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Experimental Investigation on the Mechanical and Durability Properties of concrete using Metakaolin and Copper slag

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Abstract: Durability, workability and toughness are the equally important criteria which have to be met by the concrete in addition to the high strength. It is reported that the use of mineral admixtures in concrete with low water/binder (w/b) ratio and 50% replacement of slag as fine aggregate has shown increased compressive strength and high performance.This study includes the performance of concrete by using both Metakaolin and Copper slag with respect to compressive strength, flexural strength and its durability. Strength of the concrete is determined by the compressive and flexure test and the durability of the concrete is studied by means of water absorption test and RCPT.

Key Words: High performance concrete, pozzolana, copper slag, metakaolin, super plasticizer.

1. INTRODUCTION

Concrete is the most widely used construction material next to water due to the easy availability of its constituents, its versatility and adaptability. Inspite of the technical and economic advantage of the material and the tremendous understanding of its engineering and microstructure, deterioration of concrete has become a major problem and there is widespread concern about the durability of the reinforced concrete structures.

Development of concrete mixtures with enhanced durability properties to avoid premature deterioration of concrete due to environmental effects can be made by the addition of pozzolanic admixture in the concrete mixtures.

The pozzolanic material when used in concrete mixture reacts with calcium hydroxide resulting in C-S-H compounds which, in turn, renders the transition zone between the matrix and aggregates in the concrete mixture, denser and stronger. These pozzolanic materials function as supplementary cementitious materials in concrete mixtures and improve the impermeability of concrete against aggressive chemicals. Low permeability and stronger transition zone are the requirements for long term durability.Use of mineral admixtures, such as fly ash, silica fume, metakaolin act as pozzolanic materials as well as fine fillers, thereby the microstructure of hardened concrete matrix becomes denser and stronger.Copper slag can be utilized as a partial substitute for fine aggregates in concrete and there by the excess quarrying of sand can be avoided and the ecology can be maintained.

2. MATERIALS

METAKAOLIN

Metakaolin is produced by heat treating Kaolin as one of the most abundant natural minerals to a temperature of 600^0 – 8000^0 C. Kaolin is a fine white clay mineral that has been traditionally used. Metakaolin is produced under carefully controlled conditions and hence its composition, white appearance and performance are relatively consistent. It reacts rapidly with the calcium hydroxide in the cement paste, converting it into stable cementitious compounds thus refining the microstructure of concrete thereby reducing its permeation properties. Due to its high surface area and high reactivity, relatively small addition rates of MK produce relatively large increase in strength, impermeability and durability while its light colour gives it an aesthetic advantage.

COPPER SLAG

Since the construction industry is a facing a scarcity of source of materials from natural resources such as sand, stone aggregate etc. The utility of industrial wastes will go a long way in promoting sustainable development of construction industry. This slag is currently being used for many purposes ranging from land filling to grit blasting which are not very high value added applications. These applications utilize only about 15% to 22% of the copper slag generated and the remaining materials are being dumped as a waste which requires large areas of land and hence a fast diminishing high value asset. In addition there are apprehensions that the material could also cause environmental pollution. Many researchers have investigated the use of copper slag in the production of cement mortar and concrete as raw materials for clinker. The use of copper slag in cement and concrete provides potential environmental as well as economic benefits.

3. MIX PROPORTIONS

For achieving high strength concrete the Control Mix is chosen as M 50. In this Control Mix sand is being replaced by copper slag in the order of 40%, 50%, and 60% by the weight of sand and is presented in Table 1 shown below.

Table – 1:*Control mixes*

Control Mix 1	Cement	Sand	Aggregates
Control Mix 2	Cement	60% Sand +40%Slag	Aggregates
Control Mix 3	Cement	50% Sand + 50% Slag	Aggregates
Control Mix 4	Cement	40% Sand + 60% Slag	Aggregates
Mix 5	95%Cement + 5% MK	Sand + 0% Slag	Aggregate
Mix 6	90%Cement + 10% MK	Sand + 0% Slag	Aggregate
Mix 7	85%Cement + 15% MK	Sand + 0% Slag	Aggregate
Mix 8	95%Cement + 5% MK	60%Sand + 40% Slag	Aggregate
Mix 9	90%Cement + 10% MK	60%Sand + 40% Slag	Aggregate
Mix 10	85%Cement + 15% MK	60%Sand + 40% Slag	Aggregate
Mix 11	95%Cement + 5% MK	50%Sand + 50% Slag	Aggregate
Mix 12	90%Cement + 10% MK	50%Sand + 50% Slag	Aggregate
Mix 13	85%Cement + 15% MK	50%Sand + 50% Slag	Aggregate
Mix 14	95%Cement + 5% MK	40%Sand + 60% Slag	Aggregate
Mix 15	90%Cement + 10% MK	40%Sand + 60% Slag	Aggregate
Mix 16	85%Cement + 15% MK	40%Sand + 60% Slag	Aggregate

DETAILS OF MIX DESIGN

Table – 2.1: Mix Design

Details	Mix 1	Mix2	Mix3	Mix4	Mix 5	Mix 6	Mix 7
	0% MK				0% SLAG		
	0%slag	40% slag	50% slag	60% slag	5% MK	10% MK	15% MK
Cement	450	450	450	450	427	405	382
MK	0	0	0	0	23	45	68
Sand	713	481	401	320	711	709	707

Slag	0	444	555	665	0	0	0
20mm	675	619	619	619	674	672	670
10mm	453	416	416	416	452	451	450
W/C= 0.36	162	162	162	162	162	162	162
Water absorption	14	16	16	16	14	14	14

Note: Water absorption for 20mm @ 0.40%, 10mm @ 0.60%, river sand @1.20%, Slag 1.10%

Table – 2.2: Mix Design

Details	Mix8	Mix 9	Mix10	Mix 11	Mix12	Mix13
	5% MK			10% MK		
	40%slag	50 %slag	60% slag	40 %slag	50% slag	60% slag
Cement	427	427	427	405	405	405
MK	23	23	23	45	45	45
Sand	480	400	320	479	399	319
Slag	442	553	664	441	551	662
20mm	618	618	618	616	616	616
10mm	415	415	415	414	414	414
W/C= 0.36	162	162	162	162	162	162
Water absorption	16	16	16	16	16	16

Note: Water absorption for 20mm @ 0.40%, 10mm @ 0.60%, river sand @1.20%, Slag 1.10%

Table – 2.3: Mix Design

Details	Mix14	Mix15	Mix16
	15% MK		
	40%slag	50%slag	60%slag
Cement	382	382	382
MK	68	68	68
Sand	477	398	318
Slag	440	550	660
20mm	614	614	614
10mm	412	412	412
W/C=0.36	162	162	162
Water absorption	16	16	16

Note: Water absorption for 20mm @ 0.40%, 10mm @ 0.60%, river sand @1.20%, Slag 1.10%

4. EXPERIMENTAL PROCEDURE

Four trial mixes of M50 grade were used. Sieve analysis was carried out for both fine and coarse aggregates.

CURING

The most intricate part is High performance concrete (HPC) has very low w/binder ratio and better particle distribution due to the use of mineral admixtures, which result insignificantly in less pore per unit volume of cementations materials in the mixture than the CCC. Filling of the voids by hydration product in HPC is much faster than that of CCC as smaller pores needs less hydration products to fill. Therefore, moisture loss due to capillary action *stops earlier* .in case of HPC compared to CCC under the same curing conditions. The moisture loss from HPC has been found predominant up to the first 24 hours. Owing to very low water/binder ratio and use of super plasticizer,the early stage hydration rate of HPC is higher

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than CCC leaving less long term hydration potential. Curing duration after the initial moisture protection has been found to have little effect on long term chloride permeability of HPC containing micro-silica or fly-ash. Method of curing has similar effect on HPC both for creep and shrinkage of concrete, which are again influenced by the type and duration of curing.

INITIAL CURING

Curing compound has not been found to be very effective for initial curing. Immediately after the placement of fresh concrete, water sheen (bleed water) appears on the top of the concrete surface. If curing compound is spread before this water sheen dries, local ponding of the curing compound mixed with the water sheen occurs on the concrete surface. Again, allowing the water sheen to be completely evaporated may be harmful for the long-term properties of concrete especially in dry and hot climate.

FINAL CURING (WET CURING)

For final curing, wet curing as adopted for conventional concretes, such as ponding water on the exposed surface or covering the exposed surface by wet burlap and keeping it wet by continuous sprinkling of water has been found to be effective.

TESTS: The high strength behavior of concrete and the durability enhancement of the concrete using the above said admixture and the copper slag over the control concrete are being studied by performing the following tests.

1. Compression test of concrete at 28 days
2. Flexure test of concrete
3. Rapid Chloride Permeability Test
4. Water absorption test

5. RESULTS AND DISCUSSION

COMPRESSION TEST

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concretes are employed primarily to resist compressive stresses. Concrete cube specimens of 150mm x 150mm x150mm were cast with different combinations as mentioned earlier.

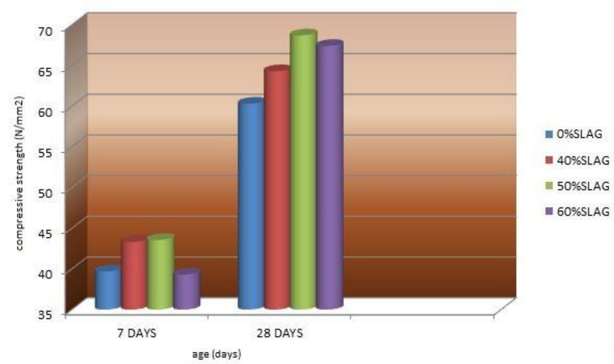

Chart – 1.1: Compressive Testing results for control

From the graph it is clear that there is a considerable increase of compressive strength with 40% and 50% replacement of sand by copper slag. The compressive strength has increased by 6.63% with 40% replacement of fine aggregate by copper slag and an increase of 13.43% has been observed in the case of sand replaced with 50% of copper slag. However with more addition of copper slag the compressive strength does not increase appreciably and is found to increase the compressive strength by 11.77% with 60% replacement of sand by copper slag.

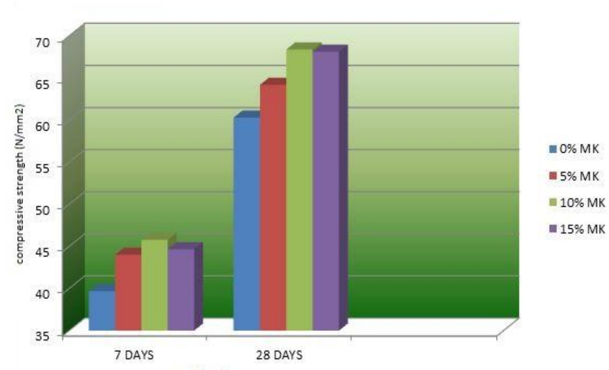

Chart – 1.2: Compressive Testing results of 0% slag

The compressive strength of concrete with varying percentages of metakaolin and without replacement of sand with copper slag is presented in chart 1.2.The values above indicate that there is an increase in compressive strength of concrete in the range of 6.5 to 13.4 % and is found to be maximum with a replacement of 10% of MK. With a replacement of 15% of metakaolin the compressive strength is found to slightly decrease.

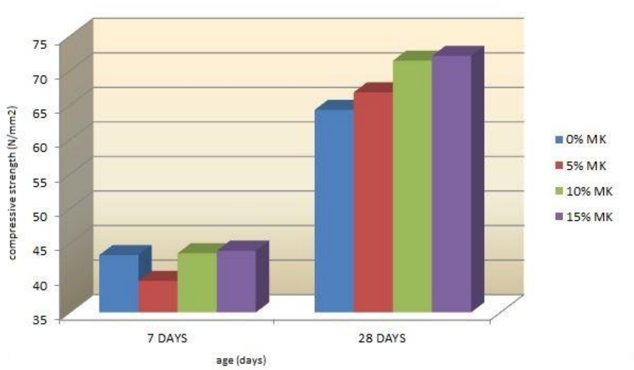

Chart – 1.3: Compressive Testing results of 40% slag

The compressive strength of concrete with varying percentages of metakaolin and with 40% replacement of sand with copper slag is shown in the chart 1.3.From the above results it is observed that by maintaining a constant % replacement of slag and by varying the % replacement of metakoalin, the compressive strength is found to proportionately increase with the increase of metakaolin. Similar trend was observed with 50% and 60% replacement of slag also.

Comparative study

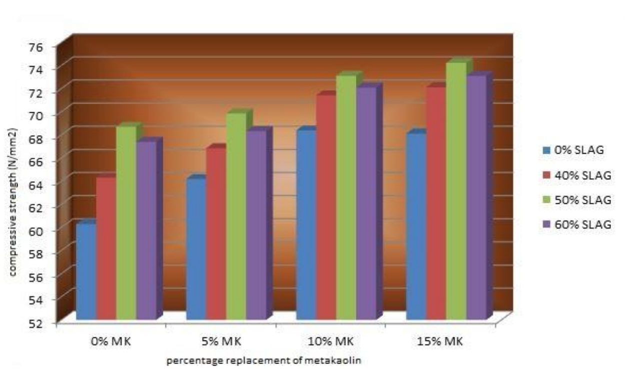

Chart – 1.4: Comparative study on Compression Strength with respect to replacement of Metakaolin

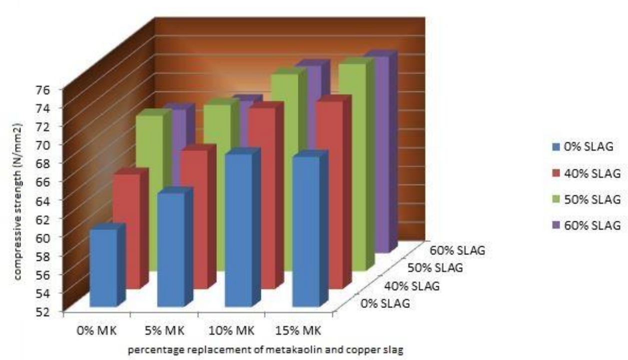

Chart – 1.5: Comparative study on Compression Strength with respect to the replacement of Slag

From the chart presented above it is interesting to note that the compressive strength of concrete is found to increase by the replacement of cement with Metakaolin and also by the replacement of sand with Copper Slag. It is also observed that the replacement of Copper Slag over and above 50% shows reduced compressive strength than that of 50% replacement.

FLEXURE TEST

The beam test is found to be dependable to measure the flexural strength property of concrete. The standard sizes of the specimens are 150mm x150mm x700mm. Alternatively if the largest nominal size of the aggregate does not exceed 20mm the specimens of 100mm x 100mm x 500mm can be used. In this study specimens of 100mm x100mm x500mm are used as the max size of aggregate is 20mm.

The flexural strength of the specimen is expressed as the modulus of rupture which is calculated using the following relation.

$f_b = [\ 3\ P \times e\ ]\ /\ [\ b \times d^2\ ]$ ....(A)

Table – 3: Flexural Strength of concrete by the replacement of Metakolin and copper slag

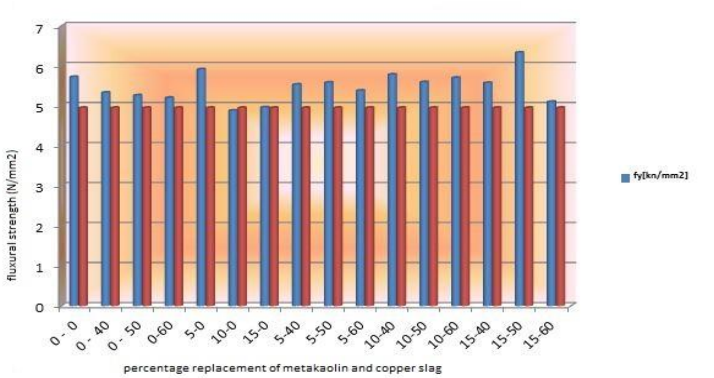

Chart – 2: FLEXURAL STRENGTH OF CONCRETE

Chart 2 shows the effect of partial replacement of metakaolin and copper slag on the flexural strength of concrete. From the above values it is inferred that the flexural strength of the concrete is not falling below the theoretical value of 0.7 x $f_{ck}^{0.5}$. Hence the replacement of cement with Metakaolin and replacement of sand with slag is found to have considerable influence on the flexural strength of concrete.

WATER ABSORPTION TEST

Water Absorption Test is conducted on 100mm x100mm x 100mm concrete specimen. The 28 days cured cubes are taken out from the curing yard and allowed to dry at atmospheric temperature. These specimens are carefully weighed and the initial weight is noted { W_i }. After 24 hours the dried specimens are taken out of the oven and allowed to cool at normal room temperature. These specimens are again weighed carefully and the weights are noted {W_f }. The values obtained are plotted as shown in the chart 3.These are derived from the formula.

[{ W_i - W_f} / Wi] x 100 ....(A)

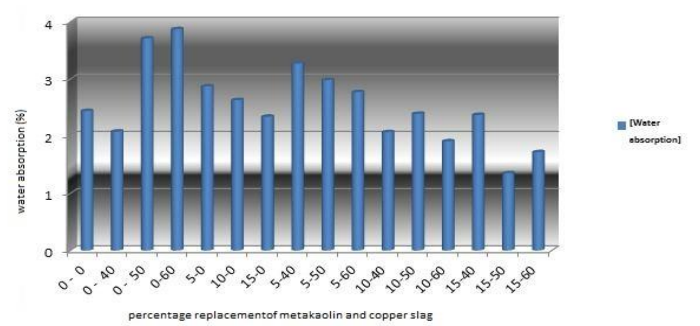

Chart – 3: Percentage of water absorption

From the graph presented above it is clear that the percentage of water absorbed is low with 15% replacement of cement with metakaolin and 50% replacement of sand with copper slag.

RAPID CHLORIDE PENETRATION TEST

This method consists of monitoring the amount of electrical current passed on 51 mm thick slices of 84 mm

Mix .No	Details of Mix	P = LOAD [KN]	Eccentricity [e] mm	Cross section [b x d] mm^2	Flexural Stress [kn/mm^2]
1	0% MK-0%Slag	15.50	123	100x100	5.72
2	0% MK-40%Slag	14.44	123	100x100	5.33
3	0% MK-50%Slag	14.25	123	100x100	5.26
4	0% MK-60%Slag	14.09	123	100x100	5.20
5	5% MK-0%Slag	16.01	123	100x100	5.91
6	10% MK-0%Slag	13.22	123	100x100	4.88
7	15% MK-0%Slag	13.44	123	100x100	4.96
8	5% MK-40%Slag	14.98	123	100x100	5.53
9	5% MK-50%Slag	15.12	123	100x100	5.58
10	5% MK-60%Slag	14.57	123	100x100	5.38
11	10% MK-40%Slag	15.66	123	100x100	5.78
12	10% MK-50%Slag	15.15	123	100x100	5.59
13	10% MK-60%Slag	15.45	123	100x100	5.70
14	15% MK-40%Slag	15.09	123	100x100	5.57
15	15% MK-50%Slag	17.15	123	100x100	6.33
16	15% MK-60%Slag	13.82	123	100x100	5.10

nominal diameter cores or cylinders during a 6 hours period.

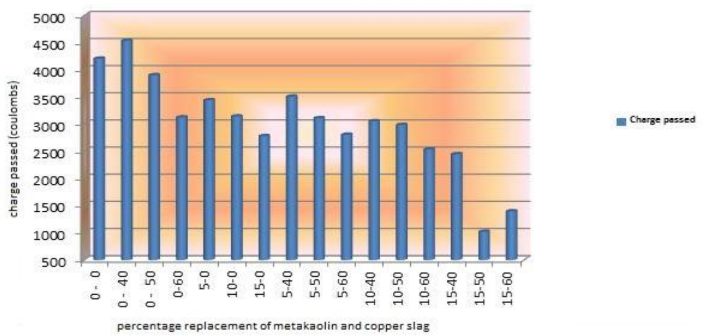

Chart – 4: Comparison of RCPT results

From the above chart it is observed that the metakaolin mixtures showed remarkably lower permeability than control specimens. The control samples have *high* chloride ion permeability at the order of around *4000 coulombs.*

The replacement of Metakaolin has definitely reduced the chloride ion permeability from *High to Moderate* at the range of *2000 to 4000 coulombs.*

The test results also show that the replacement of sand with copper slag also had a significant role in the durability of concrete. The replacement of sand by slag has reduced the chloride ion permeability form *Moderate to Low* at the range of *1000 to 2000 coulombs.*

The RCPT results suggest that concrete blended with Metakaolin and Slag greatly densified the matrix that reduces the permeability in addition to increase in strength as observed in compression and flexural strengths. The resistance of Metakaolin concrete to chloride-ion penetration was found to be significantly higher.

6. CONCLUSIONS

• The addition of Metakaolin along with cement has increased the compressive strength of the concrete when compared to the conventional concrete.

• The more effective percentage of replacement with metakaolin seems to be between 10% and 15%.

• The flexural strength of concrete increases when 5% of Metakaolin is added but shows a reduction in the strength with more addition of metakaolin.

• The durability of the concrete has enhanced by the addition of Metakaolin as the Water Absorption percentage decreases with the addition of Metakaolin over the control concrete.

• Similarly the concrete shows much improved resistance to chloride ions and hence high permeability character with the addition of Metakaolin because of more pore filling effect.

• The replacement of Copper slag in fine aggregates also shows much improved compressive strength when compared to control mix.

• The more effective percentage of replacement seems to be between 50% and 60%

• However the flexural strength of the concrete used with Slag shows decreased strength when compared to the control concrete and the reduction is at the order of about around 7.5%.

• The addition of Slag in concrete has shown increased water absorption percentage when compared to control.

• The RCPT values of concrete used with slag have shown increased coulombs when compared to the control because of non-cohesive nature of the slag.

• The combination of replacements of both Metakaolin and Copper slag however shows much improved results in compression strength when compared to their respective controls and the increase in strength is inthe range of around 40% than the control concrete and in some special cases [10% MK & 50% slag, 15% MK & 50%slag] it is found to be in the range of even around 80%.

• The flexural strength of concrete using both Metakaolin and Copper Slag has shown improved strength when 15% MK & 50% Slag is used.

• The durability tests conducted on the concrete specimens using both MK and Slag have shown much improved result than that of their respective control specimens.

- The concrete mix with 15% Metakaolin and 50% slag has shown much durability results with respect to water absorption and RCPT when compared to the other combinations.

- By replacing the cement and sand with Metakaolin and copper slag the reduction in the consumption of cement and sand can be achieved. By reducing the consumption of cement and sand, the ecology of the earth can be improved enormously and the air pollution due to the production of cement can also be reduced.

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8. BIOGRAPHIES

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