The 2014 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM14)
Busan, Korea, August 24-28, 2014

Effect of coarse and fine recycled aggregates and natural pozzolana on fresh properties of self-compacting concrete

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ABSTRACT

Self-compacting concrete (SCC) is a highly fluid concrete that takes place under the influence of its own weight. It is characterized by high paste volume and the use of superplasticizers. The performance of SCC using natural aggregates is well studied. However, information or the properties of SCC with recycled aggregates is limited. The main objective of this paper is to study the effect of substitution of 50 or 100% of natural aggregates by coarse and fine recycled aggregates on the fresh properties of SCC made with 15% of natural pozzolana. The results showed that the use of recycled aggregates gives a SCC with comparable rheological properties to that of control concrete. The substitution of cement by natural pozzolana decreases the workability of the control concrete. However, an improvement has been noted for SCC made with recycled concrete aggregates.

1. INTRODUCTION

Self compacting concrete (SCC) is a high performance material which has favorable characteristics such as high fluidity, good segregation and bleeding resistance and leads to complete filling of formwork, without vibration (Melo and Carneiro 2010, Panda and Bal 2013). Recently, the need to decrease CO_2 diffusion related to the production and use of cement became an environmental concern. The use of natural and/or industrial mineral additives reduces carbon emission and increases the stability of the mix towards bleeding and segregation and hence minimizes the need for superplasticizer. On the other hand, the use of recycled aggregates (RA) is an important step towards protecting the environment. Using recycled aggregates contributes to the conservation of natural aggregates resources and reduces the needs for disposal of demolition waste. However, recycled aggregates differs from natural aggregate in that it is mainly composed of two materials, namely, the original aggregate and the adhered mortar (Etxeberria et al. 2007, De Juan and Gutierrez 2009). They are also characterized by their high porosity due to the old mortar adhering to the original aggregates. It is therefore important to investigate the effect of these aggregates on the rheological performance of concrete. Hence, the material on which this research focuses is SCC made by incorporating recycled aggregates and natural pozzolana (Pz) as an environmental friendly material. The fresh properties of SCC made with 50 and

100% (RA) (coarse and fine) with or without natural pozzolana (Pz) as cement replacement were studied.

2. EXPERIMENTAL DETAILS

2.1 Materials

The SCC mixtures were prepared with CEM II/B 42.5R Portland cement conforming to EN107-1. The mineral additive used is natural pozzolana with a specific density of 2.81 which was ground in a laboratory mill to a fineness of 3500 (g/cm^2). The cement specific density is 3.05 and its fineness is 3000 (g/cm^2). The chemical and physical properties of cement and mineral additive used are shown in Table 1.

Table 1: Chemical and physical properties of cement and natural pozzolana

	Chemical properties (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	L.O.I
Cement	21.06	3.60	4.47	63.40	1.85	2.00	0.13	0.57	0.65
Pozzolana	45.67	15.10	10.14	8.98	3.45	0.19	3.0	-	-

Natural and recycled aggregates were used as the coarse and fine aggregates in the concrete mixtures. The recycled concrete aggregates were prepared in the laboratory by crushing manually and then in a laboratory mill of (1mx1mx0.10m) natural aggregates concrete slabs. The slabs were water cured for 28 days before being crushed. Finally, to obtain the different fractions of recycled aggregates, the crushed material was passed through the sieves with different dimensions. Table 2 summarizes the properties of natural and recycled concrete aggregates. The superplasticizer used in this study is a polycarboxylates superplasticizer with 30% of solid content. The specific density is about 1.07.

2.1 Mixtures proportions

The mix design is based on the Okamura SCC mix design method (Okamura et al. 2000). Preliminary tests were performed on mortar to optimize the mix. The preliminary tests led to a water to binder ration (w/b = 0.40) and a constant superplasticizer content of 1.8% by mass of binder material. The proportion of the recycled aggregates used was 0, 50 and 100%. Cement was partially substituted by 15% of natural pozzolana. The mixtures proportions of concrete are given in Table 3.

In a laboratory mixer, all the mixtures were mixed first for 30 seconds to homogenize the dry powder with the aggregates. Then 1 minute with 70% of amount of water thereafter, the Sp dissolved in the remaining water (30%) were added and all the concrete was mixed for 5 minutes. Then the mixer was stopped for 2 minutes and again the concrete was further mixed for 30 seconds before it was discharged from the mixer.

Table 2: Properties of natural and recycled aggregates

	Bulk density (kg/m^3)	Specific density (kg/m^3)	Water absorption coefficient (%)	Humidity (%)
Natural aggregates				
Fine aggregates	1450	2560	1.10	1.70
CA 3/8	1475	2700	0.50	0.13
CA 8/15	1465	2730	0.50	0.30
Recycled aggregates				
Fine aggregate	1390	2290	7.03	4.70
CA 3/8	1241	2310	6.50	3.84
CA 8/15	1278	2330	4.67	2.29

CA: Coarse aggregates

Table 3: Mix proportions of SCC mixtures

	Cement	Pozzolana	Natural aggregates			Recycled aggregates		
			3/8	8/15	Sand	3/8	8/15	Sand
SCC(N)	494	-	245	490	921	-	-	-
SCC(N)15Pz	422	69	245	490	921	-	-	-
SCC(R)	494	-	-	-	-	210	420	823
SCC(R)15Pz	422	69	-	-	-	210	420	823
SCC(NR)	494	-	122	244	463	103.2	203	402
SCC(NR)15Pz	422	69	122	244	463	103.2	203	402

2.2 Test methods

As per EFNARC guidelines for self compacting concrete (EFNARC 2002), the fresh properties of all concrete mixtures were measured to ensure that the concrete is stable and has flowing ability. Fresh concrete properties of SCC mixtures were determined by using the slump-flow, V-funnel, L-box and U-box tests. The slump flow test assesses the horizontal free flow of SCC in the absence of obstruction. The capability of concrete to flow under its self weight is also judged by this test (Felekoglu et al. 2007). T_{50} time measured in this test is the time required for a concrete spread of 50 cm diameter. This time gives an indication for the viscosity of the SCC mixtures. The filling ability was measured with respect to slump flow and T_{50}.

Among the tests used to assess the mobility of confined concrete test, V-funnel is the most widely used (Assié 2004). The V-funnel flow time gives an indication of the filling ability of SCC, its viscosity and indicates the blocking effect caused by segregation.

The passing ability, which is defined as the ability of SCC to flow in confined conditions and completely fill all spaces within the formwork under self weight and without vibration, is tested using the L-box and U-box tests when the concrete flowing through confined or reinforced areas. While the values of T_{20} and T_{40} represent the times for concrete to reach 20 and 40 cm flow, respectively. The L-box and U-box tests allow testing the filling ratio of the concrete by measuring the passing ability ratio (H_2/H_1) through the reinforcement bars.

3. RESULTS AND DISCUSSION

The results of fresh properties of the six (06) self compacting concrete mixes are shown in Table 4.

Table 4**.** Fresh properties of self compacting concrete mixtures

Mixtures	Slump flow		L Box			V-funnel time	U Box (H_2/H_1)
	D (mm)	T_{50} (s)	H_2/H_1	T_{20}(s)	T_{40}(s)		
SCC(N)	764	2.67	0.63	2.91	7.10	9.7	0.63
SCC(N)15Pz	711	3.35	0.60	1.42	2.12	12.8	0.60
SCC(R)	769	3.29	0.95	2.2	5.20	11.0	0.43
SCC(R)15Pz	736	6.2	0.97	2.7	5.9	14.4	0.98
SCC(NR)	744	3.23	0.98	1.67	3.94	9.7	0.31
SCC(NR)15Pz	715	5.2	0.83	2.01	8.25	38.6	0.53

3.1. Slump flow test

Figure 1 shows the results of slump flow of the different SCC mixes with and without recycled aggregates and pozzolana. As can be seen in Fig. 1, the slump flow values for different concrete mixes were measured in the range of 711–769 mm. According to EFNARC (2002), all concrete mixtures under investigation can be categorized as slump flow class 2 (SF2) or class 3 (SF3). The diameters of SCC (N) and SCC (NR) are less than the diameter of SCC containing 100% recycled aggregates. Tu et al. (2006) obtained a cone slump for a high performance concrete (HPC) with 100% recycled aggregates higher than that of an HPC with natural fine and coarse recycled aggregates, with a rapid loss of workability. Moreover, Khatib (2005) found that increasing the amount of recycled concrete aggregates in ordinary concrete generates an increase in its cone slump.

On the other hand, Yong and Teo (2009) found that substitution of 50 and 100% natural aggregates by recycled aggregates leads to a reduction of the slump of ordinate concrete. Grdic et al. (2010) found that the values of flow diameters were comparable for SCC with natural aggregates, 50 and 100% recycled aggregates. The substitution of cement by natural pozzolana decreases the workability of concrete with and without recycled aggregates. This reduction in slump flow may be attributed to the higher water demand of the pozzolana finer particles.

The incorporation of pozzolana as cement replacement in concrete increases the porosity of the paste and hence a higher water demand (SCC contains a higher paste volume) and hence the decrease of the workability of SCC mixtures containing natural pozzolana. It should be noted, the higher slump flow values are given by SCC mixtures made with 100% of recycled aggregates for both 0% and 15% Pz as cement replacement. Arya et al. (1990) reported that the incorporation of pozzolan improves workability of vibrated concrete.

The T_{50} flow time for the three concretes (Fig. 2) is less than the maximum limit of 5 seconds. We can also note that the SCC prepared with natural aggregates presents the smallest T_{50} of 2.67 seconds followed by SCC (NR) and SCC (R) with a T_{50} equal to 3.23 and 3.29 seconds respectively. These results indicate clearly that the incorporation of natural pozzolana increases T_{50} flow time of SCC. Grdic et al. (2010) found a T_{50} exceeding 5 seconds for the three types of concrete, but the values were very similar. SCC mixture made with 100% recycled aggregates with and without pozzolana gives the highest slump flow time T_{50} with 3.29 and 6.22 seconds, respectively compared to control mixtures, which indicates a more viscous SCC mixture. However, the lowest flow time value T_{50} is given by SCC (N) with and without pozzolana.

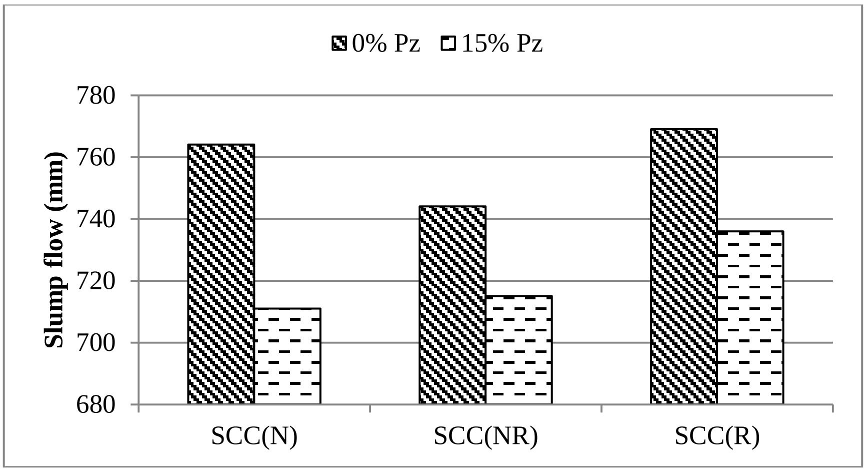

Figure 1. Slump flow test of SCC mixtures.

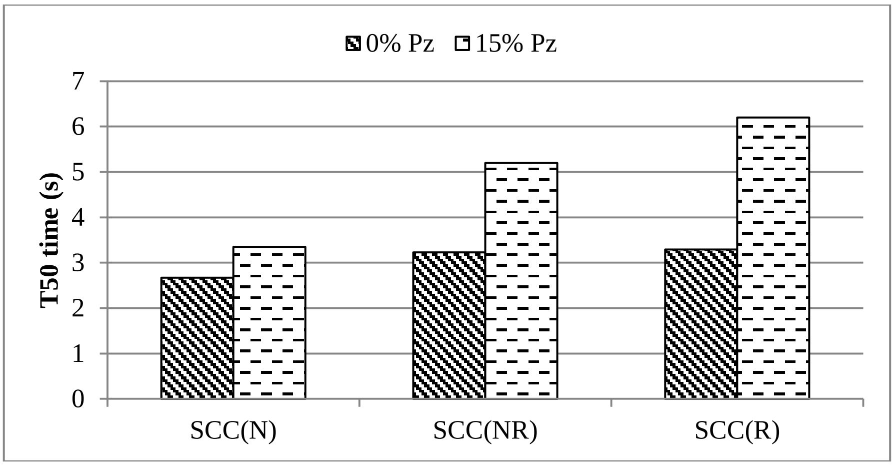

Fig 2. T_{50} flow time of SCC mixtures.

3.2. L Box test

This test gives the passing ability of concrete through reinforcement bars, its filling capacity and its deformability. Figure 3 shows the measured ratio H_2/H_1 from this test. It can be seen that the mixes made from 50 and 100% recycled concrete aggregates with and without pozzolana have better flow near the obstacles that the mix made from 100% natural aggregate with and without pozzolana.

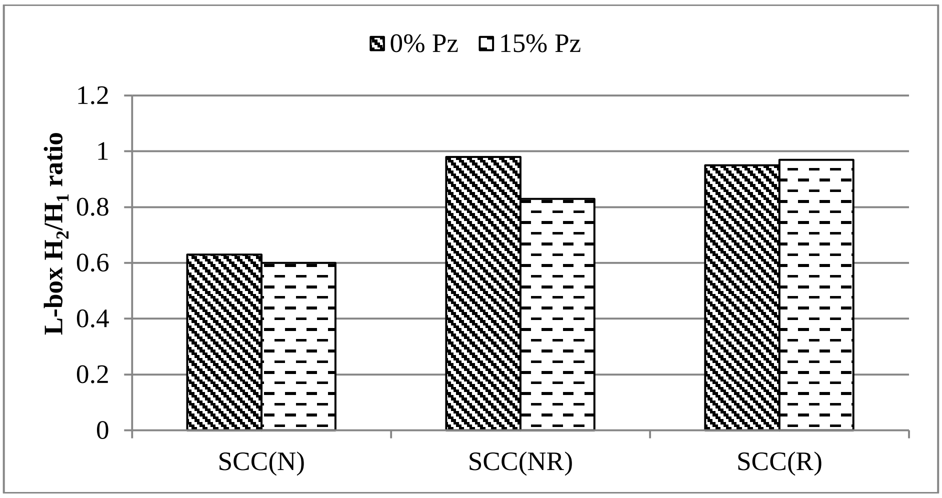

Fig 3. L-box ratio H_2/H_1 of SCC mixtures.

A very high ratio was obtained for both SCC with 50 and 100 % recycled aggregates (98 % and 95 % respectively) and no blocking was noticed. This presents an improvement of the filling and passing ability relative to the SCC with natural aggregates where the H_2/H_1 ratio did not exceed 63 %. Grdic et al. (2010) found comparable results with a ratio of 95 % and 98 % for SCC with 50 and 100 % of recycled aggregates, respectively. This high passing ability of SCC with recycled aggregates may be due to the change in size and grading of the aggregates during mixing due to breakage of the adhering mortar. Corinaldesi et al. (2002) showed that the SCC containing recycled aggregates has a satisfactory behavior in L- Box test. However, the passing ability of SCC mixtures with 15% pozzolana and 0, 50 and 100% recycled aggregates are 60%, 83% and 97%, respectively.

It should be noted that the SCC mixtures made with natural aggregates with and without natural pozzolana present a slight blocking at the steel bars. The incorporation of natural pozzolana as a partial replacement by weight of cement led to an increase in T_{20} and T_{40} as compared with mixes without pozzolana. This is due to the high porosity of cement paste resulting from the use of pozzolana which leads to increased viscosity of mixes.

3.3. V-funnel test

This test evaluates the passing ability of concrete in confined space and provides an indication of segregation. Figure 4 gives the values of the flow time of the different SCC mixtures with and without 15% pozzolana. The V-funnel flow time is comparable for the three compositions of SCC without pozzolana, without segregation. So it can be said that the viscosity of the SCC is at least considered identical. The three values of T_v are below the upper limit which is equal to 12 seconds. However, the incorporation of 15% of pozzolana increases the V-funnel flow time, for all SCC mixtures with either natural or recycled aggregates, above the limits specified by EFNARC (2002).

The higher V-funnel flow time observed is for SCC containing 15% of pozzolana and 50% of recycled aggregates indicates a higher viscosity compared to SCC prepared with natural aggregates. Increasing natural aggregates substitution from 50% to 100% decreases the V-funnel flow time by 62%. Hence, it can be concluded that the plastic viscosity of SCC mixture decreases with increasing the substitution level of natural aggregates to 100% of recycled aggregates. From these results, it can be concluded also that the natural pozzolana increases the viscosity of all SCC mixtures and this increase is more important for SCC (NR).

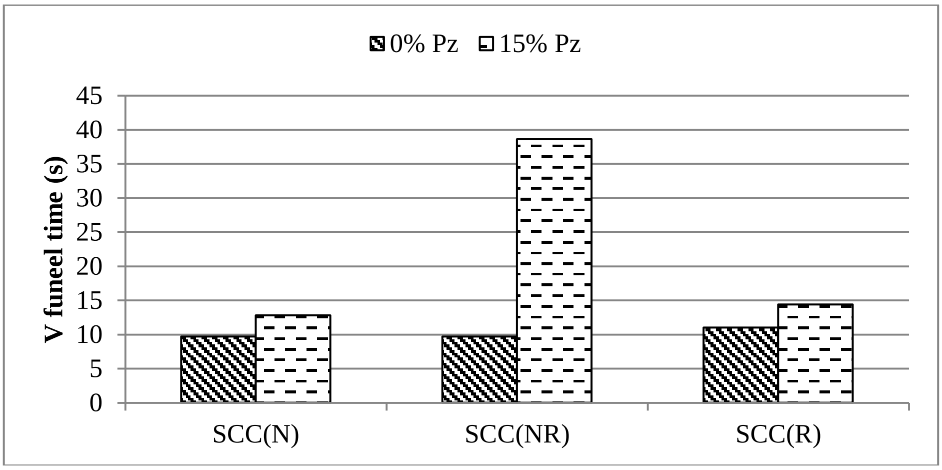

Fig 4. V-funnel time of SCC mixtures.

3.4. U Box test

Figure 5 shows the results obtained for the six SCC mixes. This test is used to measure the filling ability of SCC. In this test, the degree of compactability can be indicated by the height that the concrete reaches after passing through obstacles. The results obtained show that the SCC with 50 and 100% recycled aggregates has a less important filling rate than SCC with natural aggregates. However, a remarkable improvement was obtained for concrete with 100% recycled aggregates and 15% pozzolana where it showed excellent deformability without segregation.

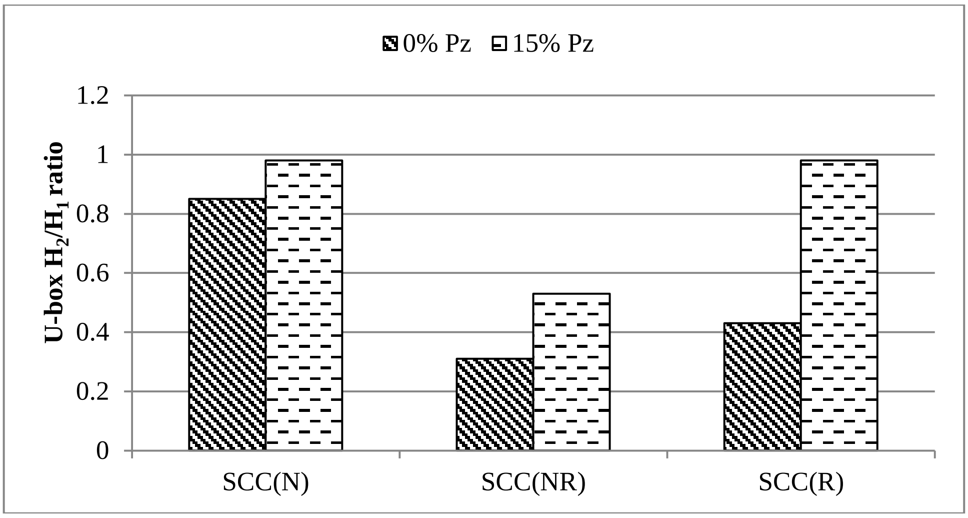

Fig 5. U-box ratio H_2/H_1 of SCC mixtures.

4. CONCLUSIONS

The analysis of experimental results presented in this paper could lead to the following conclusions:

- The total or partial substitution of natural aggregates by recycled aggregates gives SCC with comparable fresh properties and characteristics compared to those of SCC with natural aggregates.
- The effect of the natural pozzolana on both SCC with natural or recycled aggregates is similar. Substituting 15% of cement by the pozzolana causes a decrease in workability. However, the addition of pozzolana in SCC with recycled aggregates (50 and 100%) gives a more homogeneous concrete.
- The plastic viscosity of SCC mixture decreases with increasing the substitution level of natural aggregates to 100% of recycled aggregates.
- The passing ability through L-box test is better for recycled aggregates concrete than that for natural aggregates.
- Pozzolana improves water retention and gives a good homogeneity coupled with a reduction in bleeding tendency.

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