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Research paper

Effects of reactivity metakaolin on properties of high strength concrete

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Abstract

Reactivity Metakaolin (MK) is an engineered pozzolanic mineral admixture, reacts aggressively with calcium hydroxide, which results in significant performance of concrete.
In this work, different aspects of concrete mechanical behaviors have been studied including compressive and flexural strengths. In addition, some characteristics of concrete durability were investigated including absorption and porosity.
In mixture proportioning, 5% and 10% of cement content is replaced by MK it was observed that concrete with 5% and 10% MK would perform almost the same in improving the mechanical properties of the materials. However In term of workability and durability, a better performance was obtained in concrete with MK. All mixes compressive strength is determined at 7 and 28 days. Current experimental study shows that 10% replacement of cement by Metakaolin gives higher strength.

Keywords: *High Strength Concrete; Met Kaolin; Compressive Strength; Flexural Strength.*

1. Introduction

The construction industry has taken forward steps over the last two or three decades in regard to many cementations materials, in particular High Strength Concrete (HSC) and High Performance Concrete (HPC). HSC and HPC, the concrete products will continue to make important contributions to enhanced quality and efficiency in the construction of infrastructure in the next century [1].
HSC seems to have become the keyword in today's concrete technology. In the early 1940s, 30 N/mm^2 (at 28 days) was considered to be the representative of HSC [2]. This level jumped to 50 N/mm^2 in the late 1950s and early 1960s. Concrete strengths of 100-130 N/mm^2 is being viewed now as the criteria for high strength.
ACI 363R [3] and other ACI guidelines address some recommendations on placing, compacting and curing of HSC. However, design of HSC includes detailed knowledge of properties of local materials, i.e, aggregates, cement and pozzolanic admixtures [4].
Most pozzolanic admixtures used today are byproducts from other industries; such as Metakaolin which refined kaolin clay that is fired carefully (calcined) under controlled conditions to create an amorphous aluminosilicate that is reactive in concrete. Like other pozzolans (fly ash and silica fume are two common pozzolans), Metakaolin reacts with the calcium hydroxide (lime) byproducts that produced during cement hydration.
Reactivity Metakaolin is a highly pozzolanic material produced by calcining kaolin clay at temperature of 700 – 900° [5].
In this research, using local clay mineral materials are widely available in the western regions of Iraq. Kaolin where it was burned at a controlled temperature and turned into Reactivity Metakaolin.

2. Experimental investigation

2.1. Materials

The cement was used throughout this investigation, portland cement complying with the requirements of Iraqi Specifications No. (5), 1984 for portland cement [6].
The MK was supplied by the General Company for Mining and Geological Survey of the Iraqi Ministry of Industry and Minerals. Reactivity Metakaolin is produced by calcining kaolin clay at temperatures of 750° according to the American standard (ASTM C–311-02) [7].
Details of the main physical and chemical properties of the portland cement and MK as given in Table 1. The X-ray Diffraction (XRD) pattern of the MK used in this study as shown in Fig. 1.
The fine aggregate is from the quarries of the Nukhayb area in Karbala governorate. The sieve analysis was performed in accordance to Iraqi Specifications, 1984. The coarse aggregates were employed 5 mm maximum size supplied by a local quarry. The grading of fine as given in Table 2.
The use of super-plasticizers has become essential for designing mixtures to achieve HPC. As can be seen the w/binder ratio has an important bearing on achieving the strength parameters. In order to achieve dense concrete with reduced permeability plasticizers of following types are in general using EcoBit (VZ), produced by the Swiss Chemicals Company super plasticizer complying with (ASTM C494 Type G) [8]. It found that the percentage used was 1% of the weight of the cement, which gave proper operation. Table 3 gives descriptions of the Water-reducing, high range.

Table 1: Properties of Portland cement (PC) and MK Used in the Study.

(Property)	PC	MK
CaO	64.1	1.70
SiO_2	20.88	51.70
AL_2O_3	3.74	32.90
Fe_2O_3	4,56	1.10
MgO	1.00	0.10
SO_3	2.18	0.18
Alkalis	0.48	0.51
L.O.I	1.98	8.64
Insoluble Residue	0.89	
Lime Saturation Factor	0.95	
Mineral Composition% :		
C_3S	52,3	
C_2S	21.3	
C_3A	6,2	
C_4AF	9,3	
Physical properties:		
Color	Grey	White
Specific gravity	3.15	2.55
Fineness cm^2/g	2382.4	19000

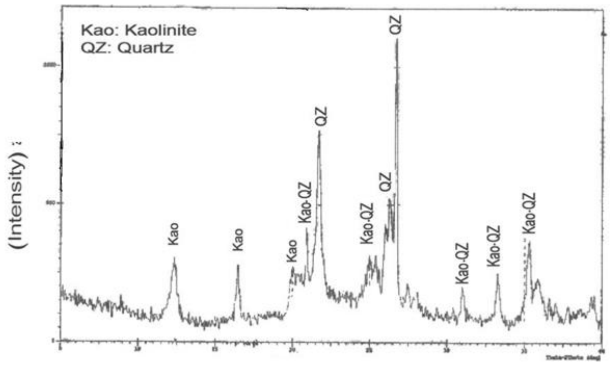

Fig. 1: X-Ray Diffraction (XRD) Pattern for Metakaolin.

Table 2: Grading of Fine Aggregates

Sieve size (mm)	Percentage Retained
10	100
4.75	97
2.36	85
1.18	71.5
0.6	56.5
0.3	18.9
0.15	8
fineness modulus	2.74

Table 3: Descriptions of the Water-Reducing, High Range

Specific Gravity	1.1
Chloride Content	nil
Appearance	liquid
color	Brown
Ph	9-7
Shelf Life	twelve months
Dosage	0.8 liter to 1.6 liter per 100 kg cement

2.2. Mixture proportions

Trials mixtures were prepared to obtain target strength of more than 72 MPa for the control mixture at 28 days. All the mixes were cast using 1:1.2:1.5 mix proportion with constant w/c ratio of 0.2, the dosage of water reducing, high range from 0.8% to 1.6%. Meanwhile, the appropriate retarder can improve the workability of concrete, so the dosage is set from 1%. The details of the mixtures for the study are presented in Table 4, three different mixtures (MK0, MK5%, and MK10%) were employed to examine the influence of low water to cement ratio on concretes containing MK on the mechanical and durability properties. The control mixture (MK0) did not include MK. In mixtures MK5%, and MK10%, cement content was partially replaced with 5%, and 10 % MK respectively.

Table 4: Plain and Concretes Containing MK (kg /m^3)

Mix ID	w/c Ratio	Water	Cement	HRM	Fine Aggregate	Coarse Aggregate	SP %
MK0	0.2	100	500	–	600	750	1
MK5%	0.2	105	500	25	600	750	1
MK10 %	0.2	110	500	50	600	750	1

2.3 Examining the Samples

The concrete samples having different dimensions used for testing. Cubic samples having 70x70x70 mm used for compressive strength and test some physical properties of samples such as absorption and porosity.
For flexural strength, testing, prismatic samples with 70x70x280 mm dimensions used testing. The details and dimensions of the examining samples as shown in Fig. 2.

Fig. 2: The Details and Dimensions of the Examining Samples.

For each examine, three samples was used. Each experimental variance defined by averaging the results gained from those samples. All of examines were held at the end of 28 day curing period.

2.4. Curing of the specimen

After molding the specimens, all the concrete elements kept in curing tank filled with water for required period of curing. All the specimens properly grouped according to their coding so that removal of the specimen from their place for testing work could be conveniently done in a proper sequence. The elements were left undisturbed for the whole period of curing according to (ASTM C-192-02) [9].

3. Test methods

The compression test according to (ASTM C-109-02) [10] compressive strength test carried out at specified ages on the cubes. For the compression test, the cubes are placed in machine in such manner that the load is applied on the forces perpendicular to the direction of cast. Fig. 3 shows compressive strength test setup.
Absorption and porosity test, such as according to American standards (ASTM C642-97) [11].
The flexural strength of the concrete can be determined under third point loading using (ASTMC 78-02) [12], or by center point loading using (ASTMC 293) [13]. The point loading is preferred technique tested on universal testing machine under third point loading. Ultimate loads were recorded for each specimen. The average of three loads was taken to calculate the flexural strength.

Fig. 3: Shows Compressive Strength Test Setup.

4. Results and discussion

The test results of concrete specimen discussed as following:

4.1. Compressive strength

The compressive strength compared with to control specimen with various percentages of MK compressive strength results of specimens presented in Table 5. The seven day Compressive Strength varied between 55.43 and 54 MPa. The reason for the low increase in the compressive strength of early ages to slow pozzolanic reactions of Metakaolin which need longer treatment to complete their interactions and this is identical to the result [14]. The 28-day strength varied between 65 and 72 MPa. The 5% replacement MK mixture exhibited lower strengths comparatively than the 10% MK percentages at 28 days. Fig. 4 presents the relation between Compressive Strength and MK percentages at 7 and 28 days. The highest for the 10% MK mixtures achieving strength of 72 MPa at 28 days. The compressive strength for 5% MK and 10% MK increases in 5.4%, and 10.7% respectively. The strength increase is attributed to the higher content of calcium silicate hydrate in the Metakaolin specimens due to the reaction of the calcium hydroxide produced from cement hydration with the active silica of the Metakaolin [15].

Table 5: Compressive Strength Results of Specimens

Type of Concrete	Compressive Strength (N/mm2)	
	7 Days	28 Days
MK0	55.43	65.02
MK5%	54.32	68.51
MK10%	53.21	72

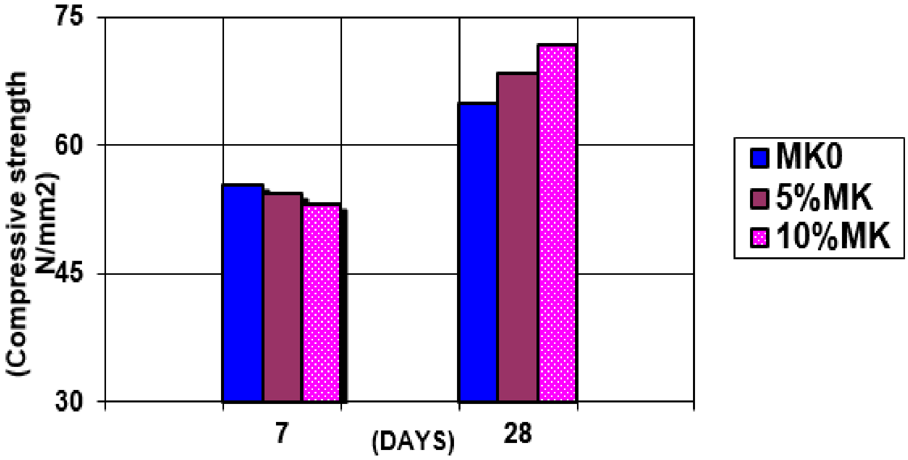

Fig. 4: Variation of Compressive Strength.

4.2. Flexural strength

The Flexural strength compared to control specimen with various ratios of Metakaolin. When compared to control specimen, the flexural strength for MK 5% increases 7.6% and 10% MK increases 11.5%. The specimen 10% MK gave high flexural strength. So 10% MK is the best proportion for add in cement. The flexural strength and various mix concrete test values are presents in Table 6 and variation of flexural strength, as shown in Fig. 5.

Table 6: The Flexural Strength and Various Mix Concrete Test Values

Type of Concrete	Flexural Strength/ 28 Days
MK0	7.8
MK5%	8.4
MK10%	8.7

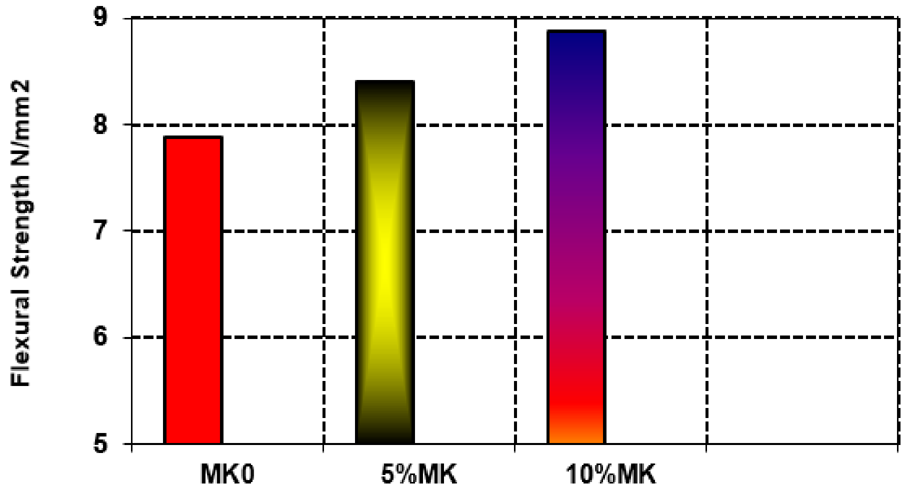

Fig. 5: Variation of Flexural Strength for 28 Days.

4.3. Absorption and porosity

In addition, 10% of Metakaolin were significantly lower in porosity and absorption compared to reference mixtures. The values presented in Fig. 6. The reduction in the volume of pores and the reduction in the absorption was 6.5%, 4.8% for 5% MK and 10.2%. for 10% MK. The results of absorption and porosity of all mixes as shown in Table 7.

The reduction in pore size and absorption ratio of all mixtures containing Metakaolin is due to pozzolanic reactions and the particle size of Metakaolin is generally less than 2.0 microns, which is significantly smaller than the cement particles. It reduces the size and distribution of pores within the hardened concert.

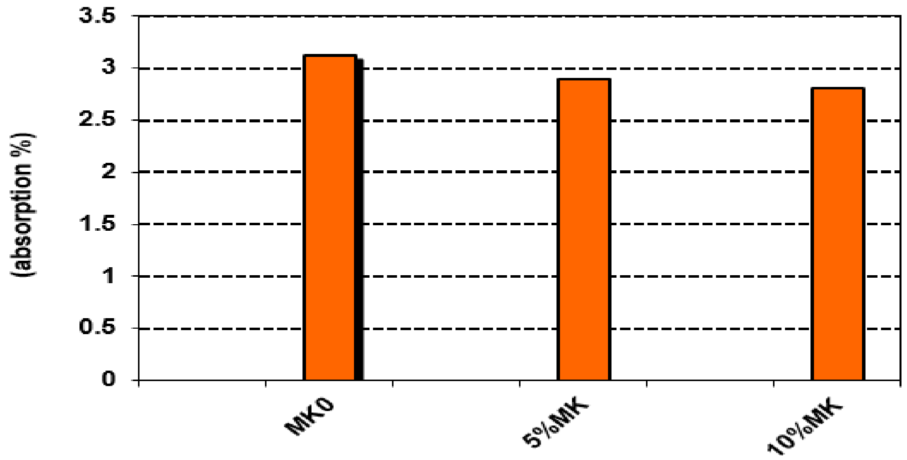

Fig. 6: Variation of Absorption for 28 Days.

Table 7: The Results of Absorption and Porosity for 28 Days.

Type of Concrete	Porosity (%)	Absorption(%)
MK0	7.61	3.12
MK5%	7.11	2.97
MK10%	6.84	2.81

5. Conclusions

From the present investigation on the effect of partial replacement of cement with MK in concrete, the following conclusions were drawn:

- The results shows that by utilizing local MK and cement designed for a low water/binder ratio of 0.2, high strength concretes can be developed and compressive strengths of more than 70 MPa.
- Both 5%MK and 10%MK showed almost the same performance in improving concrete mechanical behaviors for 28 days, including compressive and flexural strengths.
- It was observed that the addition of MK leads to decrease in absorption and porosity.
- The optimum dose of Metakaolin for achieving higher compressive strength is 10%. MK increases the compressive strength of concrete more than 10%.
- By effective usage of Metakaolin in optimum percentage of concrete may make concrete economic and environmental friendly.

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