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"EXPERIMENTAL INVESTIGATION OF SUSTAINABLE CONCRETE WITH GGBS, METAKAOLIN AND CRUSHED SAND"

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Abstract: This study investigates the performance of sustainable M40 concrete incorporating Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin as partial replacements for cement by varing percentages 10%, 20%, 30%, along with crushed sand as a partial replacement for natural fine aggregate by varing percentages 15%, 30%, 45%. Concrete mixes were prepared with different replacement levels and tested for compressive and split tensile strength following standard procedures. The results showed that the combined use of GGBS, Metakaolin, and crushed sand improved the mechanical properties of concrete at optimum replacement levels while reducing cement consumption. The study demonstrates that these alternative materials can produce sustainable concrete with comparable or enhanced performance, making them suitable for environmentally friendly and durable construction.

Keywords: Sustainable concrete, GGBS, Metakaolin, Crushed sand, Compressive strength, Split tensile strength.

1. INTRODUCTION

Concrete is the most widely used construction material; however, cement production contributes significantly to global CO_2 emissions and environmental degradation. To promote sustainable construction, Supplementary Cementitious Materials (SCMs) such as Ground Granulated Blast Furnace Slag (GGBS) and Metakaolin are increasingly used as partial replacements for cement, while Manufactured Sand (M-Sand) serves as an eco-friendly alternative to natural river sand. These materials improve the mechanical properties and durability of concrete while reducing the consumption of natural resources.

This study investigates the strength characteristics of M40 concrete with partial replacement of cement by GGBS and Metakaolin and partial replacement of river sand by M-Sand. The performance of concrete was evaluated through workability, compressive strength, and split tensile strength tests conducted after 7, 14, and 28 days of curing.

2. MATERIALS

Cement : Cement is a hydraulic binding material that reacts with water through the process of hydration to form a hard, durable mass. It acts as the primary binder in concrete by holding together fine and coarse aggregates. Ordinary Portland Cement (OPC) is the most commonly used type of cement due to its high strength, good workability, and durability.
Table No. 1 Properties of Cement

Material Specifications	Results
Type	OPC 43 Grade
Specific gravity	3.15
Normal consistency	31%
Initial setting time	30 min
Final setting time	600 min (10 hrs)
Compressive Strength	43 N / MM^2
Fineness	Less than 10%
Colour	Grey

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Fine Aggregate : Fine aggregate consists of natural river sand or manufactured sand (M-Sand) with particle sizes generally less than 4.75 mm. It fills the voids between coarse aggregates, improves the workability of concrete, and contributes to its strength and durability. In this study, fine aggregate was used in accordance with the relevant standard specifications to produce concrete of the desired quality.

Table No.2 Properties of Fine Aggregate

Material Specifications	River Sand	M Sand
Zone	Zone II	Zone II
Specific Gravity	2.73	2.81
Fineness Modulus	2.5%	2.8%
Water Absorption	1.77	2.17
Sieve Analysis	0.075 - 4.75 mm	0.15- 4.75 mm
Bulk Density	1400-1750 kg/m³	1400-1860 kg/m³

Coarse Aggregate: Coarse aggregate consists of crushed stone with particle sizes greater than 4.75 mm and forms the main skeleton of concrete. It provides strength, stability, and durability while reducing shrinkage and improving the load-bearing capacity of concrete. In this study, crushed coarse aggregate of the required size, conforming to relevant standard specifications, was used.

Table No.3 Properties of Coarse Aggregate

Material Specifications	Results
Type	Crushed Stone Aggregate
Specific Gravity	2.90
Maximum Size	20mm
Water Absorption	1.02
Bulk Density	1500-1700 kg/m³

Metakaolin: Metakaolin is a highly reactive pozzolanic material produced by the calcination of purified kaolin clay at high temperatures. It is used as a supplementary cementitious material to partially replace cement in concrete. Metakaolin enhances compressive strength, durability, and resistance to chemical attack while reducing the permeability of concrete.

Table No. 4 Physical Properties of Metakaolin

Bulk Density (Kg/ Litre)	0.4-0.5
Specific Surface Area M2/G (Bet)	10-12
Oil Absorption G/100g	45-55
S.G.	2.6
Ret.On 500 Mesh	0.05%
Ph (10% SUSPENSION)	5.5 – 6.5

GGBS: Ground Granulated Blast Furnace Slag (GGBS) is a finely ground by-product obtained during the manufacture of iron in blast furnaces. It is used as a supplementary cementitious material to partially replace cement in concrete. GGBS improves workability, long-term strength, durability, and resistance to chemical attack while reducing the heat of hydration and the environmental impact of concrete.

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Table No.5 Properties of GGBS

Sr. No.	Characteristics	Reference To Requirement As Per Is 16714:2018	Test Results
1	Loss On Ignition (L.O.I)%	3.0%(Max)	0.22
2	Moisture Content%	1.0%(Max)	0.03
3	Specific Gravity		2.91
4	Fineness ,M2/Kg	320 (Min)	340

Superplasticizer (FOSROC Conplast SP430)

FOSROC Conplast SP430 is a high-performance superplasticizer based on sulphonated naphthalene polymer technology. It improves the workability of concrete while maintaining a low water–binder ratio. In concrete containing GGBS, metakaolin, and crushed sand, it compensates for the increased water demand caused by metakaolin and crushed sand, resulting in improved workability, higher strength, reduced permeability, enhanced durability, and better surface finish with minimal bleeding.

Table No.6. Properties of Superplasticizer

Property	Value
Product Name	Conplast SP430
Type	High Range Water Reducing Admixture (Superplasticizer)
Chemical Base	Sulphonated Naphthalene Polymer
Appearance	Brown Liquid
Specific Gravity	1.12 at 25°C
Chloride Content	Nil
Air Entrainment	Less than 1%
pH Value	7 – 9
Water Reduction Capacity	Up to 25%
Compatibility	OPC, PPC, PSC Cement
Dosage Range	0.6% – 1.5% by weight of cement
Standard Compliance	IS 9103 and ASTM C494 Type F & G

Water

Fresh potable water is free from concentration of acid and organic substance is used for mixing the concrete and curing.

3. EXPERIMENTAL METHODOLOGY

Mixing : All materials were accurately weighed according to the mix design before mixing. Cement, GGBS , metakaolin , crushed sand, natural fine aggregate and natural coarse aggregate were first dry mixed until a uniform blend was obtained. Water mixed with FOSROC Conplast SP430 superplasticizer was then added gradually while mixing continued. The concrete was thoroughly mixed until a homogeneous and workable mixture free from segregation was achieved.

Casting: The fresh concrete was poured into standard cube and cylinder moulds in three equal layers. Each layer was compacted using a vibrating table to eliminate air voids and ensure proper compaction. The top surface was finished smoothly using a steel trowel. After casting, the specimens were covered to prevent moisture loss and left undisturbed for 24 hours before demoulding.

Curing: After demoulding, all specimens were immersed in a curing tank filled with clean potable water. The concrete

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specimens were cured for 7, 14, and 28 days to ensure complete cement hydration and proper strength development. Adequate curing improved the durability and mechanical properties of concrete and provided consistent test results for all mixes.

Testing: After the specified curing periods, the specimens were tested according to relevant Indian Standard (IS) codes. The slump test evaluated the workability of fresh concrete, while compressive strength and split tensile strength assessed the mechanical performance of hardened concrete. The test results were compared for all mixes to determine the influence of GGBS, Metakaolin and Crushed Sand and to identify the optimum replacement level for sustainable concrete.

4. TESTS CONDUCTED

Slump Test : The slump test was conducted to determine the workability of fresh concrete in accordance with IS 1199 (Part 2): 2018. Fresh concrete was placed in a standard slump cone in three equal layers, each compacted with 25 strokes of a tamping rod. After lifting the cone vertically, the reduction in height of the concrete was measured as the slump value (mm). The test was performed immediately after mixing to compare the workability of all concrete mixes.

Compressive Strength Test

The compressive strength test was conducted to determine the load-carrying capacity of concrete in accordance with IS 516 (Part 1): 2021. Cube specimens of 150 mm × 150 mm × 150 mm were cast, compacted, and cured in water for 7, 14, and 28 days. After curing, the specimens were tested in a Compression Testing Machine (CTM). The load was applied continuously at the specified loading rate until failure occurred, and the maximum load was recorded. The compressive strength was calculated using:

$fc=P/A$

where:
fc= Compressive strength (N/mm^2)
P = Maximum failure load (N)
A = Loaded area (mm^2)

Fig. No. 1 Compressive Test On Compressive Testing Machine Split Tensile Strength Test

The split tensile strength test was carried out in accordance with IS 5816:1976 to determine the tensile resistance of concrete. Cylindrical specimens of 150 mm diameter and 300 mm height were cured for 7, 14, and 28 days. During testing, each cylinder was placed horizontally between the compression platens of the testing machine, and the load was applied gradually until failure occurred along the vertical diameter. The split tensile strength was calculated using:

$fct=2P/\pi LD$

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where:
P = Failure load (N)
L = Length of cylinder (300 mm)
D = Diameter of cylinder (150 mm)

Fig. No. 2 Split Tensile Strength Test On Compressive Testing Machine

5. MIX DESIGN

The study uses the design mix M40 grade of concrete using 43 grades OPC in the study. The Mix design was performed as per IS 10262:2019. The water cement ratio for the mixtures were kept at 0.38. The following proportion was obtained from the mix design.

Four concrete mixes were prepared.

Mix ID	Cement Replacement (%)	Fine Aggregate Replacement (%)
CM	0	0
Mix	10	15
Mix	20	30
Mix	30	45

Table No.7 Mix 1. Final Quantities for 1m^3 for M40 Grade Concrete

Sr. No.	Material	For 1 m^3
1	Cement	416 kg
2	Water	158 kg
3	Natural Sand	810 kg
4	Coarse Aggregate 20mm	1154 kg
5	Chemical Admixture	8.32 kg
6	Water Cement Ratio	0.38

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Table No.8 Mix 2. Replacement of 10% of cement and 15% of fine aggregate

Material	Original (kg/m3)	+10% Wastage (kg/m3)
Water	158.00	173.80
Cement	374.40	411.84
GGBS	33.30	36.63
Metakaolin	8.30	9.13
Natural sand	688.50	757.35
Crushed sand	121.50	133.65
Coarse aggregate	1154.00	1269.40
Superplasticizer	8.32	9.15

Table No.9 Mix 3. Replacement of 20% of cement and 30% of fine aggregate

Material	Original (kg/m3)	+10% Wastage (kg/m3)
Water	158.00	174
Cement	332.8	366.1
GGBS	66.6	73,3
Metakaolin	16.6	18.3
Natural sand	567.0	623.7
Crushed sand	243.0	267.3
Coarse aggregate	1154.00	1269.4
Superplasticizer	8.32	9.15

Table No.10 Mix 4. Replacement of 30% of cement and 45% of fine aggregate

Material	Original (kg/m3)	+10% Wastage (kg/m3)
Water	158.00	173.80
Cement	291.2	320.32
GGBS	99.8	109,78
Metakaolin	25	27.50
Natural sand	445.5	490.05
Crushed sand	364.5	400.95
Coarse aggregate	1154.0	1269.40
Superplasticizer	8.32	9.15

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6. RESULTS AND DISCUSSION

Result For Control Mix Assumed Mix Notation
M1: 10% cement replacement + 15% crushed sand. M2: 10% cement replacement + 30% crushed sand. M3: 10% cement replacement + 45% crushed sand. M4: 20% cement replacement + 15% crushed sand. M5: 20% cement replacement + 30% crushed sand. M6: 20% cement replacement + 45% crushed sand. M7: 30% cement replacement + 15% crushed sand. M8: 30% cement replacement + 30% crushed sand. M9: 30% cement replacement + 45% crushed sand.

Compressive strength results with failure load

Table No.11. Compressive Strength Results

MIX	7 Days strength	Load	14 Days strength	Load	28 Days strength	Load
ID	MPa	(KN)	MPa	(KN)	MPa	(KN)
CM	32.54	732.17	38.76	872.17	44.50	1001.17
M1	29.6	666	38.6	871	46.8	1053
M2	30.4	684	39.4	887	47.6	1071
M3	28.8	648	37.9	853	45.7	1028
M4	31.8	716	41.5	934	49.4	1112
M5	32.6	734	42.1	947	50.2	1130
M6	30.9	695	40.2	905	48.1	1082
M7	30.1	677	39	878	46.4	1044
M8	30.8	693	39.8	896	47.2	1062
M9	29.2	657	38.1	857	45	1030

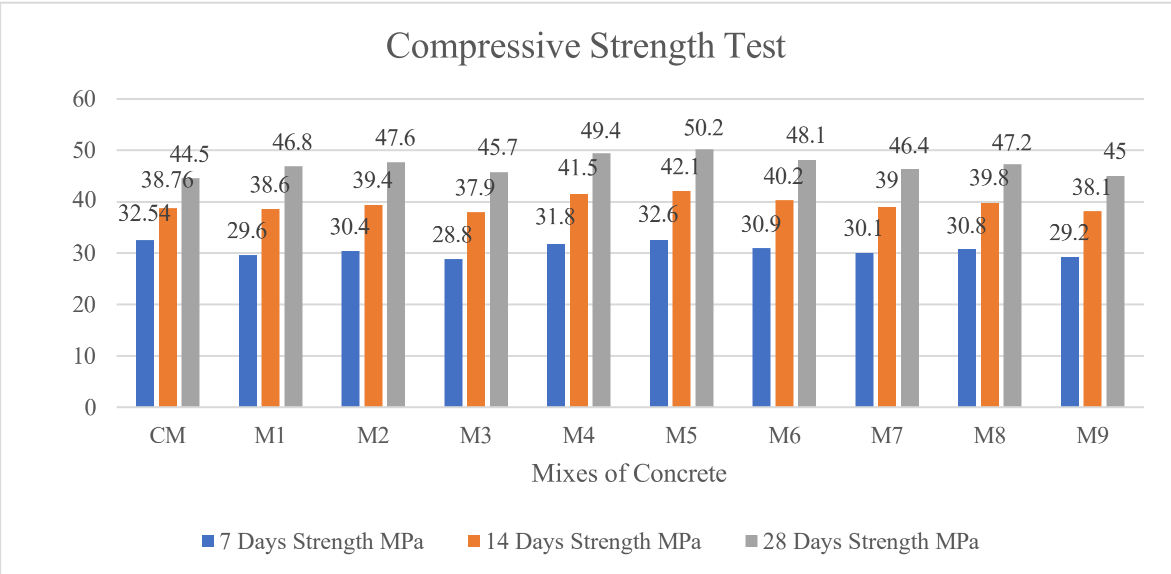

Figure No. 1 Graphical Representation of Compressive Strength Test

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Split Tensile strength results with failure load

Table No.12 Split Tensile Strength Results

MIX	7 Days strength	Load	14 Days strength	Load	28 Days strength	Load
ID	MPa	(KN)	MPa	(KN)	MPa	(KN)
CM	2.41	180	2.88	216	3,41	255
M1	2.48	175	3.06	216	3.62	256
M2	2.53	179	3.11	220	3.69	261
M3	2.41	171	2.98	210	3.5	248
M4	2.66	188	3.31	234	3.88	275
M5	2.71	192	3.37	238	3.96	280
M6	2.56	181	3.2	226	3.77	267
M7	2.5	177	3.08	218	3.6	255
M8	2.55	180	3.14	222	3.68	260
M9	2.43	172	2.99	211	3.49	247

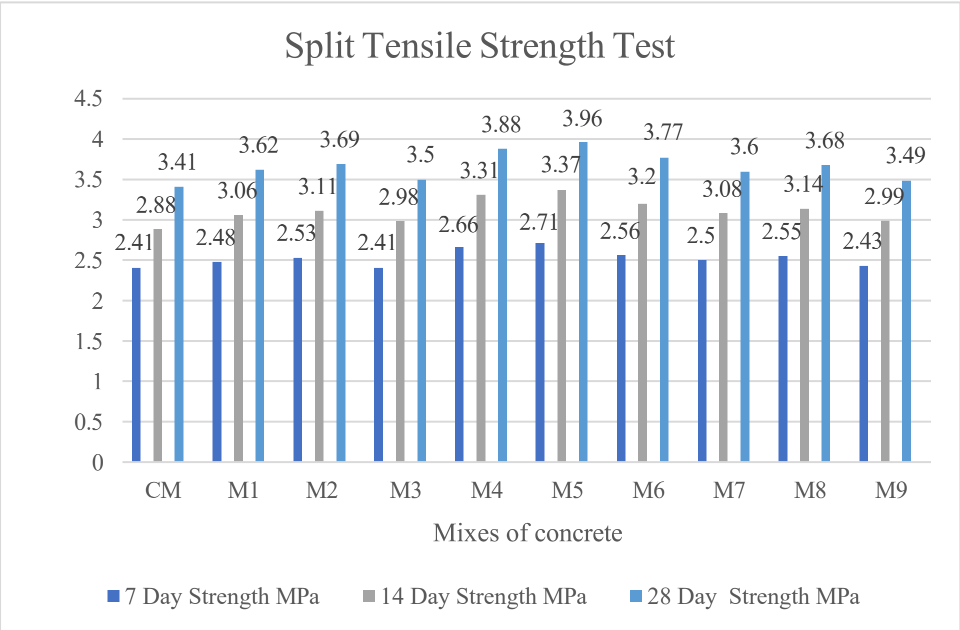

Figure No. 2 Graphical Representation of Split Tensile Strength Test

7. CONCLUSION

The study concludes that partial replacement of cement with GGBS and Metakaolin and fine aggregate with crushed sand can produce sustainable concrete with satisfactory mechanical properties. Moderate replacement levels improve strength due to better packing density and pozzolanic activity, while excessive replacement may reduce strength and workability. The mix with 20% cement replacement and 30% crushed sand replacement showed the best overall performance in terms of compressive strength and split tensile strength. The use of these materials helps reduce cement consumption, conserve natural resources, and develop economical and environmentally friendly concrete for construction applications.

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