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Fresh and hardened properties of lightweight self-compacting concrete incorporating with waste plastic and Expanded Polystyrene Beads

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ABSTRACT

The aim of this study is to develop Lightweight self-compacting concrete (LWSCC) mixtures using locally sourced waste materials such as Expanded Polystyrene Beads (EPS) and Waste Plastic Fibers (WPFs) which are all available abundantly available in Republic of Iraq at little or no cost. The fresh, hardened and mechanical properties of these LWSCC were studied, followed by results analysis. Five different mixes of LWSCC were prepared in term of WPF content (0.25, 0.5, 0.75, 1.0, and 1.25 %), in addition to the control mix (R mix) and lightweight concrete (E mix) made of EPS content as a replacement of coarse aggregate. The study showed that the LWSCC produced with these waste materials were decreased the density (lightweight) of the concrete mixes as EPS tend to form more clumps, absorb water and make the mix dry. Therefore, concrete mixtures were adjusted accordingly to be able to offset the workability caused by the addition of EPS. The increase in WPF content decreased the workability due to clumping that occurred in the mixing phase. The analysis of mechanical properties of the LWSCFRC specimens revealed that there was not much improvement. While LWSCC with 100% of EPS replacement as coarse aggregates and 1.25% WPFs provides the best flexural toughness performance.

1. Introduction

The LWSCC is one of the novel innovations in the area of “high-performance concrete as it boosts the best properties of both LWC and SCC. The LWSCC is highly suitable for the construction of structures that require less compressive strength of concrete but need low weight (Hossain and Anwar, 2015). For instance, these are elements that are prefabricated and requires transportation, structures and elements where the concrete surface should be noticeable. It is suitable for use in renovation projects where additional loads are not desired (Choi et al., 2006; Topçu and Uygunoğlu, 2010).

LWSCC was first applied in structure in Japan in 1922 when it was used to “construct a cable-stayed bridge’s main girder. Over the last few years, LWSCC has found a number of applications, such as in precast stadium benches (Hubertova and Hela, 2007) and pre-stressed beams with spans reaching up to 20 m (Dymond, 2007).” When necessary, the strength of LWC can be improved by combining coarse LWA and fine stone aggregates. However, the maximum strength can be achieved in concrete with aggregates from waste clay or slag and natural crushed stone aggregates. Spent clay aggregates are more beneficial in the grain shape as it enhances the mixtures’ rheological attributes and compressive strength (Maghsoudi et al., 2011). The use of LWSCC also reduces the construction cost as it reduces the total dead load of the structural components and requiring little or no maintenance compared to similar steel structures. LWSCC can also improve the durability and strength of structures while offering better workability (Hwang and Hung, 2005; Shi and Wu, 2005).

Numerous studies have been conducted on the compressive strength of LWSCC using different parameters. For instance, the study by (Corinaldesi and Moriconi, 2015) focused on the effect of introducing synthetic fibers into LWSCC when using spent clay and recycled concrete aggregate as partial cement replacement. From the result, “low density LWSCC with concrete strength of grade 40 at 28-day age was achieved by

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adding silica fume to improve the compressive strength development. Furthermore, the authors reported that microfibers addition had no effect on the degree of concrete compaction. However, the compressive strength of the LWSCC with fiber was found to be 10% higher compared to that of LWSCC without fibers. Similar compressive strength of LWSCC was also noted by using steel fibers at high concentrations as the addition of steel, synthetic, and macro fibers improved the compressive strength of LWSCC.

Another important metric for measuring the splitting tensile strength of concrete is the flexural strength. The study by (Corinaldesi and Moriconi, 2015) reported no obvious improvement in the flexural strength of LWSCC upon the addition of synthetic fibers. Lotfy et al., 2016 reported about 9.8-10.5% improvement in the flexural strength of LWSCC prepared with three different types of LWA. The highest flexural strength was exhibited by LWSCC prepared with furnace slag as aggregates while LWSCC with spent clay exhibited the lowest flexural strength . According to the authors, the quality, size, and volume of the coarse aggregate had influence on the flexural strength of LWSCC.

Therefore, the current study aim to develop various LWSCC mixtures utilizing expanded polystyrene beads (EPS) as lightweight aggregate and WPFs as industrial waste products in different contents (0.25, 0.5, 0.75, 1.0 and 1.25%) as aggregate replacement by evaluating the fresh, hardened, and mechanical properties of the developed LWSCC mixtures.

2. Experimental program

2.1. Materials used

Table 1 shows the physical and chemical properties of used Ordinary Portland cement (OPC). The results confirmed Iraqi standard no. 5 /1984 Limit (Iraqi Specifications, 1984). In addition to coarse and fine aggregates physical properties and grading of according to the Iraqi standard specification (I.Q.S.) No.45/ 1984 (Iraqi Specification, 1984) have been listed in Table 2. The study also used Sika Fume and Sika ViscoCrete-5930 as superplasticizers to achieve SCC requirement in terms of flowability and other fresh properties. Tap water was used in the study. Finally, the shape, dimension, and physical properties of EPS and WPFs have been listed in Table 3.

Table 1 – Physical and chemical compositions for used cement

Test Type	Iraqi standard no. 5 /1984 Limit	Content
Fineness (m^2/kg)	**> 230**	**332**
Initial Setting (min)	**≥ 45**	**112**
Final Setting (min)	**≤ 600**	**156**
Compressive strength for cement mortar cube (MPa)		
1 Day (MPa)	**-**	**-**
3 Days (MPa)	**≥ 15**	**29.3**
7 Days (MPa)	**≥ 23**	**36.2**
28 Days (MPa)	**-**	**-**
Oxide composition	**Content**	**Limits of Iraqi Specification No. 5/1984**
SiO_2	**----**	**----------**
CaO	**----**	**----------**
MgO	**2.2**	**Not more than 5 %**
Al_2O_3	**----**	**----------**
SO_3	**2.33**	**Not more than 2.8 %**
Fe_2O_3	**----**	**----------**
Loss on ignition	**2.25**	**Not more than 4 %**
Insoluble residue	**0.77**	**Not more than 1.5 %**
Lime Saturation	**0.97**	**0.66-1.02**

Table 2 – Sieve analysis for coarse and fine aggregates

Sieve Size (mm)	Passing %	Iraqi standard No. 45/ 1984 Limit
Coarse Aggregate		
10	86.5	85-100
5	6.5	0-25
Fine Aggregate		
2.36	82	65-100
1.18	67	54-100
0.6	51	25-80
0.3	22	5-48
0.15	2.5	-

Table 3 – Physical properties of EPS and WPFs

Expanded Polystyrene Beads (EPS)			
Sieve Size		**Passing %**	**ASTM C330**
12.5 mm		100	100
9.5 mm		91	80-100
4.75 mm		6.5	5-40
2.36 mm		1.5	0-20
Specific gravity		0.009	-
Water absorption		0	-
Maximum particle size (mm)		10	-
WPFs			
Length (mm)	**Width (mm)**	**Thickness (mm)**	**Aspect Ratio**
40	3	0.8	23
Tensile Strength (Mpa)	**Density (kg/m^3)**	**Water absorption**	
220	1400	0.00	

2.2. Materials used

The seven self-compacting concrete mixtures presented in Table 4 were developed according to ACI 211.4R-08 (ACI Committee 211, 2009) using large number of trial mixes using the control mix incorporating with EPS content (10, 20, 40, 60, 80, and 100) % as a replacement of coarse aggregate without WPFs in order to obtain self-compacting lightweight concrete. The objective was to have optimum density of 1600 kg/m^3 with 100% EPS replacement when WPFs were incorporated.

Table 4 – Concrete mixtures proportion ratios

Mix Code	R	E	E 0.25	E 0.5	E 0.75	E 1.0	E 1.25
C. (kg/m^3)	400	400	400	400	400	400	400
S.F (kg/m^3)	100	100	100	100	100	100	100
S.P (kg/m^3)	12	12	12	12	12	12	12
W. (kg/m^3)	165	165	165	165	165	165	165
G. (kg/m^3)	865	0	0	0	0	0	0
S. (kg/m^3)	865	865	862	859	856	853	849
EPS (kg/m^3)	0	2.92	2.91	2.9	2.88	2.87	2.86
WPFs(kg/m^3)	0	0	3.5	7	10.5	14	17.5

C = Cement, S.F = Silica Fume, S.P = Superplasticizer, W = Water, G = Gravel, S = Sand, EPS = Expanded Polystyrene Beads, WPFs = Waste Plastic Fibers

Therefore, the ratio of fine aggregate to coarse aggregate to EPS varied slightly between the WPFs contents. The control concrete specimens without WPFs underwent the same tests as to compare the results with that of the specimens with WPFs. Table 4 states that the amount of WPFs in concrete mixes were 0.25%, 0.5%, 0.75%, 1.0% and 1.25%. The selection of the amount of WPFs for each concrete was mostly based on previous studies that stated the minimum and maximum amount of WPFs in concrete. Silica fume was added to reduce the bleeding. Thus, the w/cm ratio was decreased to 0.4. In addition, Sika ViscoCrete 5930 was used as a superplasticizer to make the mixture more workable in all mixes.

3. Results and discussion

3.1. Slump Flow and T_{500}

The results of slump flow and T_{500} of concrete mixtures obtained are showed in Fig. 1. Between the control mix (R) and WPFs mixes the slump flow did in fact decrease. While the slump flow for 100% EPS replacement of coarse aggregate (E) shows an increase.

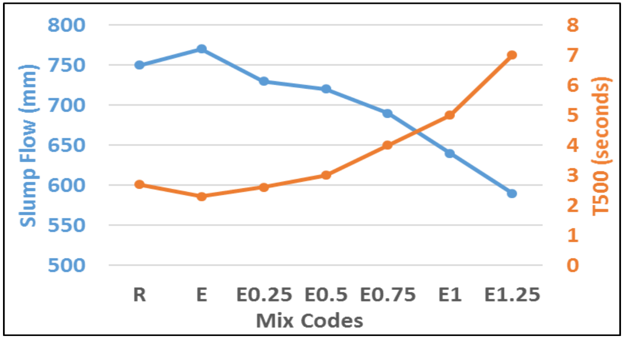

Fig. 1 Slump flow and T500 tests results for all mixtures

As shown in Fig. 1, the increase in fiber content in the concrete mixture exhibited decreased slump flow compare with mix (E) which content 0% of fibers, which resulted in decreased workability. This reduction may be attributed to the increased ability of fibers to restrict the flow ability of the fresh concrete, which impedes the workability (Hama and Hilal, 2017; Khatab et al., 2019). From the mixes (R & E) when usage of EPS beads Instead of coarse aggregate slump flow increased because of feature non-absorbing closed cellular, but most of the specimens meet the slump flow criteria of 550 mm to 850 mm according to ASTM C1611/C1611M (ASTM C1611/C1611M-18, 2018). The time needed to reach 500 mm diameter spread is related to the plastic viscosity of the mix. Fig. 1 shows mix (R) had higher T500 value than mix (E) because EPS beads had a spherical shape and smooth which increase the sliding between the mixture content. LWSCC mixes contained (WPFs) had higher T500 value than LWSCC mix (E), and T500 value increased directly with increasing replacement percentage of (WPFs),the cause of the increasing of the T500 values of mixtures was attributed of the fibers content due to increase the initial friction between fibers and the mixture particles. (Abbas et al., 2016; Freih, 2019).

3.2. L-Box

The mixes were exposed to the L-box test to evaluate their passing and filling abilities; this test is to ensure the mixes can permeate narrow gaps found in-between reinforcing bars. The blockage ratio (H2/H1) for all mixes were recorded in presented Fig. 2.

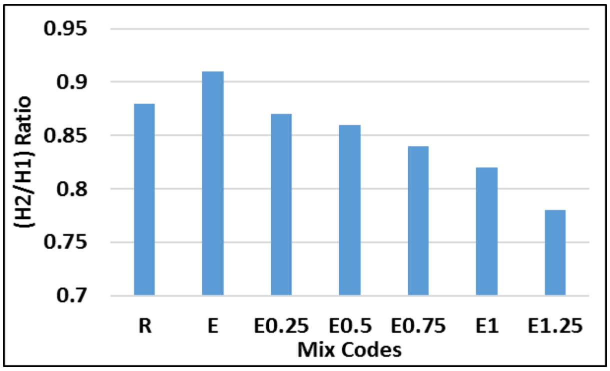

Fig. 2 L-Box test results for all mixtures

Fig. 2 shows a decrease in (H2/H1) ratio with the increase of WPFs in the mixes. The results of all mixes conform to the guidelines of EFNARC (EFNARC, 2002) which state that passing ability of SCC should be between (0.8-1). The results show that L-box test values affected by the content of using WPFs. Increasing the WPFs content caused gradual decreasing of the L-box height ratio due to less rounded particles in the mix (Hama and Hilal, 2017).

3.3. Sieve Segregation

The sieve stability test showed that all SCC mixtures in Figure 3 exhibited a good resistance to segregation. The SR% values were between 7 to 12 which are less than 15% for WPFs mixes (E0.25, E0.5, E0.75, E1.0, and E1.25). Therefore, the results proved that all mixes were within EFNRAC limits (EFNARC, 2002).

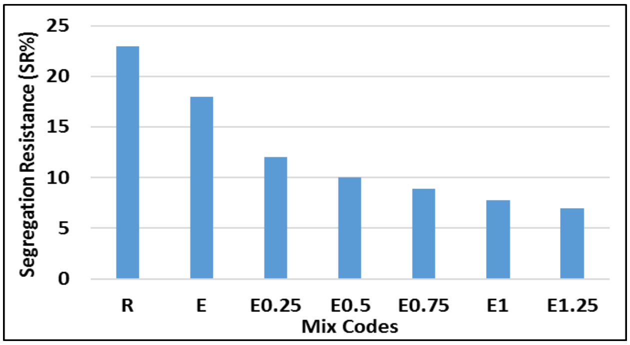

Fig. 3 Segregation Resistance (SR%) test results for all mixtures

As shown in Fig. 3, the sieve segregation test explained that mixes with higher percentage of WPFs results in better packing density and less void between the aggregates particle, allowing the excess paste in LWSCC to achieve better flowability and segregation resistance (Safiuddin et al., 2011).

3.4. Dry Density

Table 5 shows that the results of the LWSCC concrete compared with the control mix (R mix) as well as (E mix). E1.25 mix, however, Table 5 showed a greater dry density reduction in comparison to (R mix) and (E mix).

Table 5 – Dry density test results for all mixtures

Mix Code	Wet Density (kg/m^3)	Oven Dry Density (kg/m^3)	Water Absorption (%)	Voids (%)
R	2385	2374	0.57	1.61

E	1745	1694	0.78	2.02
E0.25	1681	1635	1.59	5.8
E0.50	1706	1612	1.58	8.6
E0.75	1721	1637	1.08	3.85
E1.00	1678	1570	1.59	6.39
E1.25	1700	1461	2.93	15.31

According to ASTM C642-6 (ASTM C642-13, 2013), lightweight concrete has an oven dry density of 800 kg/m^3 to 2000 kg/m^3. However, a semi-lightweight concrete has a density of 1840 kg/m^3 to 2240 kg/m^3 (Khoshkenari et al., 2014). Therefore, all mixtures be considered as a lightweight aggregate concrete. Fig. 5 represents the wet and dry density values for all mixtures in this study. The factor that caused the WPFs specimens to have lower values than control specimen (R) and EPS specimen (E) is the air voids that were created once the concrete batch was mixed. The increased amount of the waste plastic fibers could have caused voids in concrete, therefore not creating a dense concrete matrix. Same result was noticed in the work of Doukakis, 2013. The wet density for R and E mixes were approximately 11 kg/m^3 and 51 kg/m^3 higher than its dry density respectively. While the wet density of E0.25, E0.50, E0.75, E1.0, and E1.25 were 46, 94,84, 108, 239 kg/m^3 respectively are higher than their dry densities. Comparing all densities for each specimen, the decrease in density from wet to dry is due to the water evaporation and the increase of water absorption of the porous lightweight concrete. Another factor that affects the density of the concrete is the expanded EPS that is used to create the mixtures. The increased voids of the LWSCC in more water creating a heavier mixture; hence the fresh density of each specimen is higher (Rumšys et al., 2017). Newman, 1993 showed that the wet density of lightweight self-compacting concrete is generally about 100 kg/m^3 to 200 kg/m^3 higher than its dry density which confirm the results in this study.

3.5. Compressive Strength

Numerous studies have been conducted on the compressive strength of LWSCC using different parameters (Corinaldesi and Moriconi, 2015; Graboiset al., 2016; Lotfy et al., 2015, 2016; Nepomuceno et al., 2018). For instance, the study by (Corinaldesi and Moriconi, 2015) focused on the effect of introducing synthetic fibers into LWSCC when using spent clay and recycled concrete aggregate as partial cement replacement. From the result, "low density LWSCC with concrete strength of grade 40 at 28-day age was achieved by adding silica fume to improve the compressive strength development (Corinaldesi and Moriconi, 2015). The summary of compressive strengths for this study for all mixtures is shown in Fig 4. The figure shows the compressive strengths at ages 7, 28 and 90-day of curing.

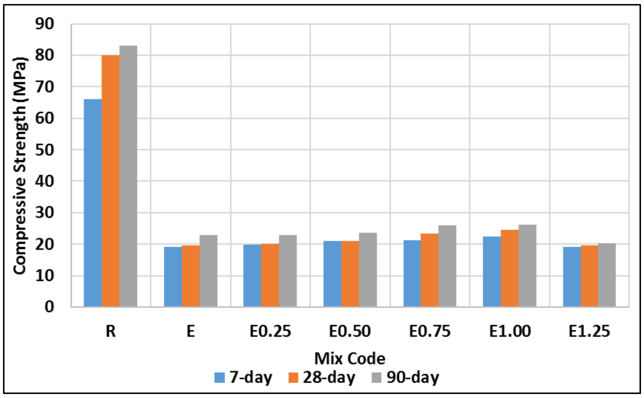

Fig. 4 Compressive strength test results of all mixtures for 7, 28, and 90 days

Overall, it can be seen from Figure 4 that the use of WPFs does not enhance the compressive strength of the lightweight concrete and the increase in WPFs content further have the same effect on the compressive strength as noted in E0.25, E0.50, E0.75, E1.00, and E1.25 specimens. The WPFs specimens were able to develop strength from seven to ninety days. From the comparison into the effects of increasing WPFs content, the (0.25, 0.5, 0.75, 1.0, and 1.25) % WPF increase had caused the compressive strength to decrease. This decrease is due to the bonding between the fibers and cement paste is weak. Furthermore, The gradual decrease in compressive strength values with increasing plastic waste fiber proportions can be attributed to the weak binding force between the surface of the plastic waste and cement paste as well as the plastic particles which it does not absorb water by nature wherever the cement hydration may be inhibited by restricting the water movement (Hilal et al., 2018; Silvaet al., 2013; Topçu and Uygunoğlu, 2010).

3.6. Flexural Strength

Flexural Strength of LWSCC mixtures varied from 2.36 to 3.57 MPa at 7-day, 2.86 to 3.88 MPa at 28-day and 3.70 to 4.35 MPa at 90-day. These values are presented in Fig. 5, with the highest values recorded for E-LWSCC mix at 90 day, while the lowest was recorded with mix made with EPS aggregate (E mix).

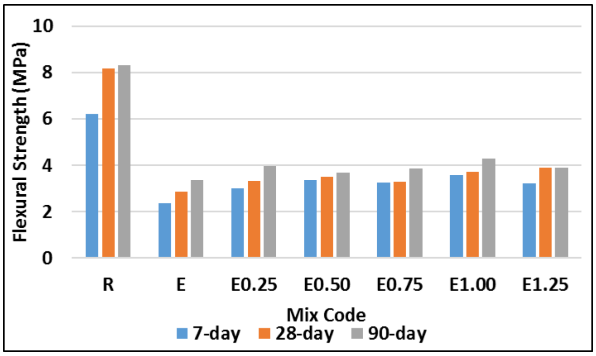

Fig. 5 Flexural strength test results of all mixtures for 7, 28, and 90-day

Fig. 5 is a comparison of the flexural strength of three different LWSCC mixtures and the control sample at different ages. Owing to the influence of the size, quality, and volume of coarse aggregate on the flexural strength of LWSCC mixes, the EPS-containing mixes showed higher strength since 100 % coarse aggregate volume as EPS was used in these mixes compared to WPFs mixes. Fig. 5 also showed the flexural strength of LWSCC to increase with the WPF content up to 1.0% (E1.0) as the fibers become densely spaced with increased WPF content which may limit the development of micro cracks within the brittle matrix and consequently increase the flexural strength of LWSCC (Al-Hadithi and Hilal, 2016; Rao and Ravindra, 2010). Moreover, the bonding property of plastics is low and can cause a decrease in the flexural strength at the highest WPFs content (E1.25) as depicted in Fig. 5. Increases in the plastic content allowed more free water around the particles which weakens the interaction between the plastic and the paste and cause the formation of a less dense zone with large voids and poor adhesion capability (Yang et al., 2015). Therefore, the flexural strength is apparently reduced at higher fiber content of >1.25%.

4. Conclusion

This research has investigated the influence of different contents of waste plastic fibers (WPF) in addition to full replacement of coarse aggregate with EPS on fresh state (slump flow, T500, L-Box, and sieve segregation), hardened state (dry density, compressive and flexural strength) properties of LWSCFRC. The following conclusions are drawn from the study:

1. The increase in WPF content decreased the workability due to clumping that occurred in the mixing phase. The oven dry densities were significantly lower than the wet density because more water was evaporated. The mixture that provided highest workability were made of 0.25% WPF with slump flow, T500, V-funnel, L-Box, and segregation resistance percentage values of 730 mm, 2.6 sec., 0.87, 8 sec., and 12% respectively.
2. The lightweight self-compacting concrete using EPS as a coarse aggregate with different contents of WPF revealed that the density of LWSCFRC decreased, the more WPF contents in concrete mixtures, the less density of these mixtures revealed.
3. The analysis of mechanical properties of the LWSCFRC specimens revealed that there was not much improvement to the compressive and flexural strengths by the addition of WPS. The 28-day compressive strength of all LWSCFRC specimens was found to be lower than the control specimen (without EPS and WPF). The LWSCFRC mix that had the highest compressive strength was made of 1.0 % WPF with 22.5, 24.65, and 26.25 MPa for 7, 28, and 90-day, respectively. The LWSCFRC mix with the highest flexural strength were made of 1.0% WPF with 3.57, 3.71, and 4.30 MPa for 7, 28, and 90-day, respectively.

To conclude this study, waste materials such as EPS WPFs should be limited in SCC because of their low values of hardened and durability properties. Also, in order to get the full strength and durability benefit from LWSCFRC, it is important to cure them further than 28 days (56 and 90) days, if the construction and service schedule can accommodate longer curing time.

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