Construction and Building Materials 131 (2017) 245–253

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Sustainable self-consolidating concrete using recycled asphalt pavement and high volume of supplementary cementitious materials

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HIGHLIGHTS

- Using 15%, 30% and 50% RAP decreased the 28-days compressive strength of mixtures.
- The split tensile strength of all mixtures decreased with the inclusion of RAP.
- The use of SCMs reduced the total unrestrained shrinkage regardless of the RAP content.
- The use of SCMs decreases the permeability of all mixtures.
- As the percentage of RAP increases, the permeability of SCC mixtures decreases.

ARTICLE INFO

Article history:
Received 8 June 2016
Received in revised form 29 September 2016
Accepted 11 November 2016

Keywords:
Self-consolidating concrete
Recycled asphalt pavement (RAP)
Supplementary cementitious materials
Fly-ash and slag

ABSTRACT

This study presents the results of laboratory investigation of fresh, hardened and durability characteristics of self-consolidating concrete (SCC) containing high volume of supplementary cementitious materials (SCMs) including class C fly-ash (FA) and slag (S) with recycled asphalt pavement (RAP) aggregate. Sixteen mixtures were prepared with different percentages of FA, S, and RAP. SCC mixtures were divided into four groups where each group had a different percentage of RAP replacing NCA (0%, 15%, 30%, 50%) and Portland cement being replaced by different percentages of SCMs (0%, 75% FA, 75% S and combination of 37.5% FA and 37.5% S). The water to cementitious material (w/cm) ratio for SCC mixtures in this study was maintained to be 0.4 with a target slump flow higher than 500 mm. The fresh concrete properties such as: flowability, deformability, filling capacity and resistance to segregation were measured. Moreover, hardened properties such as compressive strength at 3, 14 and 28 days and split tensile strength at 28 days were measured and durability characteristics including unrestrained shrinkage up to 90 days and chloride permeability resistance at 45 and 90 days were tested. The use of SCMs and RAP affected both the fresh and hardened properties of SCC. Analysis of experimental data showed that all the mixtures satisfied the SCC fresh properties requirements. The addition of RAP and SCMs had an adverse effect on both the compressive and tensile strength of concrete mixtures. However the use of SCMs has positive effects on the unrestrained shrinkage and permeability.

1. Introduction

SCC is a high performance concrete that can spread and flow in congested spaces and self-consolidate under its own weight without showing any segregation or bleeding. These properties of SCC results in reduction of labor cost and construction time while also eliminating the need for mechanical vibration [1]. SCC technology allows structural engineers to design economically and environmentally sound structures incorporating smaller highly reinforced members and build them with optimal material use. The major obstacle for implementation of SCC technology in construction industry is high material cost which is 25–50% more than conventional concrete [2].

Self-consolidating concrete (SCC) generally requires large quantity of cement, which is one of the reasons SCC is expensive as compared to other concretes available. From the past few decades research is being carried out on various fronts to make SCC cost effective and easily available in construction industry. One of the ways to reduce the cost of SCC is partial replacement of cement content in SCC with sustainable technologies such as supplementary cementitious materials (SCMs). The partial replacement of cement with SCMs usually provides enhanced concrete properties and durability. SCMs such as fly-ash, silica fume, slag and limestone

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http://dx.doi.org/10.1016/j.conbuildmat.2016.11.044
0950-0618/

Table 1
SCC mixtures matrix.

Mixture constituents	100% Cement	75% Fly-ash + 25% cement	75% Slag + 25% cement	37.5% Fly-ash + 37.5% Slag + 25% cement
0% RAP-100% NCA	0-0FA-S	0-75FA	0-75S	0-FA-S
15% RAP-85% NCA	15-0FA-S	15-75FA	15-75S	15-FA-S
30% RAP-70% NCA	30-0FA-S	30-75FA	30-75S	30-FA-S
50% RAP-50% NCA	50-0FA-S	50-75FA	50-75S	50-FA-S

Table 2
Proportion of concrete mixtures.

Mixes	% RAP	Cementitious materials (CM) (kg/m^3)				Water (kg/m^3)		Aggregates (kg)		
		CM	C	FA	S	w/cm	W	RAP	NCA	FAG
0-0FA-S	0%	375	375	0	0	0.4	150	0	865	880
0-75FA-S	0%	375	93.75	281.25	0	0.4	150	0	865	880
0-75S	0%	375	93.75	0	281.25	0.4	150	0	865	880
0-FA-S	0%	375	93.75	140.63	140.63	0.4	150	0	865	880
15-0FA-S	15%	375	375	0	0	0.4	150	129.75	735.25	880
15-75FA-S	15%	375	93.75	281.25	0	0.4	150	129.75	735.25	880
15-75S	15%	375	93.75	0	281.25	0.4	150	129.75	735.25	880
15-FA-S	15%	375	93.75	140.63	140.63	0.4	150	129.75	735.25	880
30-0FA-S	30%	375	375	0	0	0.4	150	259.5	605.5	880
30-75FA-S	30%	375	93.75	281.25	0	0.4	150	259.5	605.5	880
30-75S	30%	375	93.75	0	281.25	0.4	150	259.5	605.5	880
30-FA-S	30%	375	93.75	140.63	140.63	0.4	150	259.5	605.5	880
50-0FA-S	50%	375	375	0	0	0.4	150	432.5	432.5	880
50-75FA-S	50%	375	93.75	281.25	0	0.4	150	432.5	432.5	880
50-75S	50%	375	93.75	0	281.25	0.4	150	432.5	432.5	880
50-FA-S	50%	375	93.75	140.63	140.63	0.4	150	432.5	432.5	880

CM = cementitious materials, C = coarse aggregate, W = water, FAG = fine aggregate.

filler are generally used with chemical admixtures such as high range water reducers (HRWR) and viscosity modifying agents (VMA) to provide reasonable workability and deformability in concrete [3–5].

Recycled asphalt pavement has been used in some applications but large quantity of it is either stockpiled or wasted in landfills which do not represent the true value of RAP as construction material. Many of the recent researchers have used RAP as replacement for natural aggregates in Portland cement concrete (PCC) and have studied RAP's effect on PCC properties in their studies. Al-Oraimi et al. [6] studied the effects of RAP on the properties of Portland cement concrete. The results show that the slump decreased with the increase in RAP content as was the case with compressive strength, flexural strength and modulus of elasticity. The surface absorption of concrete was not affected significantly with the increase in RAP content. The researchers concluded that RAP can be used in concrete when concrete is being used in non-structural applications and low slump of concrete should be kept in mind when using RAP. Bermel [7] investigated the use of RAP containing concrete as a pavement in Montana. Number of mixes with different proportions using coarse and fine RAP as replacement for natural aggregate was made to be used as Portland cement concrete pavement (PCCP). Tests were performed to determine the relevant properties of RAP concrete to be used as PCCP. Results showed that using conventional practices concrete containing RAP aggregate such as 20% fine and 45% coarse replaced aggregate can yield compressive strength more than 20-MPa. As the rate of RAP replacement of natural aggregate was increased, the compressive strength of concrete decreases and fine aggregate RAP have more adverse effect on the properties of concrete than coarse aggregate. When both fine and coarse aggregate were replaced by RAP, the benefit achieved was more than when only one type of gradation was replaced. Results also showed that concrete containing RAP displayed more flexural strength as compared to conventional Portland cement concrete. The researcher concluded that concrete containing relatively high RAP replacement up to 50% fine and 100% coarse aggregate can be used in transportation industry as PCCP.

Ibrahim et al. [5] investigated the effect of RAP aggregate on self-consolidating concrete (SCC) containing high volumes of supplementary cementitious (SCMs) material such fly ash and slag. In the course of this study twelve mixes were made with different combination of slag, fly ash and RAP replacement of cement and natural aggregate respectively. RAP replacement of natural aggregate in SCC was taken as 0, 25 and 50%, fly ash and slag replaced cement by 60 and 70% respectively. Results showed that inclusion of RAP decreases the compressive strength and split tensile strength of SCC. Fresh properties of concrete such as slump flow met the SCC fresh properties requirement even mixes with 50% RAP replacement. Durability of design mixes was checked by rapid chloride permeability test but the results were inconclusive in this regard. Research concluded that even mixes with high percentages of RAP and SCMs satisfied the compressive strength requirement of pavements and bridges. Solanki and Dash [8] studied the effects of RAP as aggregate replacement and class C fly ash as Portland

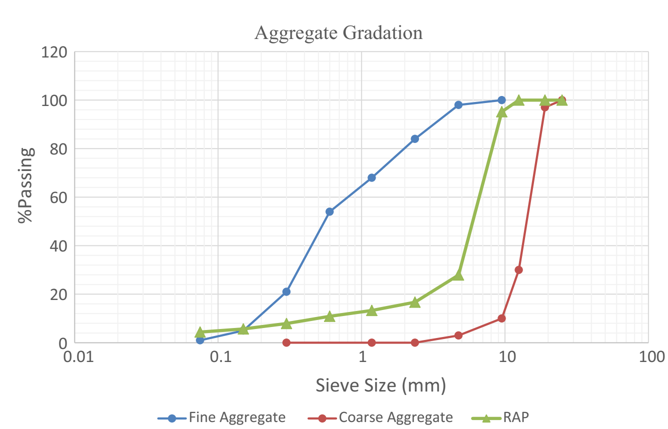

Fig. 1. Coarse and fine aggregate gradation.