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An investigation of the recycling of waste concrete as a cementitious material

Hye-Yang Kim[a], Byung-Sik Chun[b], Tae-Hyo Park[b] and Jae-Suk Ryou[b,]*

[a]*Department of Civil & Environmental Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, South Korea*

[b]*Professor, Department of Civil & Environmental Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul, 133-791, South Korea*

The purpose of this research is to investigate the use of recycled fine aggregates from waste concrete as a new cementitious material. The main experiment focused on applying the recycled fine aggregate to Self-Consolidating Concrete (SCC) by using the characteristic which the powder contained from the Recycled Fine Aggregates (RFA) which can increase strength and flowability. That is, as the powder contained in the RFA is appropriate for developing high strength and flowability, a characteristic of the SCC, it increased the ratio of mixing the RFA obtained from waste concrete and the natural fine aggregates by 25%, making in total 5 different levels which were applied to SCC. In this paper, they are often referred to as mix 1, 2, 3, 4 and 5. Hence, the experiments were performed to examine the physical and mechanical properties of concrete which tried to verify the possibility of utilizing the RFA as a material for SCC. The results indicate that among the 5-levels of mixture of the physical and mechanical analysis, the RFA could be applied up to replacement of 50%, on the other hand, a replacement larger rather than 50% could result in a deterioration in performance.

Key words Cementitious materials, Powder, Recycled fine aggregate, Waste concrete, Strength, Flowability.

Introduction

The concept of SCC was proposed by Professor Hajime Okamura of Kochi University of Technology, Japan, in 1986 as a solution to concrete's durability concerns. Inadequate consolidation of concrete and unskilled labor were the main causes for poor durability performance of Japanese structures. The development of a concrete that self-consolidates would eliminate from the construction process the factors driving the poor durability performance of concrete [1].

SCC gives designers and contractors a solution to use concrete in special situations, such as the casting of complicated shapes of elements, heavy congestion of reinforcement, or casting of areas with difficult access. In all these cases, the use of conventional concrete compromises the durability of the structure due to poor consolidation [2].

SCC is also called a "healthy" and "silent" concrete as it does not require external or internal vibration during and after pouring to achieve proper consolidation. Mechanical vibration is a noisy and demanding task for the members of a casting team. The reduction or total elimination of this activity diminishes the environmental impact for both those who are involved in the construction process and the surrounding neighbors [3].

Recently, recycling of concrete waste is necessary from the viewpoint of environmental preservation and effective utilization of resources [1, 2, 4]. For the effective utilization of concrete waste, it is necessary to utilize recycled aggregate as concrete aggregate. In the last decade, researchers have tried to relate the quality of recycled aggregate concrete to the properties of the original concrete and paste, crushing procedure, the new mix composition, and the deteriorated condition of the old concrete; their findings have been extensively reviewed and discussed [5, 6].

From the above background, experiments were performed to examine the effect of applying recycled fine aggregate to Self-Consolidating Concrete (SCC) by using the characteristic which the powder contained from the RFA which can increase strength and flowability. Therefore, these experiment tested the property of RFA in different combinations with natural sand, and prepared 5 mixes with 0%, 25%, 50%, 75% and 100% RFA replacement. Further research might be a promising option to both save money and promote green construction.

Experiments

Materials and mix proportion

Ordinary Portland Cement (Specific gravity: 3.15, Blaine fineness: 3,200 cm^2/g, Ignition loss: 1.3%) was used in this investigation. The fine aggregate and RFA used were the aggregate mixed with river sand and crushing sand, the aggregate obtained from waste concrete, respectively. The physical properties of the fine aggregate and RFA are shown in Table 1. The coarse aggregate used was crushed stone, accounting for physical properties such as follows; G_{max}(mm) : 17, Specific gravity : 2.60, Water absorption :

*Corresponding author:
Tel : +82-2-2220-4323
Fax: +82-2-2220-4322
E-mail: jsryou@hanyang.ac.kr

Table 1. Physical properties of the fine aggregate and RFA

Items	Fine aggregate	Items	RFA
Percentage of water absorption (%)	1.26	Percentage of water absorption (%)	4.5
F.M	2.49	Absolute dry weight (g/cm^3)	2.48
Specific gravity	2.58	Percentage of absolute volume (%)	61

0.86%, Fineness modulus : 7.30. As chemical admixtures, a poly-carboxylic acid system high range water-reducing admixture and viscosity modifier were used for concrete up to 0.5 to 4.0% for binder by weight and 0.6 to 1.5% for cement by weight, respectively, and fly ash (powder, Specific gravity : 2.22, Specific surface area : 3,317 cm^2/g, SiO_2 content : 56.4%) was used for the concrete to improve the workability, to reduce the mix water and enhance the remarkably water tightness as a mineral admixture.

In order to make exact measurement, a trial mix was performed prior to the real mix with the second grade regulations of SCC by the JSCE code. The mix proportion of concrete was with a water-binder ratio of 0.35, and RFA was used to replace the fine aggregate at 25%, 50%, 75% and 100% of the fine aggregate's specific weight. The mix proportions of concrete are shown in Table 2.

Experimental methods

Slump flow test

To determine the slump flow, an Abrams cone is placed on a non-absorptive surface and filled with fresh concrete without any tamping. The cone is lifted and the concrete flows out under its own weight. Two perpendicular measurements of what appears to be the maximum diameter are taken across the spread of the concrete and the average is reported. The final flow time, from to cone removing to flow completion is recorded, as well as the T_{50} flow time, which is the time needed by the paste to spread up to 50 mm. Slump flow spread diameter values of 500 to 650 mm are considered satisfactory according to Sonebi and Bartos [7]. Khayat [4] distinguishes between regular SCC and highly viscous SCC and sets a flow value of at least 570 mm with a time of 5 and 15 seconds. It has been argued that the free and unrestrained flow in the test does not reflect the real conditions of pouring the concrete in construction practice [8]. Nevertheless, the test at least can be used to assess the consistency of concrete from batch to batch [9].

Table 2. Mixture proportions of concrete

Replacement (%)	W/B (%)	S/a (%)	Unit weight (kg/m^3)							
			W	C	Na	Re	G	FA	SP	AD
0					807	0				
25					605	202				
50	35	49	191	455	404	403	851	91	6.55	1.15
75					202	605				
100					0	807				

L-box test

The L-Box test allows measurement of the filling ability, passing ability, and resistance to segregation of SCC mixes [7]. The vertical part of the box is filled with fresh concrete and left at rest for 60 seconds to allow any internal segregation to occur. The gate is opened, and the concrete flows out into the horizontal part of the box. Normally, one or two layers of rebars are located at the opening to produce a narrower flow. The parameters measured in the L-box test are the descent of the sample head (H_d), which indicates the blocking ability of fresh concrete and the final depth of the concrete at the opposite end of the apparatus (H_2), which indicates the deforming velocity. EFNARC [9] guidelines assess the blocking ability of the mix by a blocking ratio (H2/H1), where H1 is the final concrete level at the vertical end, and H2 is the level at the far end. Skarendahl and Petterson [10] consider a blocking ratio between 0.80 and 0.85 as acceptable. The EFNARC [9] guidelines set the range of acceptance to be within 0.80 and 1.0. The plan and section drawings of the L-Box apparatus with dimensions are shown in Fig. 1.

U-flow test

The U-flow test measures the filling ability, and blocking ability of SCC. It is considered by Ouchi *et al.* [11] as the most appropriate for determining the self-consolidating abilities of a concrete mix. The U-box apparatus consists of two chambers separated by a gate and a row of vertical reinforcing bars. One of the chambers is filled with concrete and allowed to rest for one minute. When the gate is opened, the concrete flows through the rebars at the gate and upward into the other chamber. The final height of concrete in both chambers is measured. The maximum height ratio is the

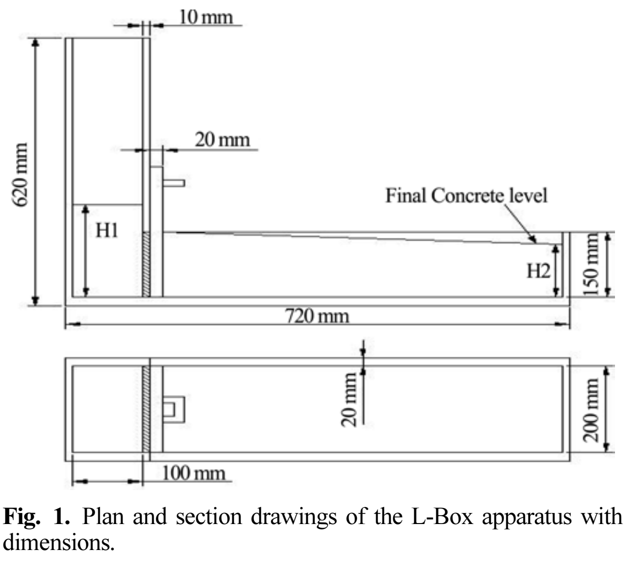

Fig. 1. Plan and section drawings of the L-Box apparatus with dimensions.

ratio of the filling height to the final height of the concrete in the first chamber (H2/H1).

Ferraris *et al*. [12] considered 70% of the maximum height as the arbitrary point for determining the acceptance of a mix design as SCC. However, other tests suggest that 60% is adequate (Bui *et al*., 2002) [13]. Saak *et al*. (2001) [14] set an empirical level of 88%. Ramage *et al*. [6] observed that SCC mixes with good stability showed 85% passing in the U-flow test. The plan and section drawings of the L-Box apparatus with dimensions are shown in Fig. 2.

Results and Discussion

Table 3 presents the slump flow according to the replacement %. As shown in Table 3, the values achieved were the results required, except for replacements of 75% and 100%, as expected at first. Mix 4, 5 was also deficient in the slump test, which showed lower slump flows than mix 1, 2 and 3.

The filling capability of the concrete, that is, accounting for the L-Box and U-Box tests is also given in Table 4. Fig. 3 and 4 present the L-Box and U-Box after filling with concrete, respectively. It appears that the L-Box and U-Box tests exhibit the required values regardless of a high replacement % of the RFA at mix 1, 2 and 3. The high level of RFA obviously inhibits workability of the mix, but mixes 2, 3, which had replacement percentages of 25% and 50% were acceptable according to the aforementioned guides. Therefore a replacement is feasible up to 50%, as far as these test concerned.

The compressive and flexural strengths were measured with time elapsed to evaluate the effects of the recycled fine aggregate on the strength characteristics of concrete mixed with RFA. Compression tests were conducted using 100 ×200 mm cylinders at 3, 7, and 28 days. Three cylinders

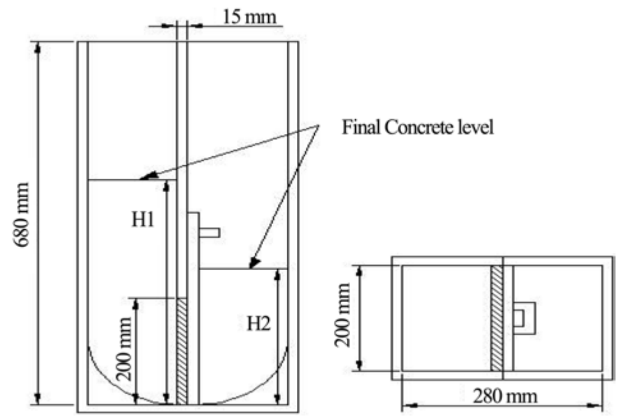

Fig. 2. Plan and section drawings of the U-Box apparatus with dimensions.

Table 3. Slump flow according to replacement %

Replacement (%)	Slump flow	
	T_{50} (sec)	D (mm)
0	9	630
25	11	610
50	14	600
75	17	560
100	24	520

Table 4. L-Box and U-Box test results according to replacement %

Replacement (%)	L-Box			U-Box		
	H_1(mm)	H_2(mm)	H_2/H_1	H_1(mm)	H_2(mm)	H_2/H_1
0	140	120	0.86	370	350	0.95
25	140	120	0.86	390	330	0.85
50	150	110	0.73	405	320	0.79
75	160	100	0.63	420	300	0.71
100	175	85	0.49	460	260	0.57

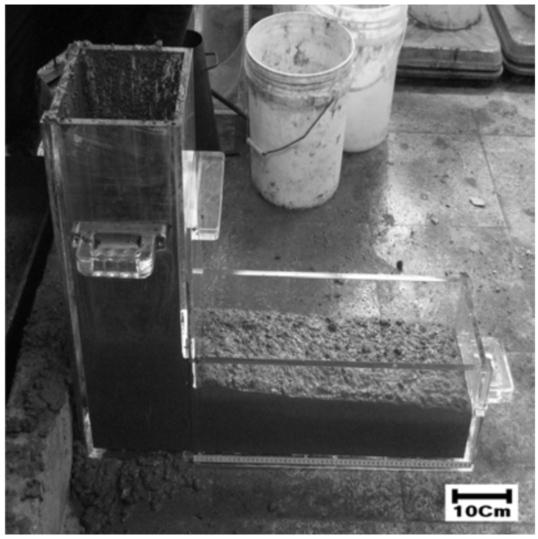

Fig. 3. L-Box Sight after filling.

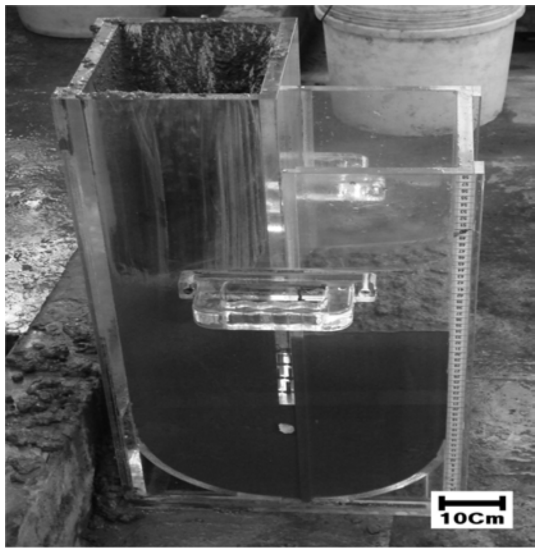

Fig. 4. U-Box Sight after filling.

were tested at each time period for every mix, and the average of these values was recorded. The corresponding results are summarized in Table 5.

The proposed W/B for all mixes was 0.35 with target strengths of 42, 45, 41, 40 and 38 MPa at 28 days, respectively. The addition of a viscosity modifier to accomplish the required slump flow decreased the strength in the mix. However, the compressive strength of the mixes was still higher than the target strength at 28 days except for mix 5. Mix 2 showed the largest value, and mix 5 showed the lowest value for compressive strength at 28 days; Mix 2 achieved 45 MPa, and Mix 5 showed a compressive strength of 38 MPa. The reason for the large increase in strength by aging the concrete using recycled fine aggregate 25% can be found in the good fineness modulus 2.8, which is filled with large and fine aggregates into the matrix concrete. It can probably take place due to the ball-bearing effect in the matrix concrete. The high level of recycled fine aggregate obviously inhibits the strength of the mix, but mixes 2-3, which had replacement percentages of 25% and 50% were acceptable in terms of the aforementioned guidelines. In addition, the flexural strength of concrete specimens 100 × 100 × 400 mm, which were fabricated following the method prescribed by KS F 2405, was determined by the method similar to the compressive strength at 3, 7, 28 and 56 days. Three specimens were tested at each time period for every mix, and the average of these values was recorded, and the corresponding results are summarized in Table 6.

The flexural strength at 28 days of concrete without the RFA reached about 6.2 MPa, which was an increase of the strength by approximately 19% compared to the flexural strength of 5.2 MPa measured at 7 days. For a replacement percentage of 25%, 50%, 75% and 100% of RFA, the flexural strength at 28 days increased by about 14%, 15%, 11% and 7% compared to the one at 7 days, respectively, and the increasing amount by aging was lower than that of a concrete using fine aggregate only. In addition, replacement percentage of 25% and 50% were acceptable in terms of the aforementioned guidelines because of the high percentages of developed strength at 28 days. Therefore a replacement is feasible up to 50%, as far as strength is concerned. However, the developed compressive and flexural strength using recycled fine aggregate as a binder decreased proportionally to the increase in the replacement percentage of RFA.

Table 5. Compressive strength according to replacement %

Replacement (%)	Compressive strength (MPa)		
	3 days	7 days	28 days
0	22	30	42
25	26	35	45
50	25	33	41
75	24	32	40
100	22	31	38

Table 6. Flexural strength according to replacement %

Replacement (%)	Flexural strength (MPa)		
	3 days	7 days	28 days
0	4.2	5.2	6.2
25	4.0	4.8	5.5
50	3.6	4.5	5.2
75	3.6	4.4	4.9
100	3.5	4.4	4.7

Conclusions

Our research shows that the workability of a mix decreases with increasing replacement due to increased percentage absorption, as well as changes to gradation. This is an area where further research could be beneficial. This paper also shows that the compressive strength was decreased significantly over a short period of time up to 100% replacement, and the best strength was achieved after 28 days for a mix with 25% replacement. The reason for the large increase in strength by aging the concrete using 25% replacement recycled fine aggregate can be found in the good fineness modulus 2.8. In the case of the flexural strength, our research shows that replacement percentage of 25% and 50% were acceptable in terms of the aforementioned guidelines because of high percentages of developed strength at 28 days, compared with the normal mix 1. In general, 75% and 100% replacements were not acceptable in terms of mechanical properties, but 25% and 50% replacements showed good results, and with further research might be a promising option to both save money and promote green construction.

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References

1. B.K. Van, D.G. Montgomery, I. Hinczak and K. Turner, “Rapid Testing Methods for Segregation Resistance and Filling Ability of Self-Compacting Concrete,” (1988).
2. Horta, Alen; Kahn Lawrence; Kurtis Kimberly; “Evaluation of Self Consolidating Concrete for Bridge Structure Applications,” (2005).
3. J. Walraven, “Self-Compacting Concrete in the Netherlands” (2002).
4. K.H. Khayat, C. Hu and H. Monty, “Stability of Self-Consolidating Concrete, Advantage, and Potential Applications,” (1999).
5. J.M. Khatib, “Properties of concrete incorporating fine recycled aggregate” Received 9 July 2003; accepted 9 June (2004).

6. B. Ramage, L. Kahn and K. Kurtis, “Evaluation of Self-Consolidating Concrete for Bridge Structure Applications: Task 1 Report,” June (2004).
7. M. Sonebi and P.J. Bartos, “Performance of Reinforced Columns Cast with Self-Compacting Concrete,” (2001).
8. P. Ramsburg, “The SCC Test: Inverted or Upright?” July (2003).
9. EFNARC, “Specification and Guidelines for Self-Compacting Concrete,” (2002).
10. A. Skarendahl and O. Petersson, Self-Compacting Concrete, (2000).
11. M. Ouchi, S. Nakamura, T. Osterberg and M. Lwin, “Applications of Self-Compacting Concrete in Japan, Europe and the United States” (2003).
12. C. Ferraris, L. Browner, C. Ozyildirim and J. Daczko, “Workability of Self-Compacting Concrete,” (2000).
13. V.K. Bui, D. Montgomery, *et al*. “Rapid Testing Method for Segregation Resistance of Self-Compacting Concrete.” Cement and Concrete Research 32[9] (2002) 1489-1496.
14. A.W. Saak, H.M. Jennings and S.P. Shah, “New Methodology for Designing Self-Compacting Concrete,” *ACI Materials Journal*, 98[6] (2001) 429-439.