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Fresh properties of self-compacting concrete with plastic waste as partial replacement of sand

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Abstract

This work aimed to investigate effecting of using plastic waste as partial replacement of fine aggregate, on the fresh characteristics of self-compacting concrete (SSC). For this purpose, different self-compacting concrete mixes were designed at constant water-to-binder ratio of 0.32 and 520 kg/m^3 of binder content. Class F fly ash was used as partial replacement of cement (30% by weight of cement). The six designated plastic waste contents of 0, 2.5, 5, 7.5, 10, and 12.5% and three different sized Plastic wastes (fine plastic wastes, coarse plastic wastes, and mixed plastic waste) were considered as experimental parameters. The workability properties of self-compacting concrete mixtures were performed regarding to slump flow diameter, T_{50} slump flow time, V-funnel flow time, L-box height ratio, and L-box T_{20} and T_{40} flow times. The 28-day compressive strengths of self-compacting concretes were also measured. The experimental results of this work are showed that the plastic waste with the sizes and contents that used in this work can be used successfully as a fine aggregate in self-compacting concrete.

Keywords: Plastic waste content; Plastic waste size; Fresh property; Self-compacting concrete; Waste plastic

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1. Introduction

European Environment Agency (2014) defined waste material, as an unwanted or undesired material or substance, is remained over from a manufacturing process such as industrial, commercial, mining or agricultural operations or from household activities. Environmental Protection Agency (European Environment Agency, 2014) grouped waste material as hazardous and non-hazardous. Hazardous wastes, which may include chemicals, heavy metals, or substances created from byproducts of commercial manufacturing processes and disposed household products, are potentially harmful to both human health and environment (National Institute of Environmental Health Sciences, 2014). However, non-hazardous wastes, which may have the opportunities for reduction, reuse, and recycling, are not specifically hazardous (United States Environmental Protection Agency, 2014). Several researchers were investigating the effect of plastic waste on concrete. Rebeiz concluded through his work that a precast concrete with a good quality could be produced using resins based on recycled plastic waste (PET bottles) (Rebeiz, 1995). Choi et al. studied the using of plastic waste

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(PET bottles) as aggregate on some properties of concrete. Their results showed that decreasing in weight using plastic wastes was about 2–6% of the normal weight concrete while compressive strength reduced up to 33% compared with compressive strength of normal concrete (Choi et al., 2005). Batayneh et al. concluded through their work that decreasing in compressive strength was function of increasing in plastic content. They found that for a 20% replacing of sand by plastic waste, compressive strength was reduced up to 70% compared with normal concrete (Batayneh et al., 2007). Other researchers (Yazoghli-marzouk et al., 2007; Mesbah and Buyle-Bodin, 1999; Remadnia et al., 2009; Hannawi et al., 2010) investigated about using plastic bottle waste to improve some properties of normal concrete. SCC is characterized by a high fluidity which provides spreading and compacting under its own weight, easily filling small interstices of formwork and complex shapes in structural members without vibration and it can also be pumped through long distances (Al-Manaseer and Dalal, 1997 and 18). The amount and size of coarse aggregate in the SCC manufacturing is limited and generally mineral and chemical admixtures are used (Güneyisi, 2010). In the literature, there are a number of studies reporting that the use of mineral admixtures improves the self-compact ability properties of the SCC (Gesoglu and Özbay, 2007; Güneyisi, 2010; Zhu and Bartos, 2003; Madandoust and Mousavi, 2012). Recently, research works showed that, the plastic is becoming a major research issue for its possibilities of using in self-compacting concrete and light weight concrete (Bayasi and Zeng, 1993; Al-Manaseer and Dalal, 1997; Avila and Duarte, 2003; Rossignolo and Agnesini, 2004; Rebeiz, 1995; Mesbah and Buyle-Bodin, 1999). The plastic wastes can beneficially be incorporated in concrete, as fine aggregates or as supplementary cementitious materials, it is important to notice that not all type of material's wastes are suitable for such use.

Batayneh et al. reported a decrease of slump with increasing PET waste as partial aggregate replacement. At 20% replacement the slump decreasing by 20–58 mm (Batayneh et al., 2007).

Al-Hadithi studied the using of plastic bottle wastes with different percentages (0.5%, 1% and 1.5%) of concrete volumes. Test results showed an improvement in both compressive and splitting tensile strengths of concretes. The improvement in splitting tensile strength appeared more clearly (Al-Hadithi, 2013). Albano et al. try with (10% and 20%) PET waste replacement percentages with different PET dimensions (2.6 mm, 11.4 mm and a mix of the two). Concretes with 20% waste content with (11.4 mm) dimensions gave the higher compressive strength loss above 60% (Albano et al., 2009).

This work covers the effecting of both plastic wastes contents and sizes on the fresh properties and compressive strength of SCC. Three different sized of plastic wastes (Fine, Coarse, and Mixed Plastic wastes) were used as partial replacement of natural sand at six different contents of 0, 2.5, 5, 7.5, 10, and 12.5% by volume. The fine plastic waste (FPW) is defined as a fine material passing from 1-mm sieve while the coarse plastic waste (CPW) is a fine material retaining on 1-mm sieve and passing from 4-mm sieve. Besides, FPW and CPW plastic wastes were mixed to achieve a new fine material with a gradation close to the natural sand. Constant water-to-binder (w/b) ratio of 0.32 and binder content of 520 kg/m^3 were designated to produce SCCs. To improve the workability of SCC, Class F fly ash (30% of cement content by weight) was incorporated in the mixture. The workability of SCC were investigated in terms of slump flow diameter, slump flow time, V-funnel time, L-box height ratio and L-box flow time. In addition, 28-days compressive strength were also measured. The experimental test results were evaluated and compared statistically.

2. Experimental study

2.1. Materials

- *Cement:* Ordinary Portland cement (CEM I 42.5R) was used in this work with specific gravity of 3.15 g/cm^3 and Blaine fineness of 326 m^2/kg. Chemical compositions and physical properties of using cement are recorded in Table 1.
- *Fly ash:* Class F fly ash (according to ASTM C 618) with a specific gravity of 2.25 g/cm^3 and Blaine fineness of 379 m^2/kg was utilized in the manufacturing of the SCCs. The chemical compositions and physical properties of using fly ash are recorded in Table 1.
- *Coarse aggregates:* A river gravel was used as coarse aggregate with a maximum size of 16 mm with specific gravity 2.71. The result of sieve analysis of using coarse aggregates are given in Fig. 1.
- *Fine aggregate:* Fine aggregate was a mixture of natural river sand and crushed limestone with a maximum size of 4 mm. Specific gravities were 2.65 and 2.43 for river sand and crushed sand respectively. The result of sieve analysis of using fine aggregates are given in Fig. 1.

Table 1
Physical properties and chemical compositions of Portland cement and fly ash.

Analysis report (%)	Cement	Fly ash
CaO	62.58	4.24
SiO_2	20.25	56.2
Al_2O_3	5.31	20.17
Fe_2O_3	4.04	6.69
MgO	2.82	1.92
SO_3	2.73	0.49
K_2O	0.92	1.89
Na_2O	0.22	0.58
Loss on ignition	3.02	1.78
Specific gravity	3.15	2.25
Blaine fineness (m^2/kg)	326	287

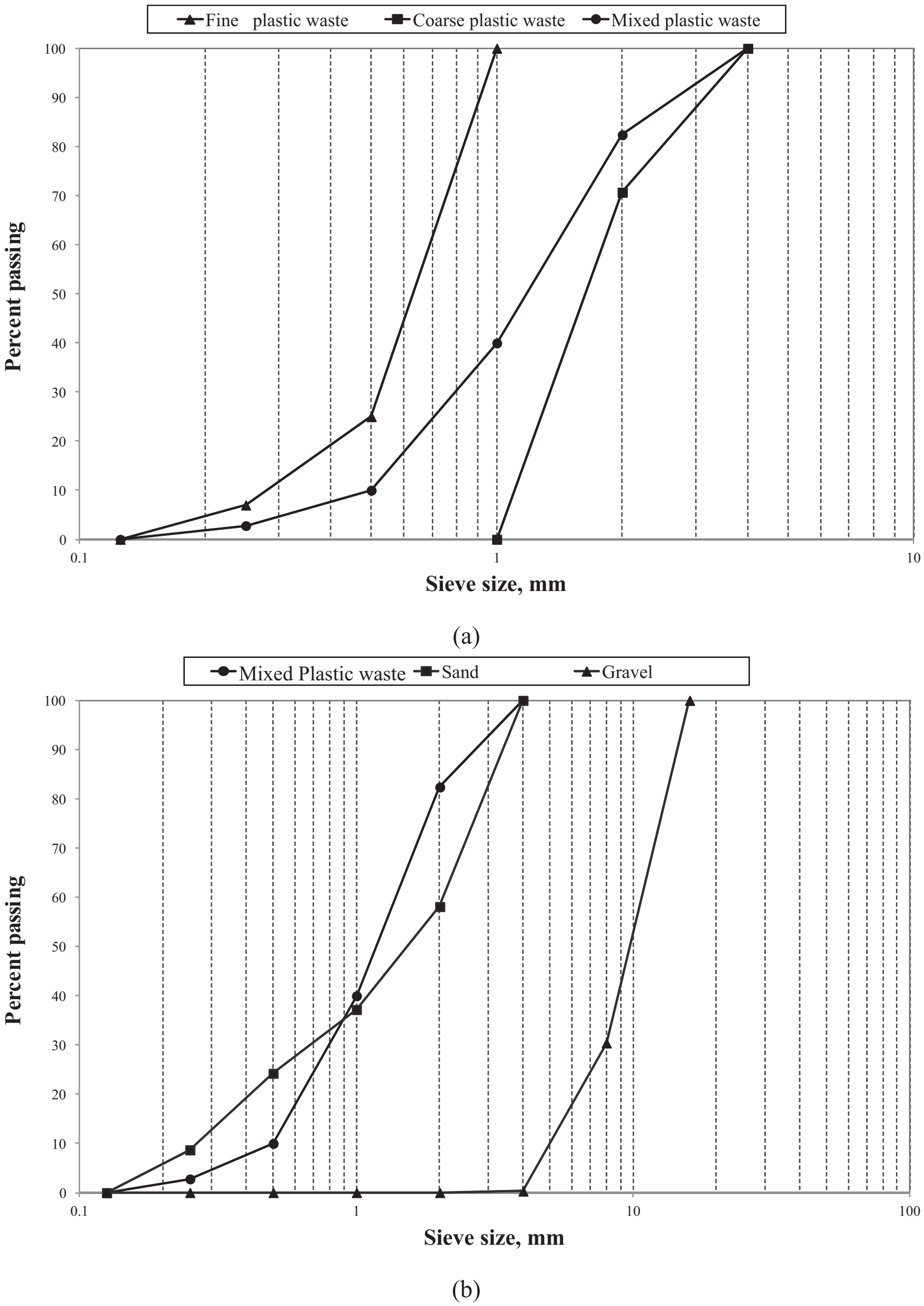


Fig. 1. Sieve analysis of (a) fine plastic waste, coarse plastic waste and mixed plastic waste, and (b) mixed plastic waste, sand and gravel.

- *Plastic waste:* Two different plastic waste sizes are used; fine plastic waste (FPW) passing through 1-mm sieve, and coarse plastic waste (CPW) retaining on 1-mm sieve and passing from 4-mm sieve (see Fig. 1a). Besides 40% of FPW and 60% of CPW were mixed to obtain a new mixed plastic waste (MPW) with sieve analysis closed to sieve analysis of using sand (see Fig. 1b). The specific gravity of (FPW) and (CPW) are 0.52 and 0.68, respectively.
- *Superplasticizer:* To improve workability of the mixes a polycarboxylic ether type of superplasticizer is used. This type acts by steric hindrance effect (Collepardi, 2005). Its specific gravity was 1.07.

2.2. Mixture design

Self-compacting plastic waste concrete (SCPWC) mixtures were designed having a constant w/b ratio of 0.32

and total binder content of 520 kg/m^3. Class F fly ash (30% of cement content by weight) was used in the mixtures. Three different graded Plastic wastes were replaced with fine aggregate at six designated contents of 0, 2.5, 5, 7.5, 10, and 12.5% by volume. Based on these variable totally 16 different SCPWC mixtures, with slump flow diameter of 700 ± 50 mm, were designed as shown in details in Table 2.

2.3. Concrete casting

Mixing procedure proposed by Khayat et al. was adopted to get the same homogeneity and uniformity in all mixes. According to this mixing procedure, the plastic waste, fine and coarse aggregates mixed homogeneously in the mixer for 30 s, and then about half of the mixing water was added gradually with mixing for one more minute. The plastic fiber with the aggregates were left to absorb the water for 1 min. Then cementitious materials (cement and fly ash) were added to the mix and blinding for one more minute. The remaining water and the SP were added to the mixer, then whole contents was mixed for another 3 min, and left for a 2 min rest. Finally, the concrete was mixing for additional 2 min to complete the production. Workability and passing ability of the fresh mixtures were tested by means of different tests mentioned previously. 150*150 mm cubes were using for compressive strength test. The cubic specimens were wrapped with plastic sheet to avoid water evaporated and left in the laboratory for 24 h at 20 ± 2 °C temperature. Next day the specimens were demoulded and tested after 28-day water curing period (Khayat et al., 2000).

2.4. Test procedure

The recommendations in EFNARC committee (European Federation for Specialist Construction Chemicals and Concrete Systems) were followed to carry out the fresh properties test for self-compact concrete: slump flow diameter, T_{50} slump flow time, V-funnel flow time, L-box height ratio (see Fig. 3). While segregation resistance and uniformity of self- compacted concrete can be investigated from the visual observations during measurement of the T_{50} time (EFNARC, 2005). The lower and upper limits for EFNARC classes are illustrated in Table 3. T_{50} slump flow time and V-funnel flow time can be used to evaluate the viscosity of the self-compacting concrete by describing the rate of flow (time of flow). Classifications of viscosity with respect to EFNARC are also presented in Table 3 according to the measured V-funnel and T_{50} slump flow times. The passing ability without segregation and uniformity of self-compact concrete, were measured in terms of L-box test. The classes of passing ability with respect to L-box height ratio values are also listed in Table 3. Compression test results of self-compacting concrete sample was carried out with respect to ASTM C39 as the average of three samples.

3. Results and discussion

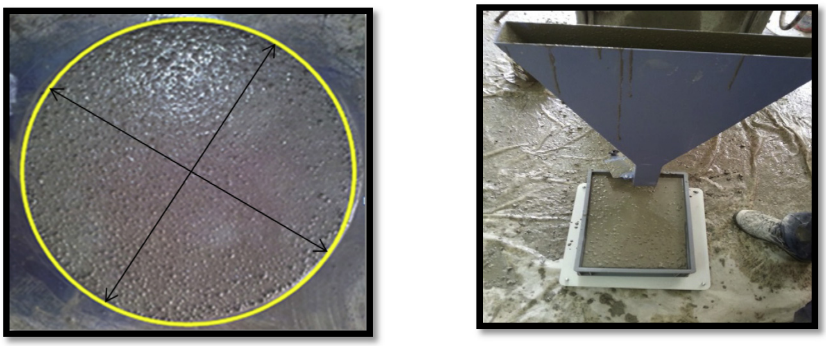
3.1. Slump flow diameter

The self-compacting plastic waste concretes with slump flow diameter values between 675 and 710 mm, which were determined as the average of two measured diameter of flowed concrete as shown in Fig. 3, were produced in the study; however, the slump flow diameter of plain self-compacting concrete was 765 mm. The slump flow diameter values regarding the plastic waste size and content were presented in Fig. 3(a). Fig. 4 illustrated the slump flow classes of the produced SCC. Test results indicated that the producing self-compacting concrete with plastic waste as fine aggregate and according to EFNARC (Table 3), can be categorized as SF2, which is suitable for many

Table 2
Mix proportions for self-compacting plastic waste concrete (kg/m^3).

Mix ID	Water-to-binder ratio (w/b)	Cement	Fly ash	Water	SP	Coarse aggregate	Fine aggregate		FPW	CPW
							Natural sand	Crushed sand		
Control	0.32	364	156	166	3.4	819.4	573.6	245.8	0.0	0.0
2.5 FPW	0.32	364	156	166	3.6	819.1	544.9	233.5	3.95	0.0
5 FPW	0.32	364	156	166	3.9	818.7	516.2	221.2	7.95	0.0
7.5 FPW	0.32	364	156	166	4.2	818.4	487.5	208.9	11.9	0.0
10 FPW	0.32	364	156	166	4.4	818.1	458.9	196.7	15.9	0.0
12.5 FPW	0.32	364	156	166	4.7	817.8	430.2	184.4	19.85	0.0
2.5 CPW	0.32	364	156	166	3.6	819.1	544.9	233.5	0.0	5.3
5 CPW	0.32	364	156	166	3.9	818.7	516.2	221.2	0.0	10.65
7.5 CPW	0.32	364	156	166	4.2	818.4	487.5	208.9	0.0	15.95
10 CPW	0.32	364	156	166	4.4	818.1	458.9	196.7	0.0	21.3
12.5 CPW	0.32	364	156	166	4.7	817.8	430.2	184.4	0.0	26.6
2.5 MPW	0.32	364	156	166	3.6	819.1	544.9	233.5	1.85	2.8
5 MPW	0.32	364	156	166	3.9	818.7	516.2	221.2	3.75	5.6
7.5 MPW	0.32	364	156	166	4.2	818.4	487.5	208.9	5.6	8.45
10 MPW	0.32	364	156	166	4.4	818.1	458.9	196.7	7.5	11.25
12.5 MPW	0.32	364	156	166	4.7	817.8	430.2	184.4	9.35	14.1

Fig. 2. Fine plastic waste (FPW) and coarse plastic waste (CPW).



a: slump flow test

b:V-funnel flow time test

c: L-box test

Fig. 3. Fresh properties tests.

normal applications such as walls and columns. To obtain the self-compacting plastic waste concrete which can be classified as SF2, the superplasticizer content was increased for each replacement level of plastic waste, however, it was kept constant for the plastic waste size at the same replacement level to investigate the effect of plastic waste size. For example, at the reference concrete 3.4 kg/m^3 was used whereas the concrete with 12.5% PW had 4.7 kg/m^{3}superplasticizer content for each plastic waste size. The slump flow diameter was decreasing with increasing plastic waste percentages. The slump flow diameter value of 765 mm for the reference mixture decreased to 710, 675, and 680 mm for the mixtures produced with FPW, CPW and MPW at 12.5% replacement level, respectively. The lowest slump flow diameter values were observed in the concrete produced with CPW. It may be due to that FPW consisted of small particles while the CPW particles were longitudinal as seen in Fig. 2. Therefore, the longitudinal particles blocked the rolling of other ingredients in the mixtures, which adversely affect the self-compatibility of concrete.

3.2. T_{50} slump flow and V-funnel flow times

T_{50} slump flow and V-funnel flow times for self-compacting plastic waste concrete are given in Figs. 5 and 6, respectively. Moreover, T_{50} slump flow time via

Table 3
Slump flow, viscosity, and passing ability classes according to EFNARC.

Class		Slump flow diameter (mm)
Slump flow classes		
SF1		550–650
SF2		660–750
SF3		760–850
Class	T_{50} (s)	V-funnel time (s)
Viscosity classes		
VS1/VF1	≤2	≤8
VS2/VF2	>2	9–25
Passing ability classes		
PA1	≥0.8 with two rebar	
PA2	≥0.8 with three rebar	

V-funnel flow time for each mixture is illustrated in Fig. 8 with respect to viscosity class according to EFNARC (2005). Slump flow time was also influenced by plastic waste content. Increasing the plastic waste content resulted in increasing the slump flow time. Also, as clearly seen from Fig. 5, CPW concrete had the highest slump flow time. The slump flow time for the reference mixture was 1.50 s while the mixture with FPW, CPW, and MPW concrete at 12.5% replacement level had the slump flow time of 3.00, 3.40, and 3.11 s, respectively. As in slump flow diameter, the lowest values of slump flow time were observed in the mixtures produced with FPW at each replacement level. Besides, V-funnel flow time of mixtures showed the almost same trend with T_{50} slump flow time. Increasing the plastic

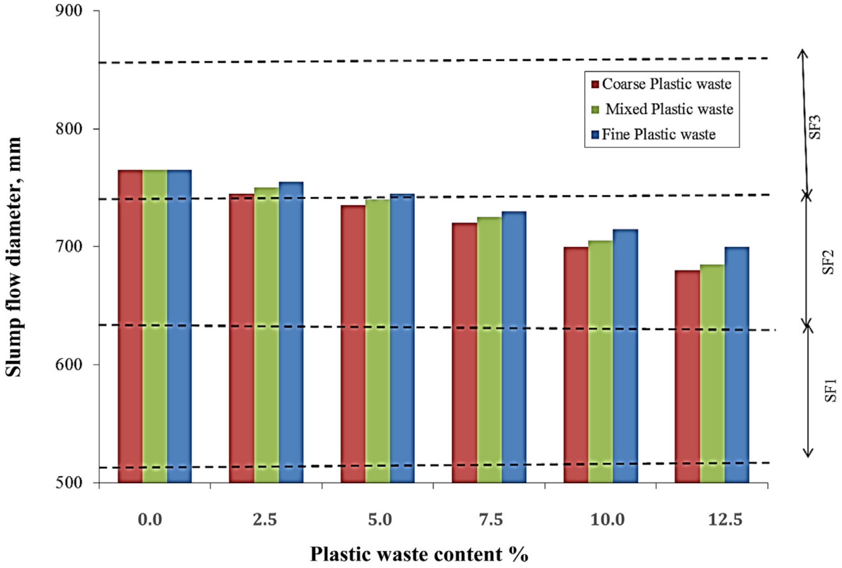


Fig. 4. Variation of slump flow diameter and slump classes of SCC with plastic waste size and content.

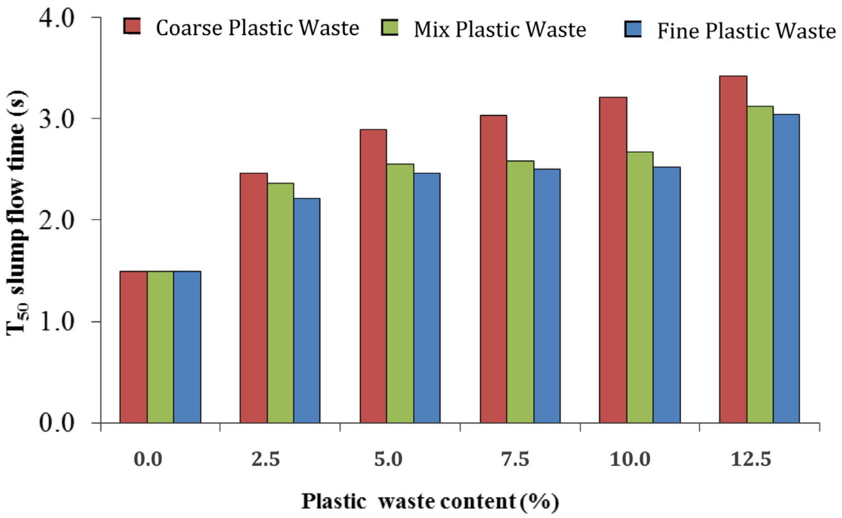


Fig. 5. Variation of T_{50} slump flow time of SCC with respect to plastic waste size and content.

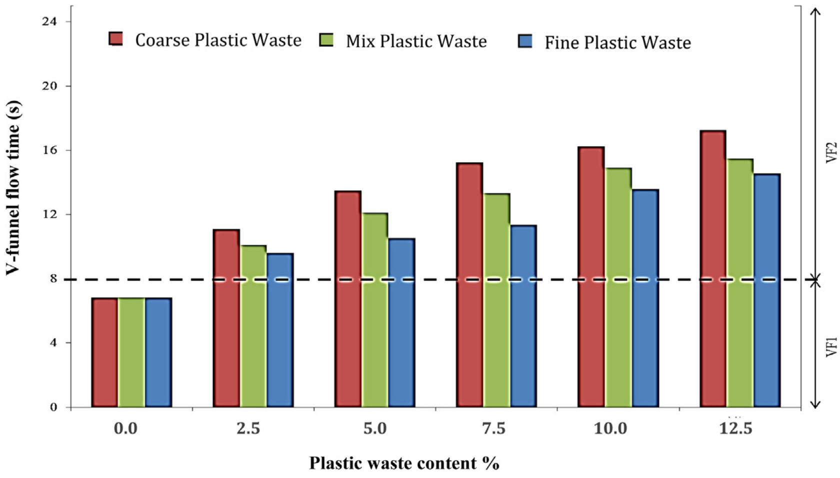


Fig. 6. Variation of V-funnel flow time and viscosity classes of SCC with plastic waste size and content.

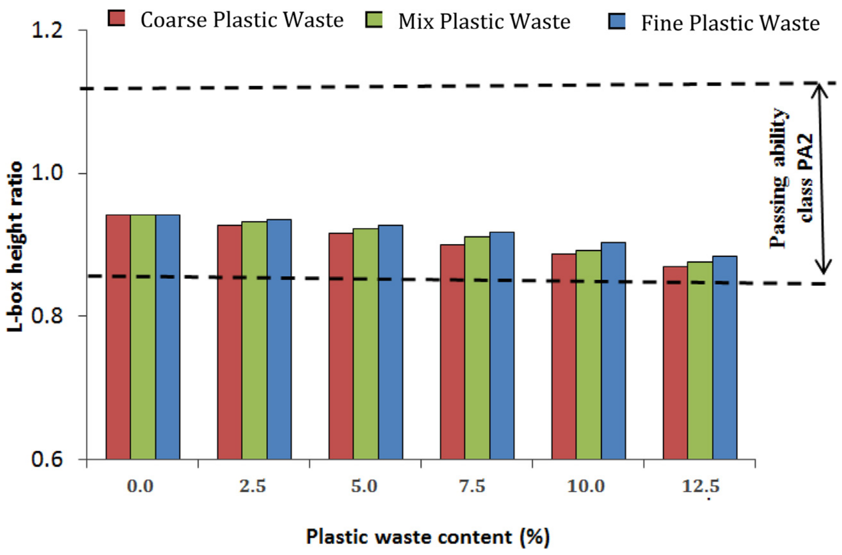


Fig. 7. Variation of L-box height of SCC with respect to plastic waste size and content.

waste content also systematically increased the V-funnel flow time. V-funnel flow times of mixtures were between 6.84 and 17.30 s. V-funnel flow time for reference mixture was 6.84 s while the mixtures 12.5FPW, 12.5CPW and 12.5MPW had V-funnel flow time values of 14.60, 17.30, and 15.51 s, respectively. Moreover, the reference concrete can be categorized as VF1 class, but replacement of plastic waste with fine aggregate changed the viscosity class from VF1 to VF2. Nevertheless, the results obtained from T_{50} slump flow and V-funnel flow times indicated that the produced concrete provides the self-compacting concrete criteria regarding to EFNARC (2005).

When Fig. 6 was considered, it was determined that all self-compacting plastic waste mixtures were in the boundaries of the VS2/VF2 viscosity specified by EFNARC (2005) while the reference mixture was in the VS1/VF1. It was also can be seen that such concretes help enhancing segregation resistance and limiting the formwork weight Bayasi and Zeng (1993).

3.3. L-box height ratio and T_{20} and T_{40} flow time

The L-box height ratio by means of H2/H1 ratio was also determined to specify the passing ability of the produced SCCs. The test carry out using three bar L-box test which simulates the case of more congested reinforcement (EFNARC, 2005) as shown in Fig. 3(c). The L-box height ratio must be equal to or greater than 0.8 to certify and ensure that the self-compacting concrete has the required passing ability. For perfect fluid behavior of self-compact concretes, L-box height ratio value is 1.0. According to Fig. 7, all mixtures satisfy the EFNARC limitation for the given L-box height ratio. The L-box height ratio value for the reference mixture was 0.94 while it was 0.88, 0.86, and 0.87 for the mixtures 12.5 FPW, 12.5 CPW, and 12.5 MPW, respectively. Even though the concretes produced with CPW had the lowest L-box height ratio, the difference between the concretes produced with FPW and MPW was not too much. In addition, increasing in the

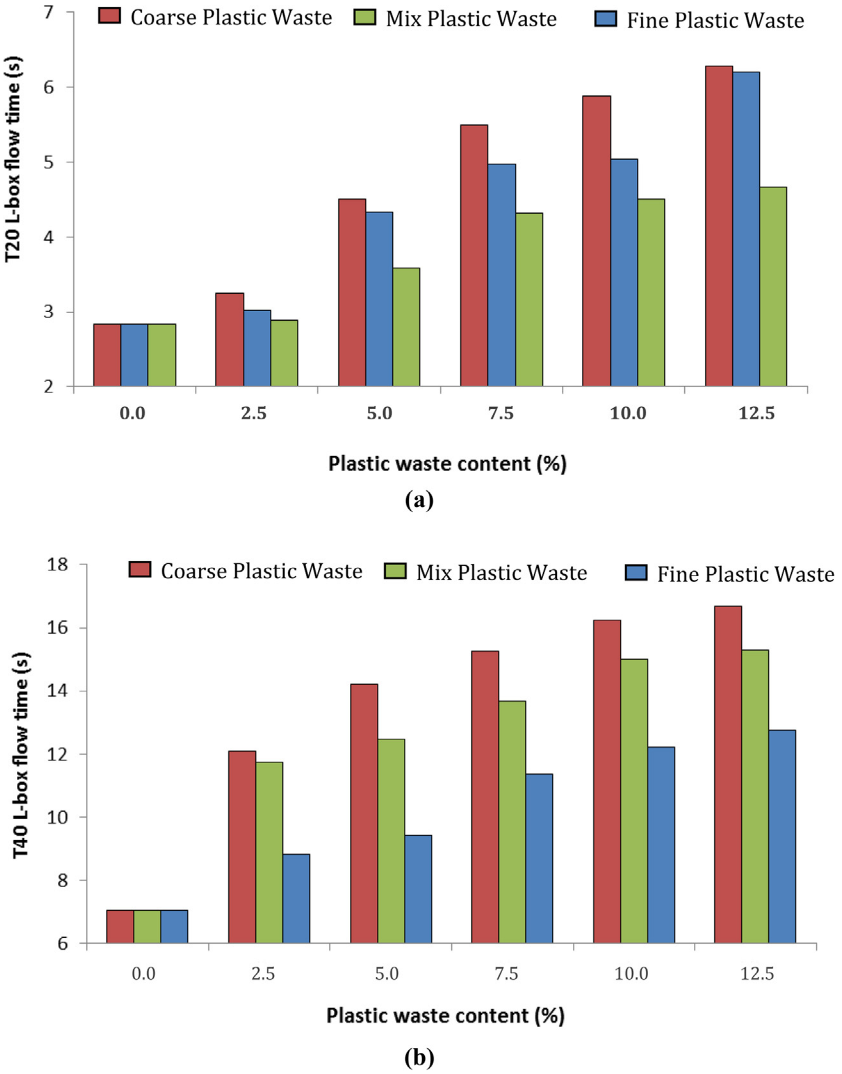


Fig. 8. (a) Variation of T_{20} L-box flow time of SCC with plastic waste size and content and (b) variation of T_{40} L-box flow time of SCC with plastic waste size and content.

plastic waste content resulted in systematical decreasing of L-box height ratio, irrespective of the plastic waste size.

T_{20} and T_{40} results which give some indication about the easy flow of the concrete mixtures are presented in Fig. 8a and b, respectively. L-box T_{20} and T_{40} times of the reference mixtures were about 2.86 and 7.07 s, respectively. It was observed that replacing the fine aggregate with the plastic waste increased the T_{20} and T_{40} times to 4.77 and 12.65 s for the mixture 12.5 FPW, 6.27 and 16.70 s for the mixture 12.5 CPW, and 6.24 and 12.77 s for the mixture 12.5 MPW, respectively.

3.4. Compressive strength

The 28-day compressive strength of mixtures is given in Fig. 9. The range of compressive strength values in this work were about 65–37 MPa. Decreasing in compressive strength was observed as plastic content increased comparison with control mix without plastic waste. This may be because the plastic waste is a soft material when compared with natural aggregate. The using of plastic waste as fine aggregate in self-compact concrete production results in decreasing of compressive strength. Other researchers (Panyakapo, 2008) reporting a reduction in compressive strength with plastic waste content increase is due to the poor adhesion between cement paste and plastic waste. The self-compacting concretes produced with CPW gave the lowest compressive strength, while those produced with FPW gave the highest compressive strength. The coarse plastic particles affect the properties more negatively than do fine particles [21]. The compressive strength values of 12.5 FPW, 12.5 CPW, and 12.5 MPW are 47.0, 37.0, and 42 MPa, respectively. Fig. 10 shows shape of failure for CPW and FPW.

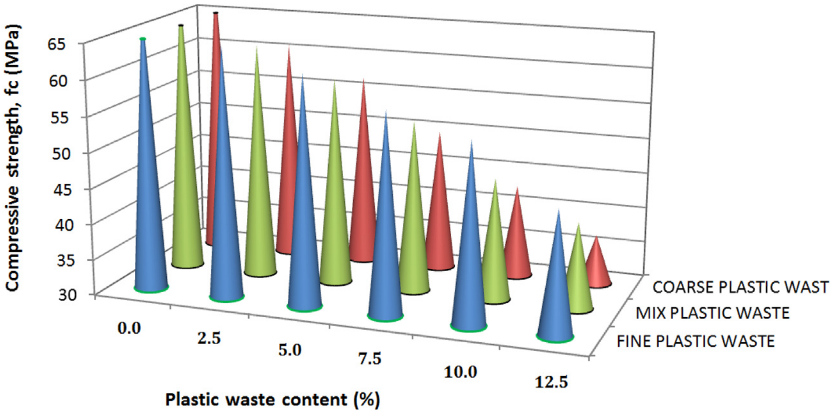


Fig. 9. Variation of 28-day compressive strength with respect to plastic waste size and content.

(a) (b)

Fig. 10. (a) Cubic failure under compressive force test for with FPW. (b) Cubic failure under compressive force test for with CPW.

4. Conclusions

Based on the results of presented work, the following main concluding remarks are made:

- Slump flow diameters ranging from 675 and 710 mm were obtained for the self-compacting plastic waste concretes. According to EFNARC limitation the reference mixture was within the SF3 class while the self-compacting plastic waste concretes was within the SF2 class. Although increasing the plastic content resulted in reducing in the slump flow diameters of concretes, the results were acceptable for the many normal application of self-compact concrete. The slump flow diameters of mixtures produced with coarse plastic waste which has the longitudinal particles were less than that of produced with fine plastic waste and mixed plastic waste.
- Using plastic waste as partial replacement of fine aggregate increased both T_{50} slump flow and V-funnel flow times. The reference mixture can be categorized as VS1/VF1 viscosity class, while the mixtures produced with partially replacement of plastic waste was in the VS2/VF2 viscosity class.
- The L-box height ratio was also affected by the content and size of using plastic waste. Increasing the plastic waste content caused systematical decreasing the L-box height ratio. However, all mixtures have the L-box height ratio values more than 0.8 which is the lower limit specified by EFNARC. The CPW concrete utilization resulted in the lower L-box height ratio whereas the concretes produced with FPW, which has the more rounded particles, gave the higher L-box height ratio. Moreover, using the plastic waste caused increasing of the L-box height ratio,T_{20} and T_{40} flow times.
- The results are showed a gap between the T20 and T40 times for FPW as comparing with those of MPW and CPW. It may be concluded that it would be better to use the FPW as partial replacement of fine aggregates.
- Self-compacting plastic waste concrete having more than 35 MPa compressive strength could be produced easily. The strength results indicated that the utilization of plastic waste in self-compacting concrete manufacturing resulted in systematical decreasing of the compressive strength. The coarse plastic waste utilization decreased the compressive strength of self-compacting concrete more than the using of fine plastic waste.

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