RESEARCH ARTICLE

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An Experimental Study on Strength Properties of Concrete by Partially Replacing Cement with Metakaolin

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Abstract

Concrete is the most commonly used material for construction. The worldwide production of cement has greatly increase d since 1990.Production of cement results in a lot of environmental pollution as it involves the emission of CO2 gas. Sup plementary cementitious materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture. These supplementary materials may be naturally occurring, manufactured or manmade waste. Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time. Metakaolin is a dehydroxylated aluminium silicate. It is an amorphous non crystallized material , constituted of lamellar particles. From the recent research works using Metakaolin, it is evident that it is a very effective pozzolanic material and it effectively enhances the strength parameters of concrete.

Keywords: *Metakaolin, Portland Cement, Compressive strength*.

1. INTRODUCTION

The use of supplementary cementitous materials (SCMs) is fundamental in developing low cost construction materials for use in developing countries. By addition of some pozzolanic materials, the various properties of concrete like workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica of the pozzolanic and calcium hydroxide, produced during the cement hydration reactions. In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolanic effect depends not only on the pozzolanic reaction, but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolanas to ordinary Portland cement (OPC) increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste.

Metakaolin is a pozzolanic material which is manufactured from selected kaolin, after refinement and calcinations under specific conditions. It is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicatehydrates. It differs from other supplementary cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under controlled conditions. It is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. This heat treatment or calcinations, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications.

Metakaolin is a fine, natural white clay which contains the highest content of siliceous, so called as High Reactivity Metakaolin (HRM). During the cement hydration process, water reacts with Portland cement and forms calcium-silicate hydrate (CSH). The by-product of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete, and hence reduces the effect of the CSH. When Metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable.

Pozzolanic materials like Metakaoline when used as cement replacement materials in concrete improves the properties of concrete due to the more consumption of $Ca(OH)_2$, better pore refinement, micro filling action, more resistant to permeability, Early gain of strength, higher pozzolanic reaction and also helps in reducing the consumption of cement. This leads to saving of natural resources and reduction in the emission of green house gases like CO_2. The above existing literature indicates that many researchers have studied the few strength properties of ordinary Portland cement concrete using Metakaoline as cement replacement material. Not much literature is available on durability properties and also no literature is available on behaviour of Metakaoline concrete exposed to different thermal cycles at various temperatures. Hence, considering the gap in the existing literature, an attempt has been made to study the strength, durability properties, flexural behaviour of beams and slabs by addition of metakaoline of various aspect ratios at different volume fractions.

2. LITERATURE REVIEW

Extensive research works both at National and International level has been done on the use of various admixtures in mortars and concrete's with a common goal.

- To combat the environmental hazards from the industrial wastes.
- To modify the properties of traditional concrete to the desired level suitable to the specific circumstances.
- To conserve the natural resources used in the production of construction materials.
- To bring down the increasing cost economics of cement, building blocks and high strength concrete.
- To combat the scarcity of traditional ordinary Portland cement and bricks.
- Of late, to rehabilitate the existing structures which are deteriorated over a period of time etc.

3. EXPERIMENTAL PROGRAMME

3.1 Materials Used

Raw materials required for the concreting operations of the present work are.
1. Cement.
2. Metakaoline.
3. Fine aggregate.
4. Coarse aggregate.
5. Water.

A) CEMENT

S.NO.	PROPERTY.	TEST RESULTS.
1	Normal consistency	32%
2	Specific gravity	3.11
3	Initial setting time	75minutes.
	Final setting time.	520 minutes.
4	Soundness(expansion) Lechatlier method	2mm
5	Fineness of cement (Dry sieving method)	98%
`6	Compressive strength of cement at 3 days 7 days 28 days	 20.56 N/mm^2 27.78 N/mm^2 36.67 N/mm^2

B) FINE AGGREGATE (SAND)

The size of the fine aggregate is below 4.75mm, natural sand used as the fine aggregate in concrete mix. Sand may be obtained from rivers, lakes but when used in concrete mix, it should be properly washed and tested to ascertain that total percentage of clay silt, silt and other organic matters does not exceed the specified limit.

For the experimental investigation locally available river sand which is free from organic impurities is used.
Specific gravity = 2.67
Fineness modulus =2.39

C) COARSE AGGREGATE

The material whose particles are of size as are retained on retained on I.S. sieve no. 4.75 mm is termed as coarse aggregate. The size of coarse aggregate depends upon the nature of the work.

The coarse aggregate used in this experimental investigation is 20mm size, crushed and angular in shape. The aggregates are free from dust before used in the concrete.
Specific gravity = 2.83
Fineness modulus =8.6265

D) METAKOLINE

METAKOLINE PHYSICAL PROPERTIES	
Specific gravity	
Colour	White
Physical form	Powder
+325Mesh(45µm) Residue	<1.0%
Pozzolana reactivity mg Ca (O)	1050
Bulk density (gm/lt)	300±30
Average particle size	<2.5 µm
Surface area(cm^2/gm)	150000-180000

Chemical properties

Constituents	Values
Silicon Dioxide(SiO_2)	62.62%
Aluminium Oxide (Al_2O_3)	28.63%
Ferric oxide(Fe_2O)	1.07%
Calcium oxide	0.06%
Titanium Dioxide (TiO_2)	0.36%
Sodium oxide	1.57%
Potassium Oxide	3.46%
Loss of ignition	2.00%

4. CONCRETE MIX DESIGN

Requirements of Concrete Mix Design

- The requirements which form the basis of selection and proportioning of mix ingredients are:
- The minimum compressive strength required from structural consideration.
- The adequate workability necessary for full compaction with the compacting equipment available.
- Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
- Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

Types of Mix

1. Nominal Mixes
2. Standard mixes
3. Designed Mixes

Factors Affecting the Choice of Mix Proportions

1. Compressive strength
2. Workability
3. Durability
4. Maximum nominal size of aggregate
5. Grading and Type Of Aggregate
6. Quality control

Factors to Be Considered For Mix Design

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS 456:2000.
- The cement content is to be limited from shrinkage, cracking and creep.The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique used for transportation, placing and compaction.

Procedure of Mix Design (Based On Is 10262-1982):

- The bureau of Indian standards, recommended a set of procedure for design of concrete mix mainly based on the work done in national laboratories. The mix design procedures are covered in is: 10262-82.ther methods can be applied for both medium strength and high strength concrete. The following mixes are designed are based on Indian standard recommended method of concrete mix design is: 10262-82.

Target Mean Strength for Mix Design

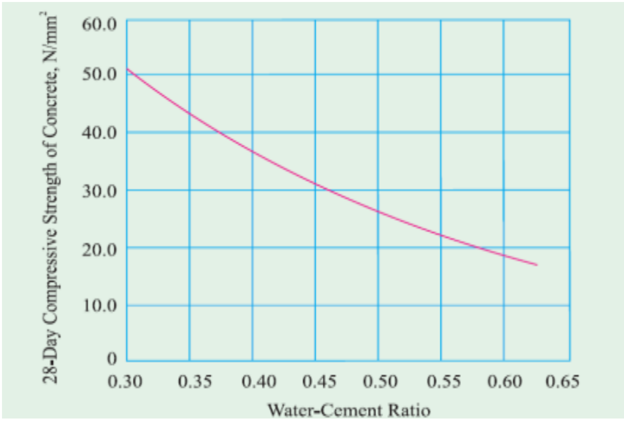
$Fck = f_{ck} + (t \times s)$

Where, f_{ck}=characteristic compressive strength at 28 days.
s = standard deviation.
t = a statistical value depending on the risk factor

ASSUMED STANDARD DEVIATION AS PER IS 456-2000

Grade of concrete	Assumed standard deviation(N/mm2)
M10 M15	3.5
M20 M25	4.00
M30 M35 M40 M45 M50 M55	5.00

SELECTION OF WATER/CEMENT RATIO:



Selection of water/cement ratio

SELECTION OF WATER CONTENT AND FINE TO TOTAL AGGREGATE RATIO:

Approximate sand and water contents per cubic meter of concrete
W/c=0.60, workability = 0.80(compaction factor) (Slump 30 mm approximately)
(Applicable for concrete up to grade m35)

TABLE SELECTION OF WATER CONTENT AND FINE TO TOTAL AGGREGATE RATIO

Approximate sand and water contents per cubic meter of concrete
W/c=0.35, workability = 0.80(c.f)
(Applicable for concrete above grade m35)

Maximum size of aggregate (mm)	Water content including surface water per cum of concrete(kg)	Sand as percent of total aggregate by absolute volume
10	208	40
20	186	35

CALCULATION OF CEMENT CONTENT:

Cement by mass = water content/water cement ratio
To be checked against the minimum cement content for the requirement of durability and the greater of the two values to be adopted.

CALCULATION OF AGGREGATE CONTENT:

Fine aggregate:

$$v= [w+(c/s_c) + (1/p)*(fa/s_{fa})]*(1/1000)$$

Coarse aggregate:

$$v= [w+(c/s_c) + (1/1-p)*(ca/s_{ca})]*(1/1000)$$

Where,

V = absolute volume of a fresh concrete (cum)
W= mass of water (kg) per cum of concrete
C = mass of cement (kg) per cum of concrete
S_c= specific gravity of cement
P = ratio of fine aggregate to total aggregate by absolute volume
Fa = total masses of fine aggregate and coarse (kg) per m3 of concrete respectively
S_{fa}, s_{ca} = specific gravities of saturated surface dry fine aggregate and coarse aggregate respectively.

MIX DESIGN FOR "M30" GRADE

(a) Design Stipulations:

(i)	Characteristic compressive strength required in the field at 28 days.	:	30 Mpa
(ii)	Maximum size of aggregate	:	20 mm
(iii)	Degree of workability	:	0.90 compacting factor 35 mm slump
(iv)	Degree of quality control	:	Good
(v)	Type of exposure	:	Mild.

(b) Test Data for Materials:

(i)	Specific gravity of cement	:	3.11
(ii)	Specific gravity of coarse aggregate	:	2.83
(iii)	Specific gravity of fine aggregate	:	2.67
(iv)	Fine aggregate	:	Zone-III

(c) Target Mean Strength of Concrete:

$$\begin{aligned} Fck &= f_{ck} + (t \times s) \\ &= f_{ck} + (1.65 \times s) \\ &= 30 + (1.65 \times 5) \\ &= 38.25 \text{ Mpa} \end{aligned}$$

Where f_{ck} = characteristic compressive strength
s = standard deviation = 5 (from code book is: 10262-1982)
t = 1.65

(d) Water-Cement Ratio:

The water-cement ratio is 0.425

(E) Selection of Water and Sand Content:

for 20 mm maximum size of aggregate, sand confirming to Zone-III
Water content per cubic meter of concrete = 186 kgs
Sand content = 35% of total aggregate

Change in condition	Percent adjustment requested	
	Water content	**Sand in total aggregate.**
For decrease in water-cement ratio by(0.60-0.425)	0	3.5%
For increase in compacting factor(0.90-0.80)	+3%	0
For sand confirming to zone-iii of table-4 IS 383-1970	0	-1.5%
Total	+3	2%

Total sand content required = 35-2 = 33%
And required water content = 186 + (3/100) x 186 = 191.58kgs/cum

(F) Determination of Cement Content:

Water cement ratio = 0.42
Water content = 191.58 litres.
Cement content =191.58/0.425 = 450.78 kgs/cum

(g) Determination of Fine Aggregate and Coarse Aggregate:

From is: 10262-1982 table-3
For the specified maximum size of aggregate 20mm, the amount of in trapped air in the wet concrete is 2 percent.

Fine Aggregate (f_a)

v= [w+(c/s_c) + (1/p)*(fa/s_{fa})]*(1/1000)
Where, v = absolute volume = 1-0.02 = 0.98
w = water content = 191.58 kgs/cum
c = cement content = 450.78 kgs/cum
Sc = specific gravity of cement = 3.11
p = ratio of fine aggregate to total aggregate by Absolute volume = sand content required/total absolute volume= $\frac{33}{100}$ = 0.33
Fa = fine aggregate, kgs/cum
Sfa = specific gravity of fine aggregate = 2.67

$$0.98 = [191.58 + \frac{450.78}{3.11} + \frac{1}{0.33} \times \frac{Fa}{2.67}] \frac{1}{1000}$$

$\therefore Fa$ =566.9655kgs/cum

Coarse aggregate (c_a)*:*

V= [w+(c/s_c) + (1/1-p)*(ca/s_{ca})]*(1/1000)
Where, Sca = specific gravity of coarse aggregate = 2.83

$$0.98 = [191.58 \times \frac{450.78}{3.11} + \left(\frac{1}{(1-0.33)} \times \frac{C.A}{2.83}\right)] \times \frac{1}{1000}$$

$\therefore$ C.A =1220.0923 kgs/cum

MATERIAL REQUIRED FOR M30 GRADE CONCRETE PER CUBIC METER QUANTITY OF CONCRETE:

Material	**Water**	**Cement**	**Fine aggregate**	**Coarse aggregate**
Kgs/cum	191.58	450.78	566.9655	1220.0923
Ratio	0.425	1	1.30	2.71

QUANTITIES OF EACH MOULD IN KGS:

Mix proportions of M30 grade: 1: 1.3: 2.7
Water cement ratio = 0.425
Air content = 2%
Specific gravity of cement s_c = 3.11
Specific gravity of fine aggregate = 2.67
Specific gravity of coarse aggregate = 2.83
Total volume
V = V_v + $V_{aggregates}$
V = volume of each cube = 0.15×0.15× 0.15 = 3.375 ×10^{-3}
V = (V_a+ V_w) + V_C + v_{sand} + v_{ca}

$$3.375\times10^{-3} = \frac{0.425}{\gamma} w_c + \frac{Wc}{3.11\,\gamma} + \frac{Ws}{2.67\,\gamma} + \frac{Wca}{2.83\,\gamma}$$

Here γ = density of water = 1000 n/m^3
W_s = 1.3 W_C
Wca = 2.71 W $3.375\times10^{-3} = 0.425W_C + \frac{wc}{3.11} + \frac{1.3\ wc}{2.67} + \frac{2.71\ wc}{2.83}$

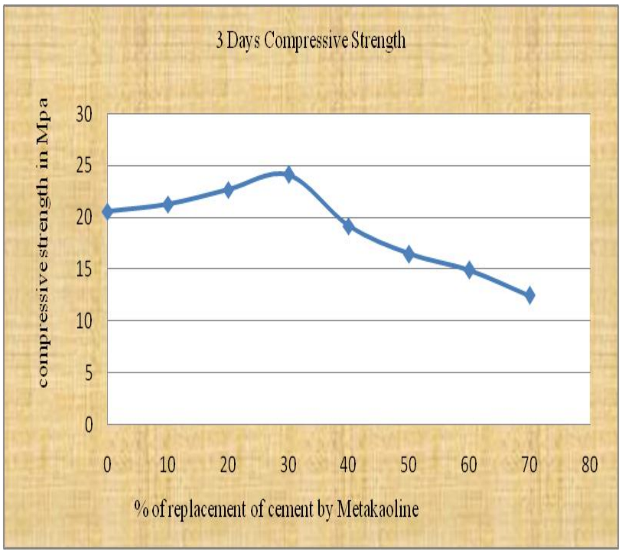
W_C = 1.54 kg
Ws = W_{fa} = 2 kg
Wca = 4.17 kg
Water cement ratio = 0.655 lt.

5. RESULTS AND DISCUSSIONS

Compressive Strength Values for Replacement of Cement by Metakaoline

3-Days Compressive Strength Results

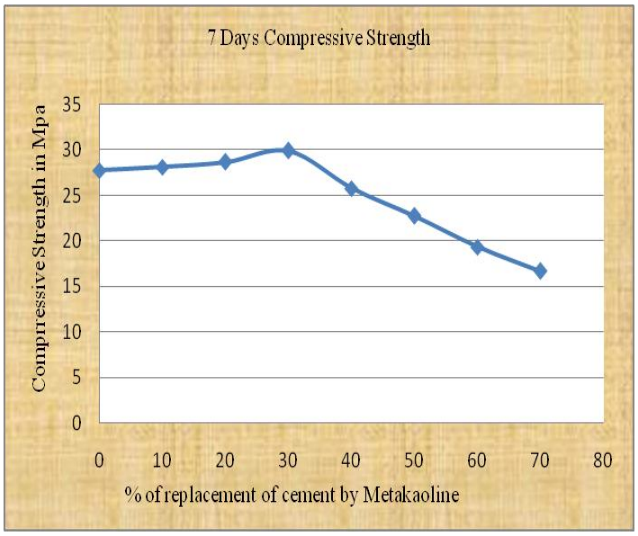
S. No	*Cement Replacement with Metakaoline by (%Mix)*	*Compressive Strength(Mpa)*
1	*0*	*20.56*
2	*10*	*21.25*
3	*20*	*22.67*
4	*30*	*24.12*
5	*40*	*19.15*
6	*50*	*16.45*
7	*60*	*14.89*
8	*70*	*12.45*



3Days Compressive Strength

7-Days Compressive Strength Results

S.no	Cement Replacement with Metakaoline by (%Mix)	Compressive Strength(Mpa)
1	0	27.78
2	10	28.15
3	20	28.7
4	30	29.92
5	40	25.76
6	50	22.72
7	60	19.33
8	70	17.84



7 Days Compressive strength

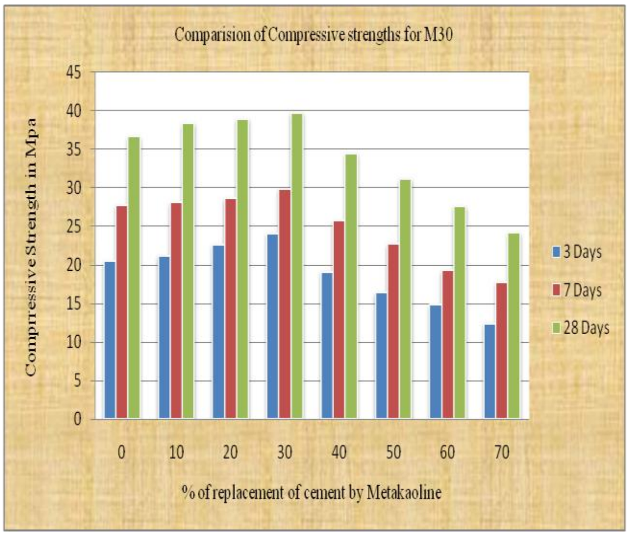
28-Days Compressive Strength Results

S.no	Cement Replacement with Metakaoline by (%Mix)	Compressive Strength(Mpa)
1	0	36.67
2	10	38.45
3	20	39.00
4	30	39.80
5	40	34.52
6	50	31.23
7	60	27.64
8	70	24.19

28 Days Compressive strength

Compressive Strength Results For Replacement of Cement by metakaoline

Cement Replacement with Metakaoline by (%Mix)	3 days	7 days	28 days
0	20.56	27.78	36.67
10	21.25	28.15	38.45
20	22.67	28.70	39
30	24.12	29.92	39.80
40	19.15	25.76	34.52
50	16.45	22.72	31.23
60	14.89	19.33	27.64
70	12.45	17.84	24.19



Comparisons of Compressive strengths for M30

6. CONCLUSIONS

- From the above study we conclude that the compressive strength of the concrete cubes has gradually increased up to addition of 10% of metakaoline.
- Compared to compressive strengths of 10%, 20% and 30% of addition of Metakaoline, the compressive strength of 40% to 70% metakaoline concrete has been decreased.
- Whereas comparing to traditional concrete, compressive strength of 30% has been increased.
- Hence for economical view 40% is preferable and in the perspective of compressive strength 30% is suggested.
- The gain in compressive strength is improved depending upon the replacement level of OPC by metakaoline.
- The metakaoline inclusion generally improves tensile strength, flexural strength, bond strength and modulus of elasticity. The quantum of increase in the individual properties depends upon replacement level.
- The Metakaoline in concrete can allow major carbon dioxide reductions and also increase the service life of concrete structures.

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