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An Experimental Investigation on Partial Replacement of Cement by Metakaolin and Coarse Aggregate by Iron Slag on M25 Grade Concrete

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Abstract: This study investigates the properties of M25 grade concrete, Cement as a partial replacement by Metakaolin and coarse aggregate by iron slag. Metakaolin is a dehydroxylated form of the Kaolin clay mineral. Various concrete mixtures were prepared by replacing cement with Metakaolin at varying percentages like 5%,6%,7% and 8% while maintaining the water-cement ratio. With optimum percentage of Metakaolin, various concrete mixes were prepared by replacing coarse aggregate by iron slag at percentages 10%, 20%, 30% ,40% and 50%. The experimental program included tests for compressive strength and flexural strength at different curing ages 7, 28, 56 and 90 days.
Keywords: Cement, Metakaolin, Compressive strength, flexural strength, iron slag.

I. INTRODUCTION

Concrete is commonly used construction material across the world and widely used in civil engineering works, including infrastructure, low- and high-rise buildings. Metakaolin is a manufactured pozzolanic mineral admixtures which may be performance characteristics of cement-based concrete. Iron slag is a by-product that comes from the iron and steel making process. The Ordinary Portland Cement is one of the materials commonly used for construction purpose. While cement production environmental problems cause such as CO_2 gas released into the atmosphere. So, to reduces this problem the construction industry used alternate materials such as fly ash, Metakaolin, slag, rice husk ash and Metakaolin.

II. LITERATURE REVIEW

J. Ramakrishna, R. Gopi [1] The journal investigates the use of rice husk ash (RHA) as a partial replacement for cement and steel slag as a replacement for coarse aggregate in concrete, aiming to create an economical and eco-friendly mix. From the study, it is understood that RHA improves the pozzolanic reaction of concrete because of its high silica content, while steel slag provides good hardness and durability as an aggregate. The research shows that replacing cement with 20% RHA and coarse aggregate with up to 25% steel slag gives the best performance, where the concrete’s compressive, tensile, and flexural strengths increase moderately compared to normal concrete. Although workability reduces with higher waste material content, the hardened properties significantly improve, and the concrete becomes denser and more durable. Overall, the journal concludes that using RHA and steel slag is a sustainable and effective method to enhance concrete properties while reducing reliance on natural materials and lowering environmental impact.

Deepram Meena [2] The journal explains how rice husk ash (RHA), silica fume (SF), and iron slag (IS) can be used as partial replacements for cement to create more sustainable and eco-friendly concrete. The study highlights that these waste materials help reduce environmental pollution, lower construction costs, and improve concrete performance. Experimental results show that replacing cement with a combined mix of RHA, silica fume, and iron slag significantly enhances both compressive and flexural strength up to an optimum replacement level of around 21%, after which the strength begins to decline. The 7-day, 14-day, and 28-day strength graphs clearly indicate that the best mechanical performance occurs at this 21% combined addition, reaching maximum compressive strengths of 29.4 MPa (7 days), 37.67 MPa (14 days), and 43.8 MPa (28 days). Flexural strength also follows a similar trend, showing peak values at the same replacement percentage. Overall, the journal concludes that using RHA, silica fume, and iron slag together improves concrete strength, supports sustainable construction practices, and provides a practical method to reuse industrial and agricultural waste materials.

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E Sandhyarani and Ch Srinivasa Rao [3] The journal studies how concrete behaves when fine aggregate is partially replaced with steel slag and cement is replaced with metakaolin and glass powder at different levels (0%, 10%, 20%, and 30%). The experimental results show that adding these industrial waste materials significantly improves the mechanical properties of concrete—especially compressive, tensile, and flexural strength—when compared to normal concrete. Strength tests conducted at 7 and 28 days demonstrate that the maximum improvement occurs around 30% replacement, where the concrete becomes stronger and more resistant to chemical attack. The study concludes that steel slag, metakaolin, and glass powder not only enhance concrete performance but also help in producing sustainable, cost-effective, and eco-friendly concrete by reducing the use of natural materials and utilizing waste resources efficiently.

III. EXPERIMENTAL INVESTIGATION

A. *Concrete Properties*

This concrete contains Ordinary Portland Cement 43 grade, fine aggregate with fineness modulus 2.7 confirming to zone-2, Coarse aggregate with a maximum size of 20mm, water-cement ratio of 0.49 for M25.The aim of this research is to use Metakaolin and iron slag as replacement of cement and coarse aggregate. The concrete cubes were prepared with Metakaolin for 0%, 5%, 6%, 7% and 8% and tested for 7 and 28 days for compressive strength test to obtain optimum percentage of Metakaolin, by taking optimum percentage remaining cubes and beams were casted for 56 and 90 days for compressive strength and 7, 28, 56 and 90 days for flexural strength. Then maintaining the same percentage of Metakaolin and iron slag is replaced with coarse aggregate of percentage 10%, 20%, 30%, 40% and 50% the cubes were casted for 7 days for compressive strength test to obtain optimum percentage of iron slag, By taking optimum percentage, remaining cubes and beams were casted for 28, 56 and 90 days for compressive strength and 7, 28, 56 and 90 days for flexural strength.

B. *Mix Design*

Mix design is done according to IS code method and trial mixes were conducted to obtain the target strength of M25 grade concrete. Once the target strength obtains, it is used to cast concrete with 0%, 5%, 6%, 7% and 8% replacement of cement with Metakaolin and maintaining the optimum percentage of Metakaolin, it is used for cast concrete with 10% 20%, 30%, 40% and 50% of iron slag is replaced with coarse aggregate. This concrete is casted to find compressive strength and flexural strength. The mix proportion is shown in below table.

Grade	Cement	Fine aggregate	Coarse aggregate	Water
M25	320	716	1222	157
	1	2.24	3.82	0.49

IV. RESULTS AND DICUSSION

A. *Compressive strength test*

Compressive test is carried out on specimen of cubical size 150mm x 150mm x 150mm. compressive test is confirming to IS:516-1959.

Formula Compressive strength = $\frac{failure\ load}{cross\ section\ area}$

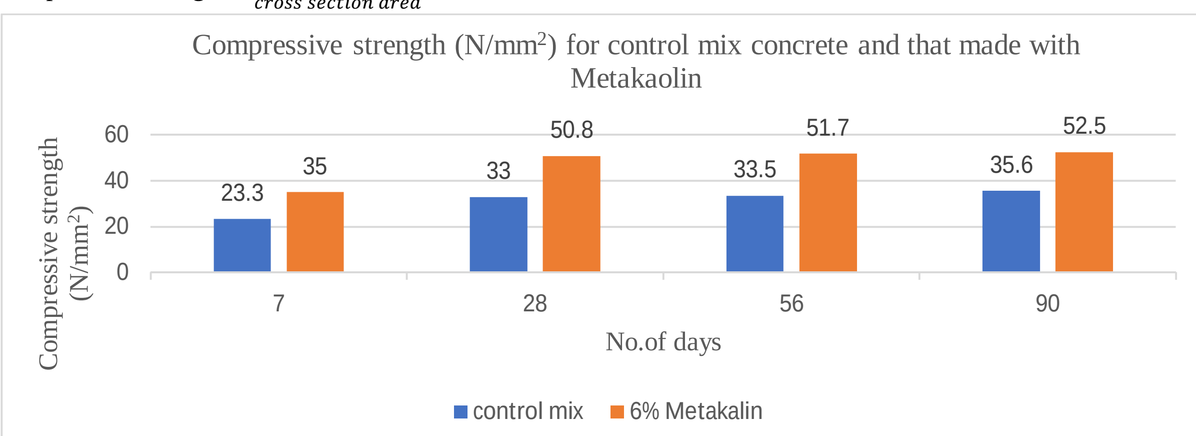

Fig 1: Variation of compressive strength for control mix concrete and that made with cement replaced by 6% Metakaolin concrete and cured for 7, 28, 56 and 90 days

The bar chart shows the compressive strength of control mix concrete and 6% Metakaolin concrete. For 7days curing we found 23.3 N/mm^2 in control mix and 35 N/mm^2 in 6% Metakaolin concrete. Similarly for maximum curing 90 days we found 52.5 N/mm^2 in 6% Metakaolin concrete.

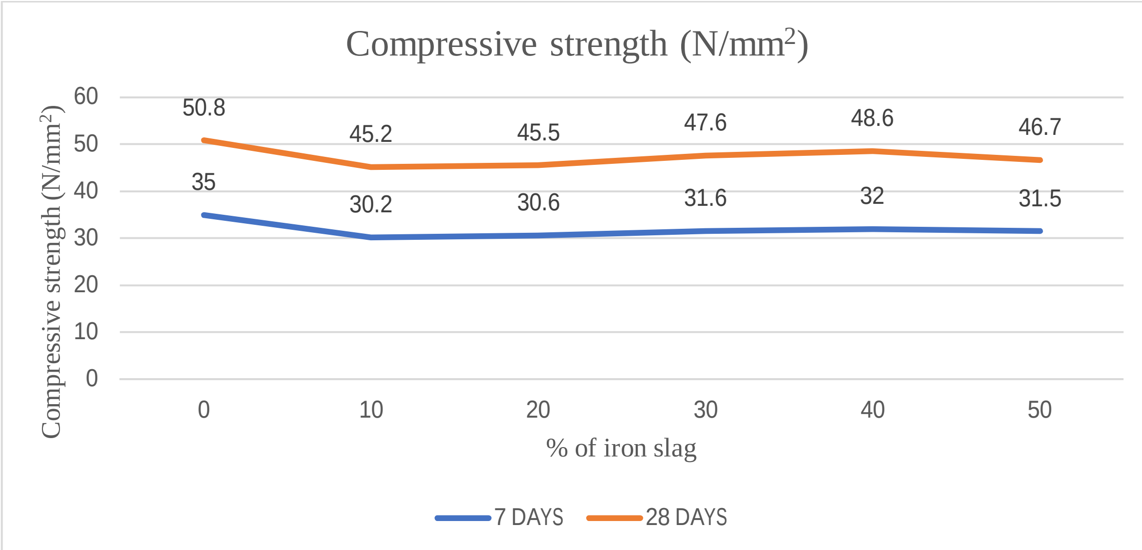

Fig 2: Compressive strength of Concrete at Optimum of Metakaolin and Various Percentage of iron slag at 7 and 28 days

The above bar chart shows the compressive strength of concrete with 6% Metakaolin and different percentage of iron slag, by maintaining Metakaolin percentage for all different percentage of iron slag. At 40% percentage mix it shows the optimum percentage of iron slag.

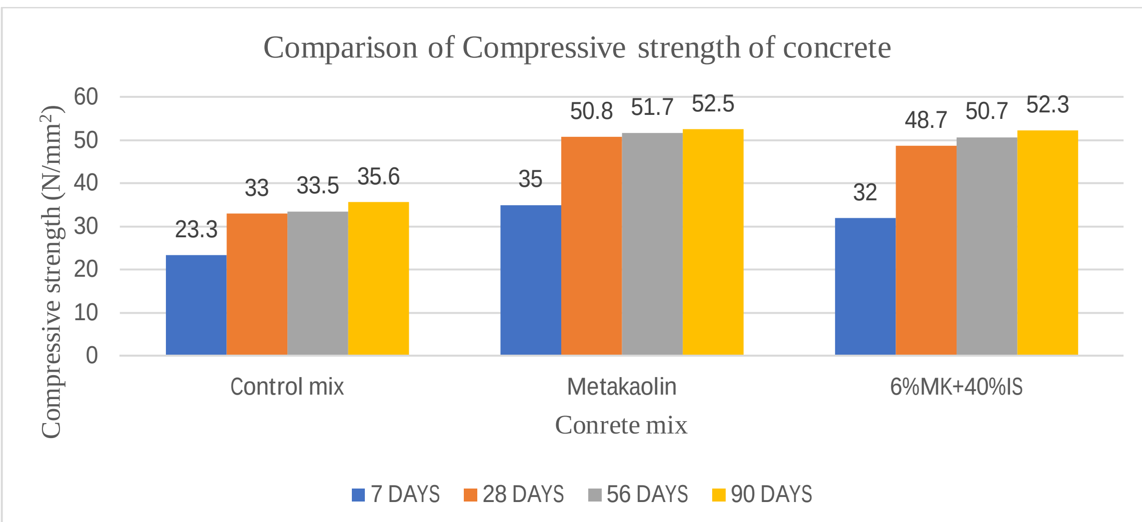

Fig 3: Comparison of Compressive strength of concrete with control mix, 10% Metakaolin and 40% iron slag at 7, 28, 56 and 90 days of curing.

V. FLEXURAL STRENGTH TEST

The flexural strength can be determined by standard test method of two point loading. Flexural strength is crucial in concrete because it indicates the concrete ability to resist bending flexural stress. The beam of size 150mm x 150mm x 700mm was used to find flexural strength.

Formula: MR = $\frac{PL}{bd^2}$

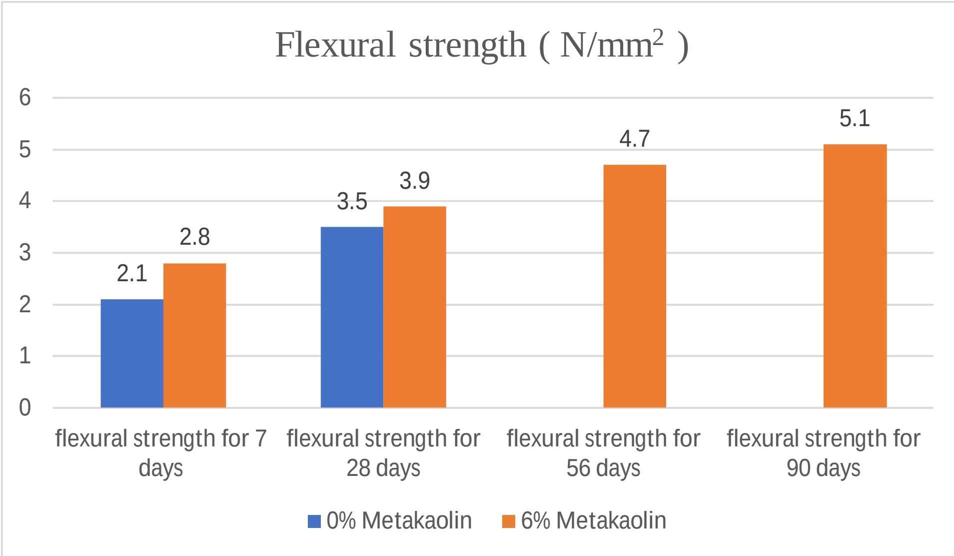

Fig 4: Flexural strength at 7, 28, 56 and 90 days of curing with 0 and 6% Metakaolin

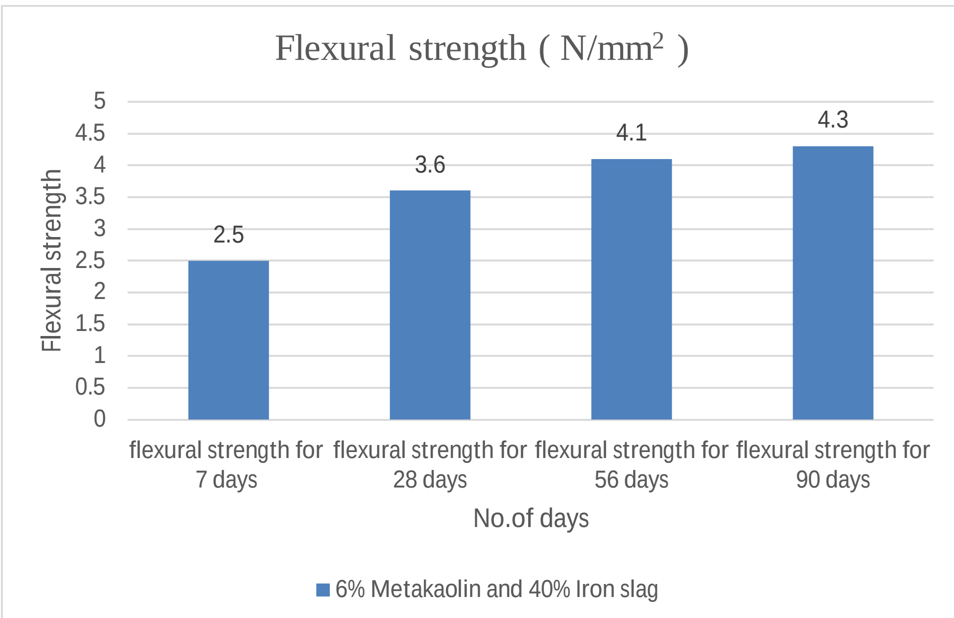

Fig 5: Flexural strength of concrete with 6% Metakaolin and 40% iron slag

From the experimental results, it is evident that the incorporation of Metakaolin and iron slag significantly enhances the mechanical properties of M25 grade concrete. The compressive strength graph shows a notable improvement when cement is partially replaced with 6% Metakaolin, where the strength increased from 23.3 MPa in the control mix to 35 MPa at 7 days, and continued to develop up to 52.5 MPa at 90 days. This enhancement is mainly due to the pozzolanic reaction of Metakaolin, which refines the microstructure and produces additional C–S–H gel. When iron slag is introduced as a replacement for coarse aggregate, the mix containing 6% Metakaolin and 40% iron slag exhibited the optimum performance, indicating that slag contributes to denser packing and improved interlocking. The flexural strength results also follow a similar trend, showing higher bending resistance for mixes with Metakaolin and iron slag compared to normal concrete. Overall, the combined use of 6% Metakaolin and around 40% iron slag not only increases compressive and flexural strength but also enhances long-term durability, making it a sustainable and efficient alternative to conventional concrete materials.

VI. CONCLUSION

1) The compressive strength of concrete with 6% Metakaolin in cement increases the strength up to 53% when compare to normal concrete at 28 days.
2) The compressive strength of concrete with 6% Metakaolin and 40% iron slag increases the strength up to 47% when compare to normal concrete at 28 days.
3) The flexural strength of concrete contains 6% Metakaolin increases the strength up to 12% will compare to normal concrete.
4) The flexural strength of concrete contains 6% Metakaolin and 40% iron slag increases the strength up to 4% when compare to normal concrete.

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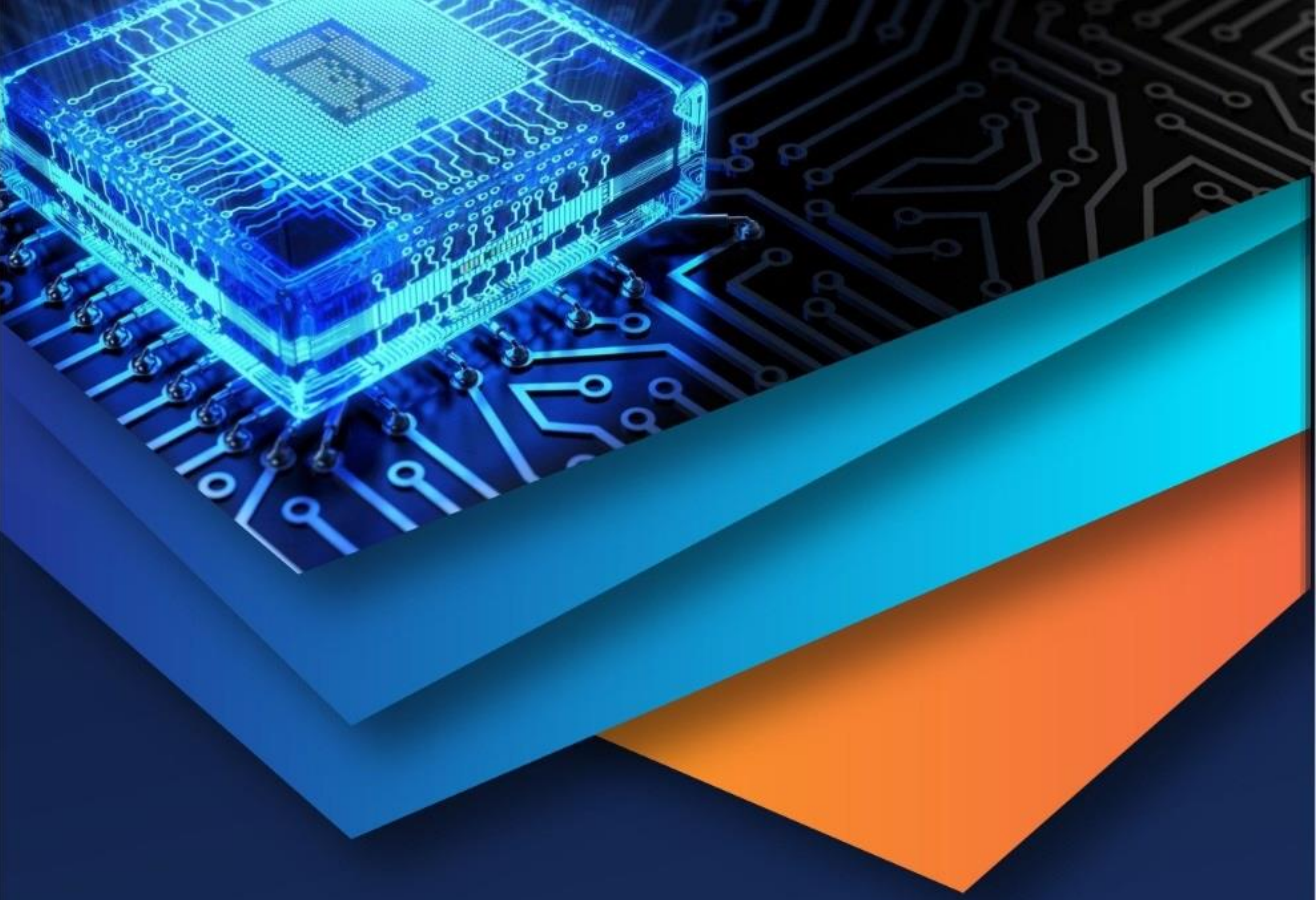

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