EFFECT ON PROPERTIES OF CONCRETE IN PARTIAL REPLACEMENT OF FINE AGGREGATE BY STEEL SLAG AND CEMENT BY METAKAOLIN

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ABSTRACT

In the present investigation, metakaolin is used to replace a portion of the cement and induction furnace steel slag as partial replacement of fine aggregate in concrete. Metakaolin is a dehydroxylated aluminium silicate pozzolanic material obtained from kaolinite clay mineral. Induction Furnace steel slag is obtained as an industrial by-product during steel production. Hexagonal shaped paver block specimens of side 120 mm and height 80 mm are casted. Compressive strength, flexural Strength, split tensile strength, abrasion, water absorption, acid and alkali attack tests were performed. The results show that optimum level replacement of metakaolin (cement) and IF steel slag (fine aggregate) in concrete is 10% and 20% respectively.

Keywords: Steel Slag, Metakaolin, Concrete, Paver Block, Compressive Strength

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INTRODUCTION

Concrete is being widely used the material in construction because of its unique structural applications such as buildings, industries, residential drainage units, water supply plants and highway infrastructure. Increase of CO₂ gas in the environment increases global warming. Cement industries release CO₂ while CaCO₃ is burnt to produce OPC and hence causes global warming significantly. The research community in the globe is focusing on the development of binders which can be used as an alternate for conventional OPC.¹ Utilization of metakaolin (MK) as a binding material in mortar/concrete is practice in recent years.²⁻⁴ The properties of concrete led to greater demand for it and hence the aggregates in it, which occupies almost 3/4 of the total volume of concrete.¹ The continuous use of natural sand leads to the depletion of river beds results in the ecological imbalance. In order to satisfy the aggregates need in concrete, utilization of industrial by-products are highly encouraged to preserve natural resources.^{5,6} Groundwater pollution increases near solid waste dumping sites and hence solid waste needs to be disposed of/recycled properly to overcome these issues.⁷ Replacement of natural aggregates/binders using industrial by-products and other materials has been continuously emphasized during recent years.⁸⁻¹¹ Natural coarse/fine aggregate has been partially replaced by steel slag in concrete to avoid industrial by-product landfilling and natural resource exploitation.¹²⁻¹⁶ The present investigation focuses to utilize metakaolin and IF steel slag in concrete for the partial replacement of cement and fine aggregate respectively.

EXPERIMENTAL

In the present study materials used are cement, fine aggregate, coarse aggregate, metakaolin, steel slag, and superplasticizer. Mix proportion opted as per IS 10262-2009.¹⁷

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Cement

Cement is a binding material in construction. It is produced over 1450°C by burning cementitious materials. The binder (cement) used in the present study is of specific gravity 3.14, consistency 32% and initial setting time 30 min.

Fine Aggregate

Fine aggregate is the material obtained from rivers called natural sand that will pass through 4.75mm sieve. The fine aggregate fills the voids of coarse aggregate and improves the workability. The specific gravity of fine aggregate used is 2.6 and the fineness modulus is 3.45 which conforms to zone III of IS 383.

Coarse Aggregate

In the present study coarse aggregate of size 10 to 12.5 mm was used and the specific gravity is 2.71.

Metakaolin

Metakaolin is a pozzalonic characteristic material and can be used for the partial replacement of cement. Figure-1 shows the metakaolin used. The specific gravity of metakaolin used in the present study is 3.1.

Steel Slag

Steel slag is an industrial by-product and is obtained from the steel manufacturing process. In the present study natural fine aggregate is partially replaced by Induction furnace steel slag. Figure- 2 shows the Induction furnace steel slag used. The specific gravity is 2.6

Fig.-1: Metakaolin

Fig.-2; Induction Furnace Steel Slag

Optimization of Steel Slag

As per IS 15658:2006 concrete grade chosen in the present investigation is M_{35} for Light traffic.¹⁸ Optimum replacement of Induction furnace steel slag was found for 28 days strength of concrete cubes of size 150x150x150 mm. Concrete cubes were cast for M_{35} grade by varying fine aggregate with Induction furnace steel slag by 0%, 20%, 40%, 60%, and 80%. Six cubes for each replacement ratio were cast as shown in Fig.-3 and tested for 28 days compressive strength. The optimized level of replacement of IF steel slag as fine aggregate is 20%.

Casting of Paver Blocks

Totally 96 hexagonal shaped paver blocks of side 120mm, thickness 80mm were cast and cured in room temperature and tested. The paver blocks were cast into four groups, M1 (0% metakaolin), M2 (10% metakaolin), M3 (20% metakaolin), and M4 (30% metakaolin) based on the percentage of metakaolin added. Fine aggregate was replaced by 20 % steel slag for all the percentages of metakaolin. The paver block is in a hexagonal shape. Also, 8 numbers of cubes of 7cm x 7cm x 7cm were cast for abrasion test. Fig.-4 shows the casted paver blocks.

Fig.-3: Cubes for Optimisation of Steel Slag

Fig.-4: Casted Paver Blocks

Testing of Paver Blocks

Compressive Strength Test

Figure-5 shows the compression strength performed for the prepared specimens. All the specimens are tested in a saturated condition, after drying the surface of the specimen containing no moisture in it. For each mix proportion, cubes are tested for 7 days, 14 days and 28 days using 3000 KN compression testing machine as per IS 516:2009. The tests are carried out at a uniform rate stress level with the specimen properly placed and centered in the testing machine. Loading applied gradually with the help of hydraulic pumps until the dial gauge get reverses its direction of motion. The reversal of needle indicates the total failure, the which is the ultimate failure load of the specimen. The tested specimen is given below:

$$\text{Compressive strength} = P / A$$

Where, P - Failure load (N); A - Area of the specimen (mm²)

Split Tensile Strength

Prepared specimens were tested for its split tensile strength (Fig.-6). The test has been performed as per standard protocols with the splitting tension stress range of 0.7 to 1.3 Mpa. The splitting tensile strength is computed from the formula according to IS 5816:1999. The tested specimen is given below,

$$T = 2P / \pi l d^2 \quad (1)$$

Where, T - Tensile strength (N/mm²); P - Failure load (N); l - Length of the specimen (mm); d - Diameter of the specimen (mm)

Flexural Strength Test

Flexural strength of specimens prepared was tested is shown in Fig.-7. Simple beam loading is applied from the top of the specimen via a roller of diameter 25mm. The roller is placed exactly between the supporting rollers at the bottom and the load is applied without shock. The failure load (maximum load) is recorded. Flexural strength is calculated using the following formulae,

$$R = 3pl / 2bd^2 \quad (2)$$

Where, P - maximum load (N); l - span length (mm); b - specimen width (mm); d - specimen depth (mm)

Water Absorption Test

The prepared specimens were immersed in water for 28 days after the drying process. Specimens are weighed before and after immersion in water. The percentage of water absorption has been calculated using the following formulae:

$$\text{Percentage of water absorption} = (w_d - w_w / w_d) * 100 \quad (3)$$

Where, w_w = weight of specimen immersed in water (kg)
 w_d = weight of specimen before immersing in water (kg)

Acid Attack Test

Figure-8 shows the acid attack test of specimens prepared (28 days). Alkaline nature of the concrete block is expected to undergo acid attack when in contact with acid. Sulphuric acid of 5% is used for acid attack test. The percentage of an acid attack has been calculated using the below formulae:

$$\text{Percentage of acid attack} = (w_d - w_{ac} / w_d) * 100 \quad (4)$$

Where, w_{ac} = weight of specimen immersed in the acid solution (kg)
 w_d = weight of specimen before immersing in acid solution (kg)

Alkali Attack Test

Sodium hydroxide is used as an alkali for the present study. Specimens were immersed in 4% of sodium hydroxide solution for 28 days (Fig.-9) and the alkali attack has been calculated using the below formulae:

$$\text{Percentage of alkali attack} = (w_d - w_{al} / w_d) * 100 \quad (5)$$

Where, w_{al} = weight of specimen immersed in alkali solution (kg)
 w_d = weight of specimen before immersing in alkali solution (kg)

Abrasion Test

Three cubes of 7cm x 7cm x 7cm were casted in each mix and cured in room temperature for 28 days. The initial dry weight of the cubes is noted. Abrasion test has been carried out as per standard protocols for the specimens prepared (Fig.-10). Abrasion of the specimen prepared has been calculated after 25 cycles using the following formulae,

$$\Delta V = \Delta m / PR \quad (6)$$

Where, ΔV – loss in volume (mm^3)
 Δm – loss in mass (g)
 PR – specimen density (g/mm^3)

Fig.-5: Compressive Strength Test

Fig.-6: Split Tensile Strength

Fig.-7: Flexural Strength Test

Fig.-8: Acid Attack Test

Fig.-9: Alkali Attack Test

Fig.-10: Abrasion Test

RESULTS AND DISCUSSION

Compressive Strength

The casted paver blocks have been tested and the compressive strength test results are shown in Fig.-11. Compression strength is maximum for the M2 (10% Metakaolin) paver blocks. This indicates that compression strength decreases with the addition of metakaolin.

Fig.-11: Compressive Strength

Spilt Tensile Test

The paver blocks have been tested and split tensile test results are shown in Fig.-12. The split tensile strength is maximum for M2(10% metakaolin) paver blocks.

Fig.-12: Split Tensile Test

Flexural Strength

The paver blocks have been tested and the flexural test results are shown in Fig.-13. Flexural strength is maximum for the M2 paver blocks.

Fig.-13: Flexural Strength

Acid Attack Test

The paver blocks are immersed in 5% sulphuric acid and the percentage of acid attack is shown in Table-1.

Water Absorption Test

The paver blocks are immersed in water for 28 days and the percentage absorption of water is tabulated in Table-2.

Table-1: Acid Attack in Percentage (%)

S.No.	Specimen designation	Percentage of metakaolin added	Percentage of water absorption
1	M1	0%	0.87
2	M2	10%	1.26
3	M3	20%	1.1
4	M4	30%	1.18

Alkali Attack Test

The paver blocks have been immersed in 4% sodium hydroxide and the percentage absorption of alkali is tabulated in Table-3.

Abrasion Test

The cubes of side 7cm were casted and tested for abrasion. The abrasive wear of the specimen after 25 cycles of testing shall be calculated as the mean loss in specimen volume (ΔV) and is shown in Table-4. It was found that loss in volume is maximum for M2 specimen.

Table-2: Water Absorption in Percentages (%)

S.No.	Specimen Designation	Percentage of Metakaolin Added	Percentage of Acid Attack
1	M1	0%	1.96
2	M2	10%	2.1
3	M3	20%	2.04
4	M4	30%	2.08

Table-3: Alkali Attack Test in Terms of Percentage (%)

S.No.	Specimen Designation	Percentage of Metakaolin Added	Percentage of Alkali Attack
1	M1	0%	2.10
2	M2	10%	2.2
3	M3	20%	2.17
4	M4	30%	2.0

High-Resolution Scanning Electron Microscope (HR SEM) Analysis

HR-SEM analysis of metakaolin is shown in Fig.-14. The particles in metakaolin are mostly hexagonal in shape with some pentagonal shaped particles and have no sharp edges which enhance binding of the material. The size of the majority of the particles present in metakaolin is ranging from 100 to 250 nm. The smaller size of the particles present in metakaolin improves binding which increases the strength of the concrete blocks.

EDAX analysis of metakaolin is tabulated in Table-5. The elements present in metakaolin are in oxide form. Silicon, aluminum and magnesium are the major elements present in metakaolin with 32.22%, 25.57% and 1.06% by weight percentage.

Table-4: Abrasive Wear Resistance

S.No.	Specimen Designation	Percentage of Metakaolin Added	Loss in Specimen Volume (mm ³)
1	M1	0%	1020
2	M2	10%	1050
3	M3	20%	1040
4	M4	30%	1000

Fig.-14: Morphology of Metakaolin

Table-5: Elements Present in Metakaolin

Elements	Wt %	At %
OK	41.15	54.60
MgK	1.06	0.93
AlK	25.57	20.12
SiK	32.22	24.35
Matrix	Correction	ZAF

X-Ray Diffraction (XRD) Analysis

The XRD results are shown in Figure-15.

Fig.-15: XRD Analysis

In XRD analysis the major peak values of metakaolin correspond to 2θ values are 16,27,29,32,36, and 39. The JCPDS values of the metakaolin utilized in the present study correspond to 50-1333.

CONCLUSION

The increased strength is obtained by replacing cement by metakaolin up to 10% and steel slag as 20% constant for all mixes. Due to shape size and surface texture of steel slag aggregate and also by the nature of the metakaolin which provides better adhesion between the particles and cement mix. The optimum level of replacement for metakaolin is found as 10% and increase in strength initially and decreases in strength beyond 10%.

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