© 2015 IJSRSET | Volume 1 | Issue 4 | Print ISSN : 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

# Partial Replacement of Metakaoline in Cement Concrete

**K. Rajasekhar, K. Spandana**
Department of Civil Engineering, Krishna Chaitanya Institute of Technology and Sciences, Markapur, Andhra Pradesh, India

## ABSTRACT

Concrete is the extensively used construction material in the world. However, environmental concerns both in terms of damage caused by the extraction of raw material and $CO_2$ emission during cement manufacture have brought pressure to reduce cement consumption by the use of supplementary materials. The utilization of calcined clay, in the form of metakaolin (MK) in concrete has received considerable attention in recent years. On this matter, a study has been conducted to look into the performance of metakaolin as cement replacement material in concrete. The study focuses on the compressive strength performance of the blended concrete containing different percentage of metakaolin. The cement is replaced accordingly with the percentage of 5 %, 10%, 15% & 20% by weight. Concrete cubes are tested at the age of 7 and 28 days. In addition, the effect of calcination temperature to the strength performance is included in the study. Finally, the strength performance of metakaolin-concrete studied in this work. The results show that the strength development of concrete blended with metakaolin is enhanced. It is found that 15% replacement appears to be the optimum replacement where concrete exhibits enhanced compressive strength at all ages.

**Keywords:** Metakaolin (Mk), Puzzolonic, Concrete, Compressive Strength, Mix Design

## I. INTRODUCTION

Concrete is one of the most common materials used in the construction industry. In the past few years, many research and modification has been done to produce concrete which has the desired characteristics. There is always a search for concrete with higher strength and durability. In this matter, blended cement concrete has been introduced to suit the current requirements. Cementitious materials known as puzzolonic are used as concrete constituents, in addition to Portland cement. Originally the term puzzolana was associated with naturally formed volcanic ashes and calcined earths will react with lime at ambient temperatures in the presence of water. Recently, the term has been extended to cover all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess cementitious properties. The current area of research in the concrete is introducing clay metakaolin in the concrete. Clays have been and continue to be one of the most important industrial minerals. Clays and clay minerals are widely utilized in our society. They are important in geology, agriculture, construction, engineering, process industries, and environmental applications. Traditional applications of clay including ceramics, paper, paint, plastics, drilling fluids, chemical carriers, liquid barriers, and catalysis.Research and development activities by researchers in higher education and industry are continually resulting new and innovative clay products. Metakaolin is one of the innovative clay products developed in recent years. It is produced by controlled thermal treatment of kaolin. Metakaolin can be used as a concrete constituent, replacing part of the cement content since it has puzzolonic 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.

**1.1 Objective of Study**

This study is conducted to accomplish some predefined objectives. These objectives are

- To study the performance of concrete containing different percentages of metakaolin and to identify the optimum replacement percentage.
- To investigate the effect of calcination temperatures to the strength performance of metakaolin-concrete.
- To study the percentage of decreases in cost by using metakaolin-concrete.

**1.2 Significant of the Study**

Concrete has been used in the construction industry for centuries. Many modifications and developments have been made to improve the performance of concrete, especially in terms of strength and durability. The introduction of puzzolonic as cement replacement materials in recent years seems to be successful. The use of puzzolana has proven to be an effective solution in enhancing the properties of concrete in terms of strength and durability. The current puzzolonic in use are such as fly ash, silica fume and slag. Development and investigation of other sources of puzzolana such as kaolin will be able to provide more alternatives for the engineer to select the most suitable cement replacement material for different environments. Unlike other puzzolonic, 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. The performance of metakaolin-concrete will be compared to the cost of production of metakaolin to determine whether metakaolin is worthy to be developed as a new cement replacement material. In addition, the use of metakaolin is not common in the Malaysian construction sector. This study will be able to enhance the understanding on the suitability of metakaolin as cement replacement material.

**1.3 Scope of Study**

This study focuses on the strength performance of concrete with metakaolin. Strength is the most important property of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. Strength characteristic is also important because it is related to several other important properties which are more difficult to measure directly. With regard to this matter, the development of compression strength of metakaolin concrete is studied. Cement replacements by 5%, 10%, and 15% with metakaolin are studied. Concrete tests are conducted on the concrete samples at the specific ages. All the strength tests are limited to the ages of 28 days In the study of the effect of calcination temperatures to the strength performance of metakaolin, the temperatures is set within the range of 600°C-800°C. The temperatures interval used is 50°C.

**2. Sources for Metakaolin**

Metakaolin is normally produced by calcining pure clays at appropriate temperatures. Amboise etc. (1985) demonstrated that metakaolin can also be obtained by the calcination of indigenous laterite soils. On calcination of laterites in the range 750–800°C, kaolinite and gibbsite are transformed into transition phases of metakaolin and amorphous alumina both of which possess puzzolonic properties. Pera and Amboise (1985) showed that blended cements containing 30% calcined laterites produced strengths (between 7 and 28 days) higher than that of plain concrete pastes. At 180 days the strength of paste containing 50% calcined laterites was 87% of that developed by plain Portland cement. Another source for the production of metakaolin is that of calcining waste sludge from the paper recycling industry. Pera and Amboise (1985) showed that calcination of waste paper sludge at about 700°C produces highly reactive metakaolin. Using DTA to evaluate the calcium hydroxide consumption in Portland cement pastes blended with calcined sludge, it is found that the main parameters influencing the puzzolonic activity were thequantities of kaolinite in the inorganic fraction, calcium hydroxide derived from the calcitepresent in the sludge and particle sizes smaller than 10µm. Pera and Amboise (1998) foundthat despite smaller kaolinite content, the DTA analysis showed that burnt paper sludgeexhibited more puzzolonic activity than commercially available metakaolin, particularly atearly ages. This was attributed to the presence of superficial defects that occur during the calcination of the sludge.

### 2.1 Physical and Chemical Properties of Metakaolin

The physical and chemical properties of kaolin determine its use as an industrial mineral. These uses are governed by several factors including the geological conditions under which the kaolin formed the total mineralogical composition of the kaolin deposit, the physical and chemical properties. Some of the properties of metakaolin.

| PROPERTIES | DESCRIPTION |
|---|---|
| Color | Usually cream white, colorless and yellow |
| Luster | Earthy |
| Transparency | Crystals are translucent |
| Cleavage | Perfect in one direction, basal |
| Fracture | Fracture |
| Hardness | 1.5- 2 (can leave marks on paper) |
| Specific gravity | 2.6 |

## II. METHODS AND MATERIAL

**Slump**

Early age properties measure the workability and setting behavior of fresh concrete. These generally include slump, unit weight, setting time, and heat of hydration. The properties of fresh concrete are important because they affect the choice of equipment needed for handling and consolidation and because they may affect the properties of hardened concrete [Mindess, 2003]. This test involves filling a cone mold with fresh concrete in three layers of equal volume, rodding each layer 25 times, lifting the mold away vertically, and measuring the height difference between the cone mold and the concrete. Metakaolin has been shown to produce smaller slumps than control mixtures, although its effect relative to mixtures containing silica fume is not agreed upon. Ding and Li [Ding, 2002] reported that MK offered much better workability than did silica fume for the same mixture proportions. These mixtures contained 5, 10, 15, 20% replacement with either MK or silica fume, and a w/c of 0.35. Additionally, they found that at 5% and 10% replacement, MK mixtures had a slightly higher slump than the control mixture. At 20% replacement with MK, slump decrease approximately 20% from the control value.

| Mix | Mix description | Slump (mm) |
|---|---|---|
| Normal mix | 100% cement | 25 |
| Mix1 | 95%cement & 5% mk | 25 |
| Mix2 | 90%cement & 10% mk | 28 |
| Mix3 | 85%cement & 15% mk | 29 |
| Mix4 | 80%cement & 20% mk | 30 |

**CEMENT:**In the present study Portland puzzolana cement of JP cement was adopted. The cement used is 53grade. The physical properties of the cement tested according to Indian Standards procedure confirms to the requirements of IS: 122-69 and the test results are given below.

| S.No | Properties | Results |
|---|---|---|
| I | Fineness of cement | 0.02% |
| II | Specific gravity of cement | 3.15 |
| III | Normal consistency of cement | 33% |
| IV | Initial setting time | 36min. |
| V | Soundness of cement | 1mm |

**Fine aggregate:**The sand mentioned here is confirming to zone III as per IS:383-1987 was used for making concrete and its specific gravity was found out.

**Sieve Analysis Fine Aggregate:**

| s.no | IS sieve no. | Weight retained (kg) | Cumulative weight retained (kg) | Cumulative % weight retained | Cumulative % weight passing |
|---|---|---|---|---|---|
| 1 | 4.75 | 0 | 0 | 0 | 100 |
| 2 | 4.25 | 0.86 | 0.86 | 10.6965 | 89.3035 |
| 3 | 2.36 | 0.01 | 0.87 | 10.8208 | 89.1792 |
| 4 | 2.00 | 0.01 | 0.88 | 10.9452 | 89.0548 |
| 5 | 1.18 | 0.01 | 0.89 | 11.0696 | 88.9340 |
| 6 | 0.6 | 0.02 | 0.91 | 1.3184 | 88.6816 |
| 7 | 0.3 | 0.88 | 1.79 | 22.2636 | 77.7364 |
| 8 | 0.15 | 0.05 | 1.84 | 22.8855 | 77.1145 |
| 9 | 0.09 | 0 | 0 | 0 | 0 |
| Pan | 0 | 0 | 0 | 0 | 0 |

| S.No. | Properties | Results |
|---|---|---|
| I | Specific gravity | 2.45 |
| II | Fineness modulus | 1 |
| III | Water absorption | 1.0% |
| IV | Surface moisture | 0.5% |
| V | Bulk density | 1448 kg/$m^3$ |

**COARSE AGGREGATE:** Coarse aggregate conforming to IS: 387-1987 of size 20mm.The experimental results are shown in given below:

| S.No. | Properties | Results |
|---|---|---|
| I | Specific gravity | 2.58 |
| II | Fineness modulus | 2.93 |
| III | Water absorption | 0.5% |
| IV | Surface moisture | 0.1% |
| V | Bulk density | 1660kg/$m^3$ |

**Sieve analysis of coarse aggregate:**

| S.No. | IS sieve size | Weight retained (kg) | Cumulative weight retained (kg) | Cumulative % weight retained | Cumulative % weight passing |
|---|---|---|---|---|---|
| 1 | 80 | 0 | 0 | 0 | 100 |
| 2 | 40 | 0 | 0 | 0 | 100 |
| 3 | 25 | 0.020 | 0.020 | 0.4 | 99.6 |
| 4 | 20 | 1.244 | 1.264 | 25.2 | 74.72 |
| 5 | 16 | 2.272 | 3.536 | 71.72 | 28.28 |
| 6 | 12.5 | 1.264 | 4.8 | 96 | 4 |
| 7 | 10 | 0.2 | 5 | 100 | 0 |
| 8 | 4.75 | 0 | - | - | - |
| Total | | 5.00 | | 293.40 | |

**Compressive strength of cubes:** A Metakaolin concrete mix design procedure is developed (or) tailored to existing IS 10262-1982 concrete mix design procedure. In this view the influence of metakaolin on concrete is represented by modification factor, which is obtained by designing an experimental program, consisting of mortar cubes (7.07cm x 7.07cm x7.07cm), in which the percentage of metakaolin with cement is the variable. Metakaolin varied from 0%-20% replacement with cement in mortar cubes.

| S.No. | . % Metakaolin | Cement | MK | Compressive strength of cement mortar cubes (MPa) |
|---|---|---|---|---|
| 1 | 0 | 300 | 0 | 6 |
| 2 | 5 | 285 | 15 | 16.85 |
| 3 | 10 | 270 | 30 | 12.47 |
| 4 | 15 | 255 | 45 | 23.67 |
| 5 | 20 | 240 | 60 | 7.22 |

From the above results, 15% of metakaolin replaced by cement gives optimum compressive strength.

## 4. METAKAOLIN CONCRETE MIX DESIGN (As per IS 10262 - 1982)

### MATERIALS USED

**Cement** The cement used was ordinary Portland cement of 53grade (Jaypee cement). The cement for entire experiment was procured in a single consignment and properly stored.

**Coarse aggregate** locally available coarse aggregate, having a size of 20mm was used throughout the work.

**Fine aggregate** River sand produced locally was used for fine aggregate. Size of 4.75mm to 600microns was used as fine aggregates.

**Metakaolin** The metakaolin used in this project is transported from 20microns, Baroda.

**Water** Potable water was used in the work for mixing concrete and also for curing.

**Design stipulations:**

Grade designation – M25

Characteristic compressive strength required in the field 28 days: 25MPa

Maximum size of aggregates: 20mm

Degree of workability: 0.9 compacting factor

Degree of quality control: Good

Type of exposure: Mild

Type of aggregate: 20 mm (angular)

Test data for stipulations:

Specific gravity of cement: 3.15

Specific gravity of coarse aggregate: 2.58

Specific gravity of fine aggregate: 2.45

Water absorption:

Coarse aggregate: 0.50%

Fine aggregate: 1.0%

Surface moisture:

Coarse aggregate: 0.1%

Fine aggregate: 0.5%

**4.1 MIX DESIGN PROCEDURE:**

Target mean strength of concrete (As per IS 10262 of 1982): The target mean strength for specified characteristic cube strength is

$F'_{ck} = f_{ck} + t*s$

Where $F_{ck}$ = characteristic compressive strength at 28 days.

t = risk factor = 1.65 (As per table 11.21 of IS 10262-1982)

s = assumed standard deviation for M25 is 4. (As per IS 456 of 2000)

$f'_{ck} = 25 + 1.65*5$

$f'_{ck} = 31.6$MPa.

**Selection of water-cement ratio**: The water-cement ratio required for target mean strength of 31.6MPa is 0.5. And the water-cement ratio for mild exposure is 0.55. Hence, we have to take minimum water-cement ratio. Adopt water-cement ratio of 0.5.

Selection of water and cement content: From table 11.24, for 20 mm maximum size aggregate, sand conforming to grading zone II, water content per cubic meter of concrete is 186kg and sand content as percentage of total aggregate by absolute volume is 35 per cent.

For change in value in water-cement ratio, compacting factor, for sand belonging to zone III, correction is required.

| Change in condition | %adjustment in water content | %adjustment in sand in total aggregate |
|---|---|---|
| For sand conforming to zoneIII | 0 | -1.5 |
| For decrease in water-cement ratio by(0.6-0.5=0.1) | 0 | -2.0 |
| 0 For increase in compaction factor(0.9-0.8=0.1) | +3 | 0 |
| Total | +3 | -3.5 |

Therefore, required sand content as percentage to total aggregate by absolute volume is

35-3.5 = 31.5%

Required water content = 186 + 5.85 = 191.85 l/$m^{3.}$

**Calculation of cement content:**

Water-cement ratio: 0.50

Water: 191.6 liters

Cement: (191.6/0.50) = 383.7kg/$m^3$

This cement content is adequate for mild exposure condition.

**Calculation of fine aggregate:**

For the specified maximum size of aggregate of 20 mm, the amount of entrapped air in the wet concrete is 2 per cent.

$V = \{[w + (C/S_c) + (1/P)(fa/S_{fa})] [1/1000]\}$

$0.98 = [(191.85) + (383.7/3.15) (1/0.315)(f_a /2.45)][1/1000]$

980 = 191.85+121.8+1.29fa

fa= 516.55kg/$m^3$

**Calculation of coarse aggregate:**

$Ca = [(1-p)/p]*fa*(s_{ca}/s_{fa})$

Where, V = absolute volume of concrete. (v=100-% of entrapped air)

W = water content.
C = cement content.
$S_c$ = specific gravity of cement.
P = % of sand to total aggregate.
fa = fine aggregate content.
$S_a$ = specific gravity of fine aggregate.
Ca = [(1-0.315)/0.315]*516.55*(2.58/2.45)
Ca = 1182.89kg/m3

**Mix proportion:**

Water-cement ratio: 0.5
Cement: 383.7 kg
Water: 191.85 kg
Coarse aggregate: 1182.89 kg
Fine aggregate: 516.55 kg

The mix proportion is:

| Water | :cement | : | sand | : coarse aggregate |
|---|---|---|---|---|
| 192 | : 383.7 | : | 516.6 | : 1182.9 |
| 0.5 | : 1 | : | 1.346 : 3.1 | |

For 1 bag of cement:
Cement = 50 kg
Sand = 67.3 kg
Coarse aggregate = 155 kg
Water = 25 liters

## III. RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH OF CONCRETE CUBES AT 7 DAYS

| S.No. | Mix | Cement | MK | Compressive strength (MPa) | %of increase in compressive strength |
|---|---|---|---|---|---|
| 1 | N | 100 | 0 | 31.7 | - |
| 2 | 5% of mk | 95 | 5 | 35.96 | 13.43 |
| 3 | 10%of mk | 90 | 10 | 35.37 | 11.57 |
| 4 | 15% of mk | 85 | 15 | 40.7 | 28.3 |
| 5 | 20% of mk | 80 | 20 | 39.6 | 23.8 |

COMPRESSIVE STRENGTH OF CONCRETE CUBES AT 28 DAYS

| S.No. | Mix | Cement | MK | Compressive strength (MPa) | %of increase in compressive strength |
|---|---|---|---|---|---|
| 1 | N | 100 | 0 | 51.67 | - |
| 2 | 5% of mk | 95 | 5 | 57.3 | 10.08 |
| 3 | 10%of mk | 90 | 10 | 56.37 | 9.09 |
| 4 | 15% of mk | 85 | 15 | 63.93 | 24 |
| 5 | 20% of mk | 80 | 20 | 61.85 | 19.7 |

## IV. CONCLUSION

The work carried out to find the optimum value of compressive strength of concrete with MK.The following conclusions have been drawn from the present work. Values of compressive strength of concrete with MK after 28 days are higher by 24%. Dosage of 15% of metakaolin causes decrease of workability of suspension of time. Increasing amount of perceptual proportion of MK in concrete mix seems to require higher dosage of super plasticizer to ensure longer period of workability. From the above results, we can conclude that 15% of cement replaced by metakaolin gives the optimum value. The mix design procedure described by modifying the IS: 10262-1982 in this project can be used in designing the metakaolin concrete.

## V. REFERENCES


**[1]** Indian standard recommended guidelines for concrete mix design IS: 10262-1982
**[2]** Concrete technology by M.S.Shetty
**[3]** Specification for standard sand for testing of cement IS: 650-1966.
**[4]** Cement and concrete research Pera; Ambroise; Marwan; effect of calcinations temperature of kaolinite.
**[5]** Cement and concrete research changling; puzzolonic activity of the kaolin.

[6] Cement and concrete research Dubey and Banthia's; studied the properties of kaolin.
[7] Cement and Concrete Research 34(2004) 1035-104; E.Badogiannisa, V.G.Papadakisb, E.Chinnotakisc, S.Tsivilisa; Exploitation of poor Greek kaolin: Strength development of metakaolin concrete and evolution by means of k-value.
[8] Cement and Concrete Research (2003); Jamal M.khatib, Roger McClain; characteristics of metakaolin concrete.
[9] Cement and Concrete Research 33(2003) 579-584; Zongjin Li, Zhu Ding; property improvement of Portland cement by incorporating with metakaolin and slag. 46
[10] Cement and Concrete Research 32(2002) 1365-1369; A.H.Asbridgea, C.L.Page; ―Effects of metakaolin, water / binder ratio and interfacial transmission zones the micro hardness of cement mortars.
[11] Cement and Concrete Research 32 (2002) 145-152; B.Pacewskaa, M.bukowskab, I.Wilian skaa, M.Swatb; modification of the properties of concrete by a new puzzolana waste catalyst from the catalytic process in a fluidized bed.
[12] Cement and Concrete Research 31 (2001) 1607-1611; Xiaoqian Qian, Zongjin li; the relationships between stress and strain for high-performance concrete with metakaolin.
[13] Cement and Concrete Research 31 (2001) 1301-1306; S.Poona, L.Lam, S.C.Kou, Y.L.Wong, Ron Wong; rate of puzzolonic reaction of metakaolin in high-performance cement pastes.