Experimental Investigation on Concrete by Replacing Cement with Metakaolin Clay

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ABSTRACT

This study project presents of an experimental investigation carried out to evaluate effects of replacing cement with metakaolin clay. The properties of metakaolin are very similar to the cement properties. Metakaolin is also a mineral admixture which converts calcium hydroxide into advantageous cementitious material. The use of supplementary cementitious material in production of concrete can result in major saving of energy and cost. It also helps to improve strength, durability, impermeability and chemical resistance of concrete. The present study investigates the effects of Metakaolin clay on strength properties of M30 grade concrete. The experimental program is designed to find the compressive strength of concrete by partially replacing the cement in concrete production. The replacement levels of cement by metakaolin are selected as 10%, 20%, and 30% for constant water-cementitious material ratio. For all mixes compressive strength is determined at 7, 14, 28 days for 150 X 150 X 150 mm size cubes. And we cast cubes at various percentages of replacements and we can find the optimum percentage metakaolin clay in concrete.

Keywords: Investigation, Concrete, Replacing, Cement, Metakaolin Clay.

1. INTRODUCTION

1.1 General

Cement plays the role of a binder, a substance that sets and hardens and might bind alternative materials along. The word "cement" comes from Romans, UN agency used the term “opus caementiciumto” describe masonry resembling fashionable concrete that was made up of rock with calcined lime as binder. The volcanic ash and small-grained brick additives (surkhi) that were additional to the calcined lime to get a hydraulic binder were later brought up as cimentum, cäment, and cement. Cement is widely used by human beings and it is second largest material after water used by human beings. Based on recent survey total amount of cement is used during the financial year of 2012 247 MT and it increases up to 550 MT for financial year 2020. India is second largest country after China based on uses of cement.

During production of cement and hydration process of cement carbon dioxide is produced based on experimental investigation it has been proved that 1 tons of clinker produces around 1 tons of CO_2. This Co_2 production causes serious environmental damages and this can be prevented by two ways described as way-1 use another binding material instead of cement which is not possible right now for unavailability of such a binding material and another way is way-2 partial replacement of cement by appropriate material. Way -2 is quite simple because of lots of references are available as well as enough appropriate material is also available.

As per IS 10262:2009 code for practice for mix design of concrete we can save cement by replacing it with fly ash. As per this code if we are designing concrete grade of M 40 with fly ash, we can save cement around 80 kg/m^3 without loss in performance of concrete so way-2 is more suitable for saving environment from harmful gases. If we find suitable material as a partial replacement of cement then we can save cement and environment also. For doing this research literature survey is required and this paper is based on literature survey.

1.2 Detailed Description

Concrete is the most widely used and versatile building materials which is generally used to resist compressive force. By addition of some pozzolanic materials, the various properties of concrete viz, workability, durability, strength resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixture, which improve the micro structure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. Metakaolin is pozzolanic materials which are manufactured from selected kaolins, after refinement and calcination under specific condition. It is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration by a pozzolanic reaction, to produce calcium silicate hydrate and calcium aluminosilicate hydrates. This paper envisages the use of metakaolin as partial replacement of OPC in M-25 and M-30 grade of concrete. The percentage replacement of OPC by metakaolin was 10%, 20% and 30%. The test specimens (cubes) casted and tested as per relevant IS code of practice for 7, 14 and 28-days compressive strength by water curing and ambient curing.

1.3 Formation of Metakaolin

Concrete is probably the most extensively used construction material in the world. It is only next to water as the most heavily consumed substance and about six billion tones being produced every year. This is due to the availability of large quantity of raw materials available for cement manufacture. However, environmentalists concern both in terms of damage caused by the extraction of raw material and CO2 emission during cement manufacture have brought pressures on researchers for the reduction of cement consumption by partial replacement of cement by supplementary materials. These materials may be naturally occurring, industrial wastes or byproducts that require relatively less energy to manufacture. The other concerns contributing to these pressures are the incidents involving serious deterioration of concrete structures. In addressing these concerns and other environmental issues relating to the disposal of waste industrial by products because of economic advantages, mixtures of Portland cement and pozzolans are now very commonly used in concrete production.

Originally the term pozzolan was associated with naturally formed volcanic ashes and calcined earths, which react with lime at ambient temperatures in the presence of water. The admixtures in the form of siliceous aluminous materials which, in finely divided form and in the presence of water, will react chemically with calcium hydroxide $Ca\ (OH)_2$ to form compounds that possess cementitious properties. This generalized definition covers waste products such as fly ash (FA), rice husk ash and silica fume (SF).

1.4 Use of Crusher Sand

Artificial and produced by proper machines can be a better substitute to river sand. The sand should be sharp and coarse. The grains should be of durable material. The sizes must be such it should give minimum voids. The presence of clay and silt retards the setting of the cement and makes the weaker and the walls or the leaks and hold dampness.

Now a day'sVaastu shastra is more popular, followed by so many persons for constructing a house. As per Vaastu shastra the building materials must be free from traces of human body or animal body. The river sand contains bones of human beings and animals. The shells are also one kind of bone. It is not easy to take out all such things present in the river sand. The best solution for this is to use artificial crushers sand of good quality. Sand manufacture by vertical impactor is cubical shape. Such and can be used for all types of construction work, concreting, plastering etc. and is better substitute to river sand.

2. METHODOLOGY

Figure 1 shows the flow chart representation of methodology

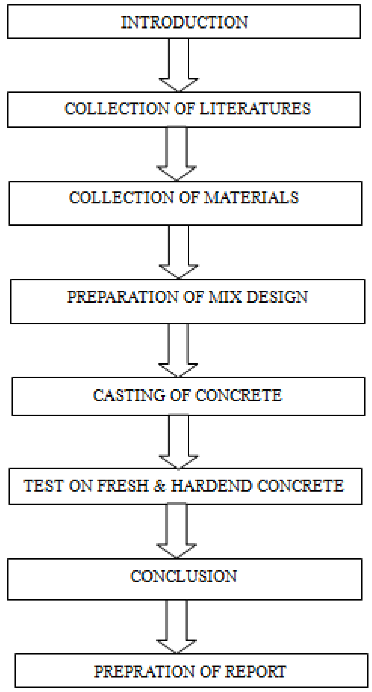

Figure 1 Flow Chart Representation of Methodology

3. MATERIALS AND ITS PROPERTIES

3.1 Materials Used

- Cement
- Metakaolin Clay
- Crusher sand as fine aggregate
- Coarse aggregate and
- Water

3.2 Cement

Ordinary Portland cement of OPC 53 grade was replaced by metakaolin clay in order to obtain preferred concrete blocks. Table 1 shows the physical properties of cement.

Table 1: Physical Properties of Cement

Test conducted	Observed values
Specific gravity of cement	3.15
Consistency	35%
Initial setting time	28 min
Final setting time	600 min

Table 2 shows the chemical properties of cement.

Table 2: Chemical Properties of Cement

Test Conducted	Observed Values (%)
Calcium oxide	62.68
Silica	20.36
Alumina	6.87
Iron oxide	3.67
Magnesia	1.77
Sulphuric anhydride	2.24
Tri calcium silicate	42.57
Di calcium silicate	26.33
Tri calcium aluminate	12
Tetra calcium alumina ferrite	2.24

3.3 Metakaolin Clay

Metakaolin is a dehydroxylated form of the clay mineral kaolinite Stone that are rich in kaolinite are known as China clay or kaolin, traditionally used in the manufacture of porcelain. The particle size of metakaolin is smaller than cement particles, but not as fine as silica fume.Most of metakaolin is used in Portland cement industries as an additive to improve the compressive strength of the cement. Using Cicalengka and Bangka kaolin as metakaolin raw material, R & D Center for Mineral and Coal Technology found that Bangka kaolin was more suitable in metakaolin preparation because its initial Al2O3 content (32.80%) rises up to 37.50% after decantation, meanwhile Cicalengka one cannot fulfill the requirements. The non-decanted Bangka kaolin (37.50% Al2O3) exceeds the Al2O3 content of metakaolin that has been produced commercially by Asian Ceratec Corporation. Figure 2 shows the metakaolin.

Figure 2 Metakaolin

Table 3 shows the physical properties of metakaolin.

Table 3: Physical Properties of Metakaolin

Test conducted	Observed values
Specific gravity of cement	2.5
Physical form	Powder
Color	Off White
Bulk Density (Kg/1)	4.0 - 5.0
Loss on Ignition (%)	1.5
Lime Re activity	1050mgCa $(OH)_2$/g

Table 4 shows the chemical properties of metakaolin.

Table 4: Chemical Properties of Metakaolin

Test Conducted	Observed Values (%)
Silica (SiO_2)	54.3
Alumina Al_2O_3	38.3
Calcium oxide CaO	0.39
Ferric oxide Calcium oxide (Fe_2O_3)	4.28
Magnesium oxide (MgO)	0.08
Potassium oxide (K_2O)	0.50
Sulphuric anhydride (SO_4)	0.22

3.4 Crusher Sand

Crusher sand was obtained from Mettur. The properties of the artificial sand were studied in accordance with BIS 2386-1963.

Table 5 shows the physical properties of crusher sand.

Table 5: Physical Properties of Crusher Sand

Test conducted	Observed Values
Specific gravity	2.74
Water absorption	1.8%
Bulk density	1.64 gm/cc
Percentage of voids	40%
Fineness modulus	2.49

3.5 Coarse Aggregate

Coarse aggregate of hard blue granite of size 12mm aggregates were used to manufacture the concrete. Table 6 shows the physical properties of coarse aggregates.

Table 6: Physical Properties of Coarse Aggregate

Test Conducted	Observed Values
Specific gravity	2.75
Water absorption	0.9%
Moisture content	10%
Bulk density	1.66 g/cc
Fineness modulus	3.20

3.6 Water

Portable tap water available in laboratory with pH value of 7.0± l and conforming to the requirement of IS 450-2000 was used for mixing concrete and curing the specimen as well.

4. EXPERIMENTAL INVESTIGATION

4.1 Design Mix

Proportioning of concrete mixtures consist of determination of respective ingredients necessary to produce concrete having adequate workability, strength and durability for the particular strength and for various exposure conditions, the mix proportioned for the controlled M25, M30 grades were arrived from the trail mixes as per IS method of design mix. These mixes were used throughout the study.

4.1.1 Design Mix for M_{25} Grade of Concrete

OPC 53 grade confirming to IS 12269

- Nominal size of aggregate -12mm
- Shape of coarse aggregate - Angular
- Workability -100 mm (slump)
- Exposure - Moderate

4.1.1.1 Tests

OPC 53 grade confirming to IS 9103

- Specific gravity of cement = 3.15
- Specific gravity of coarse aggregate = 2.80
- Specific gravity of fine aggregate = 2.70

Water absorption

- Coarse aggregate = 0.4%
- Fine aggregate = 1%
- Free (surface) moisture = Nil

Sieve analysis fine aggregate-zone 1 (table 4 IS -383)

Table 7 shows the mix proportions of concrete per M^3

Table 7: Mix Proportions of Concrete Per M^3

Replacement In %	Cement (kg/m^3)	Metakaolin (kg/m^3)	Fine Aggregate(kg/m^3)	Coarse Aggregate(kg/m^3)	Water (lit)
C90 M10	302.4	33.6	834	1114	197
C80 M20	268.8	67.2	834	1114	197
C70 M30	227.2	108.8	834	1114	197

Table 8 shows the mix proportions of concrete for 6 cubes

Table 8: Mix Proportions of Concrete for 6 Cubes

Replacement In %	Cement (kg)	Metakaolin (kg)	Fine Aggregate(kg)	Coarse Aggregate(kg)	Water (lit)
C90 M10	7.04	0.78	19.42	25.94	3.67
C80 M20	6.25	1.56	19.42	25.94	3.67
C70 M30	5.47	2.34	19.42	25.94	3.67

4.1.2 Design Mix for M_{30} Grade of Concrete

OPC 53 grade confirming to IS 12269

- Nominal size of aggregate -120mm
- Shape of coarse aggregate - Angular
- Workability -100 mm (slump)
- Exposure - Moderate

4.2 Test Procedure of Specimens

4.2.1 Compressive Strength

The strength of the concrete depends upon the properties and proportions of the constituent materials, degree of hydration, rate of loading, method of testing and specimen geometry. The properties of the constituent materials which affect the strength are the quality of fine ad coarse aggregate; the cement paste ate paste aggregate bond characteristics (properties of interfacial or transition zone). These in turn, depends on macro and microscopic structural features including total porous, pore size and shape, distribution and the bond between individual solid component. After the curing period specimen can be 15 to 20 per cent lower than that of dry specimen. After the curing before testing, the specimen should be surfaced dry. Cube specimens generally exhibit 20 to 25 per cent higher strength than the cylindrical specimen. Larger specimen exhibits lower average strength. Hydraulic digital compression testing, machine was used with the capacity of 2000 KN and the pace rate of 2.5 KN/ sec. cube specimen under compression shown in fig 5.4

The Compressive strength is found using the formula,

$$\text{Compressive strength} = P/A, \ N/mm^2$$

Where, P - Breaking load in N

A -Area in mm^2,

5. RESULTS AND DISCUSSON

5.1 Introduction

Introduction concrete must be relative impervious so as to enable it to withstand the service condition for which it has been designed without serious deterioration over the lifespan of the structure. The loss of concrete durability may be caused by the service ability of the environment to which it is exposed or by internal changes within the method concrete itself. The external causes maybe physical, chemical or mechanical attack by nature or industrial aggressive liquid and gases. the fresh and hardened concrete property of all the concrete mixtures designed for a concrete grade of M25 and M30 with the replacement are described in this chapter, Mechanical properties such as Compression strength was discussed with the replacement of 10, 20 and 30% replacement of metakaolin by cement.

5.2 Test Results for Mechanical Properties

5.2.1 Compressive Strength

All cubes of concrete were tested in a Compression Testing Machine with the references of IS: 516 – 1959 to determine Compressive Strength of concrete at the age of 7 days. Table 9 shows the compressive strength test at the age of 7 days.

Table 9: Compressive Strength Test atthe Age of 7 Days

S.NO	MIX		COMPRESSIVE STRENGTH(KN/mm^2)	
			Moisture Curing	Ambient Curing
1	M25	C90 M10	23.15	24.14
		C80 M20	20.31	21.72
		C70 M30	20.52	21.42
2	M30	C90 M10	25.75	27.74
		C80 M20	23.76	26.81
		C70 M30	24.08	24.62

Table 10 shows the compressive strength test at the age of 14 days

Table 10: Compressive Strength Test at the Age of 14 Days

S.NO	MIX		COMPRESSIVE STRENGTH(KN/mm^2)	
			Moisture Curing	Ambient Curing
1	M25	C90 M10	32.06	33.43
		C80 M20	28.11	30.07
		C70 M30	28.40	29.66
2	M30	C90 M10	35.66	38.32
		C80 M20	32.90	33.82
		C70 M30	33.35	34.09

Table 11 shows the compressive strength test at the age of 28 days

Table 11: Compressive Strength Test atthe Age of 28 Days

S.NO	MIX		COMPRESSIVE STRENGTH(KN/mm^2)	
			Moisture Curing	Ambient Curing
1	M25	C90 M10	35.62	37.14
		C80 M20	31.23	33.41
		C70 M30	31.56	32.95
2	M30	C90 M10	39.62	42.68
		C80 M20	36.56	38.91
		C70 M30	37.05	37.88

Figure 3 shows the compressive strength of concreteM_{25}at the age of 7 days.

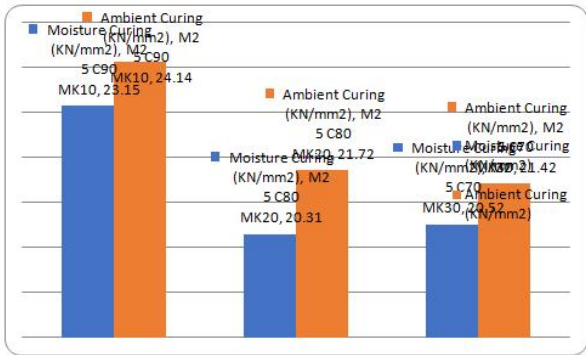

Figure 3 Compressive Strength of ConcreteM_{25}atthe Age of 7 Days

Figure 4 shows the compressive strength of concreteM_{30} at the age of 7 days.

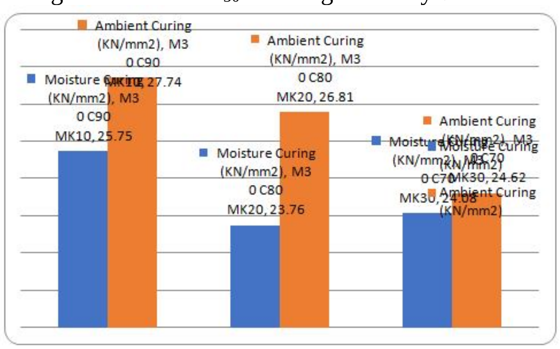

Figure 4 Compressive Strength of ConcreteM_{30}atthe Age of 7 Days

Figure 5 show the compressive strength of concreteM_{25} at the age of 14 days.

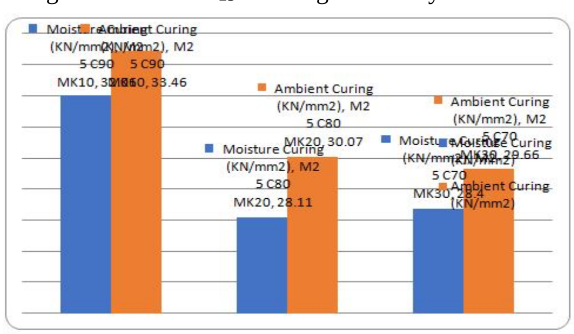

Figure 5 Compressive Strength of Concrete M_{25}atthe Age of 14 Days

Figure 6 show the compressive strength of concrete M_{30} at the age of 14 days.

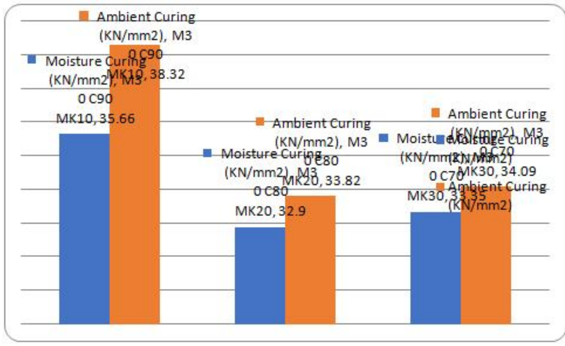

Figure 6 Compressive Strength of ConcreteM_{30}atthe Age of 14 Days

Figure 7 show the compressive strength of concrete M_{25} at the age of 28 days.

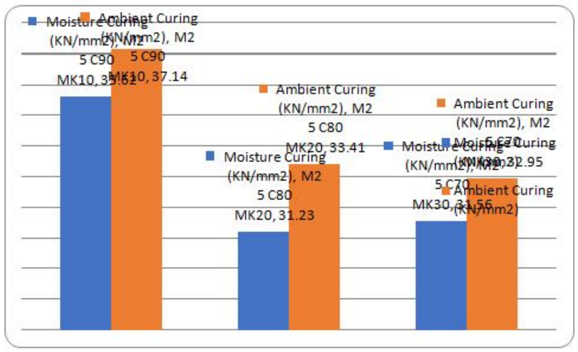

Figure 8 Compressive Strength of ConcreteM_{25} at the Age of 28 Days

Figure 8 show the compressive strength of concrete M_{30} at the age of 28 days.

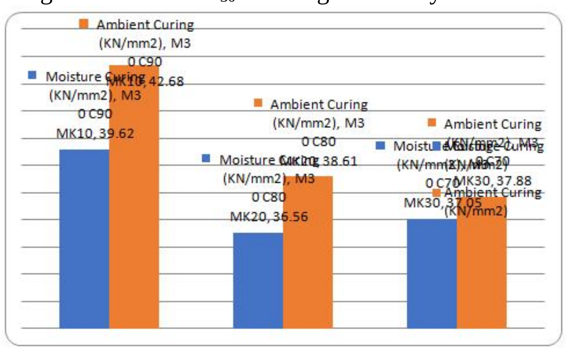

Figure 9 Compressive Strength of ConcreteM_{30} at the Age of 28 Days

6. CONCLUSION

From this investigation on the effect of partial replacement of cement with metakaolin in concrete, the following conclusion was drawn.

- Replacement of cement in cement concrete with metakaolin, it enhanced in mechanical properties.
- With replacement of cement by metakaolin fraction of concrete mix like C90 MK10, C80 MK20 and C70 MK30 with M25 and M30 grade of concrete.
- For M25 grade of concrete C90 MK10, C80 MK20 and C70 MK30, the respective compression strength for 28 days age of moisture curing is 35.62, 31.56 and 35.62 KN/mm^2& for 28 days age of ambient curing is 37.14, 33.41 and 32.95 KN/mm^2.
- For M30 grade of concrete C90 MK10, C80 MK20 and C70 MK30, the respective compression strength for 28 days age of moisture curing is 39.62, 36.56 and 37.05 KN/mm^2& for 28 days age of ambient curing is 42.68, 38.91 and 37.88 KN/mm^2.

- According to the experimental investigation the increases in metakaolin content improves the compression strength of concrete up to 10% (C90 MK10) of replacement of cement on both M25 and M30 grade of concrete.
- Furthermore, the comparison between moisture and ambient curing of concrete, it results the ambient curing of concrete gave better results than moisture curing.

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