Fracture Mechanics of Concrete and Concrete Structures -
High Performance, Fiber Reinforced Concrete, Special Loadings and Structural Applications- B. H. Oh, et al. (eds)

The quality properties of self consolidating concrete using lightweight aggregate

Y.J. Kim, S.J. Jeon, M.S. Choi & Y.J. Kim
Daewoo Institute of Construction Technology, Suwon, Korea

Y.W. Choi
Semyung University, Jecheon, Korea

ABSTRACT: Lightweight concrete is known for its advantage of reducing the self-weight of the structures, reducing the areas of sectional members as well as making the construction convenient. Thus the construction cost can be saved when applied to structures such as long-span bridge and high rise building. However, the lightweight concrete requires specific mix design method that is quite different from the typical concrete, since using the typical mix method would give rise the material segregation as well as lower the strength by the reduced weight of the aggregate. In order to avoid such problems, it is recommended to apply the mix design method of self-consolidating concrete for the lightweight concrete. Therefore experimental tests were performed as such mechanical properties, dry shrinkage according to ACI committee 209 and carbonation of self consolidating concrete using lightweight aggregate.

1 INTRODUCTION

With the developing civil construction technology and higher, larger and more specialized concrete constructions, the types of components are getting various and complicated so that rational construction by using new technology and new construction methods is required. According to overall construction environments, the study on structural lightweight concrete(LC) has been actively conducted to develop self-consolidating concrete(SCC) and reduce self-weight of the concrete and section considering improvement in efficiency and quality of construction.

In general, SCC has excellent flowability and segregation resistance ability in the fresh concrete, and it is the concrete to recharge the complex structures easily only with concrete self-weight without an additional compaction(Okamura &Maekawa).

Also, LC is known with its advantage of reducing the self-weight of the structures, reducing the areas of sectional members as well as making the construction convenient. thus, the construction cost can be saved when applied to structures such as long-span bridge and high rise buildings(Bentur, Kilic).

However, the LC requires specific mix design method that is quite different from conventional concrete. Using conventional mix design method would give rise the material segregation as well as lower the strength by the reduced weight of the aggregate.

Therefore, this study applied the mixing design method of SCC as one of ways to solve material separation and strength degradation. LC with the mixing design method of SCC increased viscosity in the fresh concrete to make it possible to have secure quality by preventing the material segregation and to manufacture LC with high strength over 30MPa of compressive strength.

In the study, SCC using lightweight aggregate properties have been evaluated in terms of flowability, segregation resistance and filling capacity of fresh concrete as per the standard of second class rating of JSCE. The measurement of the mechanical properties of hardened concrete, including compressive strength, splitting tensile strength, elastic mouduli and density, as well as its carbonation and dry shrinkage were also carried out.

2 EXPERIMENTAL OUTLINE

2.1 *Materials*

Cement used in the study was the ordinary portland cement(OPC) typically produced in Korea, with density of 3.15g/cm3 and blain fineness of 3,539cm2/g, while the artificial lightweight aggregate(ALA) was used with its major ingredients of rhyolite powder. Normal coarse aggregate(NC) of crushed stone with 20mm of G_{max} and the same size of lightweight coars aggregate(LC) were used.

Natural sand(NS) used was river sand. Physical properties of the aggregate are measured according to Korean industry standard(KS), as shown in Table 1. High-range water reducing of polycarbonate acid (HRWR) and air entraining agent(AEA) were used. density of HRWR and AEA are 1.10±0.02 and 1.04±0.01, the amount of HRWR and AEA are about 1.0% and 0.005% of cement weight, respectively.

Table 1. Physical properties of aggregate.

Components	NC	NS	LC	LS
Density(g/cm^3)	2.72	2.55	1.58 (1.23)*	1.86 (1.61)*
Bulk density(kg/m^3)	1,695	1,677	793	1,127
Absorption(%)	0.80	2.43	28.09	13.71
Percentage of solids(%)	62.3	62.6	50.2	60.3
Fineness moduous	6.72	2.81	6.40	2.64
Crusing value(%)	15	-	24	-

* Density under oven-dry condition

2.2 *Mix design and test method*

The lightweight aggregate used in manufacture of the concrete was made under the saturated surface dry condition while saturated surface dry condition (SSD) of lightweight aggregate was made by absorbing water fully through the pre-wetting process 24 hours before manufacturing the concrete.

Immediately after mixing of the concrete, the deformability and flowability of fresh concrete was evaluated using the following test: slump-flow(mm), time required to reach 500mm of slump flow(s), time required to flow through the V-funnel(s) and filling height of the U-box(mm). All speciment were cast without hand compacting or mechanical vibration. The compressive strength, splitting tensile, elastic moduli, carbonation of concrete were determined using 100×200mm cylinders. Also, dry shrinkage mould of concrete made using 100× 100×400mm. Table 2 is the mixture proportions of concrete

Table 2. Mixture proportions of concrete.

Mix No.	S/a (%)	W/C (%)	Unit Mass(kg/m^3) W	C	NS	NC	LS	LC
1			175	460	861	810	0	0
2			175	460	645	0	158	469
3	53	38	175	460	430	0	316	469
4			175	460	215	0	473	469
5			175	460	0	0	631	469

3 RESULTS AND DISCUSSION

3.1 *Properties of fresh concrete*

Figures 1, 2 and 3 show flowability, segregation resistance ability and filling ability of SCC that used lightweight aggregate. As the result of Figure 1, flowability satisfies the second grade JSCE, the evaluation criteria of SCC except for Mix No. 5. This result seems that if lightweight aggregate is mixed, then better flowability is secured by reducing the concrete self-weight. However, as to Mix No. 5, flowability is lowered due to powder in lightweight fine aggregate by mixing 100% lightweight coarse aggregate and 100% lightweight fine aggregate together.

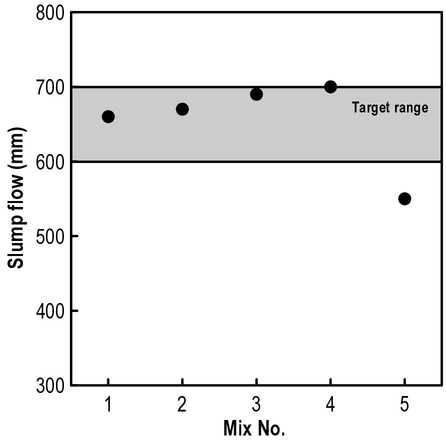

Figure 1. Slump flow results.

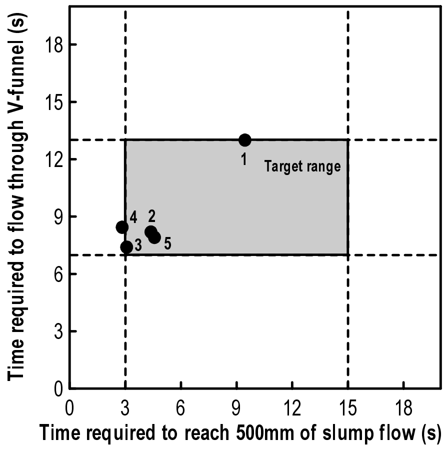

Figure 2. SCC segregation resistance ability.

Figures 2 and 3 show that segregation resistance ability and filling ability of SCC that is mixed with lightweight aggregate satisfies the second grade JSCE. This finding seems to show great result due to the reduced self-weight and the increased viscosity from powder in lightweight fine aggregate by mixing lightweight coarse aggregate and lightweight fine aggregate coincidently.

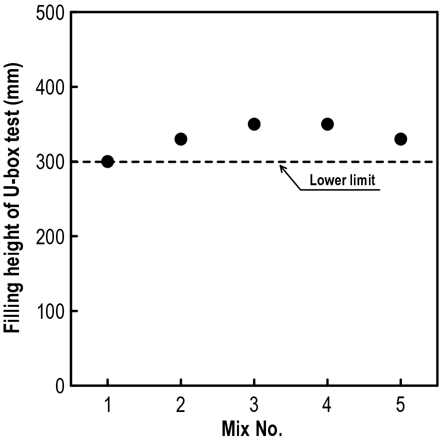

Figure 3. Filling height of U-box test.

3.2 *Mechanical properties*

Figure 4 summarized compressive strength by age. The result shows the reduction in compressive strength by the maximum 34% at the 28 days age compared to the standard concrete while compressive strength over 30MPa is measured in every mixture(Lo).

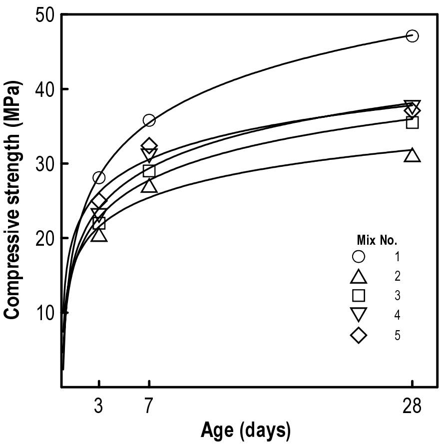

Figure 4. Compressive strength at different ages.

Figure 5 means the relations between compressive strength and splitting tensile strength in the 28 days age. The relations between compressive strength and splitting tensile strength of SCC that used lightweight aggregate show the similar inclination to the existing proposed correlations. Figure 6 shows the relation between compressive strength and elastic moduli. As the result, it is similar to the existing ACI 318 that considers density of the concrete. Figure 7 shows the measured dry density of concrete in the 28th concrete to examine the effect of self-weight of SCC with lightweight aggregate. As lightweight coarse aggregate was getting increased by 100% and lightweight fine aggregate rose by 25, 50, 75, and 100%, the maximum 25% of density was increasingly lowered.

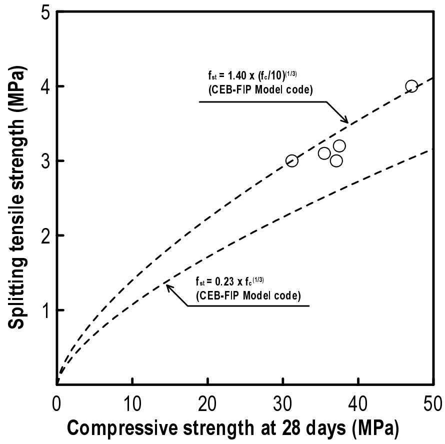

Figure 5. Relationship between compressive strength and splitting tensile strength.

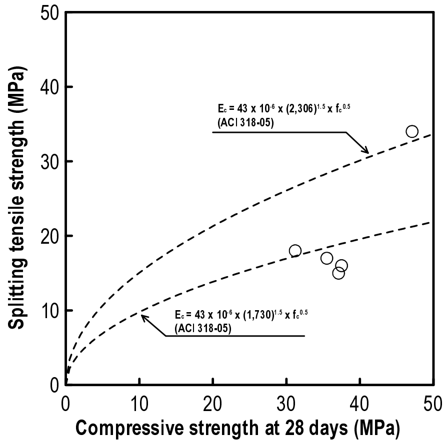

Figure 6. Relationship between compressive strength and elastic modulus.

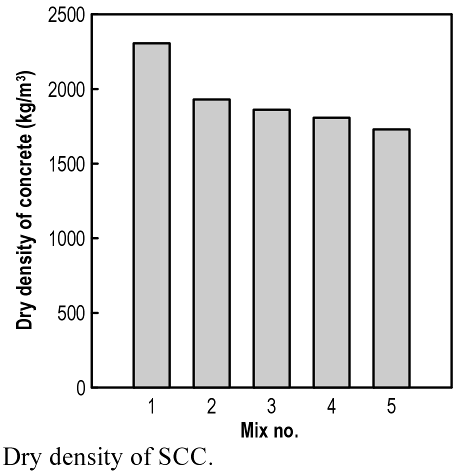

Figure 7. Dry density of SCC.

3.3 *Properties of dry shrinkage and carbonation*

The estimation of dry shrinkage rate in the long age was measured by using a equation (1) from ACI Committees 209. Figure 8 is the measurement by the 16th week age.

$$\varepsilon_{sh} = t / (a + bt) \quad (1)$$

where ε_{sh} = dry shrinkage rate; t = time(week); a and b = coefficient.

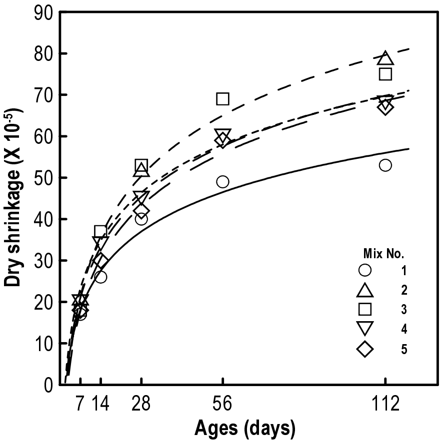

Figure 8. Dry shrinkage of SCC.

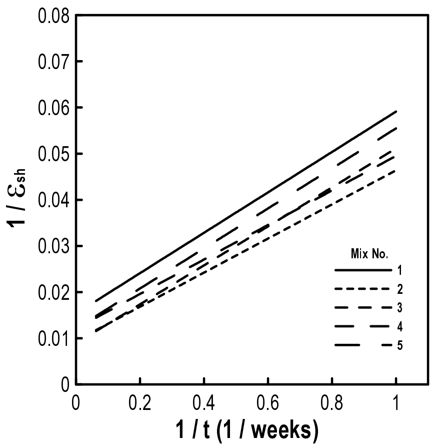

Figure 9. Relationship between 1/t and ε_{sh}.

Figure 9 is the figures by using the measurement value through the test. Table 3 shows the results measured by dry shrinkage measurement value and prediction value. The ratio of measurement value and prediction value means the ranged of 0.87-0.99.

Table 3. Results measured by dry shrinkage.

Mix No.	Measurement ($x\ 10^{-5}$, A)	Prediction ($x\ 10^{-5}$, B)	A/B
1	53	55	0.96
2	79	85	0.93
3	75	86	0.87
4	68	69	0.99
5	67	68	0.99

Table 4 means carbonation properties of concrete with lightweight aggregate. Comparing to the standard concrete, the processing carbonation had a tendency to increase by 44, 60, 76 and 110% as lightweight coarse aggregate increased by 100% and lightweight fine aggregate rose by 25%. That is because the inside of lightweight aggregate is so porous that air permeability increases and carbon dioxide enters the inside through the aggregate to increase the degree of carbonation. In general, with regards to the relations between compressive strength of the concrete and carbonation, the higher compressive of the concrete is, the slower carbonation becomes. Therefore, as to factor of carbonation, the higher incorporation level of lightweight coarse aggregate is, the lower mechanical properties of the concrete becomes.

Table 4. Carbonation properties of SCC.

Mix No.	Carbonation equation ($y = C \times t^{0.5}$)
1	$y = 0.336 \times t^{0.5}$
2	$y = 0.485 \times t^{0.5}$
3	$y = 0.537 \times t^{0.5}$
4	$y = 0.591 \times t^{0.5}$
5	$y = 0.706 \times t^{0.5}$

4 CONCLUSIONS

1) Flowability, segregation resistance ability, and filling ability of SCC that used lightweight aggregate satisfied the second grade JSCE except that lightweight coarse aggregate 100% was mixed with lightweight fine aggregate 100% at the same time.

2) Compressive strength of SCC with lightweight aggregate decreased by the maximum 34% compared to the standard concrete while there was compressive strength over 30MPa in every mixture, and splitting tensile strength and elastic moduli had a similar inclination.

3) The estimation result of dry shrinkage rate of SCC, which was mixed with lightweight aggregate by means of the equation of ACI Committe 209, showed that the ratio of measurement value and prediction value was in the range of 0.87-0.99.

4) Comparing to the standard concrete, the carbonation was faster by the maximum 110% as lightweight coarse aggregate increased by 100% and lightweight fine aggregate grew by 25%.

Through the above results of the study, the effect of self-weight of SCC that used lightweight aggregate was shown to 25%. However, the mixing ratio should be decided by considering the flowability, segregation resistance ability, and filling ability of fresh concrete as well as the mechanical properties and durability of hardened concrete.

ACKNOWLEDGEMENT

This work was sponsored and funded by the Ministry of Construction and Transportation R&D program in Korea : Super Long Span Bridge Project (2009. 5 - 2013. 3)

REFERENCES

ACI Building Code 318M-05. 2005. Building code requirements for structure concrete and commentary. ACI Committee 318.
Bentur A, Igarashi S, Kovler K. 2001. Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates. Cement and Concrete Research 31: 1587-1591.
CEB-FIP model code. 1993. CEB Bulletin information No. 213/214. Committee Euro-international Du Beton. Thomas Telford.
Japenese Society of Civil Engineering. 1998. Guide to construction of high flowing concrete. Tokoy: Gihoudou Pub.
Kilic A, Atis CD, Yasar E, Ozcan F. 2003. High-strength lightweight concrete made with scoria aggregate containing mineral admixtures. Cement and Concrete Research 33: 1595-1599.
Lo TY, Cui HZ, Li ZG. 2004. Influence of aggregate pre-wetting and fly ash on mechanical properties of lightweight concrete. Waste Management 24: 333-338.
Lo TY, Cui HZ. 2004. Effect of porous lightweight aggregate on strength of concrete. Materials Letters 58: 916-919.
Okamura H, Maekawa K, Ozawa K. 1998. High performance concrete. Tokyo: Gihoudou Pub.
Okamura H. 1999. Self-compacting high performance concrete. Tokyo: Social System Institute.