Study on Implementation of Metakaolin & Foundry Sand on Self-Compacting Concrete Properties

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Abstract - *Concrete is widely used as construction material. However, the production of Portland cement releases significant amount of CO2 (carbon dioxide), a greenhouse gas. On the contrary natural resources like fine aggregates are also depleting day by day. One ton of Portland cement clinker production releases approximately one ton of CO2 and other gases. Environmental issues are playing essential role in the sustainable development of concrete industry.*

Today many researches are ongoing for the replacement of Portland cement & fine aggregates, using many materials like metakaolin & foundry sand. Metakaolin & Foundry Sand can also be used as a binder with the partial replacement of cement & fine aggregates which take some part of reaction at the time of hydration reaction. The mix were prepared of partially replacing cement & fine aggregates to Metakaolin by 5%,10% & 15% & Foundry Sand by 10%,20% & 30%.

Tests were carried for compressive strength, tensile strength and flexural strength at the age of 7,14 & 28 days and compared with the results of conventional concrete. The overall tests results show that Metakaolin & Foundry Sand could be used in concrete as a partial replacement of cement & fine aggregates.

Key Words*: *Concrete, Metakaolin, Fine Aggregates, Eco-Friendly, Foundry Sand, Compressive, Flexural & Tensile Strength.

1.0 INTRODUCTION

Concrete as a building material plays an important role in this sector. The consumption of natural resources as an ingredient of concrete, costs high as well as it is on verge of extent. These problems force us to recover the natural resources or to find an alternative option to overcome this problem. Presently the production of waste foundry sand as by-product of metal casting industries causes various environmental problems. Usage of this waste in building material would help in reduction of stress on environment

Metal industries use foundry sand which is uniform sized, high quality silica sand that is bound to form a mould for casting of ferrous and non-ferrous metal. The burnt sand after the casting process of metal is reuse for many times but when it cannot be longer used it is removed from foundry as a waste for disposal known as "Waste foundry sand". Use of waste foundry sand as a partial replacement or total replacement by fine aggregate in concrete leads in production of economic, light weight and high strength concrete.

Metakaolin is a cementitious material used as admixture to produce high strength concrete. In order to evaluate and compare the mechanical properties and durability of concrete using metakaolin, the following tests were conducted on concrete specimens using various replacements of metakaolin; mechanical tests such as compressive, tensile and flexural strength tests. Strength tests revealed that the most appropriate strength was obtained for a substitution rate of metakaolin to binder ranging between 10% and 15%.

Metakaolin is one of the innovative clay products developed in recent years. It is produced by controlled thermal treatment of kaolinite. Metakaolin can be used as a concrete constituent, replacing part of the cement content since it has pozzolanic properties. The use of metakaolin as a partial cement replacement material in mortar and concrete has been studied widely in recent years. Despite of the recent studies, there are still many unknowns with the use of metakaolin. Study is needed to determine the contribution of metakaolin to the performance of hardened concrete. There are great concerns on the strength and durability of metakaolin-concrete when used as construction materials in the construction industries. If it is proven that the concrete is durable and strong, this will lead to the use of metakaolin to replace part of the cement. Metakaolin is not a by-product which means its engineering values are well controlled. Therefore, using metakaolin should promise some advantages compared to other cement replacement materials. In this case, studies are needed to study the performance of concrete using metakaolin.

Metakaolin is produced by burning kaolininite at a temperature of 600°C-800°C. The main constituent, kaolinite is a hydrous aluminium silicate of the approximate composition $2H_2O.Al_2O_3.2SiO_2$.

2.0 MATERIALS USED

Cement: The cement used was 53 grade Ordinary Portland Cement.

FIGURE: 1 Sanghi cement (53 grade PPC)

Fine aggregate: Locally available sand confirming to zone II with specific gravity 2.66 was used.

FIGURE: 2 Fine Aggregate

Coarse aggregate: Coarse aggregate used was 20 mm and less size and specific gravity 2.70.

FIGURE: 3 Coarse aggregate

Metakaolin: In this experiments metakaolin having particle size less than 90 micron was used.

FIGURE: 4 Metakaolin

Foundry Sand: In this experiments metakaolin having particle size less than 90 micron was used.

FIGURE: 5 Foundry Sand

Water: Water plays an important role as it contributes in chemical reaction with cement. Water is used for mixing as well as for curing purpose.

2.1 MATERIAL PROPERTIES

Foundry Sand:

Property	Fine Aggregate	Coarse aggregates
Fineness modulus	3.30	7.52
Specific gravity	2.38	2.76
Bulk density (gm/cc)	1752	1744
Water absorption (%)	1.25	1.80

Table-1

Properties of Foundry Sand

Constituent	Value (%)
SiO_2	83.93
Al_2O_3	0.021
Fe_2O_3	0.950
CaO	1.03
MgO	1.77
SO_3	0.057
LOI	2.19

Cement:

Table-2

Properties of PPC Cement

Physical Properties	Result	Chemical Properties	Result (%)
Specific gravity	2.9	SiO_2	23.7
Standard consistency (%)	31.6%	Al_2O_3	12.4
Initial setting time (min)	210 min	CaO	48.0
Final setting time (min)	250 min	MgO	1.83
Compressive strength N/mm^2 at 28 days	52 N/mm^2	Fe_2O_3	2.01
-	-	Loss on ignition	1.00

Metakaolin:

Table-3

Properties of Metakaolin

Chemical	Composition
SiO	50% - 55%
Al2O3	38% - 42%
CaO	1%-3%
TiO2	0.8-1.2
Na2O	<1%
Fe2O3	0.2-0.5
K2O	<1%
Physical	**Properties**
Bulk Density (g/cc)	0.5461 (When packed)
Color	White
Specific Gravity	2.30

Coarse & Fine Aggregates:

Table-4

Properties of Coarse & Fine Aggregates

3.0 SELF-COMPACTION TEST OF CONCRETE

Filling ability:
It is the ability of SCC to flow into all spaces within the formwork under its own weight. Tests, such as slump flow, V-funnel etc, are used to determine the filling ability of fresh concrete.

Passing ability of self-compacting concrete:
It is the ability of SCC to flow through tight openings, such as spaces between steel reinforcing bars, under its own weight. Passing ability can be determined by using U-box, L-box, Fill-box, and J-ring test methods.

Segregation resistance:
The self-compacting concrete must meet the filling ability and passing ability with uniform composition throughout the process of transport and placing.

3.1 APPLICABLE LIMITS BY EFNARC

Test	Property	Acceptable range of value	Unit
Slump Flow test	Flowing ability	650-800	mm
V-Funnel test	Filling ability	6-12	sec
U-Box test	Passing ability	0-30	mm

3.2 TEST RESULTS OF SELF-COMPACTION OF CONCRETE

Sr no.	Test name	Result
1.	Slump flow test	Test result indicates diameter of concrete spread of 27.4',26.7',28.0' which is applicable as SCC.
2.	V-Funnel test	Test result indicates concrete mixture takes 8.1,9.5,10 seconds to pass through the V-Box apparatus.
3.	U-Box test	Test result indicates height difference of 23,26,28 mm passing through reinforcement at the end of U-Box apparatus.

- **Slump flow test**

BEFORE AFTER

- **V-Funnel test**

BEFORE AFTER

3.3 EXPERIMENTAL WORK & STRENGTH TEST

Mix Design: Mix design carried out for M35 grade of concrete by IS 10262:2009, resulting to a mix proportion of 1:1.69:2.28 with water cement ratio of 0.42. The replacement of cement by Metakaolin was 5% to 15% at increment of 5% each. The replacement of fine aggregates by foundry sand was 10% to 30% at increment of 10% each.

Casting Process: Concrete contains waste foundry sand & metakaolin as a partial replacement of fine aggregate & cement is tested. Concrete is composed of cement, coarse aggregate, fine aggregate, waste foundry sand, metakaolin and water. The waste foundry sand is replaced in the range of 0%, 10%, 20% and 30% by weight of fine aggregate. The metakaolin is replaced in the range of 0%, 5%, 10% and 15% by weight of cement. The mixture was prepared and three standard cubes of 150*150*150 mm, three standard beams of 150*150*750 mm & three standard cylinders of 150*300mm were casted. After curing for 24hrs the samples were demolded and subjected to compressive, flexural & tensile strength test were cured for 7, 14 and 28 days.

Compressive Strength Test: Compressive strength tests were performed on compression testing machine of 2,000 KN capacity. Three cubes of 150*150*150 mm from each batch were subjected to this test. The comparative study was made on properties of concrete after percentage replacement of fine aggregate by waste foundry sand in the range of 10%, 20% and 30%.

Tensile Strength Test: The tensile strength of concrete is approximately 10% of its compressive strength. Tensile splitting strength tests of concrete block specimens were determined as per IS: 5816-1999. After curing of 28 days the specimens were tested for tensile strength using a calibrated compression testing machine of 2000 KN capacity.

Flexural Strength Test: Beams of dimensions 150x150x750 mm was prepared and tested under 3-point loading machine increasing loading to determine the flexural strength. The rate of load application was 1.0 MPa/min in all cases. The flexural strength can be determined as PL/BD2 , where P is the maximum node applied (N), L is the span length (mm) that is the distance between the line of fracture and the nearest support measured from the center line of the tensile side of specimen, B is the width of the specimen (mm), d is the depth of specimen (mm).

4.0 DIFFERENT TEST RESULTS

Compressive Strength Test:

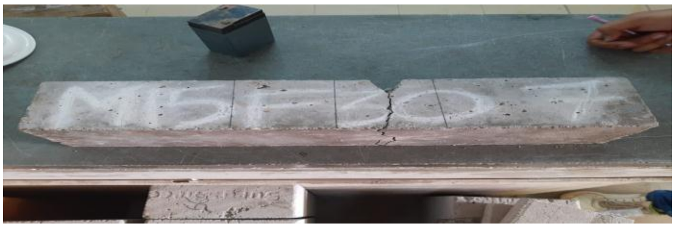
Type of concrete (M35)	Compressive strength 7 days (N/mm^2)	Compressive strength 14 days (N/mm^2)	Compressive strength 28 days (N/mm^2)
MK0+FS0	27.7	30.8	37.9
MK5+FS10	30.9	38.4	44.3
MK10+FS20	32.8	40.3	46.5
MK15+FS30	29.4	36.7	41.8

BEFORE AFTER

Flexural Strength Test:

Type of concrete (M35)	Flexural strength 7 days (N/mm²)	Flexural strength 14 days (N/mm²)	Flexural strength 28 days (N/mm²)
MK0+FS0	4.3	4.9	5.1
MK5+FS10	4.8	6.7	8.9
MK10+FS20	4.6	5.9	7.6
MK15+FS30	4.3	4.9	5.1


BEFORE



AFTER

Tensile Strength Test:

Type of concrete (M35)	Compressive strength 7 days (N/mm²)	Compressive strength 14 days (N/mm²)	Compressive strength 28 days (N/mm²)
MK0+FS0	1.5	2.1	3.4
MK5+FS10	2.5	3.0	3.6
MK10+FS20	1.9	2.8	4.1
MK15+FS30	1.8	2.9	3.8


BEFORE AFTER

5.0 CONCLUSIONS

- We conclude that by partially replacing metakaolin by 5%,10%,15% & foundry sand by 10%,20%,30% to the concrete increases its compressive strength, flexural strength & tensile strength.
- Post 40% addition of foundry sand strength as well as the workability of concrete drastically decreases.
- The workability of SCC is good while replaced with metakaolin, foundry sand and with both combination of reasonable replacement levels.
- Particle size of metakaolin is 1-2 microns smaller than cement 15-45 microns; self-compacting concrete with Metakaolin has good workability. Using foundry sand in self-compacting concrete increases the fines in the paste volume and workability.
- Maximum flexural strength was achieved by 16.5 KN, tensile strength was achieved by 4.01 N/mm2, compressive strength was achieved by 46.5 KN.

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7.0 BIOGRAPHIES

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