

Patching of pavement using MgO-based ceramic cement

Jingsung Sim and Ki Yong Ann

Hanyang University, Ansan, South Korea

ABSTRACT: The present study concerns a development of rapid mortar patching to concrete pavements subjected to frost, traffic and chemical deterioration. To accelerate a development of the strength of patch mortar, MgO-based ceramic cement was used as binder, together with an appropriate dosage of retarder (i.e. borax) to control the rate of setting. For mortar specimen, the mix ratio of MgO, K_2HPO_4 , water and sand was 1.00: 0.80: 0.40: 2.65 for all mixes after preliminary tests to derive an optimised development of strength. Fundamental properties of the mortar specimen were measured, encompassing the compressive strength, setting time and bond strength to old substrate. The pore distribution of the MgO mortar was simultaneously measured by the mercury intrusion porosimetry. For microscopic assessment, the interfacial region between the MgO mortar and OPC made-old substrate was examined by backscattered electron image analysis to quantify the porosity at the interface. As a result, the compressive strength of the MgO mortar was rapidly developed; within 3.0 hours immediately after casting, the compressive strength exceeded 32.4MPa, while 40.5MPa of the strength was achieved in 24 hours. In turn, fresh MgO mortar was set within 13-36 minutes depending on W/B and presence of retarder (i.e. borax). The bond strength of MgO mortar to old substrate was even higher than OPC mortar, accounting for about 1.8MPa, which can be explained by the porosity at the interface between MgO mortar and old substrate. In fact, there was no significant increase in the porosity, for MgO mortar patching, whereas interfacial porosity was dramatically observed in OPC patching.

1 INTRODUCTION

Concrete pavement has been widely used for its economic benefit, easy installation and rehabilitation for the last decades of years rather than asphalt. However, the pavement may be often subjected to degradation in terms of pop-out arising from physical delamination, corrosion of steel reinforcement and chemical deterioration. To repair and rehabilitate the damaged pavement, polymeric binder and Portland cement mortar are representative materials to date. For polymeric patching to the pavement, further deterioration from external sources, for example deicer is basically prevented by blocking against the pavement, of which the strength can be achieved in a quite short duration, usually within a few hours with no adverse effect on shrinkage of polymers. Portland cement mortar patching is still widely popular due to a lower its economic expense. Notwithstanding, their behaviour on bond to the old pavement in terms of strength and bonding is questionable; in fact, identical degradation of the pavement often occurs after the patching in several year, presumably due to a lower degree of bond.

Ceramic cement may enhance the bond between old and new substrate in pavement in that it has mostly nullified membrane potential on the surface, leading to a hard bond. In particular, rapid set of ceramic cement may accelerate a development of the strength at a given duration of repair installation, of which time is often given only 3-4 hours to minimise the traffic blockade [Jiusi et al 2014]. Of ceramic cement, a MgO mixture with phosphate further enhance the strength and setting time, as long as the purity of MgO powder [Motesdeoca 2008]. Moreover, once the MgO ceramic cement is set, volume change is marginal, in turn a further increase in the bond strength is achieved.

In the present study, MgO-based ceramic cement is developed by mixing with an appropriate phosphate (i.e. K_2HPO_4) to be used as patching materials in pavement. To evaluate its properties and compatibility with old substrate, the compressive strength and setting time were preliminarily measured. Simultaneously, the interfacial zone between old substrate and MgO mortar patching was examined by a microscopic observation at backscattered electron imaging. Additionally the pore structure of the MgO mortar was further examined by mercury ontrusio porosimetry to explain the relation between the porosity and bond strength, which was also measured in terms of flexural and tensile bonding capacity.

2 EXPERIMENTS

2.1 *Fundamental properties*

To achieve the optimised mix proportion of MgO ceramic mortar, the variation in the water/binder ratio (W/B) and in whether or not borax as a retarder is admixed was taken into account. The ratio of MgO, phosphate (K_2HPO_4) and river sand (Grade M) was 1.00: 0.80: 2.45 at all times, and the range of W/B was from 0.14 to 0.22. The content of borax was set at 5.0% by weight of binder, if necessary. The purity of binders (MgO and K_2HPO_4) exceeded 99.8% to enhance reactivity of MgO in the marix. Then, MgO mortar was cast in a cube mould ($50 \times 50 \times 50$ mm), after a thorough mixing together all materials at 120 rpm for 2.5 minutes and demoulded in 2 hours. Then the compressive strength was measured at 3, 24 and 672 hours (i.e. 28 days). Simultaneously the setting time was measured by the penetration resistance: the final set was defined as the time for the penetration resistance to reach 27.5MPa. Six different sizes of needles were used to measure the penetration resistance of fresh mortar until the final set was achieved. In this study, the initial set was not measured. When it comes to bond strength, tensile and flexural bond strength was simultaneously measured. For the flexural bond strength, the margin of MgO mortar was $50 \times 200 \times 400$ mm, and for the tensile bond strength $50 \times 10 \times 50$ mm, respectively, as given in Figure 1.

2.2 *Pore structure*

The pore structure of MgO mortar was examined after 24 hours of curing. The mortar samples were torn off from the middle of specimens for segmenting. The sample was dried out in an oven at $50^\circ C$ for 24 h. The sample was initially evacuated to about 50 μm mercury (Hg) and the low pressure was generated up to 0.21 MPa by nitrogen gas, and then the pressure was gradually increased to 117.21×10^3 MPa at the rate of 9.1×10^3 kPa/s. The pressure was converted to the equivalent pore diameter using the Washburn equation as given in Eq. (1). Then the pore volume distribution at a given pore diameter was achieved. The pore volume was adjusted to the percentage of the volume of sample.

$$d = \frac{-4\gamma \cos\theta}{P} \quad (1)$$

where, d is for the pore diameter, γ for surface tension, θ for contact angle and P for pressure given in the chamber, respectively. In the present study, the contact angle was taken 120° , which is often used to consider the variation in the shape of pores, encompassing flaky, longish and round pores.

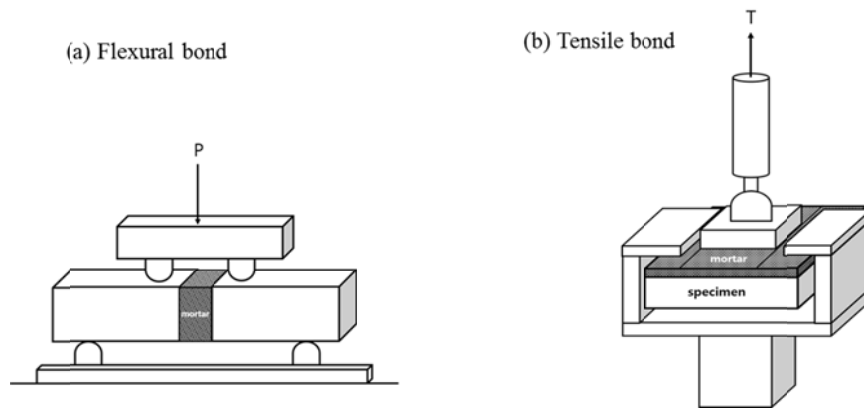


Figure 1 Schematic for measuring the flexural and tensile bond strength

2.3 Observation of interface

To observe the interface between old substrate and MgO mortar patch, Portland cement mortar was cast and cured for 28 days, which was subsequently was cut by a diamond to produce a smooth surface. The mix design for PC mortar was 1.00: 0.45: 2.50 for Portland cement, water and sand, respectively. This mortar sample was used for both old substrate and patching material; to produce two different interfaces, (1) PC mortar vs PC patching and (2) PC mortar vs MgO mortar patching were manufactured.



Figure 2 Specimen preparation for microscopic observation at the interface

Then MgO mortar was further cast in a mould from the smooth surface of Portland cement mortar to mimic patching of the pavement. After 1 days of curing, a segment containing the

interface was obtained as seen in Figure 2. The specimen was dried in an oven at $50\pm 1^\circ\text{C}$ for 48 hours before resin impregnation. The impregnated specimen was then ground with silicon carbide papers of successively finer grits and was further polished on cloths with diamond particles. After polishing, the specimen was cleaned ultrasonically in acetone and then further dried for 24 hours in a vacuum pump at an order 10^{-4} Pa, followed by carbon coating under about 7×10^{-5} Pa.

The image containing the interface was obtained at scanning electron microscopy (SEM) and the instrumental parameters used for the SEM were: accelerating voltage= 20kV; working distance= 15 mm; beam spot size (SS)= 12; lens current= $66\mu\text{A}$. The magnification was basically $\times 50$. The SEM image obtained was transferred to the backscattered electron one to clearly identify pores at the interface.

3 RESULTS AND DISCUSSION

3.1 *Development of strength and setting*

The compressive strength of MgO mortar was measured at 3, 6 and 672 hours, as given in Figure 3. It is evident that an increase in the curing duration resulted in an increase in the compressive strength of MgO mortar, irrespective of W/C and whether or not borax is admixed. In particular, a very high level of the compressive was achieved even at only 3 hours, accounting for from 9.7 to 32.3 MPa, depending on W/C and borax. However, once the strength was gained in 24 hours, a further development of the compressive strength was not highly achieved. For example, the compressive strength at 0.22 of W/C with no borax was equated to 40.5 MPa after 24 hours of curing, which was further developed only to 43.2MPa for 28 days. Additionally, the effect of W/C was adversely achieved. At a given condition for borax and curing age, an increase in the W/C resulted in an increase in the strength. This adverse effect may be attributed to reactivity of MgO with phosphate. To activate the reaction between MgO and phosphate, a certain level of mixing water must be provided to crystalise the matrix, which would otherwise would reduce the reaction ratio, leading to a less development of the strength. In this study, 0.22 of the W/C was set as the maximum level for water content in the mix.

It is evident that borax was less compatible with the strength development. When the borax was admixed in the mortar mix, the strength was always lower than for borax-free ones. For example, at 0.22 of W/C, the range of the compressive strength for borax-free specimen was 32.3-43.5MPa, whilst the mortar specimen containing 5.0% of borax produced 27.7-35.1 MPa of the strength depending on the curing age. A reduction of the compressive strength may arise from delayed reaction of MgO with phosphate. In fact, the reaction rate was reduced by the borax, which simultaneously could lower the development of strength at a given curing age.

The time to set measured by penetration resistance is given in Figure 4, depending on W/C and admixing the borax, together with a photo of measuring the penetration resistance. It is clearly seen that admixing the borax increased the time to set at all W/C.

Notwithstanding the time to set seems still very short, ranging from 21 to 36 minutes. In in-situ, it takes usually 1-2 hours to cast and patch mortar immediately after casting, accompanying delivering, pumping and other procedures. Thus, the setting time must be further obtained to be feasible in in-situ, or/and other techniques, for example spraying the mortar must be developed [Li and Chen 2013].

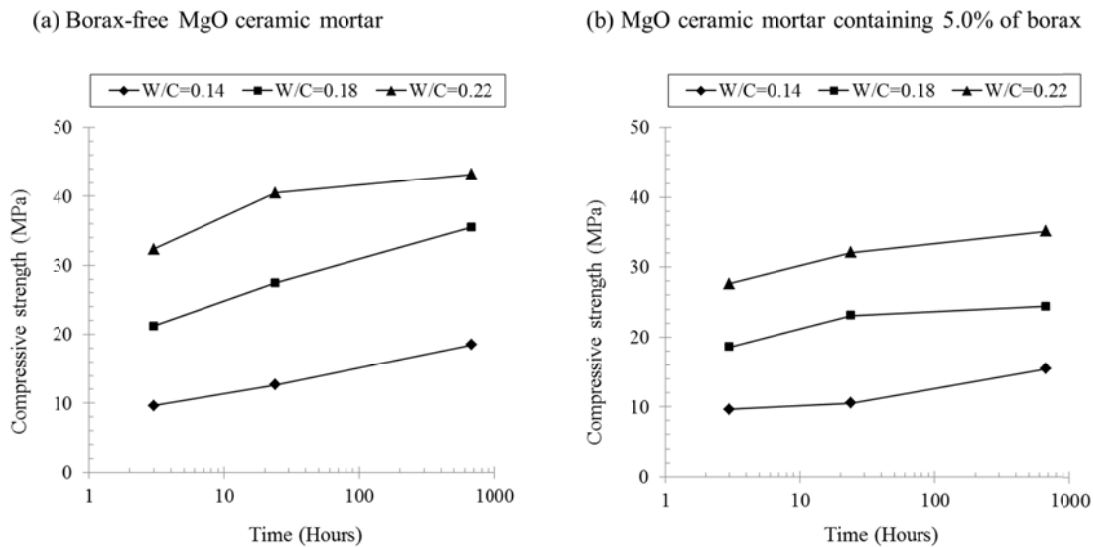


Figure 3 Development of strength for MgO mortar depending on the use of retarder

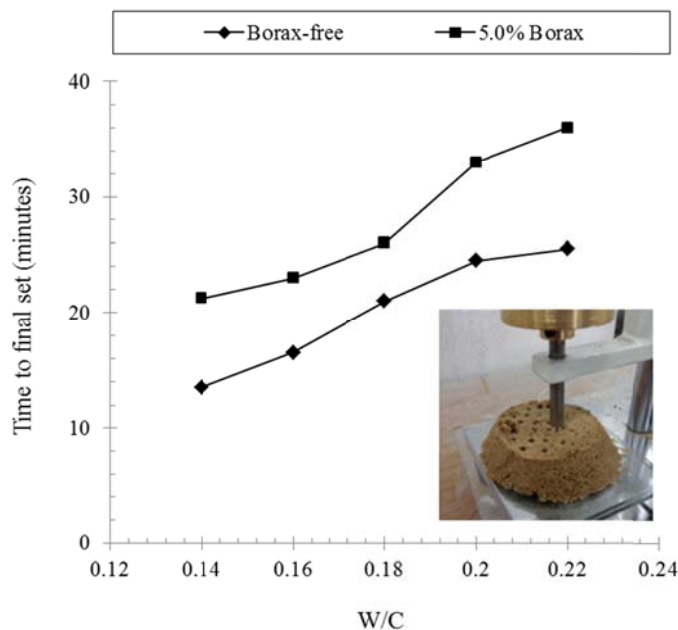


Figure 4 Time to final set for MgO mortar depending on W/C and admixing the borax Bond strength

The flexural and tensile bond strength measured at 28 days is given in Figure 5. The MgO mortar always had higher bond strength rather than Portland cement mortar patching. For flexural bond, the MgO mortar produced about 1.8MPa of the bond strength, while Portland cement mortar achieved only 0.8MPa. The higher level of bond strength was again observed in tensile bond, of which the value for MgO mortar accounted for 2.0MPa. The harder bonding of MgO mortar may be attributed to refined interfacial region between old substrate and patching.

The higher compressive strength of MgO mortar, moreover, may enhance bonding behaviour. The assessment of interfacial region was performed in Section 3.4 in this study.

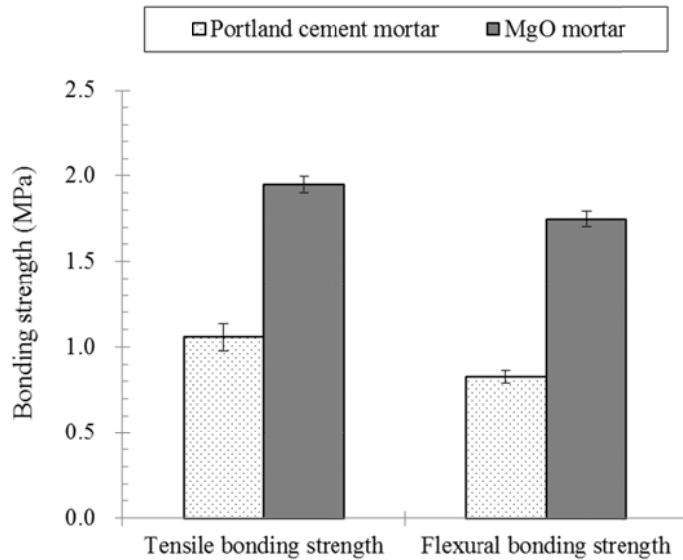


Figure 5 Flexural and bond strength of MgO mortar to old substrate, compared to Portland cement mortar patching

3.2 Pore distribution

The pore distribution of MgO mortar measured by mercury intrusion porosimetry is given Figure 6, together with peak pore volume. It is seen that total cumulative pore volume in the MgO mortar accounted for about 0.093mL/g, corresponding to 15.5% in volume. In fact, this level of porosity is mostly identical for Portland cement mortar, of which the cumulative total pore volume ranges from 10 to 18% [Kim et al 2009]. In this study, the porosity of PC mortar for MIP was not examined, rather than reviewing literature. Despite marginal difference in the pore volume in mortar, the MgO mortar gained an even higher strength within a short duration of curing. It suggests that the fragment of matrix in the MgO mortar in terms of the crystalline structure may have much higher strength than for Portland cement matrix. It is evident that the peak pore diameter for MgO mortar was in the range of 10-100 μm , as being equivalent to entrained air void.

In Portland cement matrix, the peak pore diameter is usually allocated to gel and capillary pores, which lowers the strength of the matrix fraction. Moreover, open capillary pores can make inter-network for ionic transport, leading to a percolation of external ions to concrete.

A combination of high entrained air void but lower capillary and gel pores in the MgO mortar can enhance the resistance to chemical deterioration and frost damage, respectively. As already known, entrained air void buffers the expansion of freezing pore water then to induce internal stress in a cold exposure condition. In the present study, however, ionic transport and a resistance to frost damage were not measured.

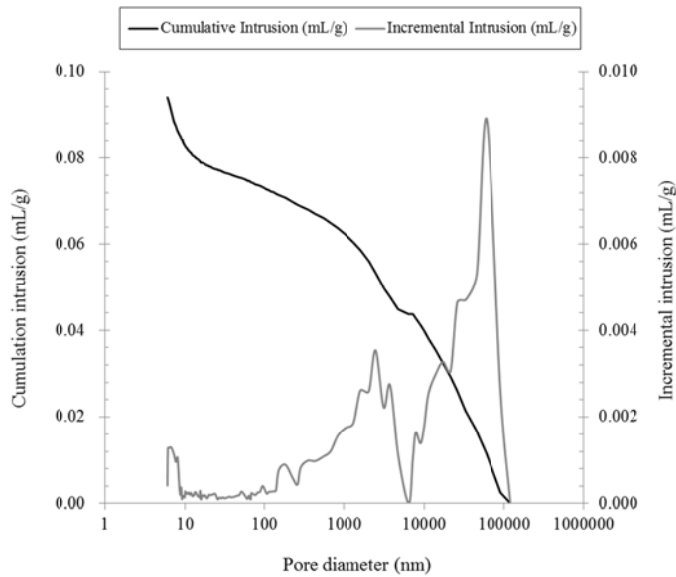
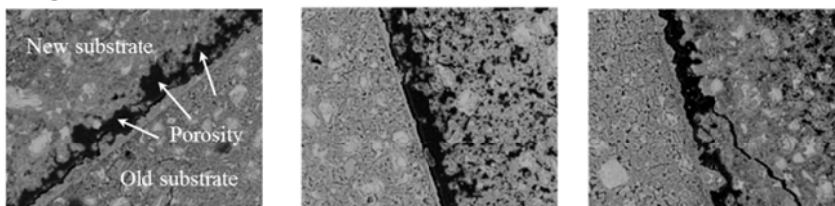


Figure 6 Pore distribution of MgO mortar with peak pore diameter

3.3 Porosity at the interface

The porosity formed at the interface between old substrate and patching of MgO mortar was achieved by backscattered electron imaging, as given in Figure 7. It is evident that MgO mortar significantly reduced the porosity level at the interface, compared to Portland cement mortar patching. The porosity generated by two different binding materials often forms a gap, of which the depth is in the range of several or decades of micro meters. However, MgO mortar patching had only a marginal porosity at the interfacial region, presumably due to a lower membrane potential. As ceramic-based materials are electrically in the state of equilibrium, no static electricity or membrane potential is charged on the surface. With no potential charge, some reactive mixture at fresh state may impregnate further old substrate then to enhance the bond strength. Moreover, the high strength of MgO mortar itself may further increase bonding.

(a) Patching of Portland cement mortar



(b) Patching of MgO ceramic mortar

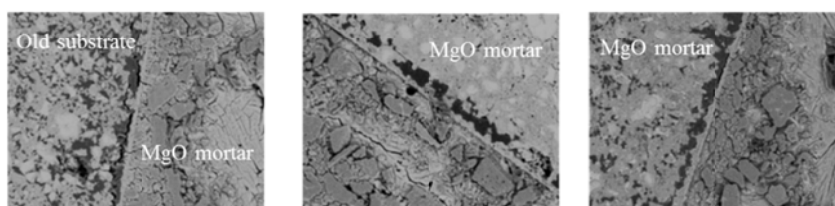


Figure 7 Porosity at the interface of MgO mortar and Portland cement mortar patching

4 CONCLUSION

In this study, a MgO mortar patching was developed to enhance the bonding strength to old substrate and simultaneously its higher properties encompassing the compressive strength and setting time. To explain the properties of MgO patching, microscopic examination at the interface and pore distribution were additionally performed. Here is the conclusion derived as follows:

- (1) The compressive strength of MgO mortar was gained within 3 hours, accounting up to 32.4MPa. In particular, a higher W/C with no borax (i.e. retarder) was the best option to increase the strength at a given duration of curing. However, Once the compressive strength was achieved within 24 hours, only a marginal development of the strength was further gained.
- (2) The setting time measured by the penetration resistance to fresh mortar was in the range of 21-36 minutes, which could be more or less increased by the borax about 10 minutes. In turn the compressive strength for MgO mortar containing the borax was lowered.
- (3) The bond strength measured in terms of flexural and tensile bond strength to old substrate was highly ached by MgO mortar, compared to Portland cement mortar patching. The flexural and tensile bond strength were 1.8 and 2.0 MPa, respectively.
- (4) The porosity at the interface between old substrate and patching of MgO mortar was significantly reduced. In fact, pores were not mostly generated by MgO mortar patching, whereas Portland cement mortar patching produced a big gap of the porosity at the interfacial region.

Acknowledgements

The authors would like to thank the Korean ministry of Land Infrastructure and Transportation for supports in finance (Grants No. 12F03).

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