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STRENGTH CHARACTERISTICS OF MORTAR CONTAINING HIGH VOLUME METAKAOLIN AS CEMENT REPLACEMENT

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Abstract

This paper investigates the compressive strength, ultrasonic pulse velocity (UPV), and density for cement mortar containing high volume of metakaolin (MK) as partial substitution of cement. Portland cement (PC) was partially replaced with 0-50% MK. Mortar specimens were cured in water at 20ºC for a

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total curing period of 7 days. The results at 7 days of curing indicate that the maximum strength and UPV of mortar occurs at around 10% MK. Beyond 10% MK, the strength of mortar reduces and it starts to be lower than that of the control after 20% MK replacement. Correlation between the various properties is also attempted.

1. Introduction

Recently, there has been some interests in the use of metakaolin (MK) as a partial substitution of cement in concrete [1-12]. MK is produced from kaolin that is calcined at temperatures of around 800 ± 100ºC, which is much lower than that of cement (1450ºC); thus reducing CO_2 emission and energy requirement. The composition of MK is similar to clay, which is silica and alumina. A pozzolanic material is a silicate or alumino-silicate materials and in the presence of calcium hydroxide, they react to from further cementitious products, which can enhance the properties of concrete provided a proper curing is adopted [13, 14]. Depending on the curing temperature and its fineness, the use of MK is reported to increase the strength of concrete especially during the first 14 days of hydration [4]. The enhancement in compressive strength of concrete incorporating MK may be attributed to the filling effect, pozzolanic reaction of MK, and acceleration of cement hydration. Silica fume exhibits similar performance [15]. The total porosity seems to increase in the presence of MK, however, the pore size is refined [16, 17]. Maximum pore refinement appears to occur at around 20% MK as cement replacement [16]. When replacing cement with MK, the calcium hydroxide (CH) is reduced, thus leading to an increase in sulphate resistance MK mortar as the gypsum and ettringite formation would reduce [6, 18]. This is in addition to the pore refinement due to inclusion of MK that restricts the ingress of sulphate ions. The chloride resistance and freezing/thawing resistance are increased when cement is replaced with MK [19]. Other cement replacement materials such as fly ash or ground granulated blast furnace slag (GGBS) can be used in conjunction with MK in order to refine the pore structure of cement paste [20, 21]. In this work, cement mortar with high volume MK as partial replacement of cement in order to examine some properties of mortar at high MK level properties included density, compressive strength, and ultrasonic pulse velocity.

2. Experimental

The materials used to produce the mortar were Portland cement (PC), metakaolin (MK), water, and sand. The sand (i.e., fine aggregate) used complied with class M of BS 882: 1992. The composition of PC and MK is given in Table 1.

Table 1. Properties of Portland cement and metakaolin

	Portland cement	Metakaolin
SiO_2 (%)	20.2	52.1
Al_2O_3 (%)	4.2	41.0
Fe_2O_3 (%)	2	4.32
CaO (%)	63.9	0.07
MgO (%)	2.1	0.19
SO_3 (%)	3	–
Na_2O (%)	0.14	0.26
K_2O (%)	0.68	0.63
Surface area (m^2/kg)	368	12000

Six different mixes were used to determine the influence of MK on compressive strength, ultrasonic pulse velocity (UPV) of mortar. Details of the binder compositions of mixes are given in Table 2. The control mix (M1) had a proportion of 1 (PC): 3 (sand) and did not include MK. In mixes M2-M6, PC was partially replaced with 10%, 20%, 30%, 40%, and 50% MK (by mass), respectively. The water to binder ratio for all mixes was maintained constant at 0.5. The binder consists of PC and MK.

Cubes of dimensions $50mm \times 50mm \times 50mm$ were prepared for each mortar mix. The cubes were cast in steel moulds and covered with plastic sheeting at 20^{o}C for 24 hours until demoulding. After that the cubes were placed in water at 20^{o}C for further 6 days (i.e., a total curing period of 7 days). The cubes were then removed and used to determine the density, compressive strength, and UPV. The determination of compressive strength and UPV was according to BS1881-Part 116: 1983 and Part 217: 1983, respectively.

Table 2. Composition of binder

	Binder (%)	
Mix No.	PC	MK
1	100	0
2	90	10
3	80	20
4	70	30
5	60	40
6	50	50

3. Results and Discussion

Figure 1 shows the density of mortar mixes at 7 days of curing. The density of all mixes appears to be similar and vary from $2135kg/m^3$ to $2275kg/m^3$ with an average value of $2198kg/m^3$.

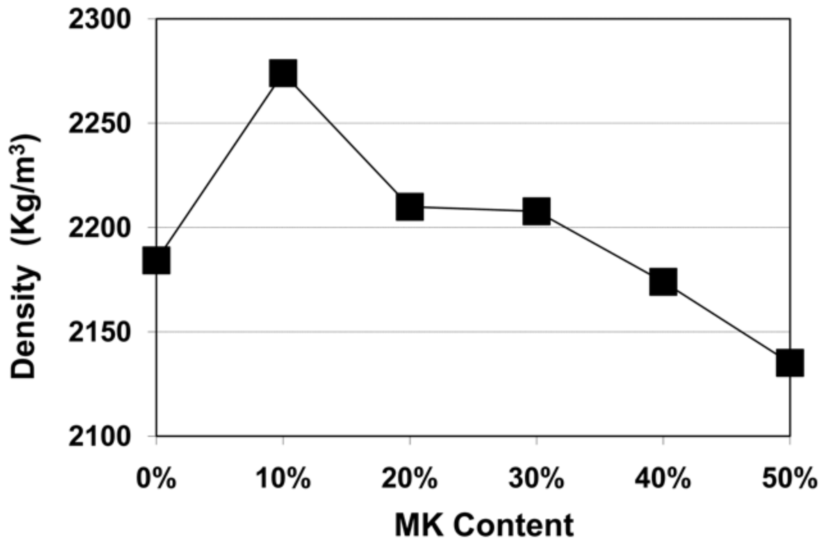

Figure 1. Density of mortars containing varying amounts of MK.

Figure 2 plots the compressive strength of mortar mixes with different amounts of MK. Mortars containing up to 30% MK as cement replacement show a strength value similar or higher than the control. The strength drops after 40% MK. This is shown more clearly in Figure 3 where the relative strength to the control at 7 days of curing is plotted against MK content of the various mortar mixes. The 10% MK mix exhibits 17% strength increase compared to the control and this is the maximum obtained among the other mixes. The maximum performance of concrete was obtained at a slightly higher MK content, which is between 15 and 20% [4].

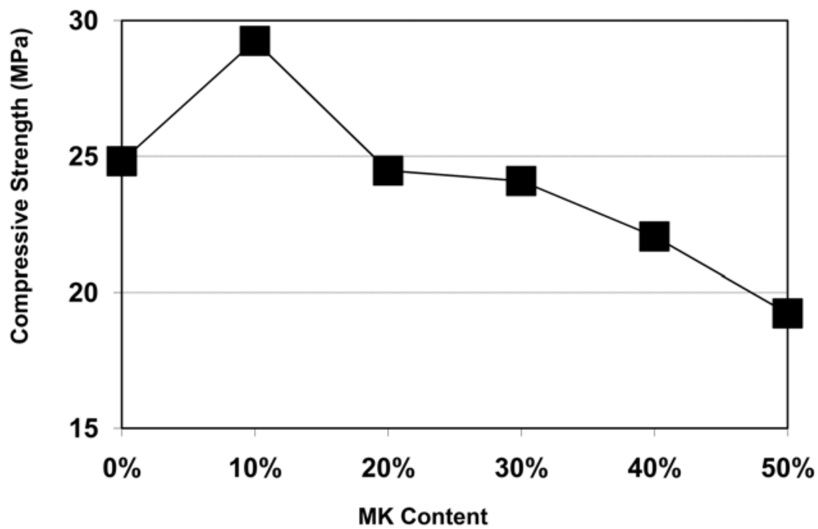

Figure 2. Compressive strength of mortars containing varying amounts of MK.

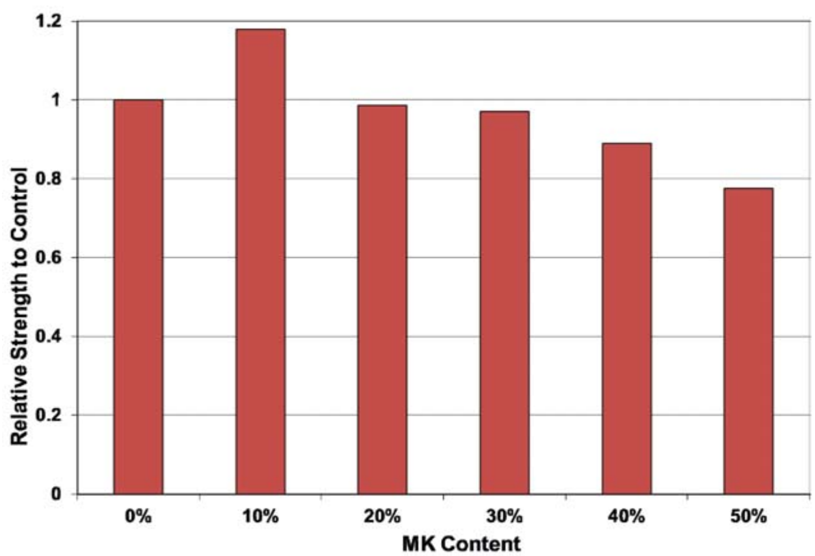

Figure 3. Relative strength of mortars containing varying amounts of MK.

The compressive strength at 28 days of curing for the same set of mortar mixes is reported elsewhere [22]. Figure 4 plots the relative strength at 7 days to that at 28 days of curing. Concrete containing 20% MK shows decreased activities at 7 days compared with the control. Also, all MK mixes showed slightly lower values of relative strength at 7 days to that at 28 days. The 50% MK mix yielded slightly lower relative strength value than the control.

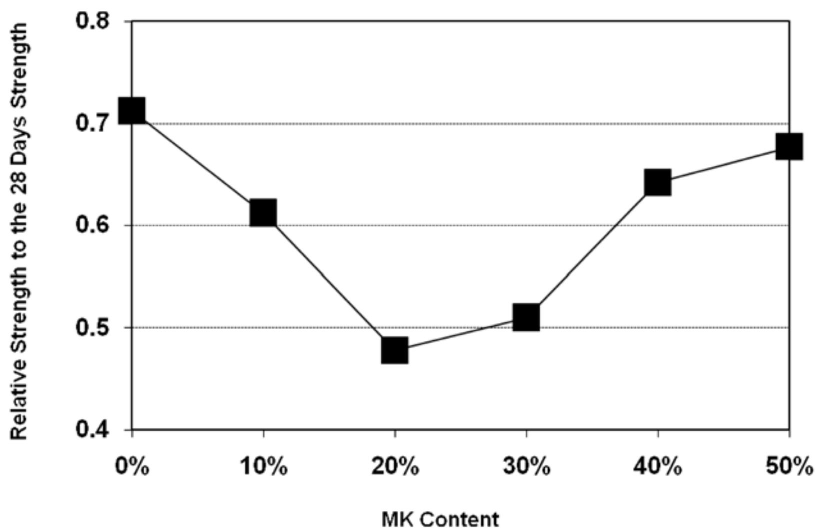

Figure 4. Relative strength (at 7 days to that at 28 days) of mortars containing varying amounts of MK.

Figure 5 plots the relative strength at 7 days to that of the control at 28 days of curing. The trend in the results is similar to those obtained in Figures 2 and 3 in that maximum relative strength to the control at 28 days occurs at around 10% MK.

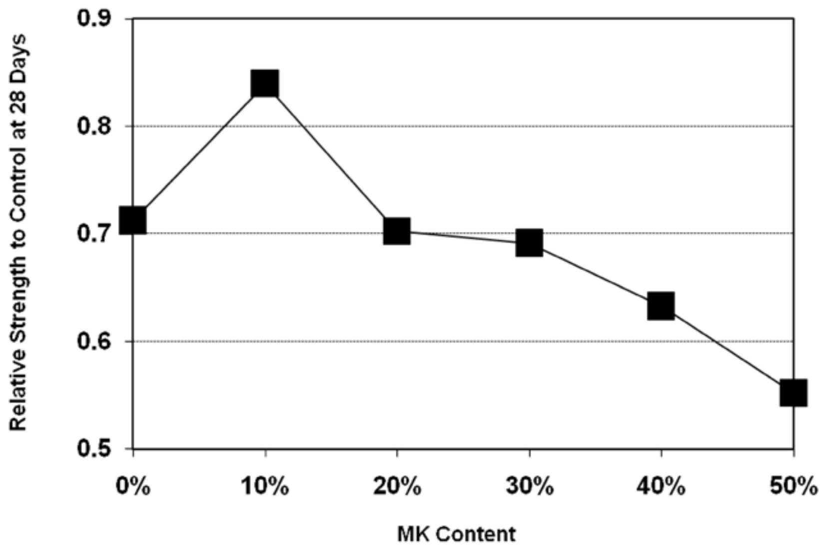

Figure 5. Relative strength (to the control at 28 days) of mortars containing varying amounts of MK.

The UPV at 7 days of curing for concrete containing varying amounts of MK is plotted in Figure 6. The 10% mortar mix shows a higher UPV than all mixes. All other MK mixes yield an UPV values lower than the control. The trend in the UPV results is similar to those of the compressive strength shown in Figure 2.

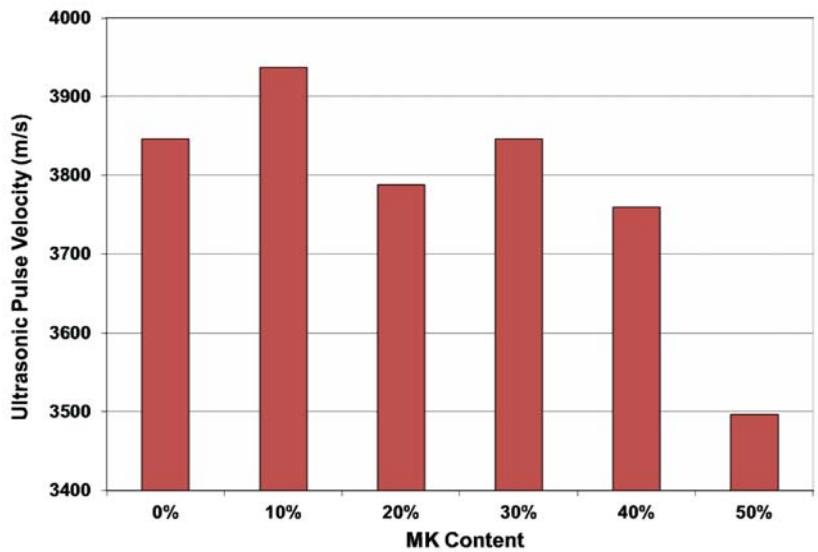

Figure 6. Ultrasonic pulse velocity (UPV) of concretes containing varying amounts of MK.

4. Conclusion

Replacing cement with up to atleast 20% MK causes increase in strength compared to the control mix. However, using more than 20% MK as partial cement replacement does not cause further increase in strength compared with the other MK mixes. The optimum replacement level that causes a maximum enhancement in compressive strength appears to be around 10%. The ultrasonic pulse velocity seems to follow a similar trend to the strength.

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