A STUDY ON THE PERFORMANCE OF LIGHTWEIGHT SELF-CONSOLIDATED CONCRETE

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ABSTRACT

This paper presents a study on the fresh and hardened characteristics of lightweight aggregate concrete incorporating self-consolidated agent (LWSCC). Self-consolidated agent (a polycarboxylic-based superplasticizer in combination with a viscosity modifying admixture) and local-produced lightweight aggregate (LWA) produced from expanded clay type were utilized. Various LWSCC mixes made with different mix proportions, namely dosage of self-consolidated agent, water/cement ratio, LWA/Sand ratio and normal weight aggregate as a partial replacement of LWA, were prepared. The initial slump flow, rate of slump flow loss and air content were then performed to assess the fresh properties of LWSCC. Twenty-eight day compressive strength, ultrasonic pulse velocity, porosity and density were determined for investigating the hardened properties of LWSCC. The results reveal that, by using local-produced materials, it is possible to manufacture a structural lightweight aggregate concrete with low density and high self-consolidating characteristics (flowability, deformability and stability). Both fresh and hardened characteristics of LWSCC are mainly controlled by dosage of self-consolidated agent (SCA), where the flowability, self-compactability, strength, homogeneity and porosity of LWSCC can be enhanced with increasing SCA content up to certain dosage of SCA (≈0.80), at which all these characteristics would start to decline with increasing SCA content. However, LWSCC losses its fresh parameters rapidly with increasing the dosage of SCA and lightweight aggregate/sand ratio. The results also showed that the compressive strength, homogeneity and porosity of LWSCC could be significantly improved with reducing the ratio of w/c and LWA/Sand ratio, and utilizing normal weight aggregate in LWSCC mixes.

Keywords: Self-consolidated, Aggregate, Lightweight concrete, Admixtures.

INTRODUCTION

Lightweight aggregate concrete (LWAC) with closed structure has been used successfully for structural purposes since the late nineteenth century. The density of structural LWAC typically ranges from 1400 to 2000 kg/m^3 [1-2]. Lightweight aggregate concrete has obvious advantages of a higher strength/weight ratio, better strain capacity, lower coefficient of thermal expansion, and superior heat and sound insulation characteristics due to air voids existed in lightweight aggregate (LWA) [1-3]. Furthermore, Topcu [3] reported that the reduction in the dead weight of a building by the use of lightweight concrete could lead to a considerable decrease in the cross section of steel reinforced columns, beams, plates and foundation. It is also possible to reduce steel reinforcement and increase cost savings. LWAC may be produced by using either natural lightweight aggregates such as pumice, scoria, volcanic cinders, tuff and diatomite, or by using artificial lightweight aggregates, which can be produced by heating clay, shale, slate, diatomaceous shale, perlite, obsidian, and vermiculite. Industrial cinders and blast-furnace slag that has been specially cooled can also be used [1-4].

Despite of the above-mentioned advantageous and the increase demand of LWAC worldwide, there are still many difficulties facing such type of industry, which requires more efforts to be tackled out. These difficulties mainly include segregation of coarse aggregate and compressive strength are not as great as ordinary concrete [5-6]. In practice, as lightweight aggregates often have lower particle densities than the density of the mortar matrix in concrete, upward segregation of the coarse aggregates may be sometimes experienced when the workability of the fresh concrete is not appropriate. This is in contrast to normal-weight aggregate concrete, in which coarse aggregate may sink to the bottom if the workability is not appropriate.

Chia and Zhang [5] studied the effect of a superplasticizer on the rheological behavior of fresh lightweight aggregate concrete and the stability of the concrete under vibration. Their results indicated that an increase in superplasticizer content in the concrete reduced the yield stress, but did not have a significant effect on the plastic viscosity. They also showed that the segregation resistance of LWAC was decreased with increasing the dosage of superplasticizer in LWAC mixes. Therefore, incorporating of water-reducing/high-range water reducing admixtures in such type of concrete (LWAC) requires a great attention, to attain all beneficial effects out of using these admixtures. Otherwise, an excessive segregation to concrete ingredients might take place.

One of the most advanced generations of water-reducing admixtures is self-consolidating admixture, also known as a self-compacting admixture. Admixing this type of admixture with viscosity modifying agent, occasionally, in concrete mixes could lead to producing a special concrete with high-fluidity, self-compactability and minimum water dilution and segregation, which nowadays known as self-compacting concrete or self-consolidating concrete (SCC) [6,7,8]. The Japanese developed this type of concrete in the early 1990s and it is now widely used in congested and non-congested members, complex formwork, deep sections and restricted areas [9-10].

RESEARCH SIGNIFICANCES

The approach of manufacturing of SCC was recently modified and developed to produce SCC with high performance and strength characteristics [11-12-13]. However, all previous efforts and attempts in the field of SCC were concerned and dealt with normal-weight aggregate concrete, and there is a lack of knowledge regarding the utilization of such innovative generation of self-compacting admixture in the field of manufacturing LWAC.

Generally, there is a great interest and tendency between researchers and concrete technologists to develop concretes with combining multi unique characteristics, which would not be attained in traditional normal-weight concrete. Therefore, an attempt was carried out herein to develop a concrete owing the main advantages of both LWAC and SCC together, called lightweight self-consolidated concrete (LWSCC). Local-produced materials will be adopted. This development aims to enhance the self-compactability and the other various fresh and hardened characteristics of LWAC, and to reduce the possibility of occurrence of segregation/floating of coarse LWA.

Consequently, an extensive experimental program was designated and conducted to achieve the following objectives:

1- To develop a lightweight aggregate self-compacting concrete (LWSCC) from local-produced materials (light expanded clay aggregate, LECA).
2- To assess the effect of self-consolidated agent content and the ratios of water/cement and lightweight aggregate/sand on fresh parameters, compressive strength, homogeneity, porosity and density of LWSCC. The assessed fresh parameters of LWSCC include flowability, deformability, self-compactability and rate of loss in fluidity.
3- To investigate the possibility of using normal weight aggregate as a partial replacement of LWA for improving the various fresh and hardened characteristics of LWSCC.

EXPERIMENTAL

Materials and Mix Proportions

Local ordinary Portland cement (OPC) complying with BS 12 (1978), ESS 373 (1991) and ASTM C618 (1992) was used. The chemical analysis of OPC is summarized in Table 1. Well-graded crushed limestone aggregate of maximum nominal size of 15 mm and washed natural desert sand were selected in accordance with ASTM C33 and ESS 1109/1971, used as a source of normal-weight aggregate. The coarse lightweight aggregate used in this study was locally produced from expanded clay type (LECA). The maximum nominal size of LECA was 15 mm. The sieve analysis of LECA is given in Table 2. The physical properties of the used coarse aggregate (normal weight and lightweight) and sand are presented in Table 3. In this study, the dry LECA was pre-soaked in water for 48 hours before mixing in concrete until steady weight of LECA was achieved, to ensure that all voids inside LECA particles are fully filled with water.

Table 1: Chemical analysis of OPC.

Oxide,	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**SO_3**	**L.O.I.**
%	22.4	4.85	3.9	61.7	2.23	0.43	0.24	2.48	1.70

Table 2: Sieve analysis of lightweight aggregate (LECA).

Size, mm	14.0	10.0	5.0	3.35	2.0	pan
Passing, %	95.6	80.9	20.1	6.8	0.40	0.00

Table 3: Physical properties of coarse aggregate and sand.

	24-hour water absorption, %	**Specific gravity**	**Fineness modulus**	**Unit weight, kg/m^3**
Normal weight coarse aggregate (NWA)	0.98	2.60	-	1571
Lightweight coarse aggregate (LECA)	20.07	1.08	-	667
Sand	0.67	2.65	2.55	1585

A self-consolidated agent was utilized for producing the lightweight self-consolidated concrete mixes. The used self-consolidated agent (SCA) contains a polycarboxylic-based copolymer-based mixture and modified cellulose product to achieve the dual action effect of high-range water reducer and viscosity-modifying admixture, respectively. SCA was in a turbid liquid with a specific gravity of 1.11, and conforms to the requirements of ASTM-C-494 Types G and F.

Sixteen mixes of lightweight aggregate concrete (LWAC) and lightweight aggregate concrete incorporating self-consolidated agents (LWSCC) were prepared using the specific gravity factor method, as described elsewhere [4-5]. Various mix proportions such as water/cement ratio, dosage of self-consolidated agents (SCA), LWA/sand ratio, and contents of normal weight aggregate (% by weight of LECA) were regarded. The mix proportions of mixes considered in this program of study are shown in Table 4.

All aggregate types used in this study were weighed on a saturated-surface-dry (SSD) basis, to achieve good moisture control in the concrete mixes. The constituent materials were mixed in a pan mixer with a capacity of 0.08 m^3 and a mixing speed of 50 rev/min at ambient temperatures of about 22±2ºC. The self-consolidated agent was separately added into the concrete after about one minute of mixing. Mixing was continued for another two minutes before the mixture was left at rest for approximately 3 minutes.

Table 4: Mix proportions of LWAC and LWSCC

Mix Code	OPC content, Kg/m^3	w/b ratio	SCA, % by weight of OPC	LWA/sand ratio	Normal-weight aggregate, % by weight of LWA
LWAC	450	0.30	-	1.50	-
LWSCC1	450	0.30	0.40	1.50	-
LWSCC2	450	0.30	0.50	1.50	-
LWSCC3	450	0.30	0.60	1.50	-
LWSCC4	450	0.30	0.80	1.50	-
LWSCC5	450	0.30	0.90	1.50	-
LWSCC6	450	0.30	1.00	1.50	-
LWSCC7	450	0.30	1.20	1.50	-
LWSCC8	450	0.35	0.80	1.50	-
LWSCC9	450	0.25	0.80	1.50	-
LWSCC10	450	0.30	0.80	2.00	-
LWSCC11	450	0.30	0.80	1.00	-
LWSCC12	450	0.30	0.80	1.50	35
LWSCC13	450	0.30	0.80	1.50	50
LWSCC14	450	0.30	0.80	1.50	65
LWSCC15	450	0.30	0.80	1.50	100

Test methods

Immediately after mixing process, slump flow, and air content tests were performed. The slump flow test was carried out as described earlier in literature [9-12-14]. The diameter of flow measured with slump flow approach for LWSCC mixes was determined at different elapsed times from the end of mixing process, 0, 30, 60, 120 and 240 minutes, to assess the initial flowability and rate of slump flow loss of LWSCC. The air content of LWSCC was determined with according to the method B described in BS 1881: part 106: 1983 and ASTM- C 173. The analysis of air content of concrete was considered in this study to provide an indicative approach for measuring the degree of compactability of concrete. Immediately after mixing, five cubical concrete specimens (150x150x150 mm) made from each considered mix were prepared for measuring the hardened properties of LWAC and LWSCC. The specimens were stored in water curing tanks at 22±2°C until age of testing.

At the age of 28 days, the homogeneity of tested specimens was determined using ultra-sonic pulse velocity (UPV). The porosity of the concretes was also calculated based on the volume of the voids occupied by the absorbed water, as described earlier in literature [4]. This was followed by determining the compressive strength by crushing the five 150-mm cubes considered for each case of study, according to BS 1881: Part 116: 1983 and BS 1881: Part 121: 1883. An average of five measurement values was then obtained. Prior to compressive strength test, the cubes were used to test the SSD density by following BS 1881: Part 114: 1983.

RESULTS AND DISCUSSION

As a newly concrete type, lightweight self-consolidated concrete (LWSCC), it is vital to judge and understand its various characteristics in both fresh and hardened states. Clarifying the factors controlling the various characteristics of such concrete will be also essential. These factors include the dosage of self-compacting agent (SCA), w/c ratio, LWA/sand ratio and lightweight/normal weight coarse aggregate ratio. In this study, the fresh characteristics of LWSCC were evaluated in terms of slump flow, air content and rate of slump flow loss, while the hardened characteristics were assessed by investigating its pore structure, homogeneity and compressive strength. Having a knowledge about these aspects can leads to develop the industry of LWAC and producing LWAC with unique properties.

Fresh Characteristics of LWSCC

Two approaches were considered to assess the fresh properties of LWSCC, Slump flow and air content. Slump flow technique is a commonly used approach in literature and recommended by Euro and Japanese standards for evaluating the main fresh parameters of self-compacting concrete, flowability and deformability [8-14]. It can also provide some information about stability of concrete mix, resistance against segregation of concrete ingredients [8]. On the other hand, determination of air content of LWSCC in its fresh state was considered to give an indicative measure for the degree of self-compactability of LWAC incorporating SCA, where the self-compactability is inversely proportionally with the amount of air content existed in fresh concrete. Moreover, the rates of loss in flowability and deformability characteristics of LWSCC were monitored at different elapsed periods from mixing, using slump flow approach.

Slump flow and air content

To develop LWSCC, the effects of SCA on flowability and self-compactability of LWAC were initially investigated. The results are illustrated in Fig. 1, at which the measurements of slump flow and air content were plotted against SCA content. As clearly seen, the slump flow increase rapidly with increasing SCA content up to certain value (≈0.8). Beyond this dosage, slump flow measurements started to decrease with increasing the dosage of SCA in LWAC mix. An opposite trend was noted when the relationship between the amount of air content in fresh LWSCC and dosage of SCA was considered. Where, the air content decreased significantly with increasing SCA content up to 0.8% and then started to increase with increasing SCA dosage. These results reveal that increasing of SCA content in LWAC resulted in significant enhancements in its fresh parameters (flowability, deformability and self-compactability). The maximum enhancements were produced when a dosage of 0.80 % SCA was utilized in LWAC mix. However, beyond this dosage, the amount enhancements were declined.

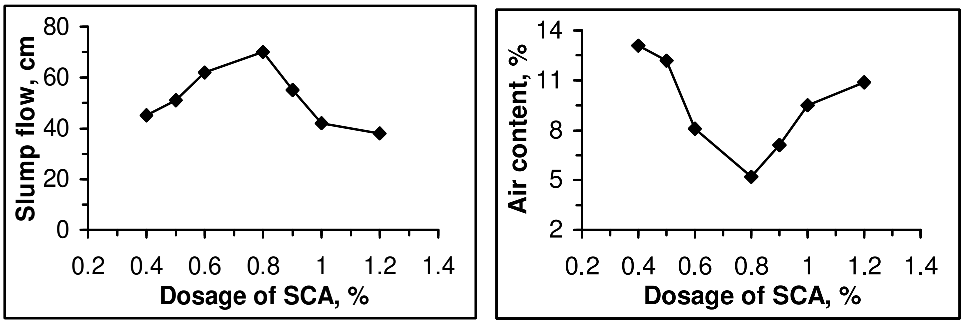

Fig. 1: Slump flow and air content of LWSCC made with different dosages of SCA, using ratios of 1.50 LWA/sand and 0.30 w/c.

Meanwhile, the stability of LWSCC mixes was examined visually to observe any possible segregation to their mix ingredients. The visual inspection of LWSCC mixes assured that despite of the high fluidity of such concrete, the uniformity of LWSCC made with 0.4, 0.5, 0.6 and 0.8 % SCA seemed to be very high, where no segregation to the ingredients of concrete mixes was noted. Whilst an opposite behavior was observed when 1.0 and 1.2% of SCA were utilized, where few particles of coarse aggregate were found on the edges of spread concrete. This agrees with the results shown in Fig. 1, where a substantial increase in the air content of fresh LWSCC was produced when a dosage of SCA of more than 0.80% was utilized.

The substantial improvement occurred to the main fresh parameters of LWSCC may be attributed to the physical effect of SCA. The incorporation of SCA affects the aqueous phase of cement phase where chains of water-soluble polymer present in SCA can absorb some of the free water in the system, thus enhancing the viscosity of the cement phase. As a result, less free water can be available for bleeding and segregation of LWSCC mix ingredients [15]. The enhanced viscosity of LWSCC mix can lead to improving the capacity of paste to suspend the solid particles (LWA) and consequently enhancing the stability, deformability and degree of compactability of LWSCC. However, this physical effect may be affected by the dosage of SCA and amount of LWA in concrete mix, which led to altering the fresh parameters of LWSCC.

Another explanation can be provided, based on the assumption that the use of SCA resulted in a notable reduction in the amount of attractive forces between oppositely charged particles (deflocculating) and increasing the amount of inter-particle repulsive forces, due to the high negative charge conveyed to the particles by SCA. Therefore, the more SCA content, the more viscosity and negative charges in concrete mixture can be produced. However, increasing of SCA content beyond a certain dosage in LWAC mixes can also leads to a contradictory effect, where it may increase the possibility of segregation/floating of LWA, due to the excessive repulsive forces created by the higher dosages of SCA.

Rate of slump flow loss

The rate of slump flow loss of LWSCC was investigated to provide a good understanding to the fresh properties during casting and placement state. The slump flow of LWAC mixes made with 0.60, 0.80, 1.00 and 1.20% SCA were monitored at different elapsed periods from mixing, 0, 30, 60, 120 and 240 min. The results are shown in Fig. 2, at which the relationships between the % of instant/initial slump flow of these mixes versus elapsed time from mixing were plotted. It can be seen the % of instant/initial slump of LWSCC are rapidly diminished with increasing elapsed period from mixing. Such diminishing effect significantly pronounced with increasing SCA content. After 120 min from mixing, LWSCC lost about 60, 65, 90 and 100 of its flowability due to inducing 0.60, 0.80, 1.00 and 1.20% SCA into LWAC mixes, respectively.

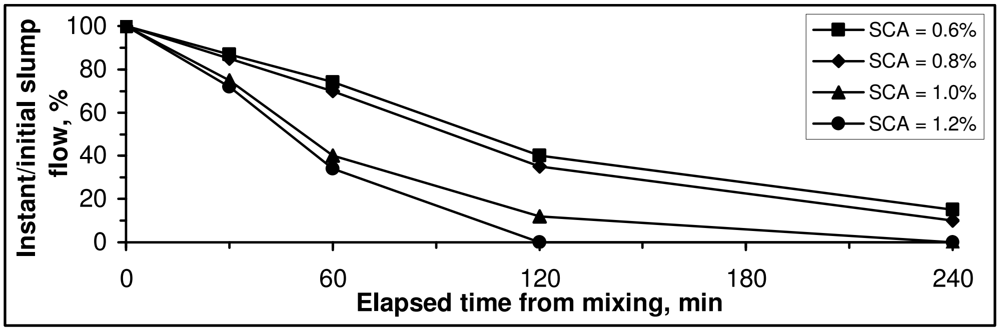

Fig. 2: Rate of slump flow loss of LWSCC made with different dosages of SCA, using ratios of 1.50 LWA/sand and 0.30 w/c .

The rapid loss in the slump flow of LWSCC indicates that the main mechanisms of SCA, necessary for improving the properties of fresh concrete, would be diminished with time. In other words, increasing of elapsed period from mixing can leads to a dramatic decrease in the viscosity and reduction in the amount of negative ions of LWSCC mixture, generated as a result of using SCA. Therefore, care is greatly important when casting and placing such type of concrete, to avoid the high losses in its fresh parameters.

Hardened Characteristics of LWSCC

After elucidating the performance of LWSCC during its fresh state, it is necessary to understand the performance of this type of concrete during its hardened state. So the 28 day-compressive strength, homogeneity, density and porosity of LWAC made with different dosages of SCA were assessed, see Fig. 3. In this study, the mechanical properties of LWSCC was investigated using compressive strength approach, while the porosity and homogeneity of

LWSCC were examined by means of porosity and ultra-sonic pulse velocity (UPV) tests, respectively.

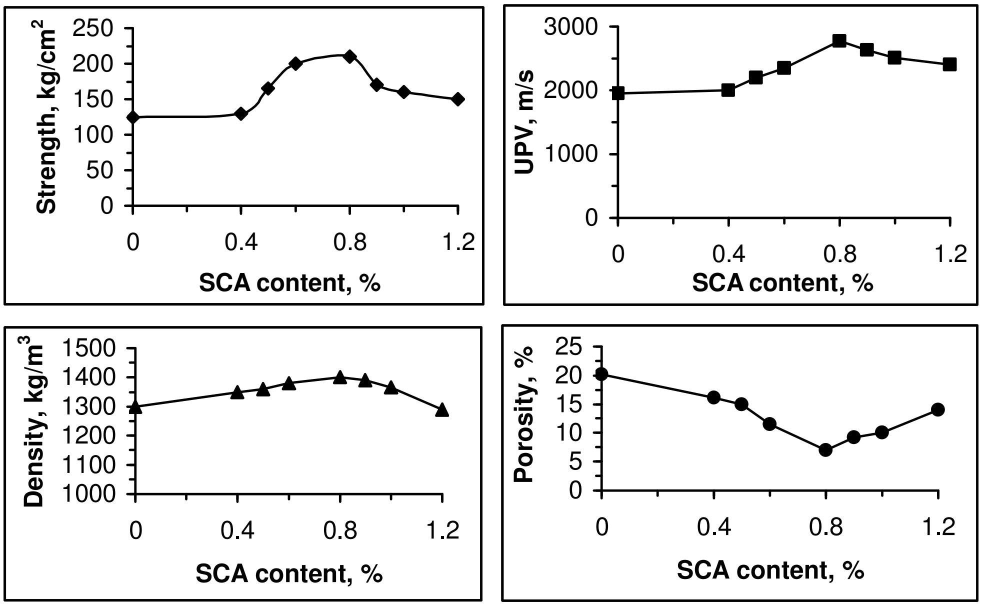

Fig. 3: Compressive strength, ultrasonic pulse velocity (UPV), density and porosity of LWSCC made with different dosages of SCA.

As noted from the results demonstrated in Fig. 3 the compressive strength, UPV and saturated-surface dried density measurements reasonably increased with increasing the dosage SCA induced in LWAC mixes till a certain content of SCA (≈0.8%), at which these characteristics started to decline with increasing SCA. The maximum enhancements in the compressive strength and UPV reach about 60 and 40%, respectively, as a result of increasing the dosage of SCA from 0.00 to 0.80%. Whilst, the compressive strength and UPV measurements were reduced by about 40 and 15%, respectively, when the dosage of SCA was increased from 0.80 to 1.20%. In addition, the density of hardened concrete at saturated-surface dried (SSD) increased from 1250 to 1400 kg/m^3, as a result of inducing 0.80% SCA in LWAC mix, and then reduced to about 1350 kg/m^3, when 1.20% SCA was used.

On the other hand, an opposite effect for SCA content on the porosity of LWSCC was shown (see Fig. 3), compared to that noted effects of SCA on compressive strength, UPV and density. The porosity measurements was significantly affected by the content of SCA utilized in LWAC mixes, where the porosity of LWSCC decreased dramatically with increasing the dosage of SCA from 0.0 to 0.80 and then started to increase with increasing SCA content. The maximum achieved reduction in the porosity reached about 70%, when 0.80% SCA was utilized.

This means that SCA has significant effects on 28-day compressive strength, homogeneity, poosity and density of LWAC. These effects mainly dependent on the adopted dosage of SCA. The noted increase in the compressive strength and homogeneity of LWSCC when the dosage of SCA was increased from 0.40 to 0.80 may be attributed to the beneficial effect of this range of SCA dosages on the pore structure of LWAC. While the decline effect of increasing the dosage of SCA beyond 0.80% on compressive strength, homogeneity and density of LWSCC can be attributed to the increase in the porosity and slight segregation occurred to mix ingredients containing high dosages of SCA, as discussed above. Generally, it can be stated that, from the mechanical, homogeneity and porosity points of view, the optimum dosage of SCA to be induced in LWAC for producing LWSCC is 0.80.

Factors Affecting Fresh and Hardened Characteristics of LWSCC

It can be seen from the above discussion that it is possible to develop a concrete made from a local materials with the following characteristics; low density, high flowability and deformability, high self-compactability and high stability against separation of concrete ingredients. However, these advantages may be controlled by many factors such as dosage of self-consolidated agent, as explained above, concrete mix proportions (ratios of w/c and LWA/Sand) and inclusion of normal weight aggregate as a partial replacement of LWA. Therefore, this study was conducted to confirm such hypothesis, i.e. to investigate the influence of these factors on the various characteristics of LWSCC in its fresh and hardened state.

Effect of LWA/sand ratio

The slump flow and air content of LWSCC made with 0.30 w/c ratio, 0.80% SCA and different ratios of LWA/Sand (2.00, 1.50 and 1.00) were studied and the results are shown in Fig. 4. As seen, reducing the ratio of LWA/Sand has led to improve the various fresh parameters of LWSCC, flowability, deformability and self-compactability. Where, the slump flow measurements increased with decreasing the ratio of LWA/Sand and the amount of increase reached about 20% as a result of using LWA/Sand ratio of 1.0 instead of 2.0. On the other hand, the air content was significantly reduced with reducing LWA/Sand ratio. The lowest value of air content was obtained when a ratio of LWA/Sand of 1.0 was considered, at which the amount of reduction in air content reached about 60%, compared to the corresponding of that mixes made with LWA/Sand ratio of 2.0.

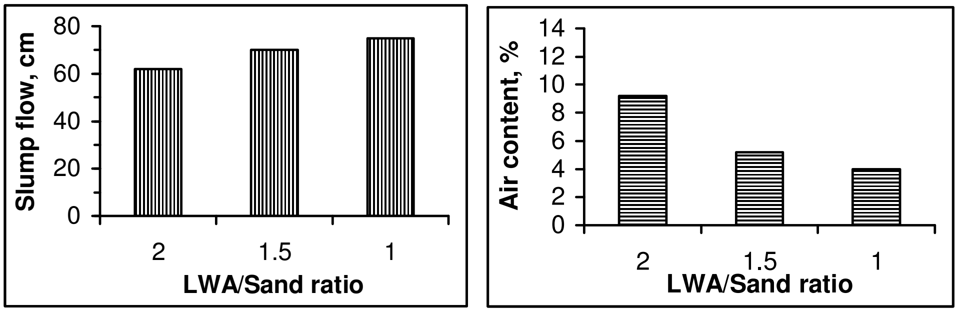

Fig. 4: Effect of LWA/Sand ratio on the slump flow and air content of LWSCC, made with 0.80% SCA and 0.30 w/c ratio.

The effect of LWA/Sand ratio on the rate of flowability loss of LWSCC was also investigated and the results are shown in Fig. 5. It can be seen that increasing the ratio of LWA/Sand resulted in an increase in the rate of flowability loss, where the % of instant/initial slump flow at later ages (60, 120 and 240 min) was notably reduced with increasing the ratio of LWA/Sand from 1.50 to 2.0. After two hours from mixing, LWSCC lost about 60, 65 and 90 % of its fresh plasticity (flowability) when LWA/Sand ratios of 1.0, 1.50 and 2.0 were utilized in concrete mix. Despite of this notable effect, the rate of loss in slump flow of mixes made with 1.0 and 1.50 LWA/Sand ratio are slightly comparable.

The improvement in the fresh concrete properties due to reducing LWA/Sand ratio may be attributed to the decrease in the friction between concrete ingredients, which may be produced from the interlocking effect between coarse aggregate particles, thus leading to increase the degree of flowability and deformability of LWSCC. The amount of air content was reduced due to the enhancement occurred in the cohesion of concrete which might increase with increasing the amount of sand in LWSCC. Increasing LWA/Sand ratio can also increase the possibility of adsorption of water from concrete mix by LWA, thus reducing the instant slump flow measurements and consequently the rate of loss in slump flow of LWSCC.

Fig. 6 demonstrates the effects of LWA/Sand ratio on various hardened characteristics of LWSCC, 28-day compressive strength, UPV, SSD density and porosity. LWA/Sand ratio had slight effects on both compressive strength and homogeny of LWSCC. The compressive strength and UPV increased from 205 kg/cm^2 to 220 kg/cm^2 and from 2700 to 2760 m/s, respectively, as a result of reducing the ratio of LWA/Sand from 2.0 to 1.0. The results plotted in Fig. 6 also show a significant increase in the SSD density of LWSCC due to reducing LWA/Sand ratio. The density increased from 1260 to 1550 kg/m^3 as a result of utilizing a ratio of LWA/Sand 1.0 instead of 2.0.

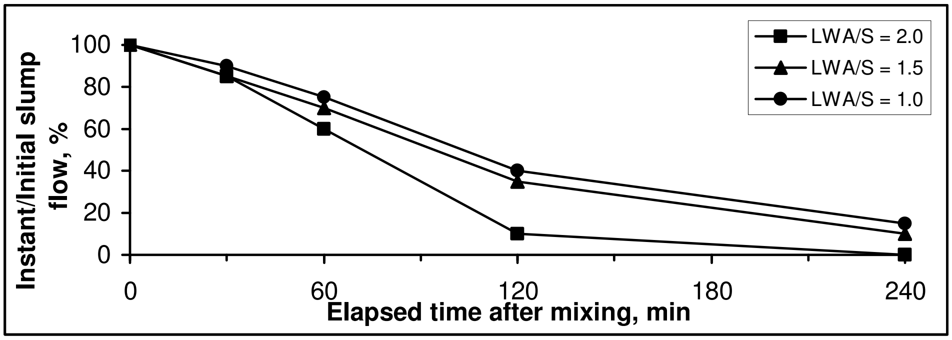

Fig. 5: Effect of LWA/Sand ratio on rate of slump flow loss of LWSCC.

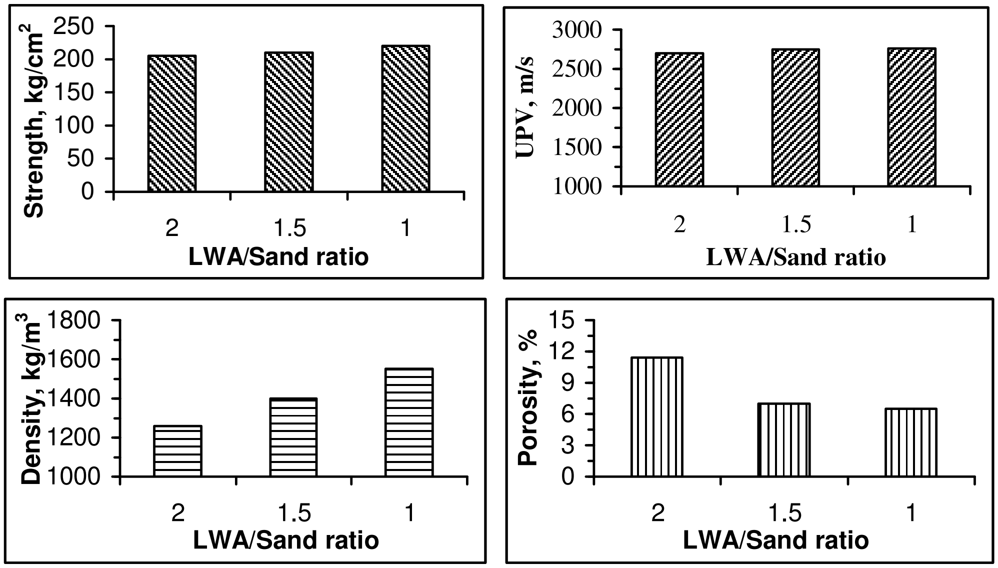

Fig. 6: Effect of LWA/Sand ratio on the compressive strength, ultrasonic pulse velocity (UPV), porosity and density of LWSCC.

On the other hand, considerable reduction in the porosity of LWSCC with decreasing the ratio of LWA/Sand was produced. The amount of reduction reaches about 40% for concrete made with LWA/Sand of 1.50, compared to the corresponding of that made with LWA/Sand ratio of 2.0. The reduction in the porosity may be attributed to the increase in the packing effect of coarse aggregate, which increases with increasing the content of sand in LWAC, where reducing LWA/Sand ratio can lead to fill the voids with fine sand grains, hence decreasing the amount of pores in concrete. The amount of pores also decreased with decreasing the amount of LWA in OPC matrix, thus reducing the amount of pores (porosity) and increasing density. The reduction in the porosity is generally in agreement with the slight enhancement occurred in the compressive strength and UPV when the ratio of LWA/Sand was lowered.

Effect of w/c ratio

The effects of w/c ratio on both fresh and hardened properties of LWSCC were also clarified and the results are listed in Tables 5 and 6, respectively. As seen from the results reported in Table 5 that, the amount air content in LWSCC was remarkably reduced with decreasing w/c ratio from 0.35 to 0.30 and the amount of reduction reached about 60%. While, reducing the w/c ratio from 0.30 to 0.25 resulted in a trivial reduction in the amount of air content (≈5%). On the other hand, the slump flow measurements seemed not to be affected by changing the w/c ratio of LWSCC mix.

Table 5: Effect of water cement ratio on the fresh properties of LWSCC.

Water/cement ratio	Fresh properties	
	Slump flow (cm)	Air content (%)
0.35	69	12.3
0.30	70	5.2
0.25	72	4.8

Table 6: Effect of water cement ratio on the hardened properties of LWSCC.

Water/cement ratio	Hardened properties			
	Strength (k/cm^2)	UPV (m/s)	Porosity (%)	Density (kg/m^3)
0.35	130	2600	14.5	1295
0.30	210	2750	7.0	1410
0.25	225	2795	5.4	1515

This means that w/c ratio has insignificant effect on the flowability and deformability of LWSCC mixes and considerable role on enhancing the self-compactability, especially when a range of 0.35 and 0.30 w/c ratio was utilized. In other words, the self-consolidation of LWSCC can be improved at low ranges of w/c ratio, which may be attributed to alterations occurred in cohesion and viscosity of concrete. However, there is a need for a further rheological study to confirm this explanation and the others discussed above concerning the fresh characteristics of LWSCC.

The results demonstrated in Table 6 emphasized that the w/c ratio had significant roles in enhancing the 28-day compressive strength and pore structure of LWSCC. Where the compressive strength increased with decreasing w/c ratio, while the values of porosity decreased with lowering w/c ratio. The amount of enhancements in compressive strength and porosity reached about 75 and 60%, respectively, as a result of lowering the w/c ratio from 0.35 to 0.25. Also, both homogeneity and unit weight of LWSCC were slightly increased with decreasing the ratio of w/c. These effects may be attributed to the significant effect of w/c on altering the porosity of LWSCC, thus leading to various alterations in concrete properties.

Effect of partial replacement of LWA with normal weight aggregate

As an attempt for improving the hardened characteristics of LWSCC, especially compressive strength, the impacts of partial replacement of lightweight aggregate (LWA) with normal weight aggregate (NWA) on compressive strength, UPV and porosity were investigated, as demonstrated in Fig. 7. The SSD unit weight of concretes made with a combination of LWA and NWA was also noted down. As obviously seen, both compressive strength and UPV substantially increase with increasing the portion of NWA in LWSCC mix. The amount of increase in compressive strength reached by about 15, 30, 50 and 90%, when 35, 50, 60 and 100% NWA were used as a partial replacement of LWA.

This increase in strength is accompanied with a significant increase in the density of concrete, i.e. to enhance the mechanical properties of LWSCC using this approach, sacrificial increase in the density of concrete has to be regarded and accepted. Where, the density increased dramatically with increasing the % of replacement of LWA with NWA and reached about 2230 kg/m^3 when LWA was fully replaced with NWA, normal weight concrete. However, the maximum content of LWA to be partially replaced by NWA in LWAC mixes should not exceed half of LWA content, to fulfill density criteria for manufacturing structural LWAC, as stated by ACI 211.2-81 [1].

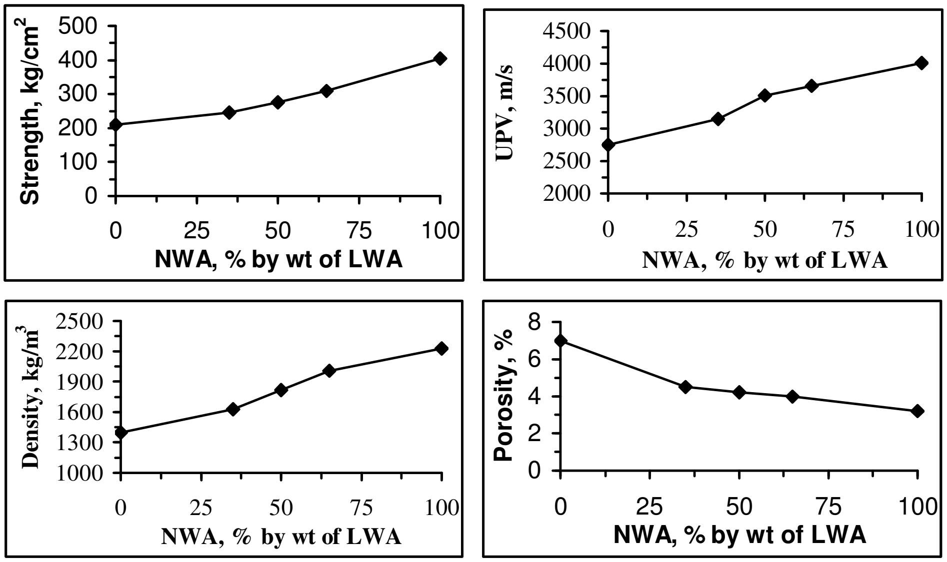

Fig. 7: Effect of partial replacement of LWA with NWA on compressive strength, ultra-sonic pulse velocity and density of LWSCC, using ratios of 1.50 LWA/Sand and 0.30 w/c, and 0.80% SCA.

The partial replacement of LWA with NWA also resulted in improvement in the porosity of LWSCC, where increasing the % NWA in LWAC mixes led to a notable reduction in its porosity results. The porosity of self-consolidated concrete made with 100% LWA is approximately twice of that concrete made with 100 % NWA. This reduction in the porosity agrees with the resulted improvements in compressive strength and UPV and can be attributed to decreasing the amount of pores as a result of inducing NWA in LWSCC.

To clarify the impact of utilizing NWA on the fresh properties of LWSCC, the slump flow, air content measurements were recorded for concrete mixes containing 0, 35, 50, 65 and 100 % NWA, by weight of LWA. The results are shown in Fig. 8. Obviously, both slump flow and air content measurements were remarkably with increasing the portion of NWA in LWSCC mix. This means that, despite the produced enhancement in the self-compactability, the LWSCC lost much of its flowability and deformability characteristics due to inclusion of NWA into LWSCC mixes. However, to overcome such problem, the proper dosage of SCA in such type of concrete, which incorporating of both NWA and LWA, has to be reviewed and adjusted.

Moreover, the rate of flowability loss of concrete made with both LWA and NWA was studied, as shown in Fig. 9. As seemed, the rate of slump flow loss of mixes made with 35% NWA is similar to the corresponding of that mixes made with 65% NWA. Both mixes however had lower rate of loss in their slump flow, compared to that made with 100% LWA. This again emphasize that the inclusion of NWA in LWSCC can improve the rate of loss in its fresh parameters as well as hardened properties of LWSCC.

The reduction in the amount of air due to increasing the portion of NWA in LWSCC may be attributed to the increase in the viscosity and cohesion of concrete mix, which can leads to improve the self-compactability of LWSCC. On the other hand, the resulted reduction in flowability and deformability of LWSCC with increasing the portion of NWA can be attributed to the amount of repulsive forces created by the considered dosage of SCA, which might decrease with increasing NWA. Generally, a rheological study is required to find an explanation for such phenomena and the others discussed above, to understand the various fresh aspects of such newly concrete.

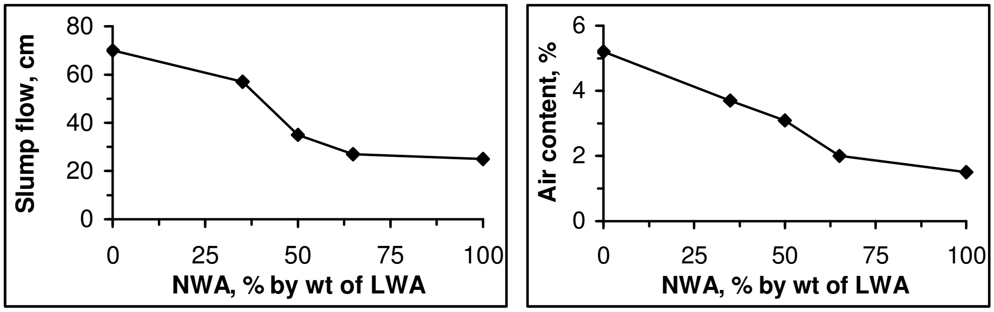

Fig. 8: Effect of partial replacement of LWA with NWA on slump flow and air content of LWSCC, made with ratios of 0.30 w/c and 1.50 LWA/Sand, and 0.80% SCA.

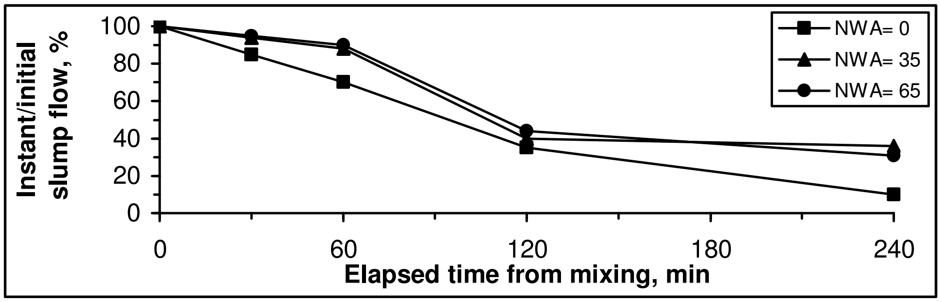

Fig. 9: Effect of replacement of LWA with NWA on rate of flowability loss of LWSCC.

CONCLUSIONS

Based on the results of this study, the following conclusions may be drawn.

1- It is possible to manufacture a structural lightweight aggregate concrete with low density and high self-consolidating characteristics (flowability, deformability, self-compactability and stability) using local-produced materials.

2- The fresh and hardened characteristics of lightweight self-consolidated concrete (LWSCC) are mainly controlled by dosage of self-consolidated agent (SCA), where the flowability, self-compactability, strength, homogeneity and porosity of LWSCC can be enhanced with increasing SCA content up to certain dosage of SCA (≈0.80), at which these characteristics started to decline with increasing SCA content.

3- LWSCC losses its fresh parameters (flowability and deformability) rapidly with increasing the dosage of SCA and lightweight aggregate/sand ratio. However, the rate of loss can be minimized with partially replacing lightweight aggregate with normal weight aggregate.

4- The compressive strength, homogeneity and porosity of LWSCC can be significantly improved with reducing the ratios of w/c and lightweight aggregate/sand, and utilizing normal weight aggregate in LWSCC mixes as a partial replacement of lightweight aggregate. However, increasing the portion of normal weight aggregate in LWSCC is accompanied with a substantial sacrificial increase in its unit weight.

5- SCA content and the ratio of lightweight aggregate/sand had a notable effect on the density of LWSCC, which increases with increasing the dosage of SCA up to 0.80%

SCA and with reducing the ratio of lightweight/sand. On the other hand, w/c ratio had a trivial role on altering the unit weight of LWSCC.

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