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An Empirical & Analytical Study on Composite RC Beams with Mineral Admixtures

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ABSTRACT: The project work delves into the investigation of composite reinforced concrete (RC) beams, utilizing standardized ISMB 150mm and a concrete grade of M25. An essential aspect entails exploring the influence of mineral admixtures on the concrete mixture while keeping the M25 grade consistent. The empirical phase involves experiments on both I-section beams and conventional RC beams, with a focus on flexural and compressive strength characteristics. This investigation encompasses the addition of mineral admixtures such as fly ash and GGBS. Furthermore, the project work includes conducting parallel assessments on conventional reinforced beams incorporating mineral admixtures like GGBS and fly ash for a holistic analysis. In the analytical phase, finite element modelling facilitated by ETABS software is utilized to simulate and predict the structural behavior of both composite and RC beams. To validate the deflection values from the calculated values of failure loads with ETABS modelling. Moreover, this project uses empirical formulae from ACI 318-19 (the American Concrete Institute code book) to establish the relationship between flexural and compressive strength. This aspect enriches the project work by providing a theoretical framework for interpreting experimental findings.

KEYWORDS: Concrete, Mineral admixture, GGBS, fly ash, Conventional RC beam, Composite beam, I section, ISMB150, MCFT (Modified Compression Field Theory), ETABS, Deflection.

I. INTRODUCTION

Reinforced concrete (RC) structures, recognized for their strength and versatility, have been an integral part in modern construction. In pursuit of enhancing the mechanical properties, durability, and sustainability of RC, researchers explore innovative strategies, including the incorporation of mineral admixtures. This research focuses on empirical and analytical investigations of composite RC beams, emphasizing the inclusion of mineral admixtures. Using M25 concrete grade, the study comprises of common structural configurations. The composite section's shape used is of I, specifically the ISMB150, crucial for various structural designs.

Concrete, being one of the most widely used construction materials, continuously undergoes innovations and improvements to enhance its properties and sustainability. In this context, the incorporation of mineral admixtures has emerged as a promising approach to optimize concrete performance while reducing its environmental footprint. This project entitled “An Empirical & Analytical Study on Composite RC Beams with Mineral Admixtures” explores the effects of mineral admixtures, namely Fly ash & GGBS, on the mechanical properties of reinforced concrete beams. The beams were cast with a dimension of 150x150x700mm and for I Section Beam ISMB 150 was selected and subjected to different replacement levels of cement with fly ash and GGBS (0%,10%, 20%, and 30%). The concrete mix proportion adhered to the M25 grade as per the guidelines provided in the Indian Standard (IS) code book (IS 10262-2019).

The experimental investigation involved the fabrication of thirty-two beams, each containing different combination of mineral admixtures. sixteen beams were designated for flexural strength testing, while the remaining sixteen were allocated for compressive strength testing. All specimens were cured under standard conditions and tested at the age of 28 days. Furthermore, an analytical study using ETABS software was conducted. The use of ETABS enables the application of Finite Element Modelling (FEM) techniques to simulate the behaviour of beams under varying loading conditions. The utilization of mineral admixtures not only enhances the mechanical properties of concrete but also promotes the utilization of industrial by-products, thereby reducing waste and environmental impact. Moreover, the findings from this study can inform engineers and practitioners in the selection and optimization of concrete mixtures for structural applications. In a departure from conventional approaches, this study concurrently evaluates both I-section composite RC beams and conventional RC beams, each subjected to mineral admixtures like GGBS and fly ash with varying percentages. To dissect structural nuances, the research employs a finite element model through ETABS software, promising detailed insights into stress distribution, deformation patterns, and potential failure modes.

II. OBJECTIVES

- Assess Flexural Strength and Compressive strength:** Determine the flexural & Compressive strength of the RC & I Section beams with varying percentage of mineral admixtures.
- To Investigate the Influence of Mineral Admixtures:** Examine the impact of varying percentage of mineral admixtures, on the mechanical properties of RC & I Section ISMB beams.
- Employ Finite Element Modelling:** Utilize the finite element model implemented through ETABS software to simulate and predict the structural behaviour of the beams & validate the deflection value from experimental values.
- Employing Empirical Formulae:** To relate the relationship between Flexural & Compressive Strength from MCFT theory (Modified Compression Field Theory).

III. METHODOLOGY

Conventional RC beams and composite RC beams (ISMB150) were fabricated. A consistent concrete grade of M25 was employed across all specimens to maintain a uniformity for comparison. For conventional RC beams, dimensions of 150x150x700 mm were used, with 10 mm main bars and 8 mm stirrups at 150 mm C/C. For composite RC beams, an I-section of ISMB150 with a length of 700 mm was used. Mineral admixtures such as fly ash and GGBS were introduced into the concrete mixture in varying percentages (10%, 20%, and 30%). These admixtures were selected to assess their individual and combined effects on the structural performance of both conventional and composite RC beams. The concrete mixture was prepared by combining the chosen mineral admixtures with conventional concrete materials. This blend aimed to evaluate the practical applicability of mineral admixtures and their impact on structural behavior while adhering to a fixed M25 grade. Both conventional and composite RC beams were cast, ensuring uniformity in size and material composition. A variety of specimens, each incorporating different mineral admixtures, were prepared. The prepared beams were subjected to experimental testing, including the determination of flexural strength, compressive strength, and deflection under various loading conditions. The structural behavior of the conventional and composite RC beams was analyzed using a finite element model. ETABS software was employed to simulate and predict the response of the beams to different loading scenarios. Data collected from both the empirical and analytical phases were analyzed and compared to assess the influence of mineral admixtures on the structural performance of the conventional and composite RC beams.



(a) Conventional Beam



(b) Composite I section



(c) Mineral admixture

IV. EXPERIMENTAL RESULTS

1. Flexural Strength (IS:516-1959):

The flexural strength test is conducted to evaluate the load-carrying capacity of Conventional RC beams and Composite beams. This test is essential for assessing the structural performance of these elements under bending loads, which is critical for structural design and analysis. The test is performed according to Indian Standard IS 516:1959 "Method of Tests for Strength of Concrete".

Flexural Strength of RC Beam (150x150x700)

Sl .no	Percentage of Admixtures	Weight of the beam (kg)	Length of the beam (mm) (L)	Load at Failure (P) (KN)		Flexural Strength (fb) N/mm ²		
				1.	2.	1.	2.	Avg
1.	0%	41.560	700	82.92	81.94	25.80	25.49	25.65

2.	10%	41.080	700	94.49	93.55	29.39	29.11	29.25
3.	20%	41.470	700	79.03	77.02	24.58	23.97	24.27
4.	30%	40.870	700	77.38	75.64	24.07	23.53	23.80

Flexural Strength of I Section Beam ISMB 150

Sl.no	Percentage of Admixtures	Weight of the beam (kg)	Length of the beam (mm) (L)	Load at Failure (P) (KN)		Flexural Strength (fb) N/mm ²		
				1.	2.	1.	2.	Avg
1.	0%	40.140	700	107.87	104.33	33.54	32.454	32.99
2.	10%	41.060	700	142.81	144.55	44.34	44.97	44.66
3.	20%	41.210	700	122.58	119.25	38.13	37.10	37.62
4.	30%	40.980	700	114.74	116.33	35.69	36.19	35.94

2. Compressive strength (IS 516-1959):

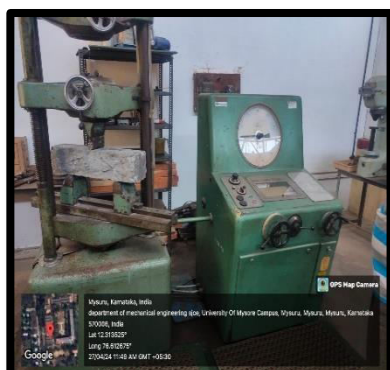
The compressive strength test is conducted to evaluate the ability of concrete to withstand axial compressive loads. This test is essential for assessing the quality and durability of concrete used in structural elements such as Conventional RC beams and Composite beams. The test is performed according to Indian Standard IS 516:1959 "Method of Tests for Strength of Concrete"

Compressive Strength of RC Beam (150x150x700)

Sl.no	Percentage of Admixtures	Area (mm ²)	Length of the beam (mm) (L)	Load at Failure (P) (KN)		Compressive Strength N/mm ²		
				1.	2.	1.	2.	Avg
1.	0%	22500	700	646	639	28.71	28.4	28.56
2.	10%	22500	700	725	728	32.22	32.35	32.29
3.	20%	22500	700	658	655	29.15	29.11	29.13
4.	30%	22500	700	610	612	27.11	27.20	27.16

Compressive Strength of I Section Beam ISMB 150

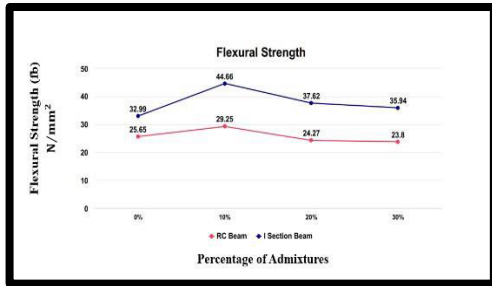
Sl.no	Percentage of Admixtures	Area (mm ²)	Length of the beam (mm) (L)	Load at Failure (P) (KN)		Compressive Strength N/mm ²		
				1.	2.	1.	2.	Avg
1.	0%	22500	700	714	719	31.73	31.96	31.84
2.	10%	22500	700	797	802	35.42	35.64	35.53
3.	20%	22500	700	736	733	32.71	32.57	32.64
4.	30%	22500	700	718	726	31.91	32.26	32.08



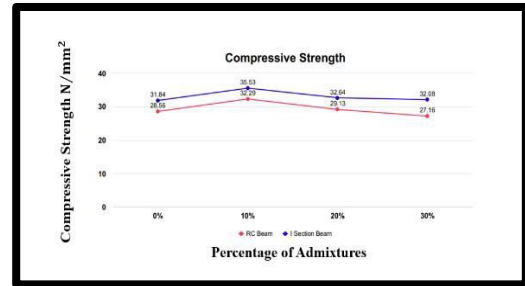
(d) Flexural Strength test



(e) Compression Strength test



(f) Graphical Comparison of Flexural Strength



(g) Graphical Comparison of Compressive Strength

V. EMPIRICAL FORMULAE

Empirical Formulae:

The empirical relationship between flexural strength and compressive strength of reinforced concrete (RC) beams is typically governed by various factors such as the concrete mix design, the reinforcement ratio, and the dimensions of the beam. However, one commonly used empirical relationship is the (Modified Compression Field Theory) MCFT, proposed by **Prof. Zdenek P. Bazant** and others which provides a rational basis for predicting the load-carrying capacity of RC beams.

The typical equation representing the MCFT relationship for flexural strength (M_{cr}) in terms of compressive strength (f_c) is

$$M_{cr} = k_1 \times k_2 \times \sqrt{f_c} \times b \times d^2$$

Comparison of Flexural Strength (RC Beams)

Sl. No	Mineral Admixture	Avg Compressive Strength (N/mm ²)	Coefficient		Flexural Strength M_{cr} (N/mm ²)		% Variation
			k1	k2	Predicted Strength	Experiment Strength	
1.	0%	28.56	0.45	0.0080	45.09	25.65	54.96
2.	10%	32.29	0.45	0.0081	47.94	29.25	46.55
3.	20%	29.13	0.45	0.0080	45.53	24.27	60.12
4.	30%	27.16	0.45	0.0080	43.97	23.80	59.52

Comparison of Flexural Strength (I Section Beams)

Sl. No	Mineral Admixture	Avg Compressive Strength (N/mm ²)	Coefficient		Flexural Strength M_{cr} (N/mm ²)		% Variation
			k1	k2	Predicted Strength	Experiment Strength	
1.	0%	31.84	0.45	0.0081	47.61	32.99	36.29
2.	10%	35.53	0.45	0.0081	50.92	44.66	13.10
3.	20%	32.64	0.45	0.0081	48.81	37.62	25.90
4.	30%	32.08	0.45	0.0081	48.38	35.94	29.51

VI. ETABS ANALYSIS

The analytical analysis of Conventional & Composite RC beams using ETABS yielded valuable insights into their structural behavior and performance. The results obtained from ETABS analysis were compared with the experimental values obtained after 28 days of curing of both RC beams and I-sections beams.



The results obtained from ETABS analysis were found to be quite similar to those obtained from the experimental method conducted. The close agreement between analytical and experimental results validates the accuracy and reliability of the ETABS software in predicting the structural behavior of both Conventional RC beams & composite RC beams. The strong agreement between analytical and experimental findings enhances confidence in the structural design and performance of Conventional RC Beams & composite beams.

The **deflection of a beam** refers to the displacement of the beam under load, typically measured perpendicular to its longitudinal axis. It's a critical aspect of structural analysis and design, as excessive deflection can affect the structural integrity and functionality of a building or structure. Deflection specifically measures the vertical displacement that occurs along the length of the beam when loads are applied.

Deflection values are validated from the ETABS to the values obtained from the experimental method (Failure flexural loads).

The formula for determining deflection for SSB Point Load at mid span of the beam is given by

$$\delta = \frac{W \times l^3}{48 \times E \times I}$$

Deflection Values RC Beam (150×150×700)

Sl. No	Mineral Admixtures	RC Beam (Failure Load) KN			Calculated Deflection δ (mm)	ETABS Deflection δ (mm)
	Conventional concrete	1.	2.	Avg		
1.	0%	82.92	81.94	82.38	0.51	0.53

Deflection Values I Section ISMB 150

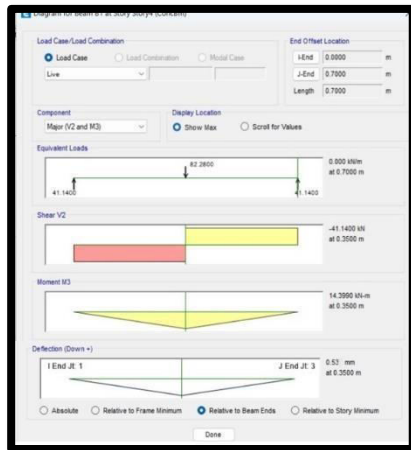
Sl. No	Mineral Admixtures	RC Beam (Failure Load) KN			Calculated Deflection δ (mm)	ETABS Deflection δ (mm)
	Conventional concrete	1.	2.	Avg		
1.	0%	107.87	104.33	106.10	0.49	0.50

Since the deflection value obtained is almost identical to that of ETABS for conventional concrete, we can conclude that the deflection of beams with concrete incorporating mineral admixtures at varying replacement percentages of 10%, 20%, and 30% will also be similar. As per **IS 456:2000** the maximum allowable deflection of beam in SSB is

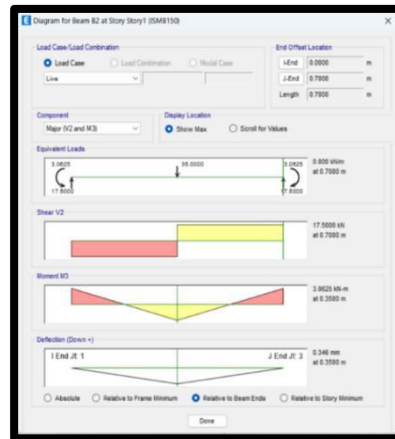
$$\delta_{permissible} = \frac{\text{Span}}{350}$$

$$\delta_{\text{permissible}} = \frac{700}{350} = 2 \text{ mm} > 0.5 \text{ mm.}$$

Hence the Deflection of the beam is under permissible limits.



(h) RC Beams ETABS



(i) I section Beams

VII. CONCLUSION

1. The present work shows that the use of mineral admixtures, such as GGBS and fly ash, influences the mechanical properties of conventional RC beams and composite beams. Therefore, when incorporating these mineral admixtures, mix designs should be optimized to achieve the desired strength and durability characteristics in concrete structures. This approach advances the efficiency and sustainability of construction practices.
2. The analysis revealed 18% strength increase in RC beam and 30% increase in Composite beams in both flexural and compressive strengths with the incorporation of mineral admixtures, particularly at lower replacement percentages (up to 10%).
3. However, diminishing incremental improvements were also observed as the replacement percentage increased this is due to GGBS and Fly Ash having slower hydration rates & Replacing cement with a higher proportion of mineral admixtures reduces the amount of cementitious material available to form calcium silicate hydrate (C-S-H), which is the primary compound responsible for the strength of concrete.
4. It is seen that Composite I section beams exhibit 25% more strength than conventional RC beams hence from this it is concluded that by adopting Composite I Section beams more strength can be achieved at same Cross section of the member.
5. The results from ETABS analysis and experimental testing demonstrates the applicability of the software. This consistency reaffirms the accuracy and reliability on ETABS in simulating the behavior of structures, providing valuable insights for engineering applications.
6. The deflection values obtained from ETABS & manual calculation were found almost equal which validates the use of software for predicting & design purpose.
7. The Modified Compression Field Theory (MCFT) predicts flexural strength based on compressive strength, but its estimates can vary from experimental values by 45% to 60% for Conventional RC Beams and 13% to 37% for Composite I-section beams. This variation arises because MCFT relies on simplifying assumptions, such as uniform stress and strain fields, perfect bond between concrete and reinforcement, and specific stress-strain relationships. These ideal conditions are often not met in practice, leading to significant variations between theoretical predictions and experimental results.

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