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Mechanical and durability properties of fly ash geopolymer concrete containing recycled coarse aggregates

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Abstract

This paper presents mechanical and durability properties of geopolymer concrete containing recycled coarse aggregate (RCA). The RCA is sourced from local construction and demolition (C&D) waste in Perth, Australia. The RCA is used as a partial replacement of natural coarse aggregate (NCA) in geopolymer concrete at 15%, 30% and 50% by wt. which corresponds to series two, three and four, respectively, while the geopolymer concrete containing 100% NCA is control and is considered as the first series. Class F fly ash is used as the source material for the geopolymer and 8 M sodium hydroxide and sodium silicate alkali activators are used to synthesise the fly ash geopolymer in this study. In all four series a constant alkali activator to fly ash ratio is used. Compressive strength, indirect tensile strength and elastic modulus of above geopolymer concrete are measured at 7 and 28 days, while sorptivity, immersed water absorption and volume of permeable voids of above geopolymer concrete are measured at 28 days. Relevant Australian standards are used to measure all the above properties except the sorptivity which is measured according to ASTM standard. Results show that the compressive strength, indirect tensile strength and elastic modulus of geopolymer concrete decrease with an increase in RCA contents, which is also true for both 7 and 28 days. Excellent correlations of compressive strength with indirect tensile strength and elastic modulus are also observed in geopolymer concrete containing RCA. Existing empirical models for cement concrete and geopolymer concrete containing NCA underestimate and overestimate the indirect tensile strength and elastic modulus, respectively of geopolymer concrete containing RCA. The measured durability properties such as sorptivity, water absorption and volume of permeable voids of geopolymer concrete were also adversely affected by the incorporation of RCA and these properties increase with an increase in RCA contents. The effects of RCA on the measured mechanical and durability properties of geopolymer concrete follow similar trend in cement concrete. Very good correlations of compressive strength with volume of permeable voids and water absorption of geopolymer concrete containing RCA are also observed, while the correlation between the compressive strength and the sorptivity is not that strong.

Keywords: Geopolymer; Fly ash; Recycled coarse aggregate; Construction and demolition waste; Mechanical properties and durability properties

1. Introduction

Concrete is the most widely used construction material in the world due to its low cost, excellent durability, easy availability of its constituent materials, easy formability to any shape, etc. Among all constituents of concrete

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ordinary Portland cement (OPC) is the main ingredient which binds the aggregates together. However, the manufacturing of OPC is an energy intensive process and the production of OPC is responsible for almost 5% of total global CO_2 emissions, which is the main cause of global warming (Malhotra and Mehta, 2002). In another estimate it was found that the production of one tonne of OPC releases approximately one tonne of carbon dioxide to the atmosphere (Malhotra and Mehta, 2002). Due to an increase in global population and urbanisation the increasing use of concrete in construction is unavoidable in near future. This concern has led to the use of new sustainable OPC less binder for concrete and supplementary cementitious materials (SCMs) as a partial replacement of a large amount of OPC in the concrete.

Additionally, extraction of natural aggregates is adversely affecting the natural eco system as the utilisation of concrete is increasing annually. On the other hand, the disposal of construction and demolition (C&D) wastes is also becoming a major environmental issue that has prompted many researchers worldwide to investigate new means of recycling it, with the aim of alleviating the pressure on the scarce landfill space available and also as a means to reduce the current reliance on natural aggregates and minerals (Kou et al., 2012; Tabsh and Abdelfatah, 2009; Zaharieva et al., 2003). Given that coarse and fine aggregates occupy 75–80% of the total volume of the concrete (Lamond and Pielert, 2006), the incorporation of C&D wastes in the form of recycled coarse aggregates (RCA) has huge potential (Corinaldesi and Moriconi, 2009). Although this is not a new concept, many researchers around the world have investigated the resulting properties and there is wide agreement that the concrete containing RCA presents inferior properties compared to conventional concrete incorporating natural aggregates (Corinaldesi and Moriconi, 2009; Etxeberria et al., 2007; Shaikh, 2013; Shaikh and Nguyen, 2013).

On the other hand, the Australian quarry industry estimates an average consumption of aggregate across Australia is about 160 million tonnes per annum; these figures are likely to increase due to the future developments of infrastructure (Aggregate industry report, 2012). The C&D industry contributes approximately 40% of total waste in landfills across Australia, and 90% of this waste is predominately concrete and masonry materials (Construction and demolition waste report, 2011). Meanwhile, the construction industry also produces 7.1% of Australia's greenhouse gasses indirectly through manufacturing, extraction, processing, and transportation of materials (Australian greenhouse office, 2010). Adopting recycled aggregates in concrete could help reduce the need to mine natural materials, both reducing waste and emissions. Thus, the incorporation of C&D waste as substitute to natural coarse aggregates (NCA) in concrete has many economic and environmental benefits to Australia's industries.

Geopolymer is an emerging cement less binder purported to provide a sustainable and environmentally friendly alternative to OPC. The term geopolymer was initially introduced by Davidovits (1991). Geopolymer is synthesised from materials of geological origin (e.g., metakaolin) or industrial by-products, such as fly ash and slag, which are rich in silica and alumina with alkaline activators. In one estimate it was found that the production of fly ash-based geopolymer requires approximately 60% less energy and has at least 80% less CO_2 emissions compared to the manufacture of OPC (Duxson et al., 2007). So far, extensive research and development on geopolymer concrete and composites have been undertaken worldwide with hopes to promote geopolymer as an ultimate sustainable construction material for the future (Wallah and Rangan, 2006; Sumajouw and Rangan, 2006; Kong and Sanjayan, 2010).

By adding the RCA as a partial or full replacement of NCA the sustainability of the existing geopolymer concrete containing natural aggregates can further be extended which together address the environmental issues of greenhouse gas emission by the manufacturing of OPC, the depletion of natural aggregate resources and the dumping problems of C&D wastes as landfill. Extensive research has been conducted on various mechanical and durability properties of geopolymer concrete containing natural aggregates and the same for OPC concrete containing recycled aggregates (Wallah and Rangan, 2006; Sumajouw and Rangan, 2006). However, a few researches on mechanical and durability properties of geopolymer concrete containing recycled coarse aggregates are reported (Sata et al., 2013; Nuaklong et al., 2016; Anuar et al., 2011; Shuang et al., 2012; Posi et al., 2013). Anuar et al. (2011) studied the compressive strength of geopolymer concrete containing recycled concrete aggregate, where the source material for geopolymer was waste paper sludge ash instead of popularly used fly ash and slag. Results show that the compressive strength is increased by about 10% from 7 days to 28 days and high molarity of sodium hydroxide shows higher compressive strength in geopolymer concrete. Shuang et al. (2012) evaluated the mechanical properties of geopolymer concrete containing 50% and 100% recycled coarse aggregate as a replacement of natural coarse aggregate and compared with those of ordinary concrete. Results show that the compressive strength and elastic modulus are all higher in the case of geopolymer concrete containing recycled coarse aggregate than its counterpart OPC concrete containing RCA and the above mechanical properties decrease with an increase in RCA contents. They also reported better interfacial transition zone in the case of geopolymer concrete than the OPC concrete. Recently, Posi et al. (2013) studied the mechanical properties of geopolymer concrete containing recycled lightweight aggregates and reported that similar to normal weight recycled coarse aggregate the compressive strength of geopolymer concrete decreases with an increase in recycled light weight aggregate contents. However, mixed results are reported on the modulus of elasticity in their study. Sata et al. (2013) also reported a study where crushed concrete and crushed brick were used as a replacement of natural

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