GFRP has a lower young's modulus than steel, the bottom strain values of GFRP beams increased dramatically when compared to steel beams. Concrete's surface strain rarely varies by more than 0.003 simultaneously.

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