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The impact resistance and mechanical properties of fiber reinforced self-compacting concrete (SCC) containing nano-SiO$_2$ and silica fume

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In this study, an extensive study including an experimental and analytical approach describes the effects of presence 1% nano-SiO$_2$ and 7% silica fume on the key mechanical properties (compressive, tensile and flexural strength) and impact resistance of such compositions with inclusion of different fibre volume fractions of Polypropylene (PP) (.25, .5, .75 and 1%) and water-to-cement ratios (.27, .34, .41). The experimental tests have been implemented on two hundred and seventy specimens. Experimental results indicated that using both silica fume and nano-SiO$_2$ instead of cement into the plain self-compacting concrete (SCC) leads to improved impact resistance and mechanical properties. This improvement was higher in terms of impact resistance compared to mechanical properties. Moreover, it was observed that using nano-SiO$_2$ particles consequences to reduce the wall effect between PP fibre and its surrounding matrix. Reduction of this effect enhanced the impact resistance and mechanical properties of fibre-reinforced SCC. Moreover, a statistical/analytical study was carried out on the executed large experimental database and it was observed that the impact resistance and mechanical properties of specimens containing silica fume and nano-SiO$_2$ follow a normal distribution. Furthermore, the highest rate of gaining the number of post initial crack blows to failure for the fibre-reinforced specimens registered for specimens with water-to-cement ratio of .41.

Keywords: fibre-reinforced SCC; mechanical properties; impact resistance; silica fume; nano-SiO$_2$

1. Introduction

In the recent years, with increasing human population and the increasing need to build houses, demands for using concrete as one of the main construction materials have significantly increased. In this regard, various supplementary cementing materials were developed and used to improve mechanical properties of concrete such as pozzolans and nanoparticles. Nanotechnology has attracted great scientific attention due to use of particles in nanometre scale (Sanchez & Sobolev, 2010). Developments of new materials with new functions or improvements in the properties of existing materials using nanotechnology are new areas of interest in civil engineering (Pacheco-Torgal & Jalali, 2011). Previous studies about using nanoparticles in concrete have indicated that employing these nanoparticles in concrete improves mechanical properties of the concrete besides the improvement in microstructure and pore structure (Nazari & Riahi, 2011a). There are
several works on incorporating nanoparticles into concrete to achieve an improvement in mechanical properties of concrete (Björnström, Martinelli, Matic, Börjesson, & Panas, 2004; Ji, 2005; Jo, Kim, Tae, & Park, 2007; Qing, Zenan, Deyu, & Rongshen, 2007). In general, nanoscale particles are characterised by a high surface area-to-volume ratio and many are highly reactive, as shown in Figure 1. In 2006, Shih, Chang, and Hsiao indicated that the addition of nano-silica in cement or concrete, even in small dosages could significantly improve mechanical properties of cementitious materials. Due to more formation of hydrated products in presence of SiO₂ nanoparticles, the compressive strength, tensile strength and flexural strength of concrete specimens is increased by increasing the content of nanoparticles up to 4% (by mass of cement) (Nazari & Riahi, 2011b). Additionally, the pore structures of concrete containing silica nanoparticles was improved and recovered by acting as nanofillers, filling the voids of the C–S–H, and nano-SiO₂ reacts with Ca(OH)₂ (pozzolanic reaction) (Land & Stephan, 2011; Pacheco-Torgal, MIRALDO, DING, & LABRINCHA, 2013). The hydration heat of ordinary Portland cement blended with nano-silica increases significantly with an increasing surface area of silica and reducing the size of Ca(OH)₂ crystal (Land & Stephan, 2011; Pacheco-Torgal et al., 2013).

Despite all these improvements in mechanical properties of plain concrete which utilise nanoparticles, the main problem of plain concrete stands in dealing with significant reduction of mechanical properties of concrete due to form the initial crack under tensile or flexural loading. Localisation of the initial crack in the plain concrete can reduce significantly mechanical properties of concrete. Therefore, in order to minimise this weakness and employ advantages of nanoparticle, fibres were introduced into the matrix. This effectively restricted growth of cracks through bridging action which subsequently improved properties of the concrete. Various studies about effects of Polypropylene (PP) fibres on bridging action of fibres in the matrix have been implemented (Alberti, Enfedaque, & Gálvez, 2014; Fakharifar et al., 2014; Ghasemi, Mastali et al., 2014;