# POTENTIAL USE OF RECYCLED CORK AS AGGREGATES FOR LIGHTWEIGHT SELF-COMPACTING CONCRETE PRODUCTION

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***Abstract:***

*This work questions the possibility of using expanded black cork aggregates (EBCA), for the production of lightweight self-compacting concrete. Five concrete mixtures were tested: concrete made entirely with natural aggregate as a control concrete and four concrete mixtures made with cork recycled aggregate (5, 25, 50 and 75% replacement in volume of natural aggregate). The estimation of the success of the formulations was judged by studying the properties of concrete in the fresh state by the slump flow, $T_{500}$, L-box and the sieve stability tests. In the hardened state, the properties of the concrete produced have been determined by compressive and flexural strengths and bulk density tests. The experimental results showed that as the replacement level of natural aggregates by EBCA increased, the flowability of the concrete decreased. However, a good flowability was obtained for concrete mixtures containing EBCA until 50%, satisfying the recommendations of self-compacting concrete given by EFNARC 2002. The obtained results indicate the possible use of EBCA for the production of lightweight self-compacting concrete, the replacement of 50% of natural aggregates by EBCA allows obtaining a formulation which corresponds to a lightweight self-compacting concrete with a density of 1750kg/m$^3$ and a compressive strength of 8MPa.*

## 1 Introduction

In civil engineering, concrete is one of the materials widely used with massive quantities, in the latter aggregates represent on average 75% of its total volume [1]. The recycling of waste as a source of concrete aggregates has attracted increasing interests from the construction industry. While the environmental benefits of using recycled aggregates are well accepted, the concrete's performance characteristics require reassessment in relation to natural aggregate concrete. Self-compacting concrete (SCC) is a concrete which can flow under its own weight without segregating and can fill formwork as well as spread into any reinforcement without providing any mechanical vibration or compaction [2]. The incorporation of lightweight aggregates in the concrete to produce the Lightweight concrete (LWC), can reduce the density of the concrete which ranges from 300 to 2000 kg/m$^3$ [3], and therefore can result in a higher strength-to-weight ratio, enhanced thermal properties and fire resistance, and lead to a decrease in dead loads [4], [5]. In the last few decades, there have been numerous studies in the production of lightweight self-compacting concrete (LWSCC) that aim to combine the benefits of both SCC and LWC. Due to the various lightweight aggregates and their different characteristics, the fresh and hardened properties of LWSCC are depending on the type of aggregates used.

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In the literature there are many studies on the use of lightweight aggregate (LWA) in the production of SCC [6] - [8] and most of them are usually focused on the workability properties and mechanical properties of lightweight self-compacting concrete (LWSCC). Several properties of self-compacting pumice aggregate lightweight concretes were conducted in the work of Murat Kurt et al [9], pumice aggregate was used as a replacement of natural aggregate, at the levels of 0, 20, 40, 60, 80, and 100% by volume.

The concrete produced from pumice aggregates satisfies not only the strength requirement of semi structural lightweight concrete but also the flowing ability and thermal conductivity requirements of self-compacting lightweight aggregate concrete. Another work realized by Ramanjaneyulu et al. [10], chows that, the spherical shape of Pumice lightweight aggregate has significantly improved rheological properties of the fresh concrete mix. An experimental investigation to study the fresh and hardened properties of conventional and self-compacting concrete using fly ash lightweight aggregate (FALWA) as partial replacement of natural coarse aggregate was carried by Bidyadhar Basa and Jagadeep Sethi [11]. The FALWA has great influence to enhance the flow characteristics of self-compacting concrete. However, appreciable results corresponding to the strength is obtained at 30 to 50% replacement in case of conventional concrete and at 30% replacement in case of self-compacting concrete. But the great reduction in the weight of concrete with use of FALWA can serve it as a better structural material for both conventional as well as self-compacting concrete. Light expand clay aggregate (Leca) if well produced are suitable for use in SCLWC by reason of spherical shape improving rheological properties of fresh concrete mix and it can also effected on the rising of compressive strength of lightweight self-compacting concrete (SCLWC). It is possible to produce a structural self-compacting light concrete with a specific weight less than 1900 $kg/m^3$ and with compressive strength ranging from 20.8 to 28.5MPa at 28 days by the use of Leca as lightweight aggregate [12]. An experimental investigation on the effects of expanded polystyrene polymeric (EPS) beads on the properties of lightweight self-compacting concrete in fresh and hardened states was been realized by Ranjbar et al [13], when this EPS beads were partially substitute for natural aggregates. It was shown that Lightweight self-compacting concrete with density higher than $1900kg/m^3$ satisfies the fresh-state behaviors of concrete related to viscosity, cohesion and segregation, while concrete with lower density doesn't satisfies the recommendations of self-compacting concrete. Cork is a natural, organic and lightweight product with high dimensional stability.

These features allow cork to be used in a wide range of applications, such as, lightweight filler in thermal insulating solutions, aggregate for concrete, reduced weight concrete panels and also for acoustic insulation in floating floors. But cork also has other important characteristics in addition to being a natural and ecological product. It does not release noxious fumes or odours and it is a material that remains unchanged while maintaining its efficiency over long periods of time [14]. It is also a material suited for various demands of the construction sector, many studies was done on the use of cork aggregates in the mixtures of concrete [15] - [19]. In This work, expanded black cork aggregates (EBCA) are used, and their effect on the fresh and hardened properties of lightweight self-compacting concrete mixtures incorporating different EBCA content (0%, 5%, 25%, 50% and 75%) by volume of natural aggregates are studied.

## 2 Materials and methods

The cement used in this work is a CEMII/A 42.5. Marble powder has been used as an addition in mixing concrete to increase its fluidity; it is characterized by great whiteness and purity, it is a by-product that has undergone grinding to reach a specific surface similar to that of cement. The typical chemical and mineralogical compositions and some physical properties of binder materials are tabulated in Table 1.

*Table 1. Chemical and mineralogical compositions and some physical properties of binder materials*

| | Binder materials | |
|---|---|---|
| **Chemical composition (%)** | **Cement** | **Marble Powder** |
| $SiO_2$ | 18.47 | 2.08 |
| $Al_2O_3$ | 4.63 | 0.48 |
| $Fe_2O_3$ | 3.34 | 0.11 |
| CaO | 61.08 | 54.15 |
| MgO | 1.16 | 0.19 |
| $K_2O$+ $Na_2O$ | 1.11 | 0.09 |
| $SO_3$ | 2.64 | 0.01 |
| Insoluble | 2.15 | / |
| Loss of ignition | 6.69 | 42.86 |
| **Mineralogical composition (%)** | | |
| $C_3S$ | 58 | / |
| $C_2S$ | 16 | / |
| $C_3A$ | 7 | / |
| $C_4AF$ | 12 | / |
| **Physical properties** | | |
| Bulk specific density (g/cm$^3$) | 1.01 | 0.81 |
| Specific weight (g/cm$^3$) | 3.07 | 2.55 |
| Blaine fineness (cm$^2$/g) | 4465 | 4791 |
| Color | Grey | White |

*2.1 Aggregates*

- *Natural aggregates*

Natural silica with a maximum diameter of 2.5mm is used. Also a crushed coarse aggregates (3/8) mm and (8/15) mm with the same mineralogical nature were used.

- *Lightweight aggregates*

The expanded black cork aggregates (EBCA) were used as a Lightweight aggregates, it is aggregates of vegetable nature with a fraction (4/16) mm coming from the cork factory of Bejaia from Algeria. The EBCA were used as a substitution of natural coarse aggregates to produce the Lightweight self-compacting concrete (LWSCC). The main characteristics and granular size analysis of all aggregates used in this work are listed and presented in Table 2 and Figure 1, respectively. Figure 2, chows all coarse aggregates used.

*Table 2. Characteristics of aggregates*

| | Natural aggregates | | | Lightweight aggregates |
|---|---|---|---|---|
| **Characteristics** | Sand | Gravel (3/8) | Gravel (8/15) | Expanded black cork aggregates (EBCA) (4/16) |
| Bulk density (g/cm$^3$) | 1.53 | 1.41 | 1.41 | 0.054 |
| Absolute density (g/cm$^3$) | 2.62 | 2.63 | 2.64 | 0.13 |
| Water absorption (%) | 1.4 | 0.67 | 0.30 | 6.66 |
| Micro Deval (%) | / | 26.64 | 26.64 | / |
| Los Angeles (%) | / | 0.67 | 0.67 | / |
| Fineness modulus | 2.49 | / | / | / |
| Sand equivalent (%) | 80 | / | / | / |

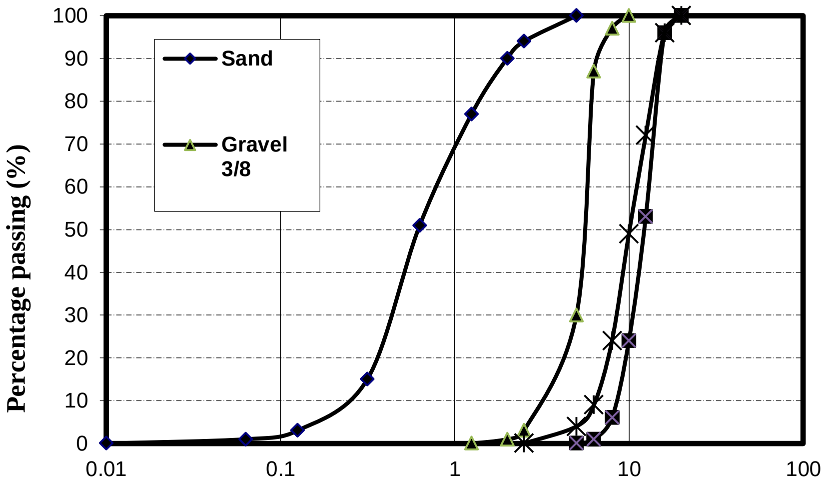


*Figure 1. Granulometric curve of all aggregates*

**Particle size (mm)**

*a) Gravel (3/8) mm* *b) Gravel (8/15) mm* *c) EBCA (4/16) mm*

*Figure 2. Coarse aggregates used*

### *2.2 Superplasticizer (SP)*

As superplasticizer a Polycarboxylic ether based high range water reducer (HRWR) Master Glenium SKY 841 with density 1.06 g/cm$^3$ and a solids content of 26% was used to enhance the flowability of the mixtures.

### *2.3 Detail of mixes and preparation*

Based on self-compacting concrete mix design Japanese method [20], all SCC mixes were produced with the water/binder (w/b) ratio of 0.39 and the cement dosage of 430 kg/m$^3$. In all of the mixtures, 10% of marble powder relative to the weight of cement was added. The mixing procedure and time are very important, thus the mixing process was kept constant for all SCC concrete mixtures. Expanded black cork aggregates (EBCA) was substituted for 0%, 5%, 25%, 50% and 75% natural coarse aggregates. Since the grain size analysis curve of EBCA (4/16) mm is close to that of gravel (8/15) mm (Figure 1), the substitution of natural coarse aggregates will be greater on this fraction in order to optimize the grain size skeleton. The percentages of coarse aggregates substitutions by volume for each mixtures are in the order of 25% for (3/8) mm, and 75% for (8/15) mm coarse aggregates. Table 3, shows the detail compositions of different concrete mixtures prepared in this study, in which the mixes were designated according to the replacement level of natural aggregates (NA) by incorporated EBCA. For example, for, the mix ‘‘SCC25” indicates concrete made with 25% EBCA. The SCCs casting procedure began by mixing all the ingredients under dry condition in the concrete mixer for one minute. It is worth mentioning that the EBCA was first mixed with natural aggregates (NA) by shaking in a dry closed container five minutes in order to attain a better possibility of mixture homogeneity, to promote uniform distribution of EBCA throughout the mix and to prevent any agglomeration which may occur during the mixing process. Then 70% of water was added and mixed thoroughly for one minute.

The remaining amount of water was mixed with the superplasticizer and was poured into the mixer. Just after mixing, unit weight test and tests on fresh concrete were carried out. After that the concrete was cast in cylindrical shaped molds (16x32) $cm^3$ and prismatic shaped molds (7x7x28) $cm^3$ and were not subjected to any compaction other than their own self weights. The prepared specimens were cured in laboratory conditions for 24h until demolding. After demolding, specimens were cured in water for 28 days at a temperature of 20±2°C. After that, test specimens were taken out of the water, wiped, and weighed. The compressive and flexural strengths were determined.

*Table 3. Details of mix proportions in kg/m³*

| Mix No | Mix description | Cement | Water | Marble powder | Sand | Gravel (3/8) | Gravel (8/15) | EBCA (4/16) | SP |
|---|---|---|---|---|---|---|---|---|---|
| ***1*** | **SCC** | | | | | 445 | 445 | 0 | |
| ***2*** | **SCC5** | | | | | 439.4 | 428.3 | 1.1 | |
| ***3*** | **SCC25** | 430 | 183 | 43 | 866 | 417.2 | 361.6 | 5.5 | 8.3 |
| ***4*** | **SCC50** | | | | | 389.4 | 278 | 11 | |
| ***5*** | **SCC75** | | | | | 361.6 | 194.5 | 16.5 | |

*2.4 Tests on fresh concrete*

The tests on fresh concrete were designed to determine how the EBCA replacement ratios affect the properties of SCC. These properties were assessed through the bulk density test as well as the tests specified under the guidelines and SCC criteria defined by the European Federation of Specialist Construction Chemicals and Concrete Systems EFNARC [21], [22] such as the flowability, viscosity, passing ability and resistance to segregation (Figure 3). The slump flow and $T_{500}$ tests were conducted using an Abrams cone, the $T_{500}$ time is a measure for the speed of flow and it therefore represents the viscosity of SCC. In this test, the fresh concrete is poured into a cone for the slump test. When the cone is pulled upwards, the time from commencing upward movement of the cone to when the concrete has flowed to a diameter of 500 mm is measured. This is named as the $T_{500}$ time. The largest diameter of flow spread of concrete and the diameter of spread in the longitudinally perpendicular dimension are then measured and the mean is taken as the slump-flow. The higher slump flow, the greater the capacity of the concrete to fill the formwork. According to Nagataki and Fujiwara [23], a slump flow diameter ranging from 500 to 700 mm is considered as the slump required for a concrete to be classified as Self- compacting concrete. More than 700 mm, the concrete might segregate, and at less than 500 mm, the concrete is considered to have insufficient flow to pass through highly congested reinforcement. It should be noted that EFNARC [21], [22] has set the allowable value for the slump test to be located at the range of 550-850 mm. However, it recommends three categories as SF1 (550-650) mm for particular purposes, SF2 (660-750) mm for typical applications such as beams, columns and walls, and SF3 (760-850) mm for places with a high density of rebar's and unique shapes.

The L-box test was used for testing the passing ability of SCC. In this test, the fresh concrete flows through tight openings between reinforcing bars without segregation or blocking. The L-box is supported on a level horizontal base and the gate between the vertical and horizontal sections is closed. The concrete from the mixer is poured into the filling hopper of the L-box. The gate is raised within 1min so that the concrete can flow into the horizontal section of the box. When movement is ceased, the depths of concrete that are immediately behind the gate (H1) and at the end of the horizontal section of the box (H2) are measured and the ratio of H2/H1 is calculated. According to EFNARC (2002), when the ratio of H2/H1 is larger than 0.8, SCC has good passing ability. The sieve stability test is carried out to characterize the static segregation of SCCs, it consists in evaluating the percentage by mass of milt of a 5kg concrete sample, passing through a sieve having 5mm openings and the sieve stability values must be in the range of 0–15%. Good flow ability and stable concrete would take a short time to flow out. According to Barr et al [24], flow times were in the range of 6–12s. According to Khayat and Guizani [25], flow times were in the range of 0-5sec. According to the EFNARC [21], [22], the $T_{500}$ slump limit is 2 to 5 seconds. EFNARC (EFNARC 2002) also divides the $T_{500}$ slump flow into two classes VS1 (T500 <2 sec) and VS2 ($T_{500}$ >2 sec). The fresh unit weight was tested according to per ASTM C 138 [26].

*(a) Bulk density* *(b) Slump flow test* *(c) L-box test* *(d) Sieve stability test*

*Figure 3. Tests on fresh concretes*

### *2.5 Tests on hardened concrete*

The Bulk density test at 28 days and the compressive and flexural strengths were determined. The test results were reported as the average of three tested specimens (Figure 4). Compressive strength has been determined at 28 days in accordance with NF EN 12390-3[27]. The specimens (16x32) cm$^3$ were loaded under a monotonic uni-axial compressive load up to failure by using a hydraulic testing machine with the capacity of 3000kN. The loading rate was approximately 0.6MP/s. Before testing, the faces of the specimen were suffered with a surfacing machine, to ensure parallelism and flatness of the faces of support. Flexural strength test was carried out at 28 days, using three-point loading method conforming to NF EN 12390-5 [28]. The bending tests were performed on (7x7x28) cm$^3$ prismatic specimens, with a loading rate of 0.05MPa/s.

*(a) Bulk density* *(b) Compressive strength test* *(c) Flexural strength test*

*Figure 4. Tests on hardened concretes*

## 3 Results and discussion

### *3.1 Fresh properties*

The results of the fresh properties tests including the bulk density, slump flow test (slump flow diameter and time taken to reach 500mm diameter $T_{500}$), L-box height ratio and sieve stability are presented in Table 3. From the observations shown in table 4, it is noted that the substitution of natural aggregates by EBCA reduces the fresh bulk density of the concrete significantly; this is due to the physical properties of the EBCA, having a very low density which is around twenty times less compared to natural aggregates. The decrease in fresh bulk density of the concrete containing 50% of EBCA is about 21% compared to the control SCC. Slump flow diameter value describes the flowability of a fresh mix in unconfined conditions. The slump flow results presented in figure 5 indicate that the slump flow diameter of control concrete containing natural aggregates and all mixtures containing 5, 25 and 50% of EBCA was 660–800 mm. It is clearly seen that the slump flow diameter decreased as the percentage of replacement natural aggregates (NA) by EBCA increased.

The control mixture and the mixture containing 5% of EBCA are within the permissible range of the SF3 class while the mixtures containing 25 and 50% of EBCA are within the permissible range of the SF2 class. We can conclude that a good flowability was obtained for these mixtures. The adding of 75% EBCA gave a concrete that doesn't satisfies the recommendations of self-compacting concrete (slump flow diameter less than 550mm, it is around 300mm. For this raison, this mixture was not tested because it did not meet the requirements for fresh self-compacting concrete. Viscosity can be assessed by the $T_{500}$ time during the slump-flow test. The values of the T500 time of LWSCCs with different percentages of replacement EBCA was shown in Table 3. $T_{500}$ ranged between 70s and 120s for all mixtures. It was observed that the addition of EBCA increases $T_{500}$ (figure 5). Additions of EBCA increase viscosity of the mixtures but all mixtures were in the allowable range, and they are placed in the VF2 class given by EFNARC [21], [22]. Ability of mixtures to flow through tight openings, such as spaces between steel reinforcing bars without segregation or blocking was measured by L-Box test. As shown in figure 6, the L-box height ratio for all mixtures was greater than 0.8. Adding EBCA to the control mixture decreases the passing ability but, as shown in Table 4, H2/H1 ratio met the EFNARC [21], [22] limitation (0.8-1) for all mixtures. The sieve stability test is used to deduce whether the concrete has satisfactory or not stability. The results of the sieve stability test used to measure ability to withstand the segregation of LWSCCs with different percentages of replacement EBCA was shown in figure 6. Sieve stability for all mixes ranged between 2.9 and 10%. Addition of EBCA improves concrete stability. The obtained values are lower than 15%, synonymous to proper stability.

*Table 4. Fresh properties test results*

| Mix No | Mix description | Slump flow diameter (mm) | $T_{500}$ (s) | L-box (%) | Sieve stability (%) | Bulk density (kg/m$^3$) |
|---|---|---|---|---|---|---|
| ***1*** | **SCC** | 800 | 70 | 100 | 10 | 2500 |
| ***2*** | **SCC5** | 800 | 76 | 100 | 7.5 | 2375 |
| ***3*** | **SCC25** | 740 | 87 | 97 | 6.6 | 2202 |
| ***4*** | **SCC50** | 660 | 120 | 97 | 2.9 | 1981 |
| ***5*** | **SCC75** | 300 | / | / | / | / |

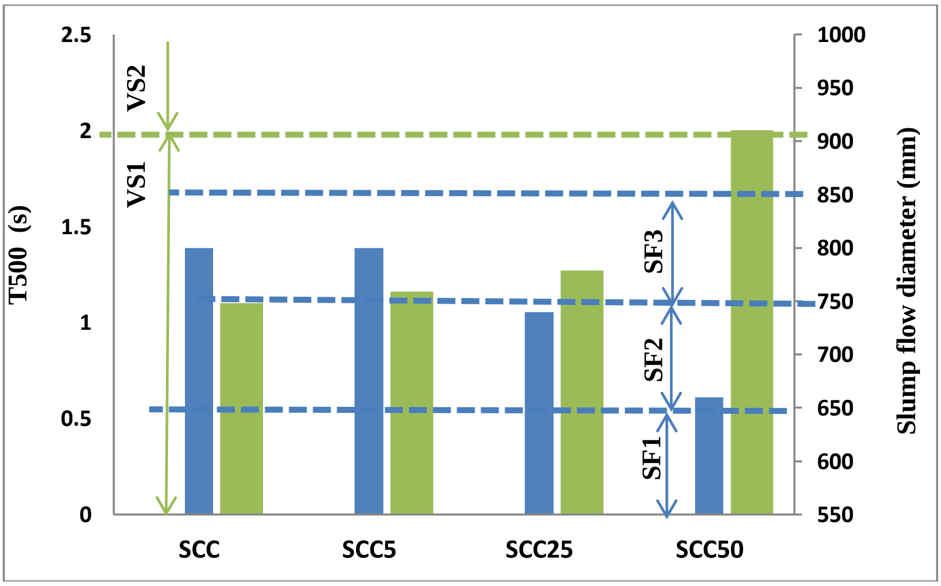


*Figure 5. Variation of slump flow diameter and T500 slump flow time of all SCCs*

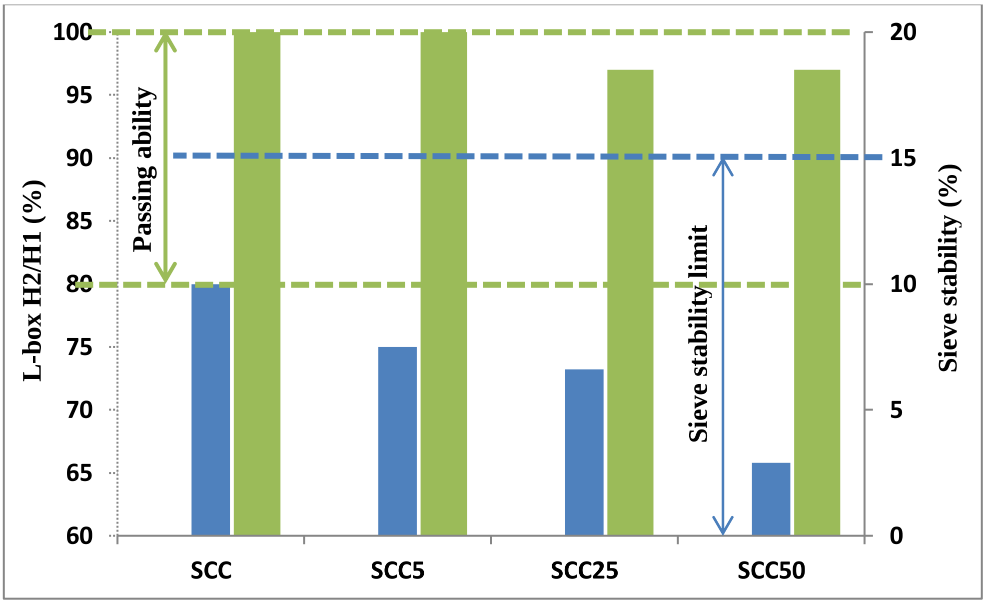


*Figure 6. Variation of L-box height ratio values and sieve ability of all SCCs*

### *3.2 Hardened concrete properties*

The test results of bulk density, compressive and flexural strengths at 28 days; were given in table 5. From obtained results presented in figures 7 and 8, it was observed that adding of EBCA aggregate, as substitute part of natural aggregates led to a decrease the compressive and flexural strengths of LWSCCs. The reduction values of the compressive strength ratios of all mixtures containing EBCA, in comparison with its value for the control specimen containing natural aggregates at 28 days, are 11.1%, 26.01% and 77.7% for the SCC5, SCC25 and SCC50 specimens, respectively. However, the reduction values of the flexural strength ratios are 14.28%, 21.42 and 42.85% for the SCC5, SCC25 and SCC50 specimens, respectively. The mixture containing 50% of EBCA (SCC50) was considered as not structural lightweight self-compacting concrete, since their 28-day compressive strength value was lower than 17MPa (ACI 213R-14. [29]).
The decrease of compressive and flexural strengths is explained by:

- The very low hardness, friability and resistance of EBCA in comparison with natural aggregates;
- The incorrect rupture mode of specimens containing EBCA (see Figure 9);
- The poor distribution of EBCA in the matrix which tends to raise to the surface during the preparation of the test specimens (see Figure 10).

In order to classify the concretes produced as lightweight, the Bulk density test at 28day was performed, the values of which are shown in Figure 11. From the presented values it can be observed that the bulk density of SCC decreased as the percentage replacement of EBCA aggregates increased. The mix containing 50% EBCA have the least value of bulk density. The Bulk density is reduced to a maximum of 26.16% for 50% replacement of natural aggregates (NA) by EBCA, this occurs due to the low density of EBCA in comparison with NA. However, the mixture containing 50% of EBCA (SCC50) can be classified as lightweight self-compacting concrete, since, according to ACI 213R-14 [29], the bulk density value must be equal to or less than 1850 kg/m$^3$.

The increasing of bulk density of concrete by increasing the lightweight aggregate ratio was found by several authors, in the work of Murat Kurt et al [30], the bulk density of concrete significantly decreased with the increasing pumice lightweight aggregate ratio. Since, bulk density of all mixtures except for mixtures containing normal aggregate 100% and 80% are lower than 1840 kg/m$^3$. The lightweight concrete produced by crushed red brick aggregate reduced the weight of the normal concrete by 26%. The density of the crushed red brick concrete at 28 days was found to be 1771.26 kg/m$^3$, which agree with the range of the lightweight concrete standard, Eltayeb A/Ellatif Ahmed Habib et al [31]. Demirboğa et al [32], indicated that depending on the production method of lightweight concretes and type of aggregate, the bulk density of lightweight concretes may vary between 1360 and 1840 kg/m$^3$ for structural lightweight concretes and 320–1120 kg/m$^3$ for heat insulating concretes.

*Table 5. Hardened properties test results*

| Mix No | Mix description | Flexural strength (MPa) | Compressive strength (MPa) | Bulk density (kg/m$^3$) |
|---|---|---|---|---|
| ***1*** | **SCC** | 7 | 36 | 2370 |
| ***2*** | **SCC5** | 6 | 32 | 2300 |
| ***3*** | **SCC25** | 5.5 | 19 | 2100 |
| ***4*** | **SCC50** | 4 | 8 | 1750 |

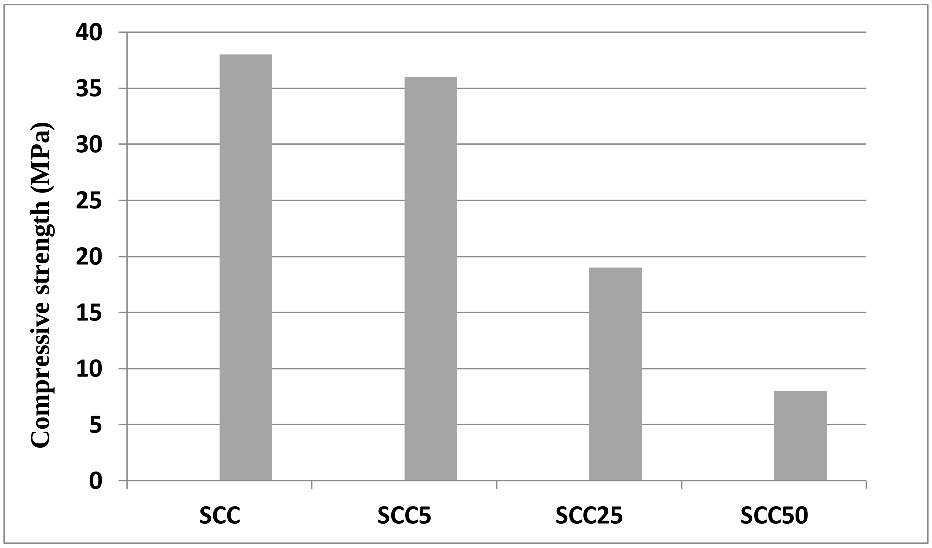


*Figure 7. Variation of compressive strengths of all SCCs*

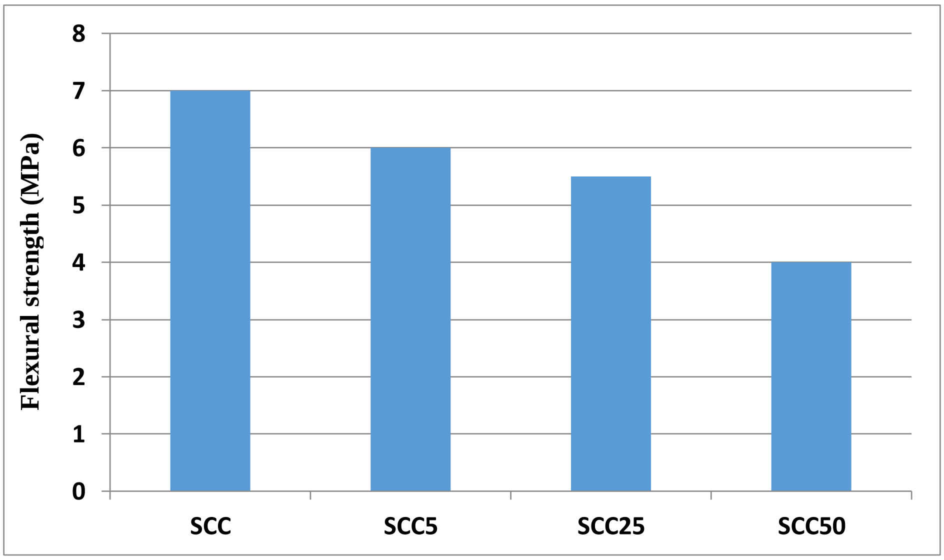


*Figure 8. Variation of flexural strengths of all SCCs*

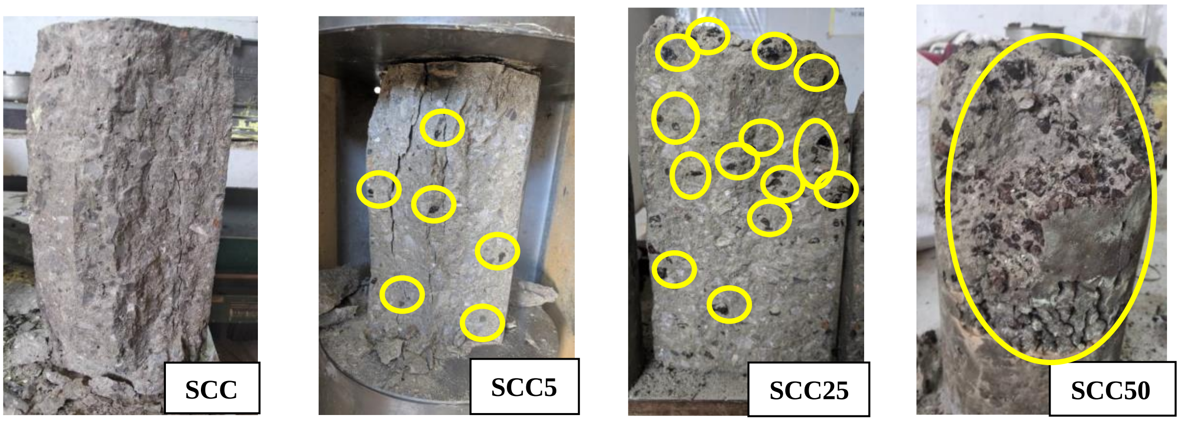


*Figure 9. Failure mode of all self-compacting concretes specimens*

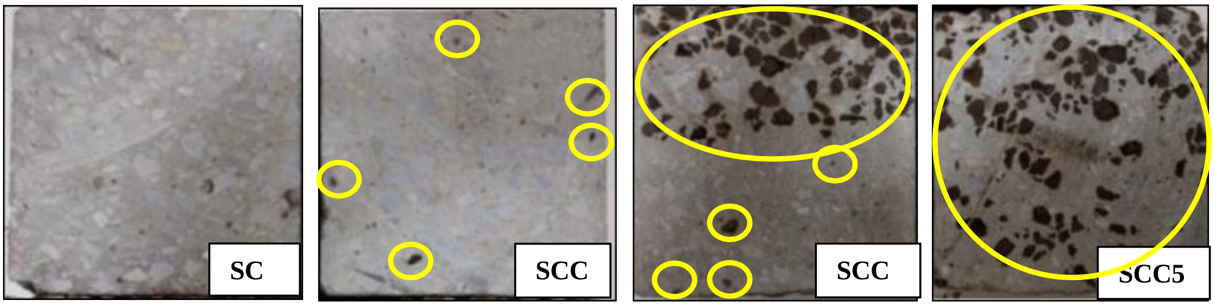


*Figure 10. Breaking Facets of all self-compacting concretes specimens*

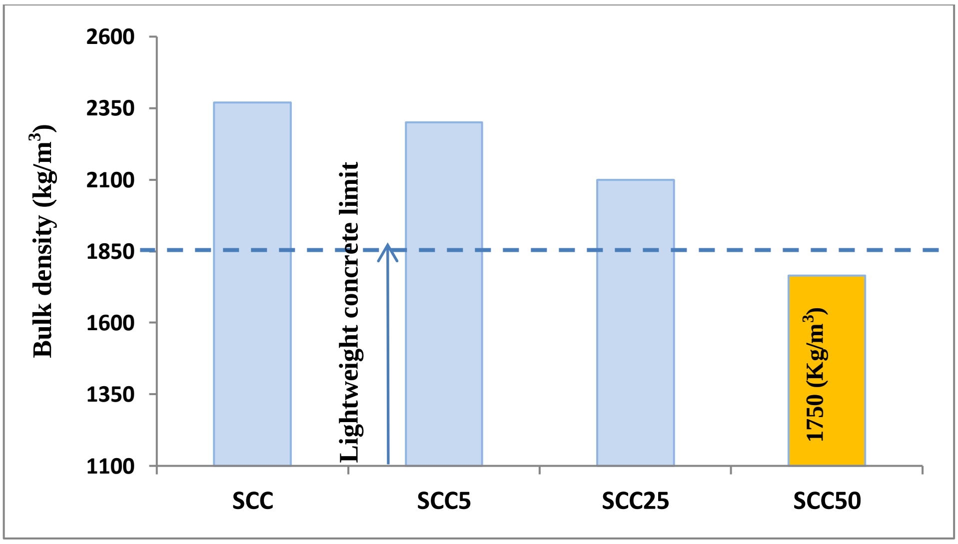


*Figure 11. Bulk density evolution of all SCCs*

## 4 Conclusion

The experimental investigation to assess the fresh and hardened properties of self-compacting concrete with partial replacement of natural aggregates with expanded black cork aggregates (EBCA) was carried out.

From the fresh and hardened concrete test results the following conclusions can be drawn:

-The substitution of natural aggregates by expanded black cork aggregates (EBCA) reduces the fresh unit weight of the concrete significantly,

-The increase in the rate substitution of natural aggregates by expanded black cork aggregates reduces the fluidity of the concrete. The control and the mixtures concretes containing (EBCA) until 50%, verifies the fresh properties of self-compacting concrete.

-Additions of expanded black cork aggregate (EBCA) increase viscosity of the mixtures but all of the mixtures were in the allowable range, and they are placed in the VF2 class given by EFNARC (2002, 2005).

-Adding expanded black cork aggregate (EBCA) to the control mixture decrease the passing ability but, the L-box height ratio for all mixtures was greater than 0.8.

-Addition of expanded black cork aggregate (EBCA) until 50% dos not affect the concrete stability, sieve stability for all mixes ranged between 2.9 and 10%. The obtained values are lower than 15%, synonymous to proper stability. However the homogeneity of the concrete decrease with the presence of cork aggregates.

-The adding of 75% EBCA decrease significantly the flowability of concrete, this concrete mixture does not meet the requirements for fresh self compacting concrete.

-Adding of expanded black cork aggregate (EBCA) aggregate, as substitute part of natural aggregates led to a decrease the compressive and flexural strengths and the bulk density of SCC. However, the mixture containing 50% of EBCA (SCC50) it can be classified as lightweight self-compacting concrete in terms of unit weight and not structural in term of strength properties, since their 28-day compressive strength and bulk density values, were 8MPa and 1750kg/m$^3$ respectively.

Finally, we concluded that expanded black cork aggregates (EBCA), can be used as partial replacement of natural aggregates for the production of lightweight self-compacting concrete.

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