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Effect of zinc oxide on the hydration, microstructure and compressive strength of ternary mixtures

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The use of supplementary cementitious materials as partial Portland cement substitutes in concrete is one of the best strategies for reducing carbon dioxide (CO_2) emissions in the cement industry, and also improves the properties of concrete. When highly reactive calcined pozzolans such as metakaolin are used, the setting time of concrete is reduced, and the use of retardants is necessary. The effect of zinc oxide (ZnO) as a cement hydration retarder has already been investigated; however, the influence of zinc oxide on ternary mixtures is unknown and needs study. In this research, the effect of adding zinc oxide on the hydration, microstructure and compressive strength of ternary mixtures is studied using setting time and compressive strength tests, X-ray diffraction, Fourier transform infrared spectroscopy, thermogravimetric analysis with differential scanning calorimetry and scanning electron microscopy. The results show that the hydration process of ternary pastes is delayed or even inhibited when the amount of zinc oxide in the paste is increased. With the addition of 0.5 wt.% zinc oxide, the initial setting time and compressive strength of ternary mixtures after 3 days of curing are similar to those of the cement paste without the addition of pozzolans and zinc oxide.

Introduction

The cement industry is one of the largest producers of carbon dioxide (CO_2) emissions in the world (Barker *et al.*, 2009; Rehan and Nehdi, 2005); this generates important ecological and energetic problems. Because of this, methods and strategies for the production of sustainable cements are required (Scrivener and Kirkpatrick, 2008). The environmental problems related to cement production are mainly associated with the calcination of raw materials and the burning of fuels to achieve high temperatures inside a kiln (Ali *et al.*, 2011; Zhang *et al.*, 2014). In addition, global production of cement continues to increase and is projected to rise to 6 Gt by 2050 (Juenger and Siddique 2015). Consequently, different techniques to reduce carbon dioxide emissions from the cement manufacturing industry are being investigated. One of the main techniques, and probably the most favoured carbon dioxide reduction strategy currently used by this industry, is the partial replacement of Portland cement clinker in a concrete mixture with supplementary cementitious materials (SCM) (Scrivener *et al.*, 2018). The term SCM covers a broad range of materials, including natural and manufactured pozzolans and industrial by-products. Although the properties of the different types of SCM vary considerably, they share the ability to react chemically in concrete to produce supplementary cementitious compounds that, together with the hydration products of Portland cement, contribute to the properties of concrete through hydraulic or pozzolanic activity (Thomas, 2014). Pozzolans commonly used in concrete include fly ash, silica fume and a variety of natural and calcined pozzolans, such as metakaolin. Metakaolin is a highly reactive pozzolan obtained by the calcination of kaolin at temperatures between 600 and 800°C and is used to produce high-performance concrete (Bapat, 2012; El-Diadamony *et al.*, 2018). This thermal process is characterised by a considerable reduction in the amount of carbon dioxide emissions compared with those generated during clinker production and has a thermal energy input of 0.35 GJ/t clay, which is about 10% of that used for Portland cement clinker production (Juenger *et al.*, 2019). It is reported that the use of metakaolin increases compressive strength during the early ages of hydration by the filler effect and the pozzolanic reaction of metakaolin (Barbhuiya *et al.*, 2015; Frías *et al.*, 2000). This increased strength can be attributed to two main factors. First, when pozzolans are substituted for cement particles, more space is generated for the formation of hydrates of the clinker phases; and second, the surface of pozzolan