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Flexural Behavior of Alccofine-Incorporated Concrete Beams Reinforced with Steel and GFRP Bars

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Fiber reinforced polymers have emerged as a viable alternative to steel for reinforcing concrete structures, especially in aggressive environments. Cement-based materials remain vital in construction and are expected to maintain their significance in the future. However, these materials face increasing demands in terms of productivity, economy, quality, and environmental sustainability, as they compete with other construction materials like fly ash, ground granulated blast furnace slag (GGBS), and Alccofine. This experimental study investigates the flexural behavior of concrete beams reinforced with both steel and glass fiber reinforced polymers (GFRP), incorporating Alccofine 1203. Four beams, each measuring 150mm wide x 250mm deep and 3000mm long, were cast for the study. The concrete mix used was of M20 grade. Two pairs of beams were cast: one pair with conventional concrete reinforced with steel and GFRP bars, and another pair with Alccofine 1203 at a 14% incorporation rate, also reinforced with steel and GFRP bars. The beams were subjected to two-point loading until failure. The study examines the effects of reinforcement and Alccofine 1203 on the load-bearing capacity, deflections, crack formation, and moment capacities of the beams. The results indicate that the steel-reinforced beams failed under flexure, while the GFRP-reinforced beams exhibited brittle failure. These findings shed light on the performance of different reinforcement materials in Alccofine-incorporated concrete beams, contributing valuable insights for future construction practices and material selection.

Keywords: Alccofine 1203, Glass fiber reinforced polymers (GFRP) bars, Flexural behavior.

1. Introduction

Supplementary cementitious materials (SCMs) have gained traction in the concrete industry due to considerations of economy, environmental friendliness, and the utilization of industrial byproducts. Cement manufacturing is associated with significant carbon dioxide emissions, which adversely affect the environment. By reducing cement usage through SCM incorporation, it is possible to mitigate global warming. SCMs, such as fly ash, ground granulated blast furnace slag (GGBS), metakaolin, silica fume, and Alccofine, play a pivotal role in environmental protection while enhancing the strength and durability of concrete. Alccofine 1203 is a novel SCM utilized in concrete production. It is a high-reactivity slag with a substantial glass content, manufactured through controlled granulation. This ultrafine material comprises low calcium silicate compounds and is a nonmetallic byproduct of steel industries, containing silicates, aluminates of calcium, and other bases. The molten slag undergoes rapid cooling through quenching water, resulting in the formation of granulated material.

Fiber reinforced polymer (FRP) has emerged as an alternative to conventional steel reinforcement in concrete elements, particularly in corrosive environments. FRP, a composite material consisting of a polymer matrix reinforced with fibers such as glass fiber reinforced polymer (GFRP), carbon fiber reinforced polymer (CFRP), or aramid fiber reinforced polymer (AFRP), is widely utilized in civil engineering. FRP offers high tensile strength and non-magnetic characteristics. Manufacturing techniques for FRP bars vary, resulting in unique surface deformation patterns such as plane, ribbed, and surface-coated configurations. A notable advantage of FRP is its lighter weight compared to conventional steel reinforcement. This paper focuses on investigating the flexural behavior of conventional steel and surface-coated GFRP bars in both conventional concrete and Alccofine-replaced concrete. The study aims to evaluate how these reinforcement materials perform in different concrete compositions, shedding light on their suitability for various applications in the construction industry.

2. Experimental Investigation

2.1 Test Specimens

In this experimental study, four beams were casted and tested under two-point load conditions. The beams have a rectangular cross-section measuring 150mm wide x 250mm deep and 3000mm long, as depicted in Figure 1. Beam I and Beam II were constructed using a conventional concrete mix, reinforced with 2 No. of 12mm diameter steel bars at the tension face and 2 No. of 10mm diameter hanger bars of GFRP. Similarly, Beam III and Beam IV were made with a concrete mix where 14% of the cement was replaced by Alccofine, and reinforced with the same configuration of steel and GFRP bars. In addition to the tension face reinforcement, longitudinal reinforcements were also included. Beam I and Beam III were reinforced with 8mm diameter steel bars spaced at 150mm centers, while Beam II and Beam IV were reinforced with 8mm diameter GFRP bars at the same spacing.

Table 1 provides detailed specifications for each beam.

Beam	Concrete Mix	Tension Face Reinforcement	Longitudinal Reinforcement
I	Conventional	2 No. of 12mm dia steel bars	8mm dia steel bars at 150mm c/c
II	Conventional	2 No. of 10mm dia GFRP bars	8mm dia GFRP bars at 150mm c/c
III	Alccofine (14%)	2 No. of 12mm dia steel bars	8mm dia steel bars at 150mm c/c
IV	Alccofine (14%)	2 No. of 10mm dia GFRP bars	8mm dia GFRP bars at 150mm c/c.

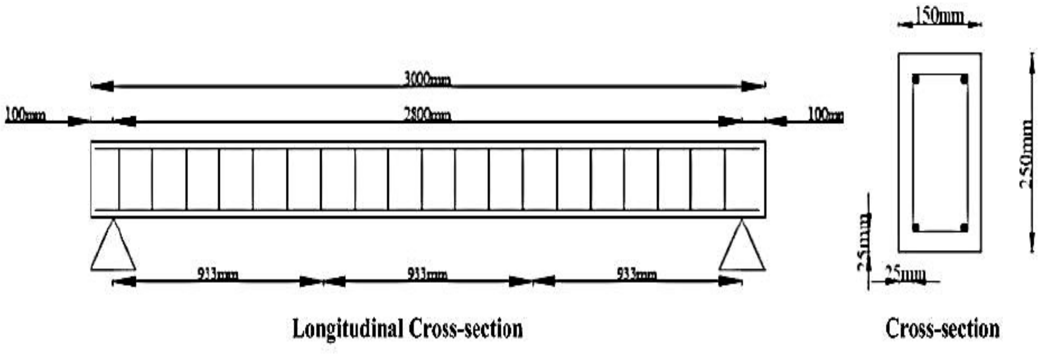

Figure:1 Cross sections of the beam

Table:1 Beam details

Mix		CC		A(14%)	
Mix Description		CC-SUR-B	CC-GUR-B	A-SUR-B	A-GUR-B
Longitudinal no.of bars and diameter	STEEL	2#12	-	2#12	-
	GFRP	-	2#12	-	2#12

2.2 Material Properties

The concrete preparation for this study involved using Ordinary Portland Cement (OPC) 53 grade, specifically Ultra-Tech Cement, in accordance with IS 12669-1987 standards. The specific gravity of the OPC was measured to be 3.15. Alccofine 1203, as per IS 16715-2018, was utilized as a replacement for cement. The specific gravity of Alccofine 1203 was determined to be 2.72. Fine aggregates comprised locally available river sand conforming to zone III specifications outlined in IS 383-1970. The specific gravity of the river sand was recorded as 2.60. Coarse aggregates retained on a 4.75mm sieve, meeting the requirements of IS 383-1970, were used, with a maximum aggregate size of 20mm. Tap water from our laboratory was utilized for concrete mixing purposes. For reinforcement, Fe550 steel (TMT) bars were employed. Plain Glass Fiber Reinforced Polymer (GFRP) rebars were treated by initially layering them with epoxy resins. Subsequently, the surface was coated with sand, and the bars were rolled, resulting in sand-coated rebars being utilized.

2.3 Reinforcement structure

The main reinforcement bars and hanger bars were properly stripped to ensure adequate adhesion with the surrounding concrete. Additionally, the stirrups were correctly tied using binding wires to provide structural integrity and support to the beams..For monitoring purposes, two strain gauges were strategically placed at the tension zone of the beams to measure the deformation under loading conditions. The reinforcement configuration of the beams is illustrated in Figure 2.

Figure:2 Reinforcement structure of beams

2.4 Mix design:

Based on IS 10262-2019, the concrete mix design for M20 grade concrete was prepared with a water-cement ratio of 0.55 to maintain workability. The mix proportions for M20 grade concrete are presented in Table 2 below: The specific quantities for each material are determined based on the design requirements and specifications outlined in IS 10262-2019 for M20 grade concrete.

Table 2 Mix proportions of concrete

Mix	Cement %	Alccofine %	Fine aggregate %	Coarse aggregate %
M1	100	0	100	100
M2	86	14	100	100

2.5 Experimental Test setup of beam:

In the experimental setup for testing the beam, the length of the beam was measured and divided into sections at distances equal to L/3. The loading frame was then adjusted to accommodate the length of the beam. A grid was drawn at the center portion of the beam to facilitate the observation of deflection during testing. The beam was placed in the loading frame under simply supported conditions. Two point loads were applied to the beam, as illustrated in Figure 3 below. The experimental setup allowed for the accurate measurement of beam deflection and the assessment of its structural behavior under loading conditions.

Figure:3 Experimental setup of testing the beam

3. Results and Discussions

3.1 Load Vs Deflection Behaviour

Before loading, the beams exhibit rigidity. As the load is gradually increased, minor cracks begin to form. With further addition of loads, additional cracks and deflection of the beams are observed at the flexural zone. From the observations, it is noted that both conventional concrete and Alccofine-replaced concrete exhibit linear elastic behavior when reinforced with GFRP, while non-linear elastic behavior is observed in steel-reinforced concrete beams.

Table : 3 Load Vs Deflection @ Ultimate Load

Beam description	Ulitimate load (kN)	Deflection at ultimate load (mm)	Moment at ultimate load (kN-m)	Crack width (mm)
CC-SUR-B	53.9	18.4	25.15	0.5
CC-GUR-B	22.1	20.94	10.31	2.3
A-SUR-B	53.9	21.05	25.15	1
A-GUR-B	27	26.155	12.6	1.6

Table : 4 Load Vs Deflection @ First crack

Beam description	Load at first crack (kN)	Deflection at first crack (mm)	Moment at first crack (kN-m)
CC-SUR-B	14.7	3.21	6.86
CC-GUR-B	9.8	3.52	4.57
A-SUR-B	9.8	1.04	457
A-GUR-B	7.4	1.185	3.45

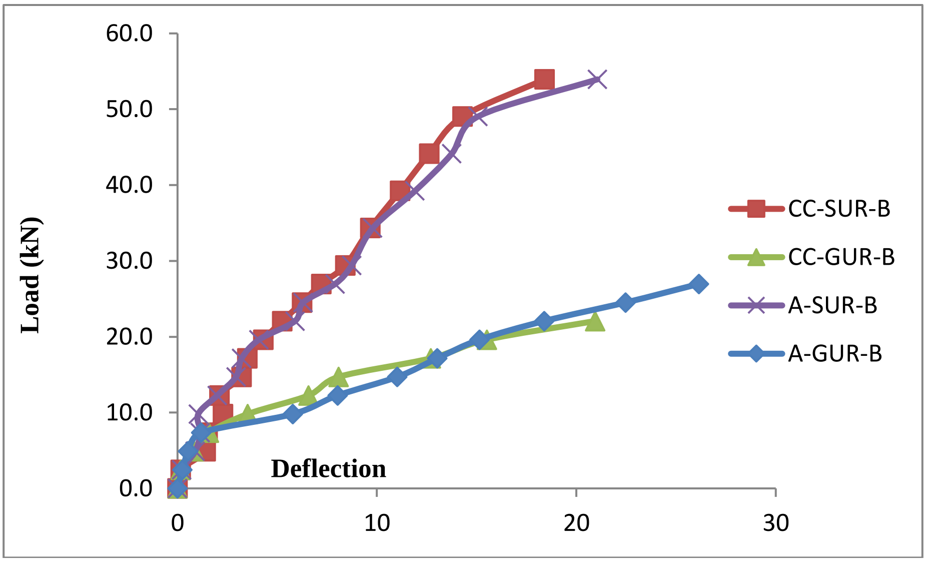

Figure :4 Load Vs Deflection of beams

3.2 Load cracking behavior

Figure: 5 shows the crack patterns of conventional concrete with reinforced steel and GFRP bars. Load was applied on the beam cracks are formed. Gradually increasing the load the crack patterns are formed at flexural zone of beam. Figure:6 shows the crack pattern of alccofine replaced concete with reinforced steel and GFRP bars. From the figures 5 & 6 GFRP bars were used beams shows the less cracks when compare to the steel reinforced concrete beams. GRP reinforced concrete beams gave higher crack widths. From Figures 5 and 6, it can be observed that when GFRP bars were used in the beams, there are fewer cracks compared to the steel-reinforced concrete beams. However, the GFRP reinforced concrete beams exhibit higher crack widths. These crack patterns provide valuable insight into the behavior of both conventional concrete and Alccofine-replaced concrete when reinforced with different materials under loading conditions.

Figure: 5 Crack paterrn of Conventioanal concrete

Figure: 6 Crack paterrn of Alccofine replaced concrete

3.3 Moment curvature behavior

Figure : 7 shows the moment curvature of reinforced steel and GFRP bars with conventional concrete and alccofine replaced concrete.The moment curvature formula as shown in below.

$$\Phi = \frac{\varepsilon c + \varepsilon st}{d}$$

εc = Compressive strain in extreme concrete fiber

εst = Strain in the tension steel

d = Effective depth of beam section

Φ =Curvature

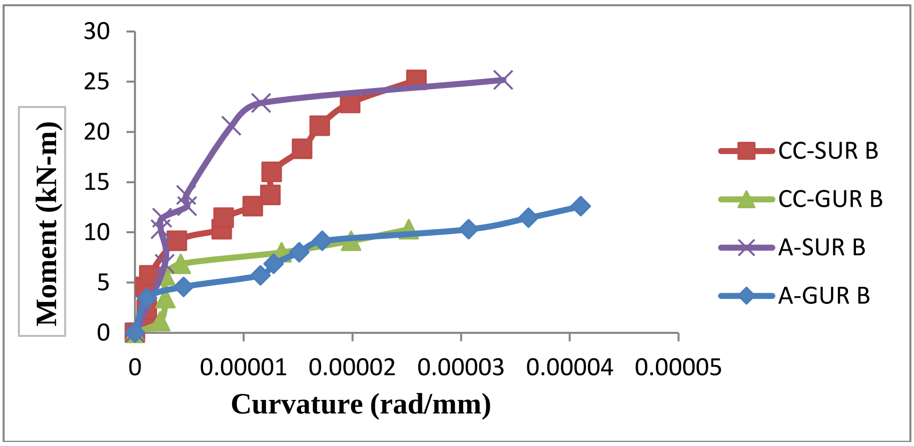

Figure : 7 shows the moment curvature of reinforced steel and GFRP bars with conventional concrete and alccofine replaced concrete.

4. Conclusion

- This study investigated the flexural behavior of concrete beams reinforced with steel and GFRP rebars in Alccofine-based concrete. The results indicated that beams reinforced with steel failed in flexure, whereas GFRP beams failed due to brittleness. GFRP exhibited a partially linear elastic condition.
- There was no observed increase in the load-bearing capacity of concrete strength. Load-bearing capacities and deflections of beams were found to be highly influenced by steel compared to GFRP reinforcement.
- Efforts were made to minimize cracks in GFRP reinforced concrete beams compared to steel-reinforced concrete beams. However, the crack width of GFRP reinforced concrete beams was higher than that of steel-reinforced concrete beams.
- Due to the brittleness of GFRP bars, sudden failures occurred in the beams, and premature cracks were also observed compared to steel-reinforced concrete beams.
- The use of GFRP bars is restricted in certain structures due to serviceability concerns. Further investigations are required to explore the potential applications and limitations of GFRP bars in concrete structures..

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