The effect of Iran's metakaolin in enhancing the concrete compressive strength

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ABSTRACT**:** This paper presents the performance of metakaolin (MK) on compressive strength and durability of concrete. Fired (calcined) MK has a very good pozzolanicity,which could be partialy replaced with portland cement. It can decrease permeability, increase compressive strength and concrete durability. In this study, four different type of metakaolin which one of them was made in UK and the others were from different part of Iran were used. Sixteen mortar mixtures with different amount of calcinating kaolin were made. The substitution proportion of metakaolin used was 5%, 10%, 15% and 20% by weight of cement. About 380 cylinders specimens were made to determine compressive strength. The results indicates that the replacing MK up to 20% has noticeable effect on compressive strength in comparing with mixture without metakaolin. Also, shrinkage test was carried out on some specimens. The results show that shrinkage in specimens containing MK were almost the same as that in the pure cement specimens.

1 INTRODUCTION

Fly ash, silica fume and natural pozzolans are used most frequently as additives to cement to produce the blended cement. Such materials are abundant and using them brings in so many technical and economical profits [Batis & Badogiannis 2005]. In recent years metakaolin (MK) extracted from proper calcinations of kaolin and having pozzolan properties has been used as an additive for cement [Pera 2001]. Regarding various studies already done, the research focused on MK has been based on the structure of kaolin and kaolinite and methods of its processing and also the pozzolanic behavior and its effect on the properties of cement and concrete [Batis & Badogiannis 2005]. The studies done in this regard so far include absorption characteristics of MK concrete [Khatib & Clay 2003], sulphate resistance of MK Mortar [Khatib & Wild 1998, Smallwood et al. 2003], testing of the chloride-penetration strength of concrete containing high-reactivity MK [Boddy et al. 2001], effect of MK on creep and shrinkage of concrete[Brooks & Megat Johari 2001], durability of mortars modified with MK [Courard et al. 2003], performance of MK concrete at elevated temperatures [Poon et al. 2003], selected engineering properties of concrete incorporating slag and MK [Khatib & Hibbert 2005], MK effect on reducing porosity and pore size [Poon et al. 2006] and etc. These studies indicate that the blended cement that contain MK have improved concrete properties. The aim of this paper is to assess British MK and iran's metakaolins for using them as alternatives to cement and also to examine the shrinkage and concrete compressive strength of the under studied cements.

2 TEST PROCEDURE

2.1 *Materials*

Normal portland cement was used in all mixes in this work. Imported British MK (MKA) together

with three Iranian type kaolins were used.It was obtained from Abadeh (KB), Marand zonuz (KC) and Abdolabad Qazvin (KD) . The chemical compositions of the relevant kaolins compared with the consumed cement is given in table 1.

After preparing the kaolins KB, KC and KD, they got fired at $800^{\circ}c$, and were transformed to MK. This procedure through 3 stages, three hours of gradual increase of the ambient temperature to $800^{\circ}c$, temperature stabilization for 5 hours and finally their getting cooled naturally and gradually to the environment temperature [Pera 1987]. The calcined kaolins powdered by grinder mill so as to pass through the sieve 80. The morphology of the raw and calcined kaolins can be seen in figure 1.

Table 1. Properties of PC and metakaolins.

	PC	KA	KB	KC	KD
SiO_2	23.00	71.44	47.80	54.43	69.56
Al_2O_3	4.80	16.10	35.45	28.50	13.80
Fe_2O_3	2.50	0.95	1.01	5.20	1.95
CaO	57.50	3.70	2.70	1.30	2.52
MgO	2.30	0.05	0.30	0.05	1.20
SO_3	3.70	0.05	0.05	0.05	0.05
Na_2O	5.00	0.22	0.20	1.00	2.78
K_2O	1.20	0.13	0.45	1.70	3.04
Loss (L.o.I)	-	7.36	12.04	7.77	5.10

2.2 *Morphology (SEM) of kaolins*

The figures of the kaolins A, C and D have undergone structure – change due to calcinations but not much has happened to the structure of kaolin B.

This seems absolutely logical regarding the relevant kaolins getting amorphized. XRD of raw and calcined kaolins A,B,C and D indicate that the existing crystal kaolins and their (AH) have gone away and turned into glass. This classification in kaolins A,C and D is clear but it has occurred partially in kaolin B (Fig. 1).

3 LABORATORY PROCEDURE

The tests were done at two stages. At the first stage producing samples of mortars (cement + metakaolin + water) of different MK percents were concerned. At the second stage given the results gained at the first stage, concrete samples were made and compressive strength and shrinkage tests were done.

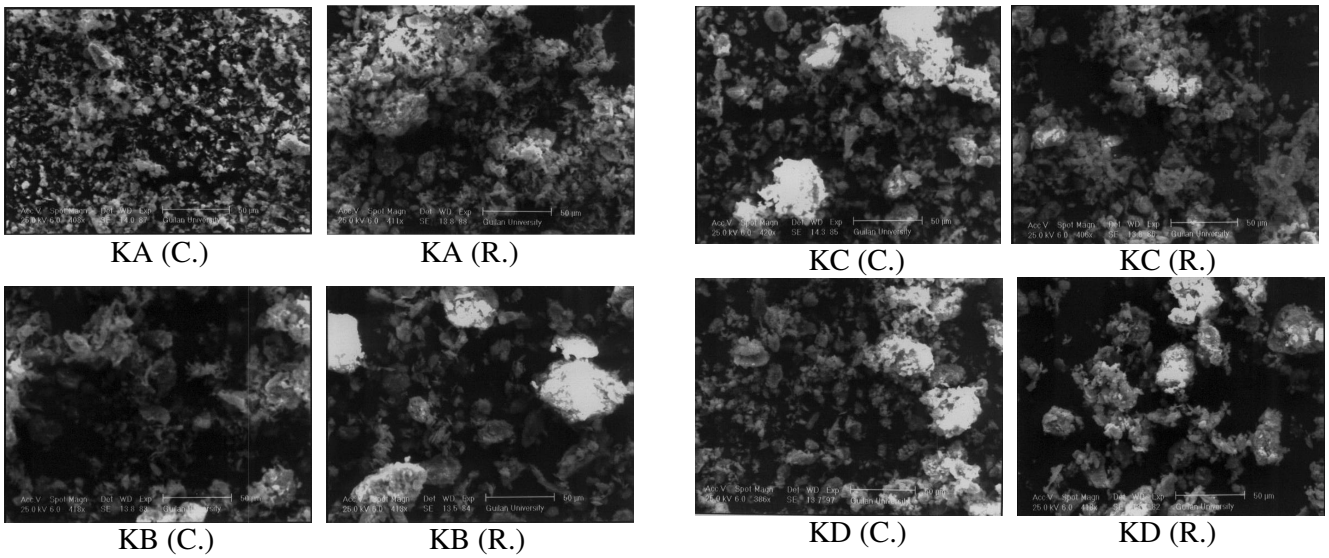

Figure 1. Morphology (SEM) of raw kaolins (R.) and calcined ones (C.).

3.1 *Cement samples*

At the first stage all the metakaolins, 5%, 10 %, 15% and 20% replaced cement and its effect on the compressive strength of blended cement has been tested.

Cements and specific percents of the existing metakaolins together with the mixing water were completely mixed in the mixer in a way to turn it into a bead (normal water).

The ratio of w/b for all the samples were $(24 \pm 0.5)\%$. The samples were made like drums of 2 cm diameter and height of 4 cm. They were removed from the mould after 24 hours and kept in caring room with 98% humidity at $(20 \pm 2)^{\circ}c$. Samples of the blended cement can be seen in figure 2.

Figure 2. Samples of the products.

3.2 *Concrete samples*

At the second stage cubes specimens, (10×10×10 cm) were made for mixture with 20% MKC and MKA and control. The mixture proportions is given in Table 2.

Table 2. mixture proportions for the produced samples of concrete.

	PC& MK	Sand 0-3	Sand 3-6	Gravel	Water
w/w %	22.30	28.90	10.80	28.90	8.90

4 THE TESTS RESULTS

The results of compressive strength tests on different sample are presented at 2 stages: At the first one the compressive results were compared regarding the age of the sample and the percent of the consumed MK. At the second stage taking into account the results gained at the first stage the two mixture samples ultimate compressive strength (s) were desirable got compared with each other.

The first sample mixture contained 20%. Replacement of MKC and the second sample mixture contained 20% replacement of MKA.

4.1 *The results gained from the blended cement samples*

In figure 3 the compressive strength of various samples with different ages and combination percents have been compared.

4.2 *Tests done on the samples of concrete*

Given the results gained in the previous section, MKC20 was selected for more investigation. The compressive strength test was carried out on the concrete samples made by MKC20, other samples made by MKA20 and the control concrete sample without any additives. The obtained results are shown in the table 3.

4.3 *Concrete samples shrinkage*

Prismatic samples that were produced and kept in a damp room were tested at various different ages (tab. 4) . Ratio of the shrinkage of metakaolin concretes to the pc concrete is shown in Figure 5. Shrinkage of the concretes containing MK and the one that does not contain any additives are very much close to each other.

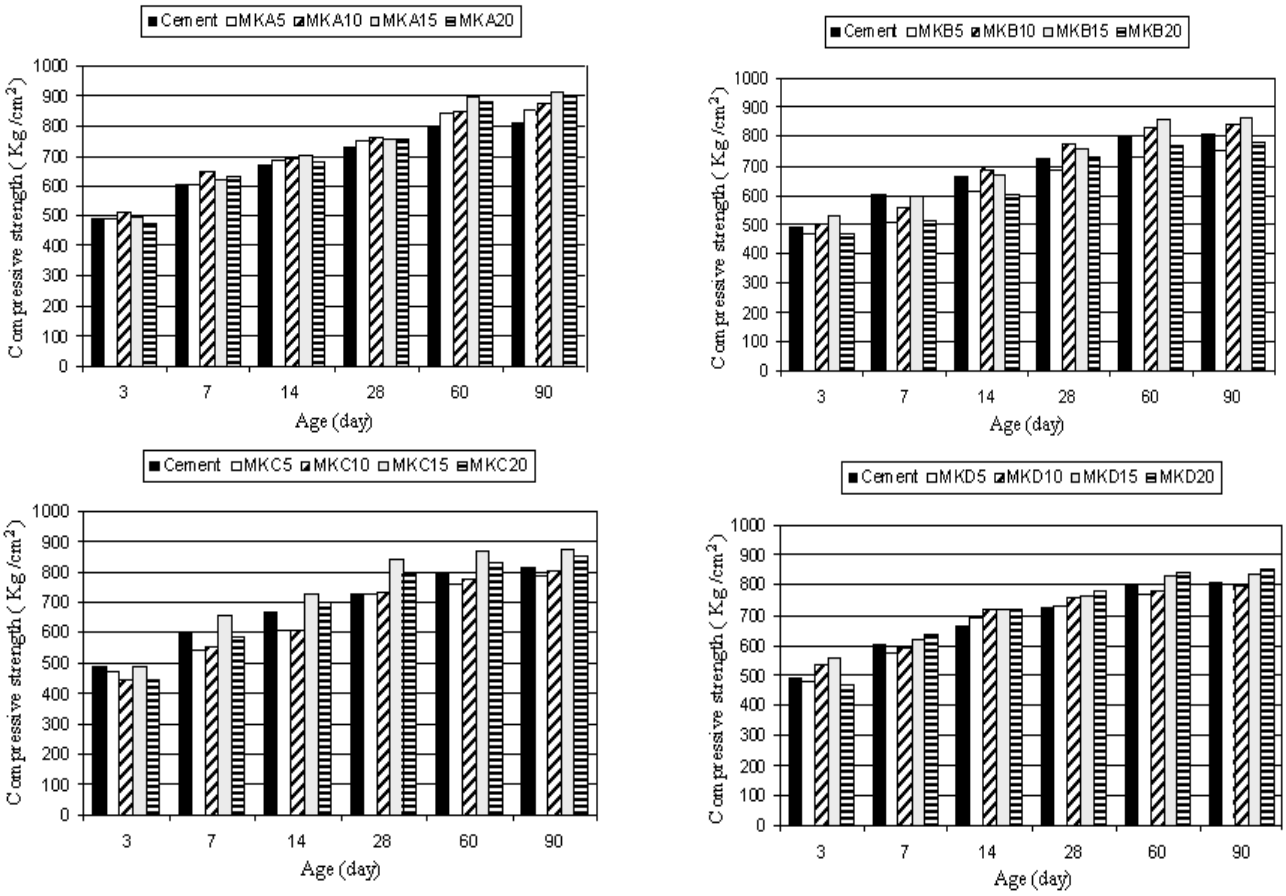

Figure 3. Compressive strength of metakaolin cement in relation to metakaolin type and content.

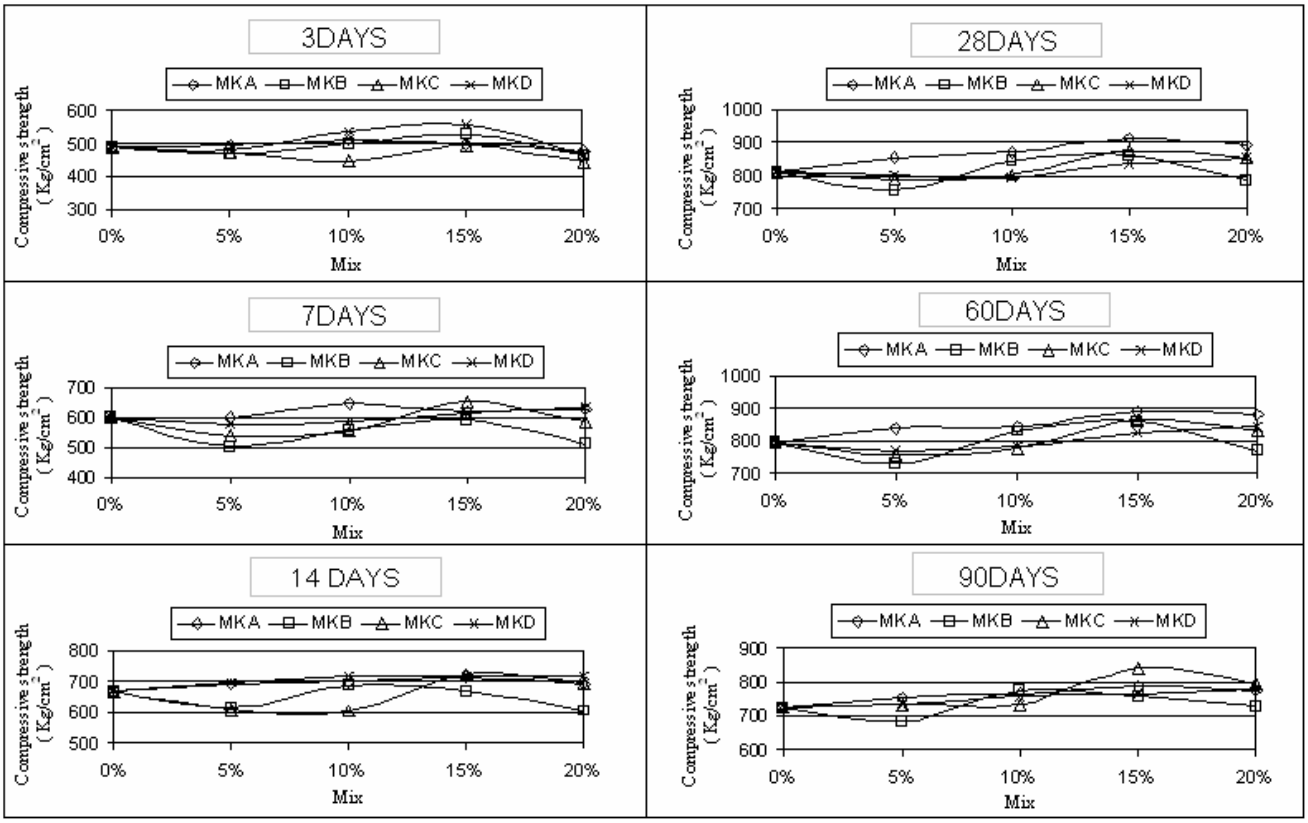

Figure 4. Compressive strength of blended cement in relation to replacing (5, 10,15,20) % w/w of MK.

Table 3. Compressive strength of concrete samples.

W/C	Mix	Compressive strength (Kg /cm^2)					
		3 days	7 days	14 days	28 days	60 days	90 days
0.4	Control	213.83	394	472.1	496.6	513.2	535.4
	MKA20	239.3	342.24	451.3	537.9	576.03	602
	MKC20	250.23	358.82	445.82	519.25	547.66	563.6

Table 4. Concrete samples shrinkage.

	Shrinkage (10^{-6})					
Age (days)	3	7	14	28	60	90
Control	180	220	270	300	320	335
MKA20	140	260	340	350	360	370
MKC20	160	260	320	340	350	360

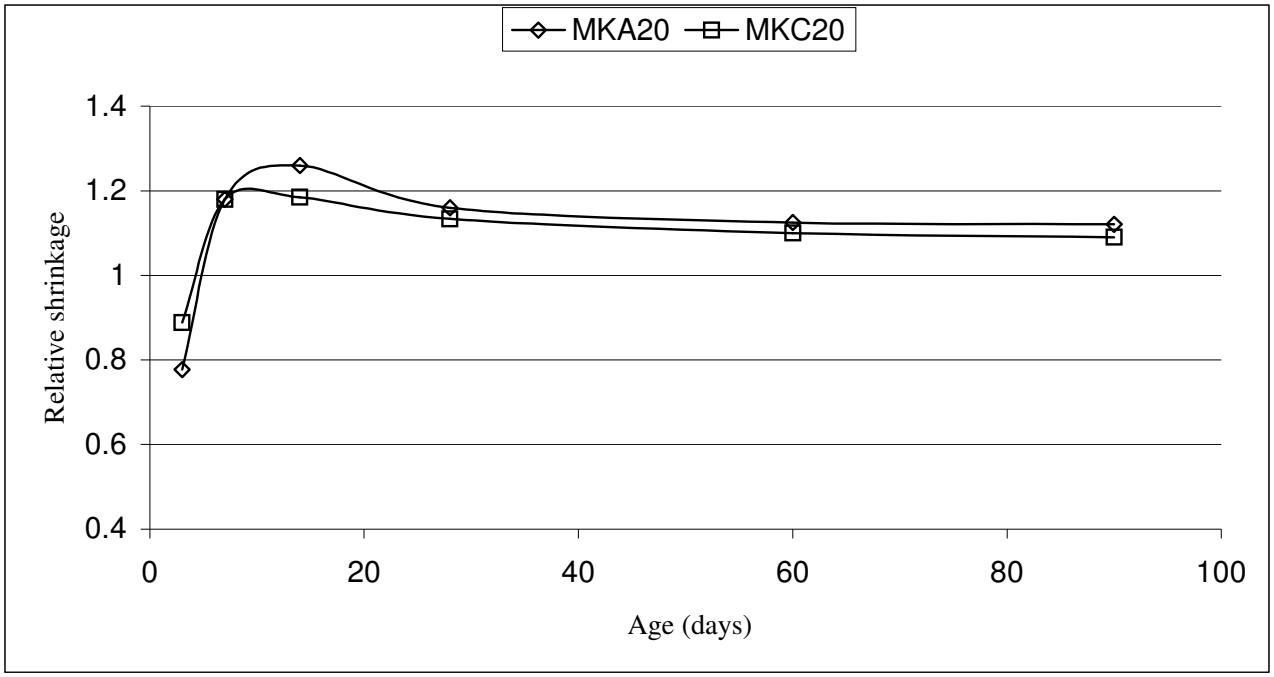

Figure 5. Relative shrinkage of MK concrete.

5 COMPARISON AND RESULTS ANALYSIS

Typical results for the Compressive strength versus curing time for different mixtures are shown in figure 6.The effect of MK to improve compressive strength is clear.

The samples of good replacement percentage and also more (stronger) compressive strength compared to samples of pure cement – offering economical merits as well – Due to the fact that the compressive strength (s) were close to each other, MKC20 and MKA20 were selected for further research and the obtained results can be seen in figure 7.

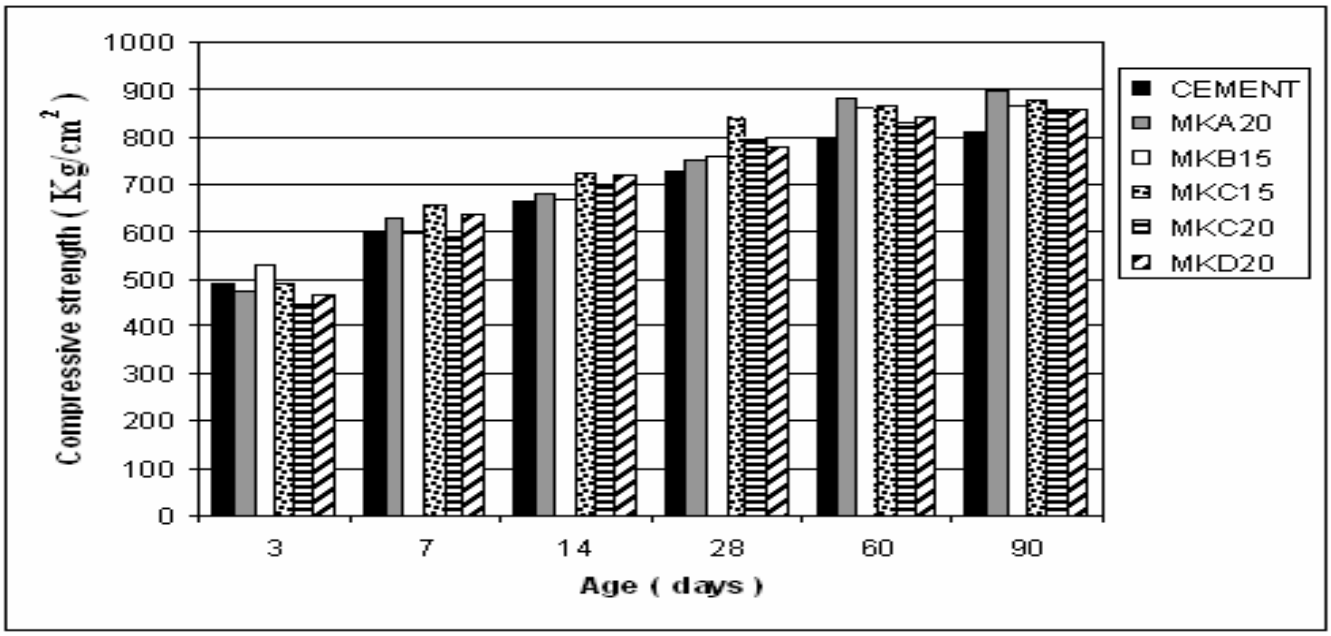

Figure 6. Compressive strength of some samples of blended cement.

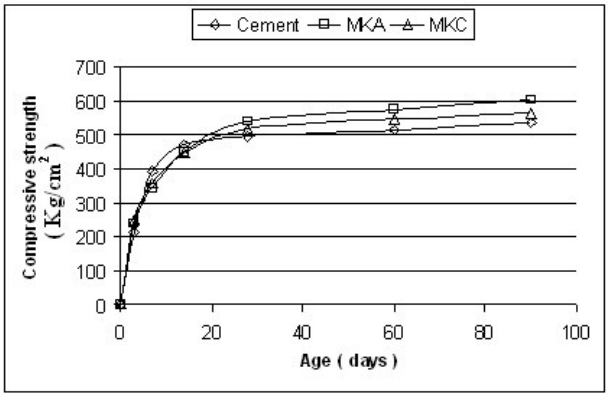

Figure 7. Compressive strength development of metakaolin concrete samples.

6. RESULTS

Given to morphology (SEM) of the raw and calcined kaolins, it can be seen that firing has made the raw kaolins – kaolin A,C,D in particular – amorphized .
The blended cement obtained from MKA, MKC and MKD of different percentages indicate that through a replacement 10% to 20% the best type of cement mortar strength can be achieved. The blended cement obtained from 20% of MKA, 20% of zonuz metakaolin (MKC) and pure cement were chosen and the concerned concretes were produced.

Test of compressive strength and compression of the concretes made by the above cements indicates that the concrete made by the cement MKC 20 is of a compressive strength comparable to pure concrete and the reference blended concrete (a bit more than pure concrete and a bit less than the reference concrete).

Shrinkage of the concretes containing MK is not significantly different from the concrete MKC20 but shows less shrinkage in comparison with MKA20.

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