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Microstructure, electrical and mechanical properties of steel fibres reinforced cement mortars with partial metakaolin and limestone addition

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HIGHLIGHTS

- Cement in normal mortars was substituted by a combination of metakaolin and limestone.
- Mechanical properties improved by increasing the amount of metakaolin.
- Electrical resistance of ternary-blended mortars was much better than normal mortars.

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ABSTRACT

This paper investigates binary and ternary binders of ordinary Portland cement, metakaolin and limestone as a possible solution to reduce the amount of cement content in mortar mixes. Furthermore, the mortar mixtures were reinforced with steel fibres and their properties were investigated. The effectiveness of metakaolin and limestone on compressive and flexural strength of mortar samples as mechanical properties was analysed. Results indicated that partial substitution of metakaolin in mortar mixtures provides higher compressive strength values at early ages; combined mixtures of limestone and metakaolin enhanced compressive strength comparing with 100% ordinary Portland cement (OPC) as the binder. Flexural strength values improved by increasing the number of steel fibres in mixtures; variations in metakaolin and limestone on mixtures seemed not to affect on final flexural results significantly. Electrical resistivity results revealed substantial improvements on the likelihood corrosion and corrosion rate of mortar mixtures. The addition of steel fibres to the admixture significantly decreased the ER mainly due to the conductivity of the fibres.

1. Introduction

The diminishing of cement consumption on mortar and concrete mixes is getting significant attention in recent years; especially its replacement by the use of supplementary materials with pozzolanic properties to address the environmental concern [1–5]. They confirm the effectiveness of calcined clay, in the form of metakaolin (MK) as pozzolanic material on mortar and concrete mixes. Souza and Dal Molin [6] also pointed out that high reactivity of MK is influenced by three parameters that have to be taken into account within its production processes such as chemical composition of the clay, calcination and grinding process. However, the dihydroxylation of kaolin clay (mineral) obtained by a calcination process under temperatures between 600 °C and 900 °C creates the active form of the mineral needed to react in a proper way with the calcium hydroxide (CH) liberated by the hydration of cement. As a result, interest in the use of MK as a pozzolanic addition on the production of concrete mixes has increased [7]. Similarly, there are already reports on the combination of OPC, MK and other minerals such as limestone (LS) that provided positive results on mortars, mainly the benefit to diminish the cement content. For instance, Antonini et al. [8] demonstrated the strong synergy between MK and LS concerning reaction with CH.

The study on the influence of fineness of LS in reaction with MK by Vance et al. [9,10] supports the theory of the compatibility of these materials, towards an adequate combination of cement substitution. Khatib and Hibbert [11] investigated mechanical properties on concrete mixes combining ground granulated blastfurnace slags (GGBS) and MK. Similarly, studies conducted by Vejmelkova

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et al. [12] show that same percentage of MK (10%) is required as the necessary amount to either improve some properties of MK concrete mixes or just to guarantee the quality level comparing with conventional OPC concrete. Likewise, Vu et al. [13] dedicated their work on to reveal the effect of variation in the OPC blended by the use of particular calcined kaolin clay regarding consistency and workability of the mixture. Qian and Li [14] indicate that the improvement occurs at the very early ages of concrete mixes (three days). Similarly, Vu et al. [13] concluded that for OPC and MK blends up to 10% cement weight replacements, the compressive strength of young mortars enhances. Antonini et al. [8] found that 30% MK content in combination with 15% LS produces better mechanical properties at seven days, even so at 28 days in reference with control mixtures containing only OPC as the binder. Nevertheless, the use of LS only as an addition to substitution on the cement content in mortar and concrete mixes does not have reasonable results to maintain the strength levels at later ages [15]. However, use of up to 15% LS in cement mixes have been claimed no to be significantly effective in reducing some critical properties [16–20].

The benefits of producing binary OPC and MK binders has been contradicted by some researchers where they have found poorer effects on concrete and mortar samples with additions of pozzolanic materials. Subasi and Emiroglu [21] stated an inversely proportional decrease in compressive strength by increasing the amount of MK replacement particularly at seven and 28 days of curing. Similarly, Vejmelkova et al. [12] highlighted worse results by the age of 28 days in mortar and concrete mixes. Opposite conclusions were indicated by Rashiddadash et al. [22] on which final results demonstrated that when MK is partially substituted by OPC, positive effects starts at early ages; this strength gain on compressive results was also noticed at later ages. An investigation carried out by Jiang et al. [23] supports the flexural strength loss for samples with MK additions at all of the considered curing ages from seven up to 90 days. To overcome this discrepancy, a comprehensive study to determine physical and mechanical properties of these combinations seems necessary.

In this paper, mechanical, microstructural and electrical properties of binary and ternary blended mixtures of OPC, MK and LS are studied. The compressive strength of samples at 7 and 28 days and flexural strength (for unreinforced and steel fibre-reinforced specimens) at 28 days of limewater curing is presented as the mechanical property of these materials. Scanning electron microscopy (SEM) and X-ray diffraction analyses are used to evaluate microstructure of different mortars. The electrical resistivity (ER) of unreinforced and steel fibre-reinforced specimens have been studied to discover the potential of corrosion resistivity of low cement mortar mixtures.

2. Experimental procedure

2.1. Materials

2.1.1. Cement

Locally general purpose (GP) Portland cement was used in the study. Properties of this material conform to the specifications required, that is AS 3972–2010 General purpose and blended cement. The average particle size distribution obtained for this material was 15.9 μm and its graphical distribution is presented in Fig. 1. Cumulative values per diameter are provided in Table 1.

2.1.2. Metakaolin

MK used was supplied by Filchem Australia Pty Ltd. Its physical characteristics consist of an uncompacted dry white powder, resultant of the flash calcination process of high-grade kaolin clay. The process of extraction refers to the dehydration of the clay by subjecting the material to temperatures between 600 and 900 °C. Its chemical composition is formed by silica (SiO_2) with a content percentage between 52–54% and alumina (Al_2O_3) around 44–46%. SEM micrograph in Fig. 2 shows the microstructure of the raw material. The particle in the powder are fine where the most particles have irregular shape. XRD analysis of Fig. 3 indicates the crystal diffraction of the material. There is not any apparent peak in XRD pattern of MK, which shows its amorphous nature and high pozzolanic reactivity capabilities. Moreover, particle size was measured through Cilas laser diffraction particle analyser, giving a grain size distribution shown in Fig. 1. Its summarised distribution in percentage values is described in Table 1. Due to the fineness and cohesiveness of the material, particle size distribution analysis was made in liquid mode. Different tested was made to get the consistency of the results.

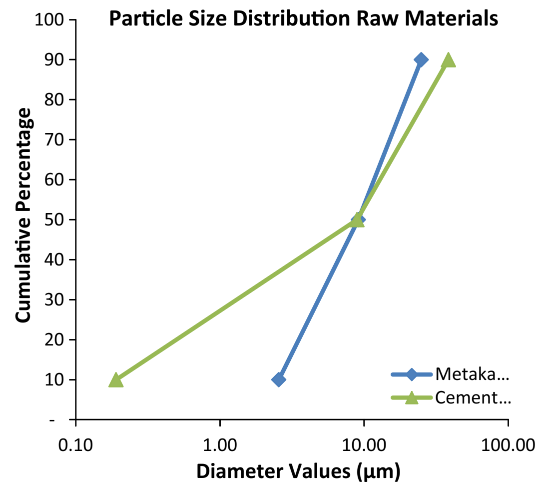

Fig. 1. Particle size distribution (PSD) of cement and metakaolin.

2.1.3. Limestone

LS powder used refers to a product from the commercial brand Richgro, with a chemical composition of 80–100% carbonate ($CaCO_3$) content and 0%-15% silica content (SiO_2). The physical aspect of this material is an uncompacted granulated powder, brown colour, and its SEM microstructural profile is shown in Fig. 4. Same as MK, most of the LS particles have irregular shape, however, with larger sizes. Furthermore, XRD analysis of the Limestone used in this study is shown in Fig. 5. The average particle size distribution obtained for this material was 275 μm and its graphical distribution is presented in Fig. 6. Similarly, Table 1 summarises particle size distribution in percentage values.

2.1.4. Fine aggregate (Sand)

Natural sand available at Cement Laboratory of Centre for Sustainable Infrastructure of Swinburne University Laboratory from local sources was used for the preparation of all the samples tested in this paper. Particle size distribution of sands is given in Fig. 7.

2.1.5. Steel fibre

Hook-end steel fibres with 60 mm length and aspect ratio of 65 produced by Dramix 65/60BG were used. Properties and geometry of the material is given in Table 2.

2.2. Mixture proportions

Nine mortar mixes were prepared to investigate the feasibility of the partial substitution of OPC by a combination of MK and LS.