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Investigating Properties of Fresh and Hardened Self- Compacting Concrete Made of Recycled Aggregates

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Abstract

Self-compacting concrete is a new high-performance concrete with high ductility and segregation resistance. In recent years, construction material manufacturers have focused their attention on lightweight concrete and have strived to use lightweight concrete, if possible, in load-bearing parts of buildings. Concrete with both self-compacting and lightweight properties is favorable in this context which is the so-called lightweight self-compacting concrete. Because of increasing on the number of construction materials resulting from destruction of different buildings, production of self-compacting concrete with these materials is justifiable in terms of costs, environmental protection, and energy conservation. Accordingly, coordination between self-compacting factor and utilizing these materials is important. So, in this research, the effect of recycled aggregates on mechanical properties of lightweight self-compacting concrete was investigated. Specimens were analyzed using 16 mix designs by Slump, J-Ring, and compressive strength tests. Results indicated that mix designs containing recycled LECA have good consistency and stability. Also, mix designs containing recycled scoria have high strength. Hence, in order to achieve self-compacting and lightweight properties, it seems logical to use those two recycled materials.

Keywords: *Self-Compacting Concrete, Lightweight Concrete, Recycled Aggregates, Compressive Strength*

1. Introduction

Today, following the rapid development of construction industry in Iran and widespread physical and financial losses caused by natural disasters like an earthquake throughout the country, it is necessary to increase accuracy and safety in production and then in operation and implementation of engineering structures [1]. One suitable solution is that we achieve a new composition of construction materials to facilitate complex projects and increase the safety factor of their implementation through mechanization and decreasing manpower intervention. Also, it seems to be effective in reducing financial costs in expensive projects [2]. Concrete is known as one of the most widely used building materials in the world [3].

Following the increased use of concrete, properties such as durability, quality, density, and Optimization have gained particular importance [4, 5]. In turn, Lightweight concrete is a way to decrease structure weight which reduces the destructive effects of the earthquake; therefore, civil engineers are interested in lightweight concrete for its economic savings for construction [6]. Mix designs for this type of concrete are developing quickly [7]. Another type of concrete is self-compacting concrete (SCC) which is fluid and homogenous mixture and could eliminate many problems of typical concrete such as segregation, bleeding, water absorption, permeability, etc. In addition, it consolidates without an internal vibrator or vibrating formwork body only through influenced by its own weight [8]. Now, given the properties of those two specific concretes mentioned above, new concrete was recently introduced and works on it have just started. It is called self-compacting lightweight concrete (SCLC). The so-called concrete has lightweight

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and self-compacting properties which in turn has changed fundamentally concrete structures. Currently, numerous research is being conducted on this concrete, but it is still at the experimental stage and has not yet been used in practice.

In this study, the effect of recycled materials on fresh and hardened properties of self-compacting concrete was studied. For this purpose, a total of 16 mix designs were made. In all specimens, parameters of concrete such as water-cement ratio, aggregate type, and gradation, cement type, fine aggregate, and super-plasticizers were constant and the effect of increased cement content and recycled materials were studied.

2. Experimental plan

2.1. material properties

For all mixtures, type 2 cement was used. Aggregate specific gravity, fineness modulus, and water absorption percentage were 2/7, 2/67 and 2/81%, respectively (Table1). The sand used in all mixtures was graded according to ASTM C33. 1% carboxylate-based superplasticizer was applied for all mix designs. Solids content and density were 36% and 1/07, respectively. All mixtures contained cement contents of 400, 500 kg/m3 with a water-cement ratio of 0.45. Specimens were taken out of formworks after 24 hours, then, they were cured in water for 7 and 27 days. All experiments were performed according to ASTM C33.

2.1.1. Aggregate

There were two types of recycled aggregates in the mix designs. The first type was prepared by crushing and grading lightweight blocks made from LECA (lightweight expanded clay aggregate) and the second type was prepared from blocks containing scoria.

2.2. mix design

Constituent materials of self-compacting concrete are similar to ordinary concrete, however, their components are different, hence, selecting components of self- compacting concrete requires more accuracy. Typically, we need a lesser amount of coarse aggregates and higher amounts of cement and admixtures (in particular superplasticizers) to obtain self- compacting property. Coarse aggregates and water- cement ratio in ordinary concrete are higher than self-compacting concrete. Instead, the number of powder materials, paste, and sand in self-compacting concrete are higher than ordinary concrete. Mix designs were prepared at cement contents of 400, 500 kg/m3. In all designs, 1% of the super-plasticizer admixture was used. in all mixes, aggregates were as saturated with a dry surface. Recycled gravel and sand ratio in all designs was 20% and 80%, respectively. Table 2 shows the relevant mix of designs.

2-3. specimen fabrication method

In this section, mix process and proper experimental methods for evaluation of self-compacting concrete properties are discussed. specimen fabrication steps were as follows: first, aggregates and cement were mixed for nearly 15 seconds. Mix time began by adding super-plasticizer-blended and water. To shape the concrete matrix, cement and aggregates were gradually added to the admixture. Then, in order to achieve a homogenous mixture, the above materials were agitated for 300 seconds (5 min.) all mixtures were constructed for preparing cement paste and concrete in accordance with ASTM C 305 standard. After mix process ended and sufficient homogeneity was achieved, Slump-flow and J-ring tests were conducted. These tests, as suggested by EFNARC were used to measure concrete consistency.

Table 1. Physical properties of recycled aggregate

Aggregate	Water absorption	Density	Fineness modulus of sand	Max. Diameter of aggregate (m)
Scoria recycled aggregate	4.38	2.31	2.7	0.019
Leca recycled aggregate	6.89	2.05		

Table 2. Mix designs

Recycled aggregate percentage	Cement content	Design name
0	400	SH-AL
0	500	SH-BL
30	400	AL-30
40	400	AL-40
30	400	AL-50
40	500	BL-30
50	500	BL-50
0	500	SH-AS
0	400	SH-BS
30	500	AS-30
40	400	AS-40
50	400	AS-50
30	500	BS-30
40	500	BS-40
50	500	BS-50

Table 3. Fresh self-consolidating test results

Design name	Slump (m)	J-ring (m)	J-ring & slump difference (m)	7-day compressive strength (kg/cm^2)	28-day compressive strength (kg/cm^2)
SH-AS	0.65	0.63	0.02	139	216
AS-30	0.63	0.59	0.04	128	164.3
AS-40	0.58	0.50	0.08	117	150
AS-50	0.55	0.46	0.09	73	92.8
SH-BS	0.75	0.73	0.02	227	293
BS-30	0.72	0.66	0.06	220.4	284.2
BS-40	0.70	0.62	0.08	161	207.2
BS-50	0.65	0.57	0.08	117	150
SH-AL	0.55	0.53	0.02	73	95
AL-30	0.56	0.55	0.01	68.6	86.2
AL-40	0.57	0.57	0	59.8	75.2
AL-50	0.58	0.58	0	51	64.2
SH-BL	0.60	0.58	0.02	134.6	172
BL-30	0.55	0.545	0.005	128	164.3
BL-40	0.56	0.56	0	73	92.8
BL-50	0.57	0.57	0	64.2	81.8

3. Experiments results

In this research, 16 concrete mixtures were fabricated. Table 3 shows the test results for fresh and hardened concrete with different percentages of recycled aggregates.

3.1. Slump test

The slump in specimens with a cement content of 400 kg/m3 was lower than that of cement content of 500 kg/m3. As expected, as cement content increases, concrete consistency increases. On the other side, in both series, increasing the percentage of recycled aggregates substitution led to a decrease in mixture consistency. This is because aggregates being used in self-compacting concrete were rounded ones. Hence, when these aggregates are substituted by rough angular and coarse ones, mixture consistency decreases.

By analyzing consistency results of mixtures containing LECA, it was observed that the more substitution percentage of LECA instead of natural aggregates, mixture consistency increases slightly. This is because of rounded LECA aggregates being used. But, it was observed that consistency of control mixture is higher than all mixtures containing recycled aggregates which are due to the rough angular form of recycled aggregates and more water absorption of these aggregates.

Figure 1 shows a comparison of mix design consistency between LECA and scoria aggregates. It can be seen that consistency of mixtures containing LECA is higher than that of scoria. Since self-compacting concrete is high-performance concrete, hence, it is better to use LECA recycled aggregates so as to maintain the self-compaction property. However, we must consider that high strength is the basic requirement of concrete. On the other hand, efficient concrete has stability and consistency properties simultaneously. So, it is necessary to investigate the consistency and stability properties together. For this reason, results of J-ring test which represents mixture stability must be compared with slump and compressive strength results.

By comparing these two diagrams, we can see that in specimens with high cement content, consistency difference between two series of mix designs is higher. Because the high content of cement leads to increased consistency. Also, applying LECA could increase mixture consistency.

3.2. J-ring test

The purpose of J-ring test is to survey both filling and passing ability parameters of self-con

solidating concrete. In addition, using this test, we can examine segregation resistance by comparing the test results of two different parts of the specimen.

Flow unrolling difference between slump and j-ring is shown in figures 2 and 3. It can be seen in this figure that increasing cement content and recycled aggregates in specimens containing recycled LECA, leads to an increased difference between slump and J-ring. This means that the more scoria contents lead to less stability. However, this is not true for LECA.

As it can be seen, mix designs containing LECA have fair stability beside higher consistency. Stability comparison of these aggregates is shown in figure 4.

3.3. hardened properties of Self-consolidating concrete

In order to investigate the effects of type and percentage of recycled aggregates on mechanical properties of hardened specimens of lightweight self-compacting concrete, 7 and 28 days compressive strength was studied. Results showed that by increasing the percentage of both types of recycled aggregates, 7-day compressive strength decreases. As can be seen, 7-day compressive strength in specimens with a cement content of 500 is higher than those with a cement content of 400 which suggests that the more cement content, the more concrete strength. Cement content plays an extremely important role in concrete performance. The minimum cement content needed for self-consolidating concrete is 400. However, since in this research, a concrete with recycled materials is fabricated instead of rounded natural materials, so, to achieve more consistency, cement content must be increased. Therefore, when considering cement content to be 400, adequate cement paste is not available for aggregate covering. As a result, concrete strength decreases. This is because durability and strength properties are affected directly by number, type, size and percent distribution of pores in cement paste, aggregate and interface between cement content and aggregate. On the other hand, pore structure and distribution in concrete are affected by various factors one of which is cement content in the mixture. On the other hand, high contents of cement along with increased content of cement paste, which is the most important factor for porosity in concrete, cause an increase in the total mass of pores in concrete. So, cement content plays a very important role in concrete performance. By comparing figures 5 and 6, it was observed that in both cement contents, the compressive strength of specimens containing scoria is much more than that of aggregates containing waste LECA.

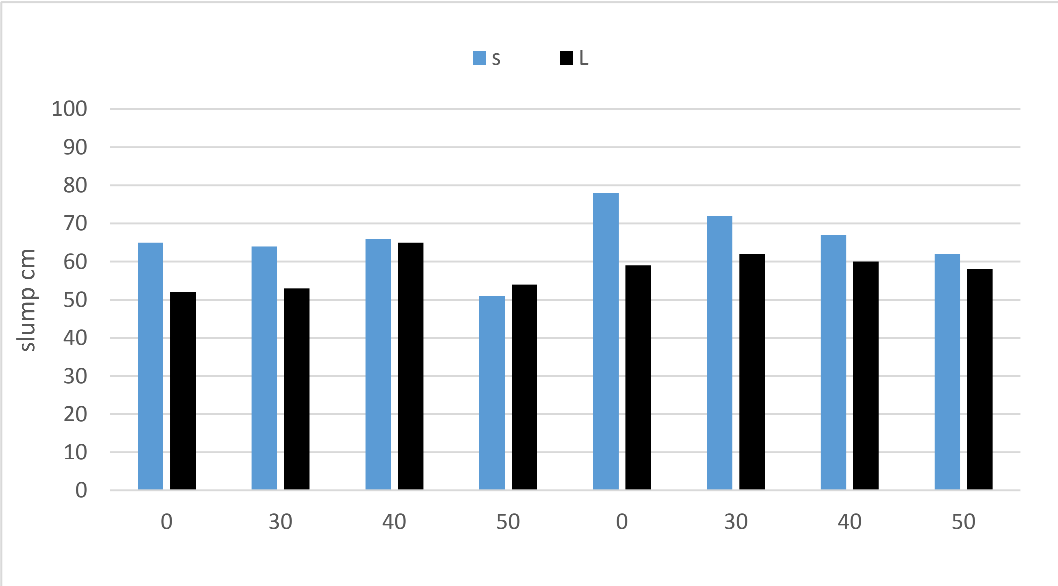

Figure 1. Slump comparison of specimens with LECA and scoria

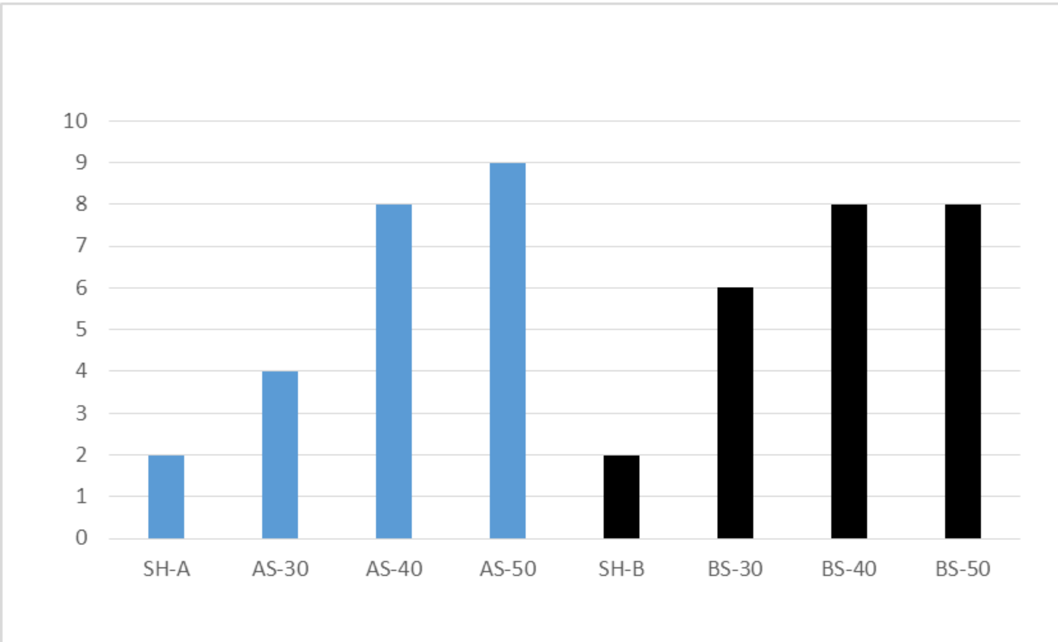

Figure 2. Difference between j-ring and slump results for mix designs with recycled scoria

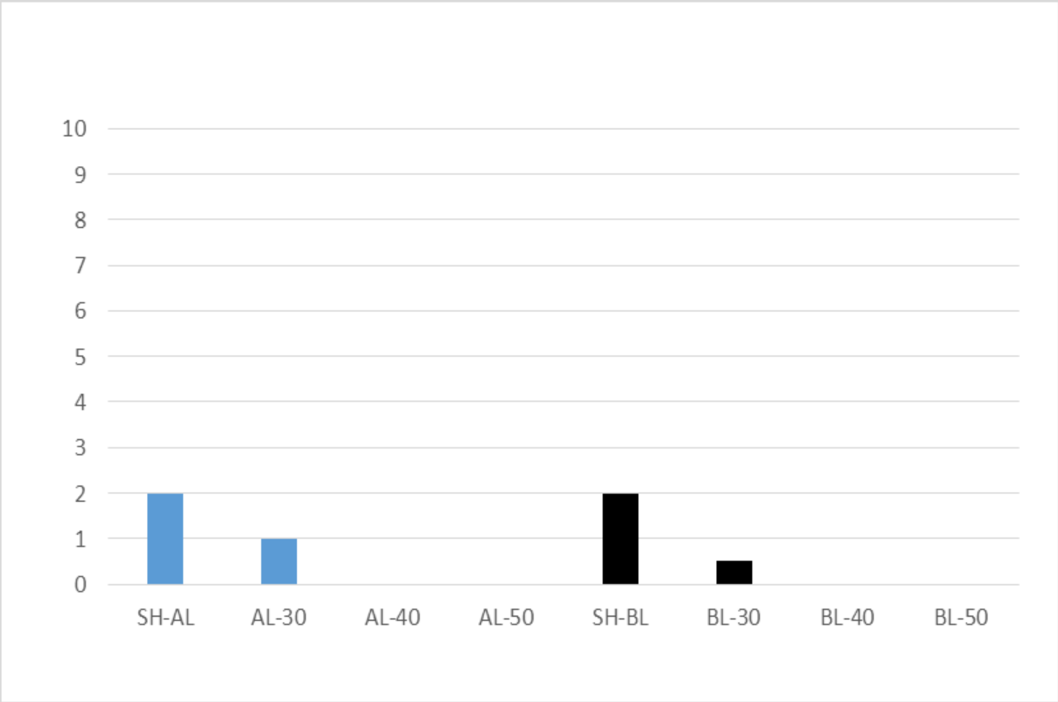

Figure 3. Difference between j-ring and slump results for mix designs with recycled LECA

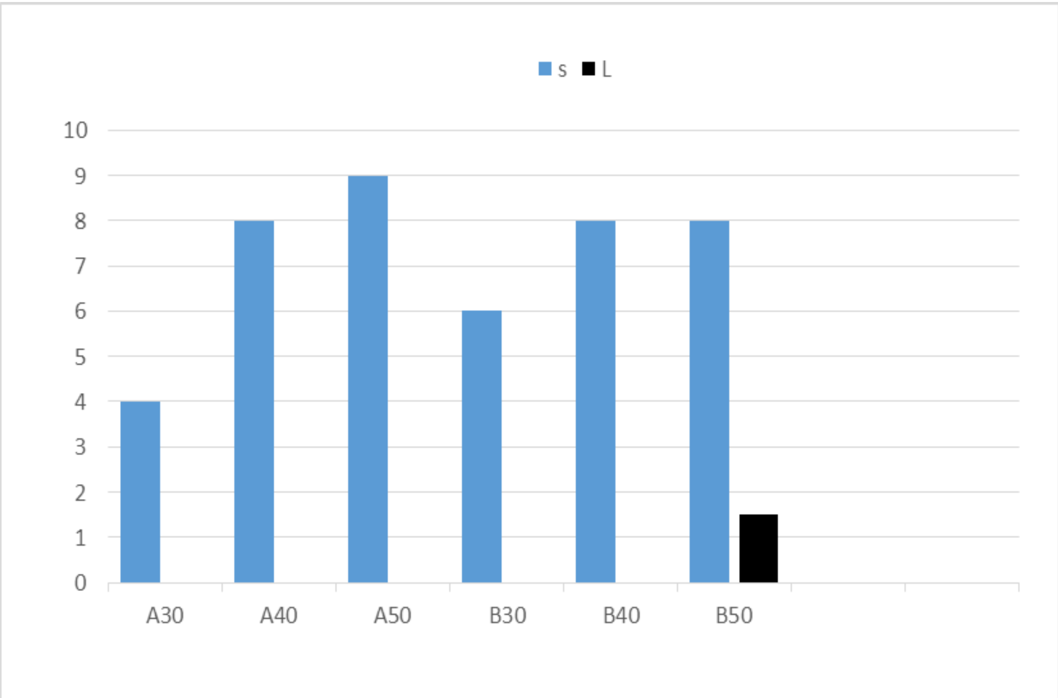

Figure 4. Stability comparison of two designs with LECA & scoria

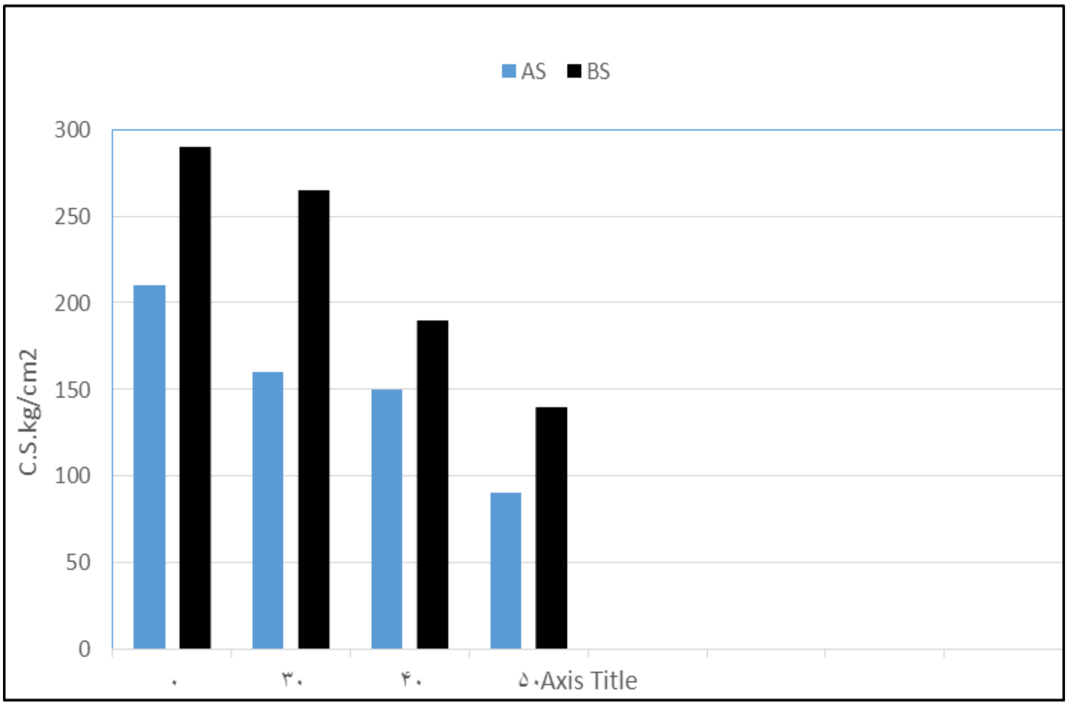

Figure 5. Results for 28-day compressive strength variation in terms of various percentage of scoria

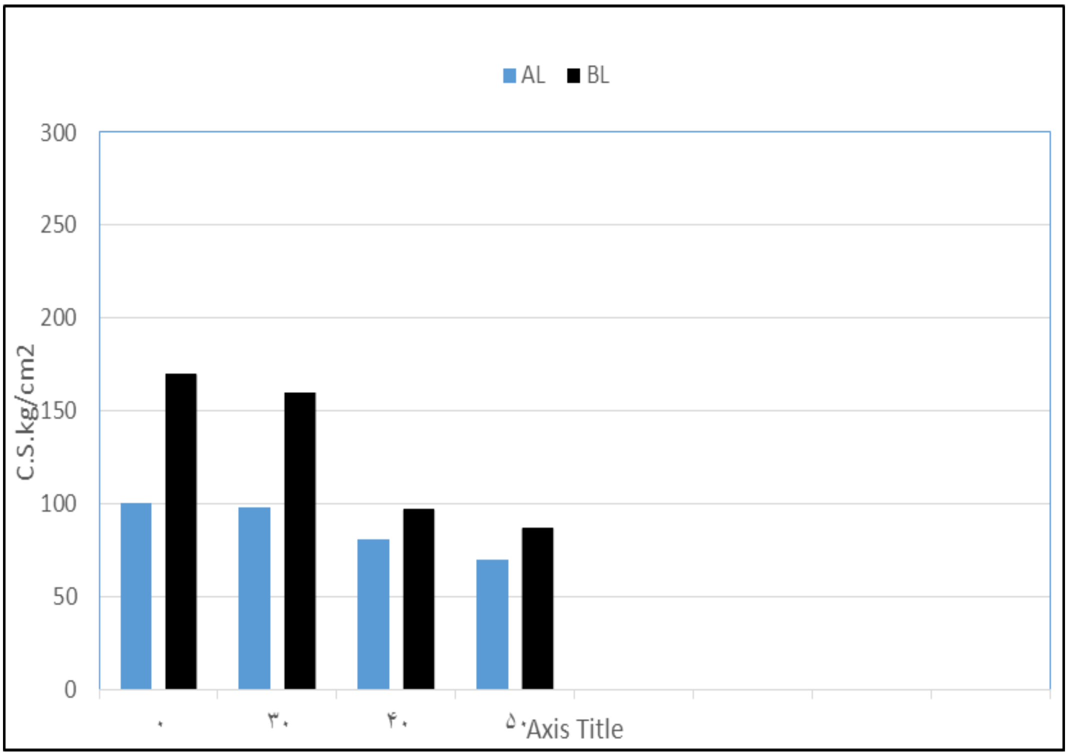

Figure 6. Results for 28-day compressive strength variation in terms of various percentage of LECA

4. Conclusions

Test results on recycled self-consolidating concrete with different percentage of aggregates show that:

1) In specimens containing scoria, increasing substitution percentage of recycled aggregates results in a decrease in mixture consistency.
2) Mix designs with LECA have higher consistency than those with scoria.
3) Increasing cement content and recycled LECA aggregates result in the increased difference between slump and j-ring results.
4) By increasing the percentage of both recycled aggregates, 7 and 28-day compressive strength decreases.
5) AL40 is the optimal design. i.e. this design contains 40% LECA and cement content of 500.
6) The combined use of both LECA and scoria aggregates leads to improved fresh and hardened self-compacting concrete.
7) 7-day compressive strength of designs with a cement content of 500 was higher than those with a cement content of 400.
8) Mix designs containing waste LECA have good stability and consistency and those with waste scoria have high strength. So, it is recommended to use a blend of both recycled LECA and scoria to achieve self-compacting and lightweight properties.

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