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High Volume Metakaolin as Cement Replacement in Mortar

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Abstract: The compressive strength, density and ultrasonic pulse velocity of mortar containing high volume of metakaolin (MK) as partial substitution of cement is determined. Up to 50% of MK was used to replace cement in increment of 10. After demoulding, specimens were cured in water at 20°C for a total period of 28 days. The results indicate that the maximum strength of mortar occurs at around 20% MK. Compressive strength starts to reduce when MK goes beyond 30%MK as cement replacement. Attempts were made to link the compressive strength with ultrasonic pulse velocity.

Key words: High volume metakaolin · Metakaolin · Mortar · Novel materials · Strength · Ultrasonic pulse velocity

INTRODUCTION

Metakaolin (MK) can successfully be used to partial replace cement in paste, mortar or concrete applications [1-12]. MK is produced by the calcination of kaolin clay at temperatures ranging from 700 and 900°C. Like clay, the main oxides in the MK are silica and alumina. Partial replacement of cement with MK can increase the mechanical and durability performance of cement based materials [4, 13, 14]. There is noticeable increase in compressive strength of concrete mainly during the first 14 days of curing at normal temperature [4]. This increase in compressive strength of concrete in the presence of MK may be attributed to the pozzolanic reaction, the fineness of MK and acceleration of cement hydration [4], which is somewhat similar to that of silica fume. Using MK as cement replacement.While the porosity of cement based system containing MK may increase in the presence of MK, however, there is refinement in pore structure [13, 15]. Replacing cement with 20%MK seems to give maximum enhancement in pore refinement of pastes [13]. MK being a pozzolanic material reduces the Calcium Hydroxide (CH) in the cement based system. The combination of pore refinement and reduction in CH when cement is partially replaced with MK lead to improved durability [14, 16, 3]. Other traditional cement replacement materials including fly ash or ground granulated blast furnace slag can be used in conjunction with MK to cause further pore refinement [17-19]. Previous work by the author used MK up to 30% as partial substitution of cement [5, 14, 16, 20]. In this work, cement mortar with high volume MK (up to 50%) as partial substitution of cement was investigated at 28 days of curing.

MATERIALS AND METHODS

Six mortar mixes were used to examine the effect of MK on density, compressive strength and ultrasonic pulse velocity (V). The mortar mixes consisted of Portland cement (PC), metakaolin (MK), water and sand. The constituents of binder are given in Table 1. The control mix (M1) had a proportion of 1 (PC): 3 (sand) without MK. In the other 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 at 0.5 and the binder consisted of PC and MK.

Cube specimens of dimensions 50mm x 50mm x 50mm were prepared. Specimens were cast in steel moulds and covered to prevent the loss of water during the first 24 hours. After that demoulding took place and cubic specimens were placed in water at 20°C for further 27 days to bring the total curing period to 28 days. The cubes

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Table 1: Constituents of binder

	Binder (%)	
Mix No.	PC	MK
M1	100	0
M2	90	10
M3	80	20
M4	70	30
M5	60	40
M6	50	50

were then taken out of the water tank and used to determine the density, compressive strength and ultrasonic pulse velocity (UPV). The determination of compressive strength and UPV was according to BS1881-Part 116: 1983 and Part 217: 1983 respectively.

RESULTS AND DISCUSSION

Figure 1 shows the density of mortar mixes at 28 days. The density seems to reduce with the increase of MK content especially at MK content above 30%. The density values ranged from 2179 to 2235 kg/m^3 with an average density of about 2210 kg/m^3. The compressive strength of the various mortar mixes at 28 days curing is plotted in Figure 2. The strength increases as the MK content increases up to about 40% MK with a maximum strength occurring at 20%. At 50% the strength reduces compared with the control. The level of change in compressive strength is shown in Figure 3 where the relative strength to the control for the various mixes is plotted at 28 days of curing. The maximum increase in compressive strength seems to take place at around 20% MK where the strength is 47% higher than the control. The 10% and the 30% MK mixes exhibit an increase in strength of around 37%. The strength of the 40% mix is similar to the control but for MK above 40% (i.e. 50%) the strength is reduced by 18% compared to the control.

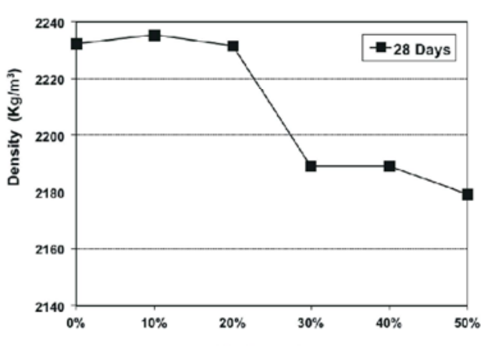

Fig. 1: Density of mortars containing varying amounts of MK

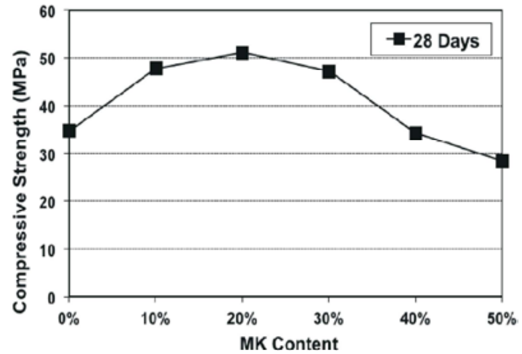

Fig. 2: Compressive strength of mortars containing varying amounts of MK at 28 days of curing

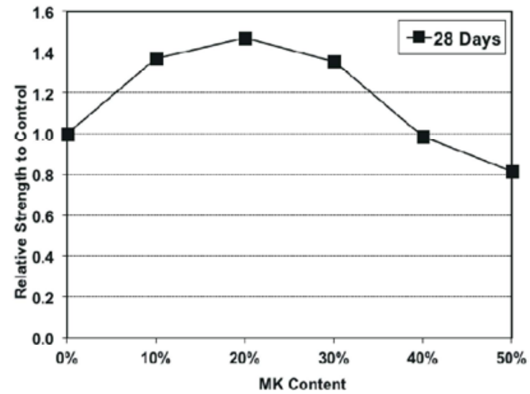

Fig. 3: Relative strength of mortars containing varying amounts of MK

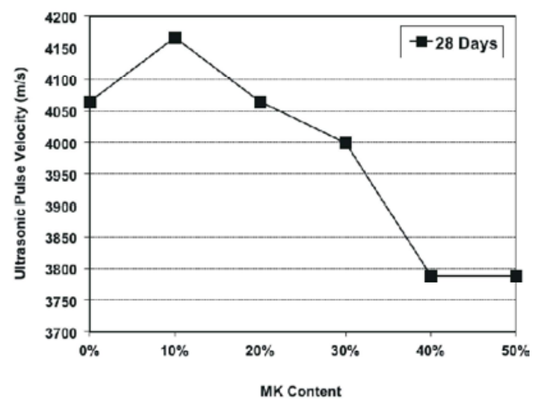

Fig. 4: Ultrasonic pulse velocity (UPV) of concretes containing varying amounts of MK

Figure 4 plots the ultrasonic pulse velocity (UPV) of all mortar mixes at 28 days of curing. The UPV shows a maximum increase at 10% MK and the 20% MK mix showssimilar UPV to the control. For MK values above 30% the UPV tend to decrease. The trend in UPV does not follow that of compressive strength. The maximum compressive strength occurred at 20% MK whereas the maximum UPV is at 10% MK.

CONCLUSIONS

Replacing cement with around 20% MK causes a substantial enhancement in compressive strength of mortar. This enhancement in compressive strength can reach a value around 50% compared with the control. Beyond 30% MK the compressive strength starts to reduce. However the maximum value of ultrasonic pulse velocity occurs at around 10% MK.

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