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Effect of Curing Temperature on Relative Strength of Metakaolin Concrete

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ABSTRACT

The performance of concrete containing metakaolin (MK), subjected to low and normal temperature curing is investigated. Cement was partially replaced (by mass) with 0, 5, 10, 15, 20 and 30% MK. The water to binder ratio was maintained at 0.5 for all mixes. Concretes were subjected to water curing at 5°C and comparison was made with MK concrete cured at 20°C in a previous investigation. The results indicate that at low temperature curing, the relative strength to the control seems to increase with the increase in curing time. This was not observed in MK concrete cured at normal temperature. The relative strength to 28 days is lower for concrete subjected to low curing temperature compared with curing at 20°C whereas after 28 days the trend was exactly the opposite. An explanation for this behaviour is attempted.

INTRODUCTION

Metakaolin [MK] is relatively a new building material which can be used in concrete to partially replace the cement. MK is considered to be a superior pozzolanic material due to silica and alumina content and to the large surface area of the particles compared with other pozzolans. If incorporated in concrete as partial replacement of cement, MK was found to increase concrete strength and durability [Abmroise et al 1994, Bredy et al 1996, Wild et al 1996, Khatib and Clay 2004].

Concrete properties, including compressive strength, are affected depending upon the curing temperature. Low temperature curing of concrete has an adverse effect on the strength during the first 28 days of hydration. Concrete strength at 28 days is reduced by more than 20% if cured at low temperature as opposed to normal curing temperature [Hussem and Guzutok 2005]. The long-term concrete strength, however, was higher [Kleiger 1958]. Gardener and Poon [1976] however, found that the compressive strength at 28 days was not affected by low temperature curing which can be attributed to the length of low temperature curing in each case. The longer the initial period of low temperature curing, the less the influence on long-term strength [Marzouk and Hussein 1995].

Most of the research on concrete containing MK has been conducted on specimens cured at normal temperature. There is a lack of published data on the behaviour of MK concrete cured at different temperatures. Therefore, this paper compares the results of two separate investigations. In the first investigation MK concrete were cured at normal temperature of 20^{o}C [Wild et al 1996] while the second investigation adopted low temperature curing of 5^{o}C [Khatib 2009]. The results are compared in terms of relative strength.

EXPERIMENTAL

Portland cement (PC) and metakaolin (MK) were used as binder. The sand used complied with class M of BS 882: 1992, and the coarse aggregate was 10 mm nominal size. The superplasticiser (SP) used was Sulphonated Naphthalene. Composition of PC and MK is given in Table 1.

Table 1: Composition and Properties of Cement and Metakaolin

		Cement	**Metakaolin**
SiO_2	%*	20.20	52.10
Al_2O_3	%	4.20	41.00
Fe_2O_3	%	2.00	4.32
CaO	%	63.90	0.07
MgO	%	2.10	0.19
SO_3	%	3.00	-**
Na_2O	%	0.14	0.26
K_2O	%	0.68	0.63
Insoluble Residue	%	0.37	-
Loss on Ignition	%	2.81	0.60
Free Lime	%	2.37	-
Specific Surface Area	m^2/kg	367.80	12,000
Initial Set	min	115.0	-
Residue Retained on 45 μm Sieve	%	15.16	0
Density	kg/m^3	3150	2900

*Percentage by weight **Not applicable or not detected

The influence of low temperature curing on concrete containing MK in terms of compressive strength and length change was examined using 6 mixes. Details of mixes are given in Table 2. The control mix (MK0) had a proportion of 1 (PC): 2 (sand): 4 (coarse aggregate) and did not include MK. In mixes MK5, MK10, MK15, MK20 and MK30, PC was partially replaced with 5%, 10%, 15%, 20% and 30% MK (by mass] respectively. The water to binder ratio for all mixes was maintained constant at 0.45. The binder consists of PC and MK. To compensate for the loss in workability, the dosage of SP was increased with the increase in MK content. Further details about the mixes are presented in Khatib [2009] and Wild el al [1996].

Cubes were used for the determination of the compressive strength. Concrete specimens were cast in steel moulds and kept covered in controlled chambers for 24 hours until demoulding. The first controlled chamber was set at 5°C and 50% RH and the second was set at 20°C and 55%RH. Thereafter, all cubes, which were covered during the first 24 hours were placed in water at either 5°C or 20°C. The remaining prisms were left in the chamber at 5°C and 50% RH or at 20°C and 55% RH without cover before and after demoulding. The cubes were used to determine the compressive strength and the determination of length change were conducted on the prisms. Testing was conducted at 1 day, 7, 14, 28 days for all mixes. In addition, long-term testing was conducted at 56 days for specimens cured at 5°C and 90 days for those cured at 20°C. The reason for the different long-term testing was that each curing regime was conducted at different times. BS EN 12390-2:2002 was used for the determination of compressive strength.

Table 2: Composition of mixes

	Proportions of binder [%]		**Content [kg/m^3]**				
Mix Code	**PC[1]**	**MK[2]**	**PC**	**MK**	**Water**	**Sand**	**Coarse Aggregate**
MK0	100	0	341	0	153	788	1168
MK5	95	5	327	17	147	794	1177
MK10	90	10	311	35	140	800	1185
MK15	85	15	296	52	133	806	1194
MK20	80	20	280	71	126	812	1203
MK30	70	30	250	106	112	824	1221

1. Portland cement 2. Metakaolin

RESULTS AND DISCUSSION

Figure 1 shows the relative strength development with time of concrete containing 5% MK as partial replacement of cement for specimens cured at 20°C and 5°C. The relative strength is the strength of MK concrete divided by the strength of the control mix at the same curing time and same curing temperature. A lower relative strength is obtained at 1 day of curing for concrete cured at 5°C compared with that at 20°C. At 7 days of curing and beyond, the relative strength of concrete exposed to low temperature curing is consistently higher than that of concrete cured at 20°C. For concrete cured at 20°C, the relative strength decreases with curing time and beyond 14 days of curing, the relative strength approaches 1 indicating the strength of MK concrete is similar to the control. Concrete cured at 5°C shows an increase in relative strength except between the age of 7 days and 14 days of curing where a drop in relative strength was observed. Between the age of 7 and 56 days, the strength of concrete cured at 5°C is about 20 to 40%

higher than that of the control. The results of Figure 1 suggest that the strength of concrete containing 5% MK and cured at low temperature is less than that of the control during the early stages (i.e. 1 day) of hydration, but beyond that the strength increases.

The development of relative strength of concrete containing 10% MK (MK10) as partial cement replacement cured at 5°C and 20°C is shown in Figure 2. As in Figure 1, the trend in relative strength at 1 day of curing is similar to that of MK5. However, concreted cured at 5°C and 20°C show the same trend, in that the relative strength increases up to the age of 7 days, and beyond that age (i.e. 7 days), there is a decrease in relative strength. The decrease is more between 7 and 28 days. The strength at 7 days of curing and beyond is higher than the control (i.e. relative strength is more than 1). Also concrete cured at 5°C shows markedly higher relative strength than those cured at 20°C after the age of 7 days. Concretes cured at either 5°C or 20°C shows a decrease in relative strength after 7 days of curing.

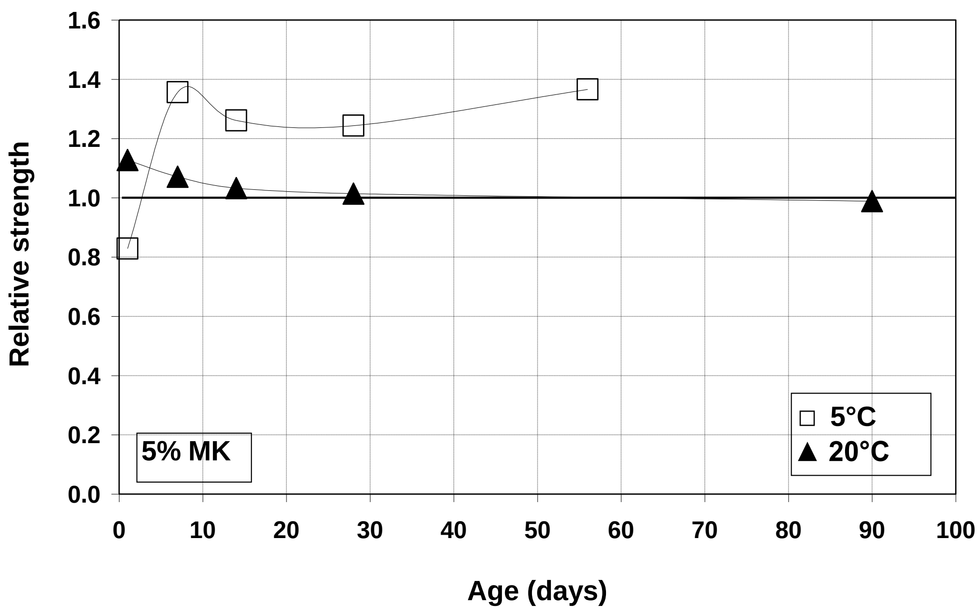

Fig. 1. Relative strength to the control of concrete at 5% MK

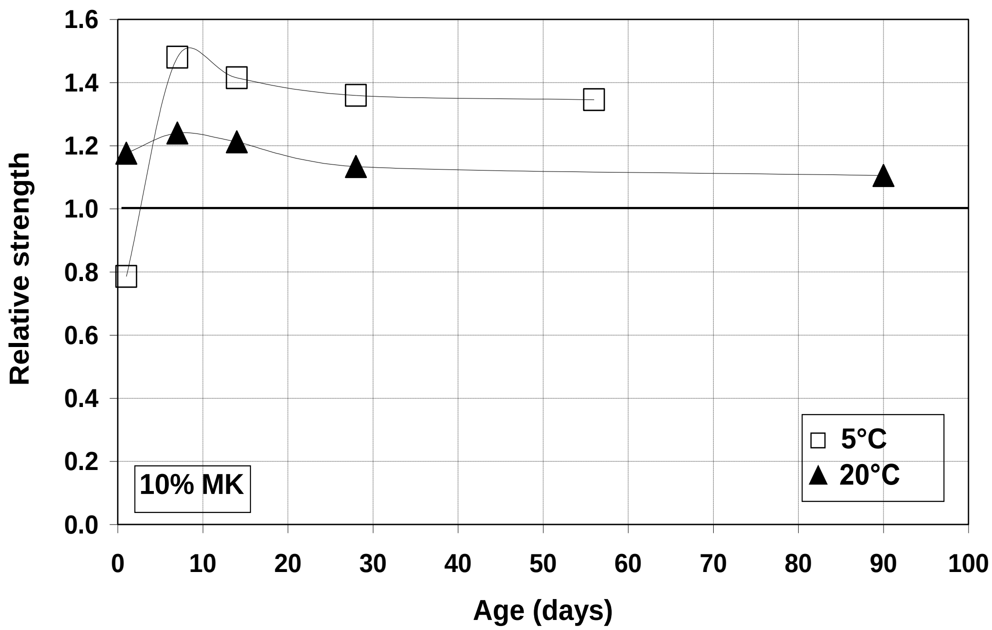

Fig. 2. Relative strength to the control of concrete at 10% MK

Figure 3 plots the relative strength with time for concrete containing 15% MK (MK15) and cured al low and normal temperature. The detrimental effect of low temperature curing on early strength can be observed. The relative strength at 1 day is less than 0.2 for concrete cured at 5^{o}C whereas the relative strength is still above 1 for concrete cured at 20^{o}C. However, the relative strength increases sharply at 7 days and exceeds the value of 1 indicating that the strength is higher than the control. There is a drop in relative strength between 7 and 14 days of curing before an increase is observed after the 28 days of curing. Concrete cured at 20^{o}C exhibits a peak in relative strength at around 10 days before it begins to decrease as reported in previous investigation [Wild et al 1996]. Concretes cured at 5 and 20^{o}C has a relative strength more than 1 at 7 days of curing and beyond.

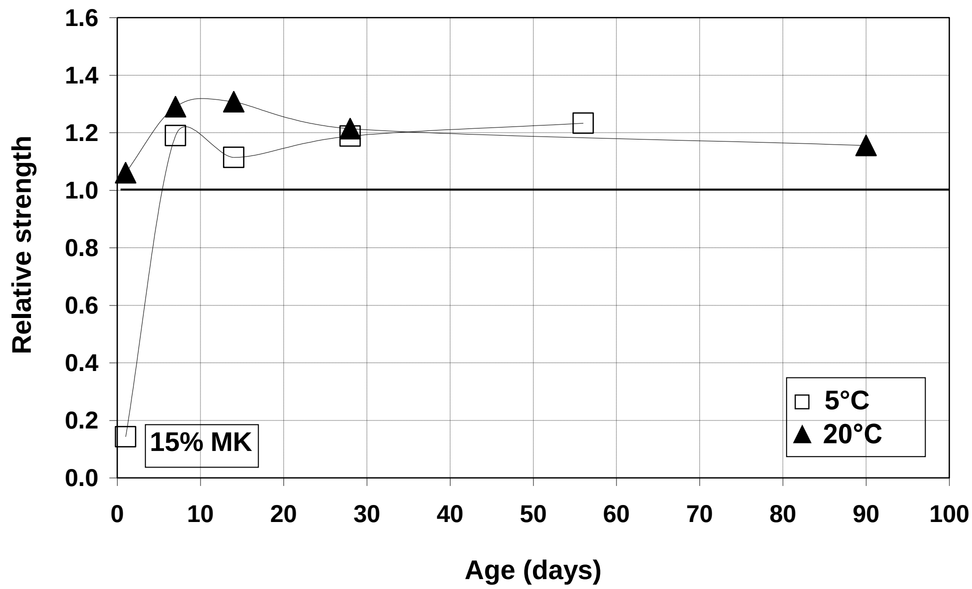

Fig. 3. Relative strength to the control of concrete at 15% MK

The influence of low and normal curing temperature of concrete containing 20% MK on relative strength development is presented in Figure 4. At one day of curing, concrete cured at 5^oC shows a drastic reduction in relative strength with a value approaching zero whereas, concrete cured at 20^oC shows a relative strength of 1. The relative strength increases drastically at 7 days for concrete cured at 5^oC with a relative strength of 1 and continue to increase up to at least 56 days of curing. The relative strength in the long term seems to be similar for concretes cured at 5^oC and 20^oC.

Replacing 30% of cement with MK has a noticeable effect on the relative strength for concrete cured at 5^oC and 20^oC especially during the early stages of hydration. This is clearly shown in Figure 5 where the relative strength development for concrete containing 30% MK cured at 5 and 20^oC. The 1 day relative strength is less than 0.8 for concrete cured at 20^oC and nearly zero for concrete cured at 5^oC. After 7 days of normal temperature curing the relative strength is more than 1 at all ages whereas at low temperature curing, the relative strength increases with time but does not reach unity until about 56 days of curing.

CONCLUDING REMARKS

As observed with previous research that the effect of low temperature curing is detrimental during the early ages of hydration and special care needs to be taken when considering striking the formwork. However, the strength generally exceeds the control at later ages depending upon the content of MK. If the content of MK is below 20%, the long term strength exceeds the control and is similar to concretes cured at 20^oC. Generally and at normal curing temperature (20^oC], the presence of up to 30% MK increases the compressive strength beyond the age of 1 day of curing.

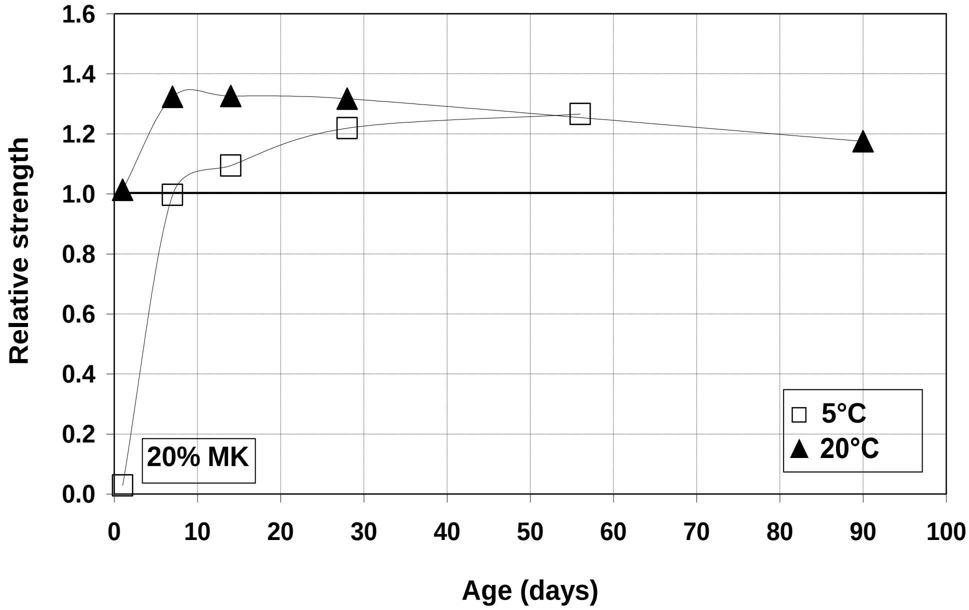

Fig. 4. Relative strength to the control of concrete at 20% MK

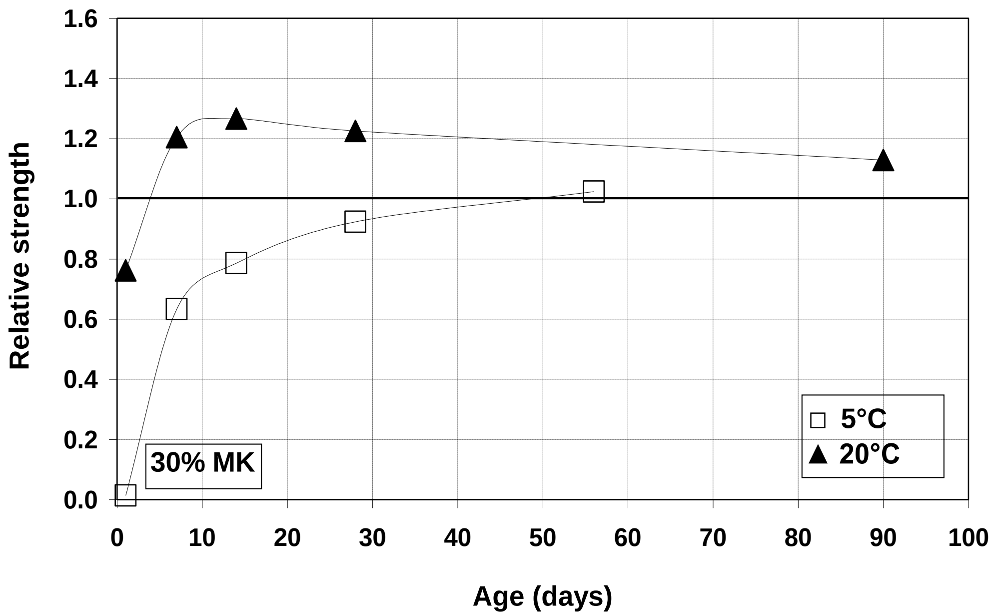

Fig. 5. Relative strength to the control of concrete at 30% MK

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