International Journal of Sustainable Built Environment (2017) xxx, xxx–xxx

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International Journal of Sustainable Built Environment

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Original Article/Research

Mechanical properties of recycled aggregate concrete containing ternary blended cementitious materials

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Received 29 May 2016; received in revised form 23 August 2017; accepted 20 October 2017

Abstract

This paper presents the effect of silica fume (SF) on early-age and long-term mechanical properties of recycled aggregate concrete containing slag. In this study six series of mixes are considered. The first series is control concrete containing 100% ordinary Portland cement (OPC) and 100% natural aggregates. The second series is similar to the first series in every aspect except the natural coarse aggregate (NCA) which was partially replaced by 50% (by wt.) recycled coarse aggregate (RCA). The third series is also similar to the second series except the OPC which is partially replaced by 50% slag. The effects of 5, 10 and 15% (by wt.) SF on mechanical properties of concrete is evaluated in fourth, fifth and sixth series, respectively. Compressive strength, indirect tensile strength and modulus of elasticity of above concretes are measured at 3, 7, 28, 56 and 91 days. Results show that the addition of 50% slag significantly reduced the above mechanical properties of concrete containing 50% RCA at early age. Among three SF contents, the 10% SF improved the above mechanical properties of recycled aggregate concrete containing slag at early ages (3 and 7 days) as well as at 28 days. The addition of 10% SF also improved the 56 and 91 days compressive and tensile strengths of recycled aggregate concrete containing slag. It is also found that the long-term (56 and 91 days) compressive and tensile strengths of recycled aggregate concrete containing slag and 10% SF are even higher than the OPC concrete containing 50% RCA and control concrete, respectively. It is also observed that the slow pozzolanic reaction of slag contributed to the long-term compressive and tensile strengths of recycled aggregate concrete containing slag and 10% SF. Strong correlations of measured compressive strength with indirect tensile strength and elastic modulus of above environmentally friendly concretes are also established.

Keywords: Slag; Silica fume; Recycled aggregate; Mechanical properties

1. Introduction

The addition of supplementary cementing materials (SCM), which are industrial by-products, as partial replacement of ordinary Portland cement (OPC) in concrete is widely practiced to reduce the carbon footprint of OPC concrete as the OPC manufacturing releases approximately 5–7% CO_2 in the air (Limbachiya et al., 2014; Malhotra and Mehta, 2002). In addition, the use of natural aggregates, which occupy approximately 75–80% of total volume of concrete (Neville, 2011), also affects the environment as the extraction of natural rocks significantly affect the natural eco-system. The release of CO_2 and the extraction of natural rocks will continue in future as the use of

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Peer review under responsibility of The Gulf Organisation for Research and Development.

https://doi.org/10.1016/j.ijsbe.2017.10.005

Please cite this article in press as: Shaikh, F.U.A. Mechanical properties of recycled aggregate concrete containing ternary blended cementitious materials. International Journal of Sustainable Built Environment (2017), https://doi.org/10.1016/j.ijsbe.2017.10.005

concrete in construction is unavoidable due to rapid urbanisation and housing demand in the world. However, efforts have been made to address these issues on environmental impact and the use of SCM e.g. 20–30% fly ash and slag and 5–10% silica fume as partial replacement of OPC and 20–30% replacement of natural aggregates by recycled concrete aggregates in concrete is accepted in many countries and significant amount of research has been done with good understanding on the properties of concrete containing these recycled aggregates and SCM materials.

In order to further improve the environmental friendliness of concrete and to maximise the use of these by-products and construction and demolition wastes in concrete the use of high volume fractions of these materials in concrete need to be incorporated. Significant amount of research is also conducted on the individual use of high volume fractions of SCM in concrete (Malhotra and Mehta, 2002; Shaikh et al., 2014a; Mo et al., 2015; Naik et al., 1994; Siddique, 2004; Kou et al., 2011, Supit and Shaikh, 2014; Shaikh and Supit, 2015) and the high amount of recycled concrete aggregates (Chen et al., 2003; Yong and Teo, 2009; Zhang and Ingham, 2010; Ahmed, 2014; Xiao et al., 2005; Yang et al., 2008; Shaikh et al., 2014b; Shaikh, 2015). It has been reported that the use of high volume fly ash and slag adversely affect the early age strength properties of concrete although in the longer term these concretes show improvement of the same strength properties due to pozzolanic reaction of fly ash and slag with calcium hydroxide of the hydration of cement. It has been also reported that the workability of these concretes is improved (Naik et al., 1994; Siddique, 2004; Kou et al., 2011). While in many research the effect of ultrafine SCMs (e.g. silica fume, nano particles, ultrafine fly ash, etc.) on the strength properties of concrete containing fly ash is studied, however, very little is reported on the effect of silica fume on the strength properties of slag concrete (Bashah, 2006; Kumar and Bhargari, 2015) and the results show that the inclusion of silica fume improves the early age as well as long-term compressive strength of high volume slag concrete.

The environmental impact of concretes can significantly be improved by adding high amount of recycled aggregates as partial replacement of natural aggregates in the concretes containing slag. However, the mechanical properties of concretes containing slag and high amount of recycled aggregates are not widely reported. In addition, it is also expected that the early age mechanical properties of recycled aggregate concrete containing slag will be lower than the RAC due to slow pozzolanic reaction of slag. The addition of small amount silica fume or other ultrafine SCMs can compensate this deficiency. However, no study so far reported the effects of different amount of silica fumes on the early age and long-term mechanical properties of recycled aggregate concrete containing slag. Therefore, this research fills this gap and presents measured mechanical properties from 3 days to 3 months of recycled aggregate concrete containing 50% slag and 50% RCA as partial replacement of OPC and natural coarse aggregate, respectively. The effects of different silica fume contents of 5, 10 and 15% on the mechanical properties of above recycled aggregate concrete containing slag are also evaluated in this study.

2. Experimental program

In this study six series of mixes were considered. The first series was control concrete consisting of 100% OPC and 100% natural aggregates. The second series was very similar to the first series with only exception of replacement of 50% natural coarse aggregate with recycled coarse aggregate (RCA). The effect of 50% slag as partial replacement of OPC on second series concrete is evaluated in the third series. In fourth to sixth series the effect of 5%, 10% and 15% SF on the properties of recycled aggregate concrete containing 50% RCA and 50% slag is evaluated. In these series total replacement of OPC by slag and SF was kept at 50% in order to compare with the third series.

3. Materials

Ordinary Portland cement (OPC) was used in all concrete mixes. The blast furnace slag used in this study was

Table 1
Chemical and physical properties of ordinary portland cement (OPC), slag and silica fume (SF).

Chemical analysis	OPC (wt.%)	Slag (wt.%)	Silica fume (wt.%)
SiO_2	21.1	32.45	89.6
Al_2O_3	5.24	13.56	–
Fe_2O_3	3.1	0.82	–
CaO	64.39	41.22	–
MgO	1.1	5.1	–
K_2O	0.57	0.35	0.225
Na_2O	0.23	0.27	0.11
SO_3	2.52	3.2	–
LOI	1.22	1.11	3.8
Particle size	–	–	95% particles < 1 μm
Specific gravity	3.17	–	0.625
BET Surface area (m^2/g)	–	–	15–30

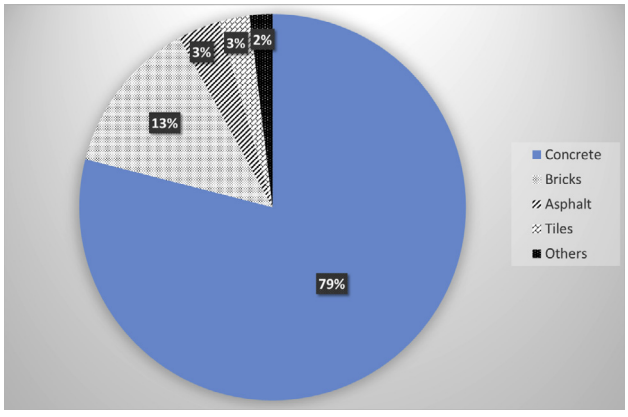

Fig. 1. Analysis of construction and demolition wastes used as recycled coarse aggregates in this study.

Please cite this article in press as: Shaikh, F.U.A. Mechanical properties of recycled aggregate concrete containing ternary blended cementitious materials. International Journal of Sustainable Built Environment (2017), https://doi.org/10.1016/j.ijsbe.2017.10.005