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Influence of Metakaolin and Recron 3S Fiber on Mechanical Properties of GGBS Blended Concrete

Racharla Babu Thomas[1], Dr. T. V. S. Vara Lakshmi[2]
[1]Research Scholar, [1]Department of Civil Engineering, [1]Dr.Y.S.R. Acharya Nagarjuna University, India
[2]Assistant Professor, Department of Civil Engineering, [2]Dr.Y.S.R. Acharya Nagarjuna University, India

ABSTRACT : *This experimental study evaluates the mechanical performance of M40 concrete in which 40% Ground Granulated Blast Furnace Slag (GGBS) replaces ordinary Portland cement (OPC) and metakaolin (MK) is varied at 5%, 10%, 15%, and 20% by binder weight while Recron 3S fiber (RF) is fixed at 0.35% by binder weight. Compressive, split tensile, and flexural strengths were measured at 7 and 28 days. Results show that the 15% MK blend produced the best overall mechanical performance in the revised dataset at 28-days compressive strength 58.99 MPa; split tensile 3.25 MPa; flexural 10.75 MPa. The ternary blend reduces OPC consumption and improves toughness and crack resistance while meeting structural strength requirements.*
Keywords: *GGBS; Metakaolin; Recron 3S fiber; Compressive strength; Split tensile; Flexural strength.*

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I.INTRODUCTION

Concrete production is a major contributor to global CO_2 emissions; replacing a portion of OPC with supplementary cementitious materials (SCMs) such as GGBS and MK reduces embodied carbon and can improve durability and long-term strength. Synthetic fibers like Recron 3S enhance post-crack behavior and toughness. This work adapts an existing experimental program and reports a revised dataset for mixes with 40% GGBS and 0.35% Recron 3S fiber**,** varying MK from 5% to 20%**.** The objective is to identify the MK level that optimizes mechanical performance while maximizing cement replacement.

II.LITERATURE REVIEW

- Lopez Alvarez et al**.** investigated steel fiber-reinforced cement mortars with metakaolin and limestone, finding that early-age compressive strength increased by approximately 12% to 15% depending on the fiber volume. They also noted improved corrosion resistance through enhanced electrical resistivity. While flexural strength improved with higher fiber content, variations in metakaolin and limestone had a minimal impact of less than 3% on flexural performance.
- Nanda et al**.** studied M30 concrete with fly ash, metakaolin, and Recron 3S fiber, identifying an optimal mix 10% fly ash, 5% MK, 0.2% fiber that enhanced compressive, split tensile, and flexural strengths by 6.92%, 4.50%, and 3.83%, respectively. The study emphasized sustainability through significant cement reduction.
- Reddy and Rao optimized ternary blended concretes with micro silica and GGBS, achieving an increase in compressive strength of up to 22% with a combination of 10% micro silica and 30% GGBS. This gain was attributed to superior pozzolanic activity and a more densified microstructural matrix.
- Anto et al. confirmed that 0.75% Recron fiber by weight enhances crack resistance and mechanical properties in fly ash concrete, reporting a 10% to 12% improvement in split tensile strength and a notable increase in impact resistance.
- Priya et al. demonstrated that replacing partial cement with sawdust powder and GGBS can improve mortar compressive strength by up to 8% while significantly enhancing thermal insulation properties for eco-friendly construction.
- Elavarasan et al. reported that a 20% replacement of cement with a GGBS and MK blend yielded the highest performance in M25 concrete, with increases of 14.5% in compressive strength, 11.2% in split tensile strength, and 9.8% in flexural strength.
- Manjunatha et al. found that combining engineered fibers with GGBS and PVC waste powder in M50 concrete maintained or improved mechanical properties, with compressive strength gains of roughly 5% to 7% when using optimal fiber dosages.

- Richhariya et al**.** developed ultra-lightweight cement using cenosphere and Recron fiber, achieving a high compressive strength increase of 18% and flexural strength gains of 14%, making it highly effective for specialized structural applications.

III.MATERIAL USED

Cement

Ordinary Portland Cement (OPC) 53 grade conforming to IS: 12269 was used. It contains lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3), with tricalcium silicate (C_3S) and dicalcium silicate (C_2S) as main strength contributors. Gypsum (3–5%) controls setting time.

Table 1. Chemical Composition of Cement

Constituent	Percentage (%)
Calcium Oxide (CaO)	60–67
Silicon Dioxide (SiO_2)	17–25
Aluminum Oxide (Al_2O_3)	3.0–8.0
Iron Oxide (Fe_2O_3)	0.5–6.0
Magnesium Oxide (MgO)	0.1–4.0
Sulphur Trioxide (SO_3)	1.3–3.0
Loss on Ignition (LOI)	0.5–3.0

Ground Granulated Blast Furnace Slag (GGBS)

A byproduct of the steel industry, GGBS has chemical composition similar to cement, mainly CaO (~40%) and SiO_2 (30–40%). It improves long-term strength, workability, durability, and reduces heat of hydration.

Table 2. Chemical Composition of GGBS

Constituent	Percentage (%)
Calcium Oxide (CaO)	34–43
Silicon Dioxide (SiO_2)	27–38
Aluminum Oxide (Al_2O_3)	7–15
Magnesium Oxide (MgO)	7–11
Iron Oxide (Fe_2O_3)	0.2–1.6
Manganese Oxide (MnO)	0.1–1.0
Sulphide Sulphur (S)	1.0–1.5

Metakaolin (MK)

A highly reactive pozzolanic material obtained by calcining kaolinite clay at 600–850°C, with particle size 1–2 µm.

Table 3. Chemical Composition of MK

Constituent	Percentage (%)
Silicon Dioxide (SiO_2)	51–53
Aluminum Oxide (Al_2O_3)	42–44
Iron Oxide (Fe_2O_3)	0.5–1.2
Calcium Oxide (CaO)	0.1–0.5
Magnesium Oxide (MgO)	0.1–0.3
Potassium Oxide (K_2O)	0.5–1.5
Loss on Ignition (LOI)	< 1.0

Recron 3S Fiber

Synthetic triangular polyester fiber used for concrete reinforcement, available in 6 mm and 12 mm lengths.

- Length: 6 mm or 12 mm
- Diameter: 20–30 µm
- Specific gravity: 1.34
- Tensile strength: >400 MPa

Aggregates

Locally sourced river sand (zone II) as fine aggregate and crushed granite (max 20 mm) as coarse aggregate conforming to IS standards.

Water

Potable water conforming to IS: 456 was used.

Chemical Admixture

A Polycarboxylate ether (PCE)-based superplasticizer (MYK Armix EmmeCrete PC-10) was employed at a dosage of 0.8% by weight of the binder.

- **Purpose:** It was used to achieve the desired rheological properties and maintain workability without increasing the water-to-binder ratio.
- **Mechanism:** The PCE-based admixture was specifically chosen for its superior dispersing action on fine particles (Metakaolin and GGBS) via steric hindrance, ensuring a homogenous mix and preventing the agglomeration of ultra-fine pozzolans.
- **Specifications:** It conforms to IS 9103 and ASTM C494 Type F.

Table 4. Properties of Admixture

Property	Description
Trade Name	MYK Armix EmmeCrete PC-10
Base	Polycarboxylate Ether (PCE)
Appearance	Light Brown Liquid
Specific Gravity	1.08 ± 0.02
pH Value	≥ 6
Chloride Content	Nil

IV.EXPERIMENTAL PROCEDURES

Mix Proportions:

M40 grade concrete was designed targeting 40 MPa compressive strength at 28 days with water-to-binder ratio of 0.36. OPC was partially replaced by GGBS (10–40%) and MK (5–20%). Recron 3S fiber was added at 0.15–0.45% by weight of binder.

Table 5. Mix Proportion

Mix ID	OPC (%)	GGBS (%)	MK (%)	Recron 3S (%)
M-A	55	40	5	0.35
M-B	50	40	10	0.35
M-C	45	40	15	0.35
M-D	40	40	20	0.35

Casting of Specimens

Concrete was cast in standard steel molds in three layers, compacted using a table vibrator.

- Compressive strength: 150 mm cubes
- Split tensile strength: 150 mm diameter × 300 mm height cylinders
- Flexural strength: 100 mm × 100 mm × 500 mm prisms

Curing

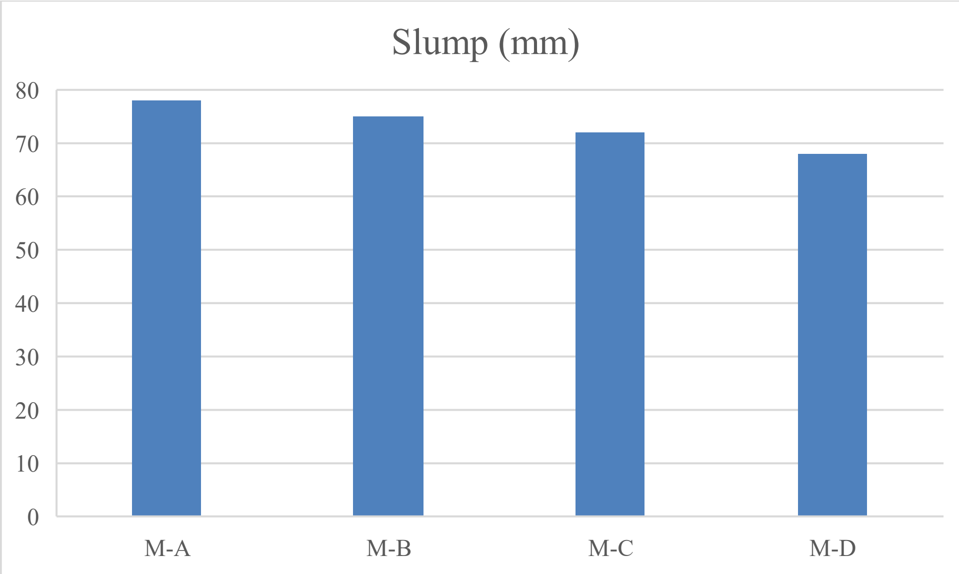
Specimens were covered with wet burlap for 24 hours, demolded, and cured in water at 27 ± 2°C until testing at 7 and 28 days.

V.RESULTS AND DISCUSSIONS

A. Workability: Conducted immediately after mixing using slump cone as per IS:1199.

Table 6. Slump Test Values of M40 grade Concrete

Mix ID	Slump (mm)
M-A	78
M-B	75
M-C	72
M-D	68



Graph 1 Slump Test Values of M40 grade Concrete

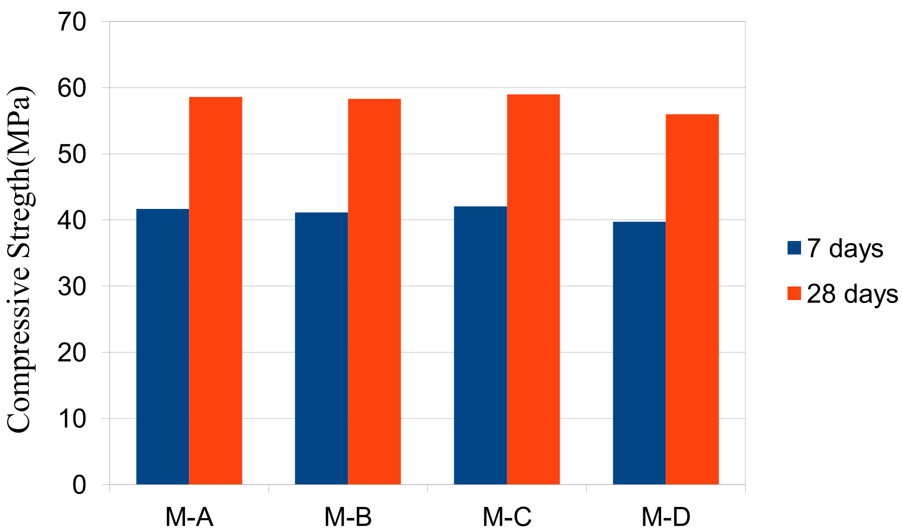
Discussion: From Table 6 and Graph 1, The measured slumps for the mixes with GGBS 40% and Recron 3S = 0.35% decreased from 78 mm MK 5% to 68 mm MK 20%, reflecting reduced flowability as MK content and fiber dosage increase. The higher fines and surface area of metakaolin and the presence of fibers increase internal friction and water demand, which lowers slump despite a constant water-to-binder ratio.

B. Mechanical properties

- **Compressive Strength:** Tested on cubes at 7 and 28 days according to IS:516. Average of three specimens reported.

Table 7. Compressive Strength of M40 Grade Concrete (MPa)

Mix ID	7 days	28 days
M-A	41.67	58.61
M-B	41.12	58.30
M-C	42.05	58.99
M-D	39.75	56.00



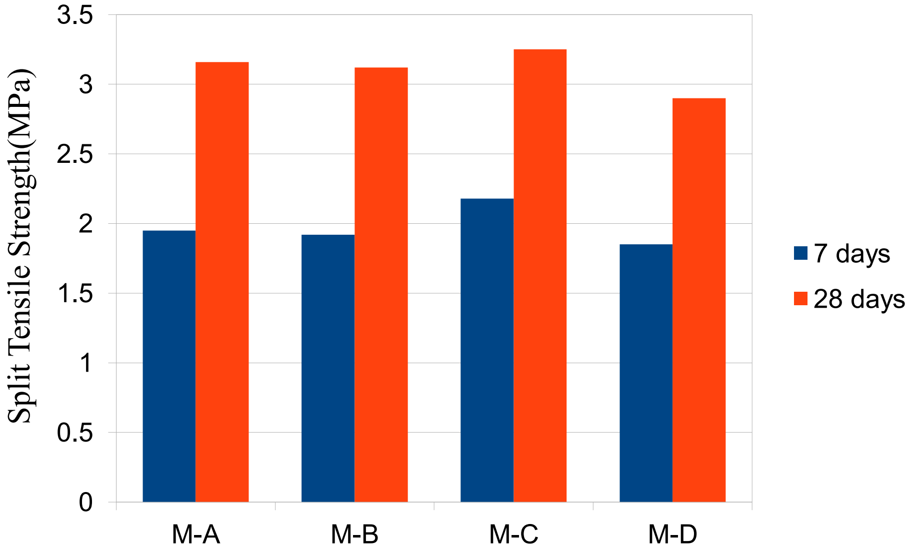
Graph 2 Compressive Strength of M40 Grade Concrete (MPa)

Discussion: From Table 7 and Graph 2, All mixes exceed the M40 target at 28 days. The 15% MK mix M-C shows the highest 28-days compressive strength 58.99 MPa, indicating an optimal balance between pozzolanic activity and binder dilution. The slight drop at 20% MK suggests diminishing returns or workability/compaction effects.

- **Split Tensile Strength:** Tested on cylinders at 7and 28 days following IS:5816. Average of three specimens reported.

Table 8. Split Tensile Strength of M40 Grade Concrete (MPa)

Mix ID	7 days	28 days
M-A	1.95	3.16
M-B	1.92	3.12
M-C	2.18	3.25
M-D	1.85	2.90



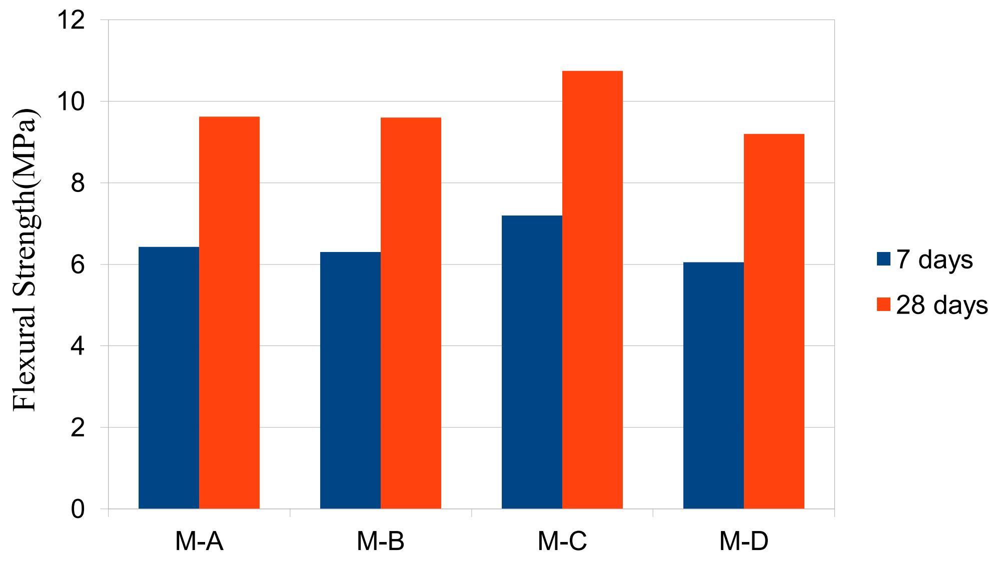
Graph 3 Split Tensile Strength of M40 Grade Concrete (MPa)

Discussion: From Table 8 and Graph 3, Split tensile strength improved marginally with fiber addition, as fibers bridged cracks and enhanced ductility. The optimum mix M-C recorded 3.25 MPa, showing better crack resistance compared to control concrete.

- **Flexural Strength:** Tested on prisms at 7 and 28 days using two-point loading method as per IS:516. Average of three specimens reported.

Table 9. Flexural Strength of M40 Grade Concrete (MPa)

Mix ID	7 days	28 days
M-A	6.43	9.62
M-B	6.30	9.60
M-C	7.20	10.75
M-D	6.05	9.20



Graph 4 Flexural Strength of M40 Grade Concrete (MPa)

Discussion: From Table 9 and Graph 4, Flexural strength showed significant improvement with fiber reinforcement. The optimum mix M-C achieved 10.75 MPa at 28 days. Fibers effectively resisted crack propagation under bending loads, enhancing toughness.

VI.CONCLUSIONS

- The study concludes that the optimal blend of 40% GGBS, 15% MK, and 0.35% Recron fibers achieved peak 28-day performance, with compressive, split tensile, and flexural strengths reaching 58.99 MPa, 3.25 MPa, and 10.75 MPa, respectively. All modified mixes exceeded the M40 target, with mechanical properties peaking at 15% MK due to matrix densification and fiber bridging. However, a slight performance decline at 20% MK suggests a threshold for optimal microstructural homogeneity.

- This ternary blend significantly enhances sustainability by reducing OPC content and embodied CO_2 without compromising structural integrity. The results demonstrate that while the combination improves durability and strength, precise optimization of MK content is essential. This research offers a viable, eco-friendly solution for high-performance construction in aggressive environments.

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