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Impact of Partial Replacement of Ordinary Aggregate by Plastic Waste Aggregate on Fresh Properties of Self-Compacting Concrete

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Abstract: Different properties of Self-compacting concrete (SCC) containing plastic waste aggregate (PWA) have been experimentally studied by researchers. However, most of these works focused on examining the properties of one type of PA. In the present paper, the influence of four different types; namely Polyvinyl chloride (PVC), Heat-treated plastic (PEL), Mixed plastic (Mix), and polyethylene terephthalate (PET) as a fine aggregate (FA) replacement; on fresh properties of SCC was examined. Results indicated that changing the PWA geometry influenced different properties of SCC. All concrete samples with PVC and PEL plastic were in the range of EFNARC classification (classified in VS2/PA2 class), causing no blocking in V-funnel and L-box test. Meanwhile, mixed plastic up to 7.5% and PET up to 5% fall within VS2/VF2 class; otherwise, the mixture was outside the range of EFNRAC standards. The best plastic waste aggregate regarding all new properties was PVC confirming all requirements for a successful SCC, causing no blocking or segregation. Thus, 10% was selected as the optimum percentage. Furthermore, PET was the worst, for PET-7.5% significant increase in the V-funnel (57.6 sec) and reduction in H2/H1 ratio (0.58) was obtained besides blocking in L-box tests, segregation, and bleeding in slump flow test. Thus, more than 5% is not recommended when using PET in Self-compacting concrete.

تأثير الاستبدال الجزئي للركام العادي بركام النفايات البلاستيكية على خصائص الخرسانة الطرية ذاتية الرص

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الخلاصة

تمت دراسة الخصائص المختلفة للخرسانة ذاتية الرص المحتوية على ركام النفايات البلاستيكية تجريبياً من قبل الباحثين. ومع ذلك، ركزت معظم هذه الأعمال على فحص خصائص نوع واحد من ركام النفايات البلاستيكية. في هذا البحث، تم فحص تأثير أربعة أنواع مختلفة وهي؛ كلوريد البوليفينيل (PVC) والبلاستيك المعالج بالحرارة (PEL) والبلاستيك المخلوط (Mix) والبولي إيثيلين تيريفثاليت (PET) كبديل للركام الناعم (FA) على خصائص الخرسانة الطرية ذاتية الرص. تشير النتائج إلى أن تغيير التكوين الهندسي لركام النفايات البلاستيكية له تأثير على الخصائص المختلفة للخرسانة ذاتية الرص. كانت جميع عينات الخرسانة التي تحتوي على بلاستيك PVC وPEL في نطاق تصنيف EFNARC (المصنف في فئة VS2 / PA2) مما تسبب في عدم انسداد في فحص الانسيابية للخرسانة وL-box. في غضون ذلك، يقع Mix البلاستيك حتى 7.5٪ وPET حتى 5٪ ضمن فئة VS2 / VF2، وإلا فإن الخليط لا يقع في نطاق معايير EFNRAC. أفضل ركام النفايات البلاستيكية فيما يتعلق بجميع الخصائص الخرسانة الطرية هو PVC الذي يوفي بجميع متطلبات الخرسانة ذاتية الرص الناجحة والتي لا تسبب أي انسداد للـ L-box أو انعزال مكونات الخرسانة. وبالتالي، يتم اختيار 10٪ من هذه المادة على أنها النسبة المثلى كبديل للركام الناعم. علاوة على ذلك، كان PET هو الأسوأ، بالنسبة لـ PET-7.5٪ تم الحصول على زيادة في فحص انسيابية الخرسانة (57.6 ثانية) وانخفاض في نسبة H2 / H1 (0.58) هذا بجانب انسداد في اختبارات L-box وانعزال مكونات واستنزاف الخرسانة في فحص الهطول للخرسانة. وبالتالي، لا يوصى باستخدام أكثر من 5٪ عند استخدام PET في الخرسانة ذاتية الرص.

الكلمات الدالة: فحص L-box، ركام النفايات البلاستيكية، الخرسانة ذاتية االرص، فحص الهطول للخرسانة، فحص الانسيابية للخرسانة.

1.INTRODUCTION

Self-compacting concrete (SCC) is a type of special concrete that can readily slide and flow inside different portions of formwork. Also, it provides exceptional consolidation within the intended formwork due to its weight. It requires no external or internal vibration and leaves no faults due to bleeding or segregation [1,2]. For this concrete, high compressive strength and durability improvements can be achieved due to the composition of a highly condensed microstructure of the mixture of these elements [3]. The issue of recycled SCC is relatively new, and studies on such type of concrete are limited. Recent experimental works on recycled concrete have been directed to investigate the best usage of plastic waste material as an aggregate or fiber added to the concrete mixture. Plastic consumption has recently dramatically increased, resulting in significant plastic waste (PW) accumulation worldwide [4]. Over the last few decades, a large amount of non-biodegradable waste, particularly PW, has posed serious environmental challenges. Additionally, PWs are considered the most threatening sources of pollution [5-8]. Recycling PW for concrete production is one possible solution to reduce the impact of PW on the environment. To pave the way for new experimental work on PWA content SCC, it is better to review the published literature comprehensively. Safi et al. [9] found that the SCC mixture flowability improved after adding PET particles. In a study, Sadrmomtazi et al. [10] conducted tests on SCC containing 5, 10, and 15% PET aggregate as FA replacement. 10% fly ash and 30% silica fume (SF) as a cement replacement were used in some mixtures. In terms of the individual mixes' performance, the slump, V-funnel, and L- box height ratio (H2/H1) were all within the SCC specifications. Only slight segregation was observed in the samples containing 15% PET. In addition, compared to the control sample, the mixtures with SF required more SP; however, mixtures with fly ash required less Superplasticizer (SP) to achieve the required workability. Based on tests by Sakin [11], the PET replacement ratio was limited to 5 % because the number of chemical additions significantly increased at a ratio of more than 5 %, and the V-funnel flow time exceeded 25 seconds at a PET ratio of 6% or more. Hama and Hilal [12] concluded that slump decreased with increasing plastic additive such that only the control sample and the mixture with 2.5% substitute complied with class SF3 according to *EFNARC* standard [1] see Table 1. This reduction was true for the L-box and was higher for the samples with coarse plastic waste (CPW) aggregates than for those with fine plastic waste (FPW) aggregates. The time required for V-funnel, slump flow, and T50 increased for the samples with waste aggregates. Mermerdaş et al. [13] found that the maximum PET aggregate in the mixture should be limited to 5% to avoid losing workability. Results showed that the flow and viscosity behavior of SCC was significantly affected. They concluded that the production of high-performance SCC with 5% PET granules met all the requirements of SCC with satisfactory results. Hamzeh [14] replaced 10% of the cement with SF to improve the strength properties. Adding PVC granules as coarse aggregate (CA) to SCC mixtures up to 60% improved workability and met the requirements for self-compacting concrete in terms of V-funnel and viscosity [1]. The best results in the fresh state obtained by Aswatama et al. [15] were for the mixture with a maximum PET replacement of 10%, which had a slump, V-funnel, and H2/H1 value of 815 mm, 9.5 mm, and 0.96, respectively, compared with those of control mixture: 760 mm, 13.4 mm, and 0.93 respectively. Neeraja and Sharma [16] found that the fresh concrete properties were in the range of SCC, the value of T50 in slump flow, and the V-funnel test was lower for all mixtures compared with the control one; however, the most significant improvement was achieved for the sample with 6% PVC and 20% fly ash. Further, Hilal et al. [17] classified the slump flow diameter and L-box for a mixture with up to 20% polyethylene waste replacement into SF3 and PA2 classes. Furthermore, Faraj et al. [18] found that a systematic relationship cannot be observed between recycled polypropylene plastic particles (RPPP) content and fresh properties of SCC. The Mixture containing 10% RPPP and 10% SF showed the highest slump diameter. According to tests by Kumar et al. [19], flowability increased with increasing PET replacement meeting SF1 class according to *EFNARC* standard [1]. The minimum flow value of 557 mm was measured for the control sample, and the maximum value for the sample with 40% PET was 627 mm. On the other hand, the V-funnel values for the samples with 0, 10, 20, 30, and 40% PET were 8.9, 8.6, 8.5, 8.0, and 9.4, respectively.

Table 1 Slump flow, viscosity, and passing ability classes according to EFNARC [1].

Class	**Slump flow diameter (mm)**	
Slump flow classes		
SF1	550 – 650	
SF2	660 -750	
SF3	760 – 850	
Class	**T50 (sec)**	**V-funnel time (sec)**
Viscosity classes		
VS1/VF1	≤ 2	≤ 8
VS2/VF2	> 2	9 -25
Passing ability classes	≥ 0.8 with two rebar	
PWA1	≥ 0.8 with two rebar	
PWA2	≥ 0.8 with three rebar	

From the previous presentation, it can be found that the experimental work conducted focused on different ratios of a single type of PWA or coarse aggregate (CA) added to SCC mixtures. In some experiments, supplementary materials such as fly ash and silica fume were used in concrete as a cement replacement. The authors think that the effect of PWA type as FA in terms of source and geometry on fresh properties of SCC has yet to be well understood, and no precise comparison with the same mixture design and materials is available. Besides, most researchers focused on studying the effect of PET plastic in SCC; only a few studies are available for PVC plastic as FA, and this is the case for Mixed plastic as well. Thus, the main goal of the present experimental study is to evaluate the influence of using different PWAs; PVC; PEL, irregular Mixed, and regular PET particles, mainly concerning the geometry, on fresh properties of SCC. The outcomes of this experiment are advantageous for the accurate mix design of recycled SCC and for producing sustainable, eco-friendly concrete for better structural and non-structural applications. Also, the present study paves the way for further research by indicating the optimum percentage for each PWA type.

2. MATERIALS AND METHODS

2.1 Materials

Ordinary Portland cement (CEM I 42.5R) was used throughout the present study. The cement's physical properties and chemical composition are shown in Tables (2, 3), respectively. The cement conforms to the specifications of ASTM C150 [20] and ASTM C114 [21].

Table 2 Physical properties of cement and limits of ASTM C150 [21]

Tests name	**Test procedure**	**Tests results**	**Allowable limits**
Blaine Fineness (cm^2/gm)	ASTM C115 [22]	3535	2600-4300
Normal consistency (%)	ASTM C187 [23]	26.9	-
Initial setting time (minute)	ASTM C191 [24]	140	Not less than 45 minutes
Final setting time (minute)	ASTM C191 [24]	190	Not more than 375 minutes
Density	ASTM C188 [25]	3.14	-
Bulk density (gr/cm^3)	-	1.44	

Table 3 Chemical composition of cement and limits of ASTM C114 [21]

Composition name	**Test results (%)**	**Allowable limit (%)**
SiO_2	19.12	-
Al_2O_3	4.53	6 (max)
Fe_2O_3	4.55	6 (max)
Cao	62.52	-
MgO	3.75	6 (max)
SO_3	2.42	3 (max)
K_2O	0.47	-
Na_2O	0.12	-
CO_2	2.53	-
LSF (Lime Saturation Factor)[1]	101.12	-
Silica Ratio	2.1	-
Aluminum Ratio	0.995	-
C_3S	65.39	-
C_2S	5.45	-
C_3A	4.31	8 (max)
C_4AF	13.86	-

[1] The ratio of the actual amount of lime in raw meal/clinker to the theoretical lime required.

Natural rounded river gravel at saturated surface dry (SSD) state was used as CA with a maximum size of 12.5 mm, specific gravity of 2.45, dry rodded bulk density of 1712 kg/m³, and water absorption of 0.48%. Grading of CA was according to ASTM C136/C136M [26] (as shown in Fig. 1). Natural river sand of fineness modulus of 2.87, a specific gravity of 2.64, dry rodded bulk density of 1785 kg/m³, water absorption of 1.43%, and materials finer than 75 microns sieve of 2.58% were used. The grading of FA is shown in Fig. 1, which conforms to ASTM C136/C136M [26] limits. SP admixture, known as PCE 4880 liquid, was used for all concrete mixtures. The chemical base is a long-chain polycarboxylic polymer complying with ASTM C494 [27] Type F and EN934-2 Chart 3.1, 3.2 [28]. Four types of plastic aggregate (PA) with different geometries were used in concrete mixtures as fine aggregate replacements. Actual PA and SEM views of PA are given in Figs. (2, 3), respectively. The physical properties and chemical composition of the plastic obtained from XRF analysis (ASTM - E1621) [29] are shown in Tables (4, 5), respectively. Fig. 4 shows the grading of different PAs according to ASTM C136/C136M [26] limits. 100% of the plastic passed through the 4.75 mm sieve and remained on the 1.18 mm sieve.

(a) The shredded PVC plastic had a white color, irregular flaky shape particles, of fineness modulus equal to 3.83, and specific gravity equal to 1.64 (ASTM C128) [30].

(b) Heat-treated plastic is produced by collecting, washing, crushing, heating it to melting temperature, and cooling it in the form of small cylinder particles. This plastic aggregate had a dark black color and a very smooth outer surface. PEL aggregate's fineness modulus and specific gravity were 4.99 and 1.0, respectively.

(c) Mixed plastic aggregate of irregular shape was prepared from collecting various plastic wastes such as fruit boxes and water pipes. After collection and washing, the plastic was crushed to pass on 4.75 mm and retain on 150 µm sieves, with a fineness modulus of 4.82 and a specific gravity of 1.08.

(d) PET aggregate was prepared from 16 L PET bottles and had a light blue, flaky, regular shape with sharp edges. The fineness modulus was 4.92, and the specific gravity was 1.22.

Table 4 Chemical composition of plastic aggregate obtained from XRF analysis.

Plastic	**C**	**Si**	**Na**	**Al**	**O**	**As**	**Cl**	**Pb**	**Cu**	**Au**	**SiO_2**	**CaO**	**TiO_2**	**LOI**
PVC						0.52	11.75	1.19	0.14		0.94	22.75	0.707	62
PEL	99.65	0.21	0.14	-	-	0.21			-	-				
Mixed	98.59	0.54	0.45	0.42	-	0.54			-	-			-	
PET	64.17	0.08	-	0.65	33.52	0.08		33.52	-	1.59				

Table 5 Physical properties of plastic aggregate.

Properties	Standard specification for test	Test results			
		PVC	PEL	Mixed	PET
Geometry	-	Irregular flaky	Cylindrical	Irregular none flaky	Regular flaky
Oven dry (OD) specific gravity	ASTM C128 [30]	1.64	1.0	1.08	1.22
Dry rodded bulk density (Kg/m³)	ASTM C29/C29M [31]	909.7	519.3	567.2	520.18
Void ratio (%)	ASTM C29/C29M [31]	45	48	48	57

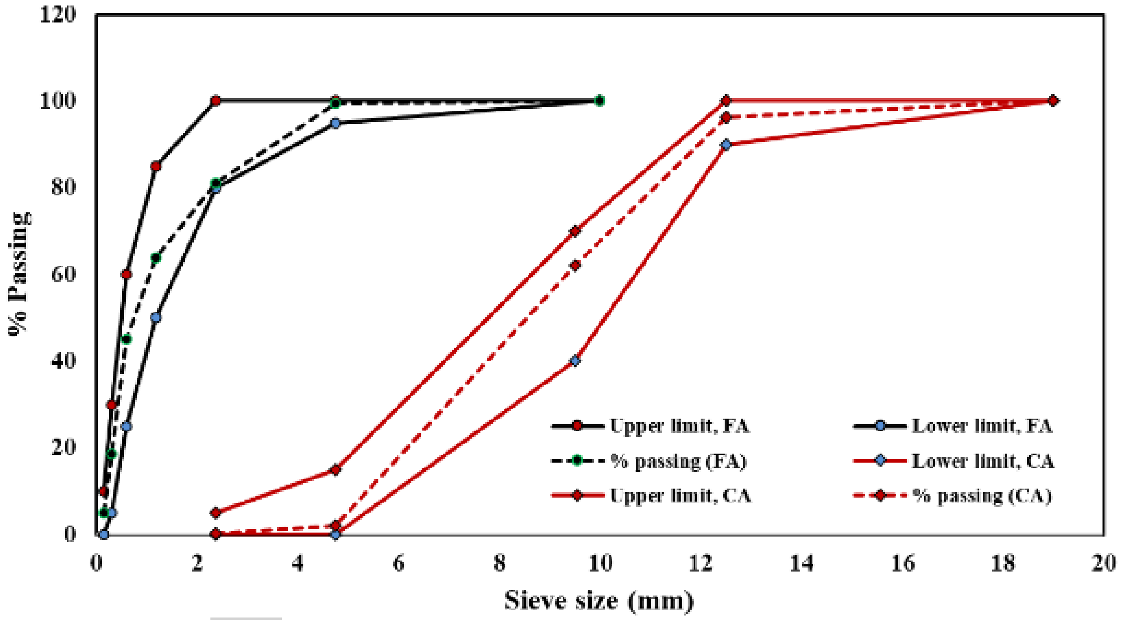
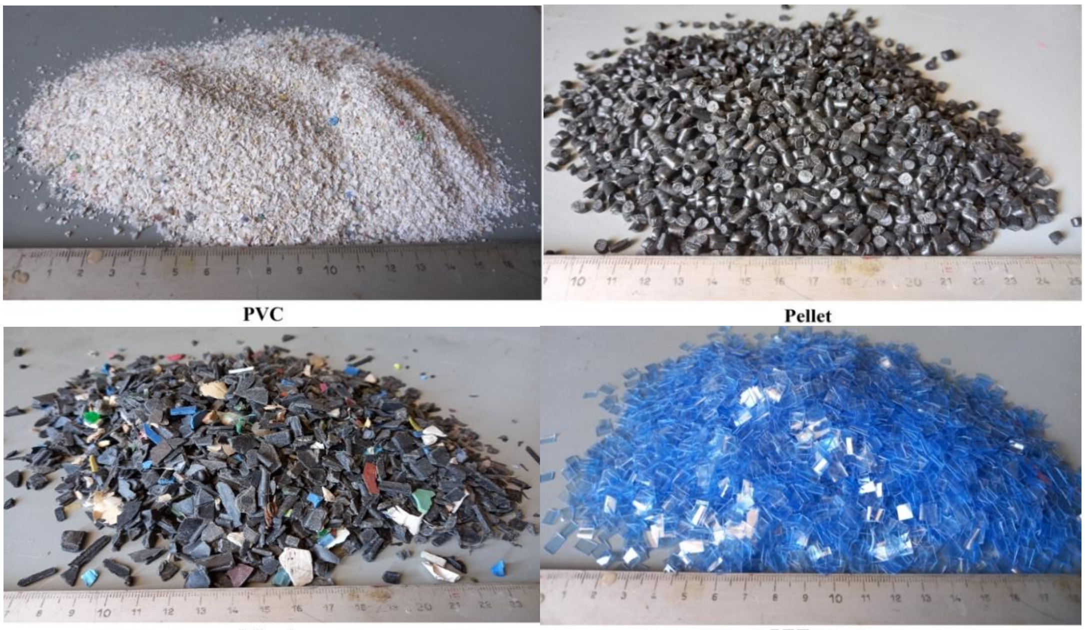


Fig. 1 Grading Curve of Aggregates and ASTM C136 Limits.



PVC Pellet

Mixed PET

Fig. 2 View of Different Plastic Waste Aggregates used in This Study.

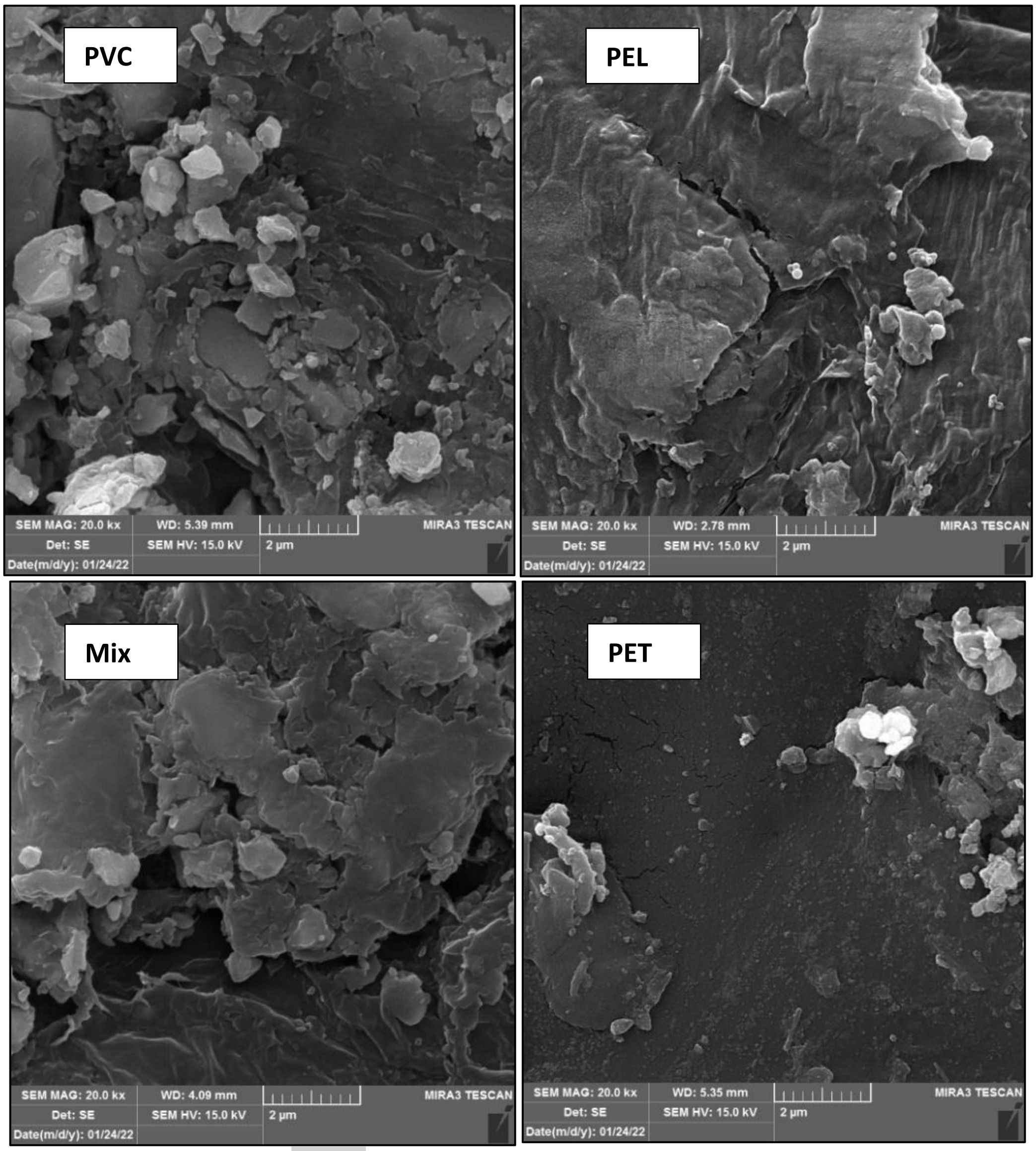


Fig. 3 SEM image of plastic aggregate.

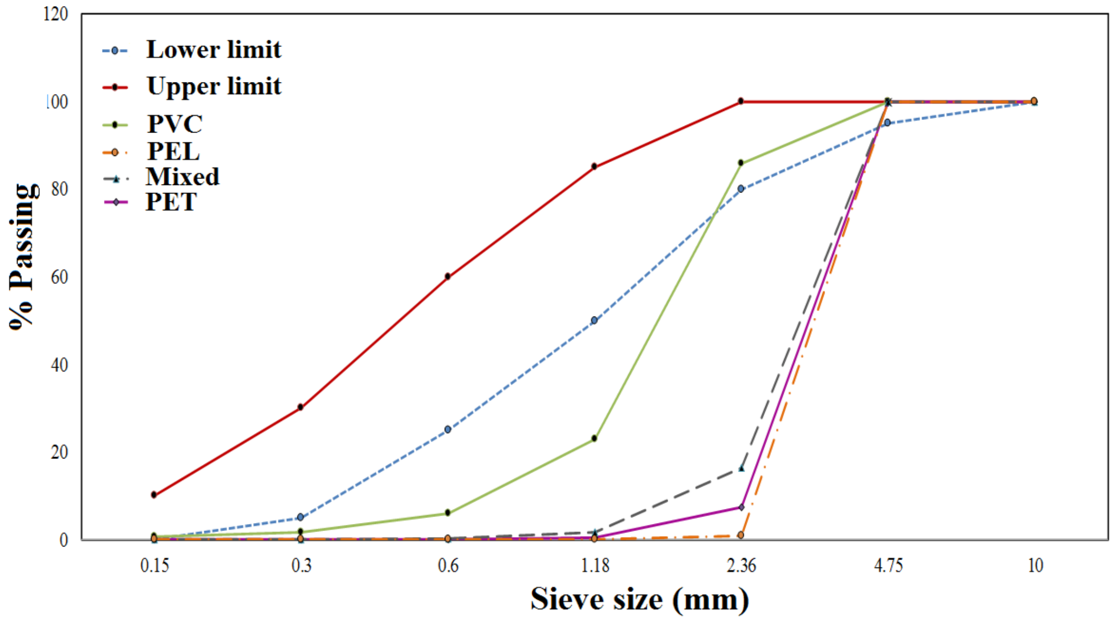


Fig. 4 Grading curve of different plastic aggregates and ASTM C136 limits.

Table 6 Mixture proportion of concrete mixtures with four PA and different replacement percentages.

Mixes	Water (Kg/m^3)	Cement (Kg/m^3)	FA (Kg/m^3)	CA (Kg/m^3)	SP (Kg/m^3)	PVC (Kg/m^3)	PEL (Kg/m^3)	Mixed (Kg/m^3)	PET (Kg/m^3)
Mix 0	155	500	906	776.0	7.75	-	-	-	-
Mix 2.5			883			14.07	7.12	9.27	10.47
Mix 5			861			28.14	14.24	18.53	20.94
Mix 7.5			838			42.21	21.36	27.80	31.40
Mix 10			815			56.28	28.49	37.07	41.87

2.2 Methodology

In this experimental study, besides the control concrete mixture without PA, a total of sixteen mixes were prepared by substituting fine aggregate with different plastic waste aggregates (PVC, PEL, Mixed, and PET plastic) by 2.5, 5, 7.5, and 10% as sand replacement. The following tests were carried out: Fresh concrete tests: slump flow, V-funnel, and L-box.

2.2.1 Mix proportion, mixing, casting, and curing

The control mix was designed with 500 Kg/m^3 cement, 0.31 w/c ratio, 776 Kg/m^3 of CA, 906 Kg/m^3 of FA, and a 1.55% superplasticizer. Other mixtures were prepared by replacing FA with four types of PA using four replacement percentages (2.5, 5, 7.5, and 10%) by volume. The mixture proportion of the different concrete mixtures is given in Table 6. The mixing procedure proposed by Khayat et al. [32] was followed. Fine and coarse aggregates were mixed homogeneously in a mixer for 30 seconds. Then about half of the mixing water was added while mixing and continued for another minute. Later, binders were added to the mixture and were mixed for another minute. The remaining water and SP were added to the mixer, and the entire contents were mixed for three more minutes and left to rest for two minutes. Finally, the concrete was mixed for another two minutes. The fresh mixtures' flowability was measured using the slump flow test. The concrete was then poured into molds. The test specimens were wrapped with plastic film to prevent water evaporation and stored in the laboratory for 24 hours. Later, the specimens were de-molded, left in a water tank for curing for 28 days, and then tested.

2.2.2 Slump flow test

The slump flow test was done according to ASTM 1611/C 1611M [33] to indicate the filling ability and, to some extent, the cohesion of SCC. The base plate was horizontally aligned, and the surface of the cone and the plate were damped with a wet cloth. The slump cone was placed gently on the base, filled with concrete, and lifted vertically. Timing started when lifting the slump cone began and stopped when the concrete reached the 500 mm circle marked on the plate (T50). When the concrete stopped flowing, two perpendicular diameters were measured, and the average result was taken as flow diameter (D).

2.2.3 V-Funnel test

The V-funnel test was carried out following the EFNARC specifications [1] to determine the filling ability of concrete. The detail of the apparatus is shown in Fig. 5. Approximately 12 liters of concrete were required to perform this test. The V-funnel was placed on a flat, firm floor, and its inside surface was moistened entirely with a damp cloth. Then it filled with concrete, and after 10 seconds, the trap door was opened. The time taken for the concrete to flow completely under its gravity was measured as the flow time. Based on the measured flow time, the concrete was divided into several classes [1].

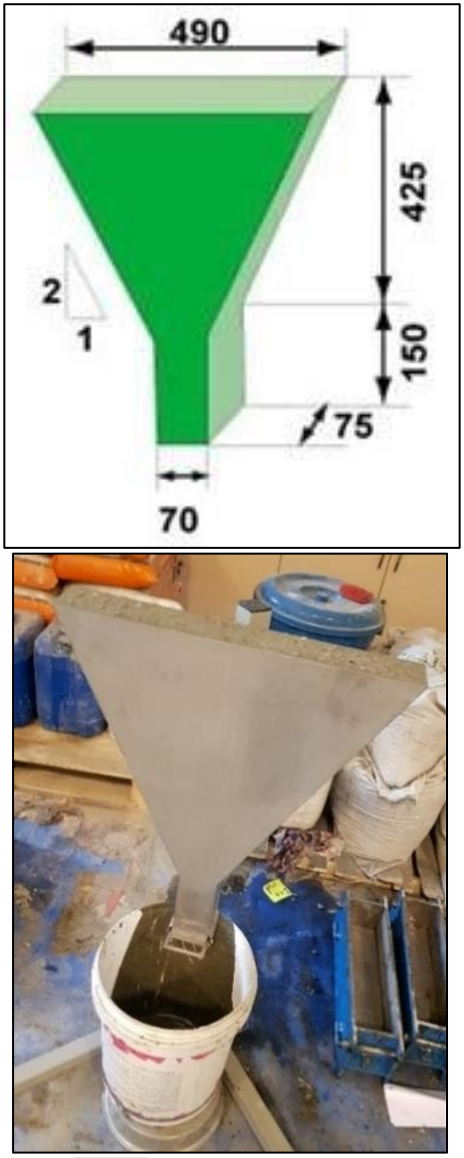


Fig. 5 V- funnel apparatus

2.2.4 L-box test

The L-box device consists of a rectangular box in the shape of an "L" with vertical and horizontal sections separated by a movable gate in front of three vertical rebars (see Fig. 6). Approximately 14 liters of concrete were required to carry out this test. The L-box was placed on a flat and solid floor. Firstly, the vertical section of the L-box was filled with concrete and left to stand for one minute. Later, the sliding gate was lifted, and the concrete was left to flow into the horizontal section. The time required to reach the 200 and 400 concrete marks was recorded. When the concrete stopped flowing, distances H1 and H2 were measured. H2/H1 was then calculated, indicating the slope of the concrete at rest and providing an indication of passing ability. The H2/H1 ratio in the range of 0.8-1 indicates the best passing ability of the concrete (ACI 237R) [34].

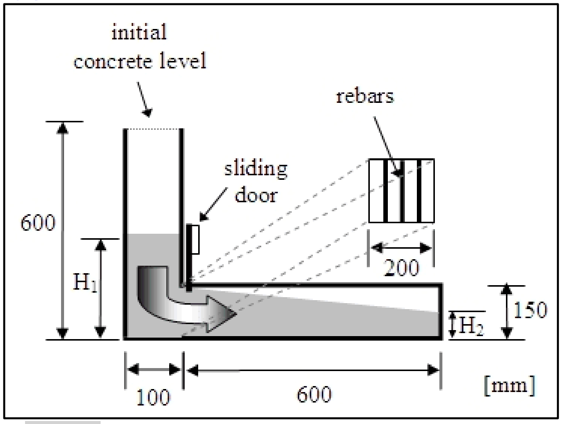


Fig. 6 Dimensions and details of the L-box

2.2.5 Compressive strength

A 100x200 mm cylinder was used to cast three samples in each mixture for the compressive strength test. The specimens were cured, capped according to the ASTM C617M requirements [35], then tested according to ASTM C39 [36] specification, under a loading rate of 0.25 MPa/sec.

3. RESULTS AND DISCUSSION

The flow diameter for the control mixture was 765 mm, and the flow time was 2.24 sec. Meanwhile, the V-funnel flow time was 12.94 sec, and H2/H1 was 0.95, which was in the range of 0.8-1.00.

3.1 Slump flow test

Figs. (7, 8) show the T-50 flow time and slump flow diameter, respectively, for all SCC mixtures. On replacing FA with PVC plastic, the slump flow time was higher than the control sample and gradually increased from 2.9 for 2.5% PVC content to 3.4 sec for 10% PVC content. Only PVC-5% had an exceptional case by recording the same value as the control sample (2.2 sec). Based on the obtained data. All samples, including the control sample, were considered in the VS2 class. On the other hand, the flow diameter decreased with increasing the PVC percentage and was classified in SF3 up to 7.5% of replacement; however, with 10% of PVC, the diameter decreased to 738 mm, which was classified in SF2. The obtained results are opposite to the results obtained by Neeraja and Sharma [16] when replaced FA with PVC aggregate may be due to the good action of fly ash when replaced with cement by 20%, which increased the consistency and flowability of the mixture. Based on the visual observations, no segregation and no bleeding were observed for all replacements (see Fig. 9). However, the workability decreased with increasing PVC percentage because the PVC particles were very soft, and some crashed during mixing. There was an increase in the time by 68% for the mixture containing 7.5 and 10% PEL aggregate (considered in the VS2 class). At the same time, the flow diameter, which was classified as SF3, was found to be higher than the control sample for mixtures up to 7.5% PEL content but decreased to 717 mm for the mixture containing 10% PEL aggregate (classified as SF2). Furthermore, a systematic relationship cannot be observed between plastic replacement and D or T50. The same results were obtained by Hilal et al. [17] and Faraj et al. [18]. No segregation or bleeding was observed for the mixture with 2.5% PEL aggregate; however, for the other replacements, the mixture tended to segregate (see Fig. 10). This could be attributed to the plastic's low density and non-absorbent property. These effects were more pronounced for the mixture with 7.5% and 10% PEL contents. For the SCC mixture with Mixed plastic aggregate, T50 time was reduced from 4.2 sec to 2.2 as PA increased from 2.5% to 7.5% (classified as VS2 class). However, T50 decreased to 1.9 sec for the mixture with 10% Mixed aggregate (classified as VS1). Therefore, the flowability of SCC containing Mixed aggregate differed from the other mixtures. According to Fig. 8, the slump flow diameter decreased for all replacement ratios, and these mixtures were categorized as SF2 class except for the Mix- 5% (SF3 class). It will be noted that with increasing Mixed aggregate from 2.5% to 10%, there was only a 3.6% change in the slump flow diameter. Based on the visual observations, no segregation or bleeding was observed for concrete mixtures with Mixed plastic aggregate up to 7.5% (see Fig. 11). However, the plastic segregated 10% in the middle of the slump cone and caused bleeding. As confirmed previously by [10-13], the addition of PET increased T50 and decreased slump flow diameter; the main reason is that plastic has more specific area compared to sand which increases friction that reduces workability. T50 increased from 3.9 for PET-2.5% to 4.3 for PET-10%, but it was highest (4.6 sec) with PET-5%, and accordingly, all mixtures were considered in VS2 class. Meanwhile, PET-2.5% had the highest slump flow diameter, and PET-10% had the lowest (670 mm), which all are classified in SF2 class with 2.5 and 5% of PET. A perfect circular cone was obtained with no segregation. However, with increasing the replacement, the deviation from the circular shape of the cone increased due to the regular, non-absorbent, and sharp edge of the plastic causing segregation and bleeding of the concrete (See Fig. 12). In summary, one can observe an appreciable role of plastic aggregate shape and size on the flowability of SCC. Regarding the slump test, the best type of plastic aggregate for SCC was the PVC aggregate, and the worst was the PET aggregate. Hence the PA particle flakiness had a vital effect on the flowability property of SCC.

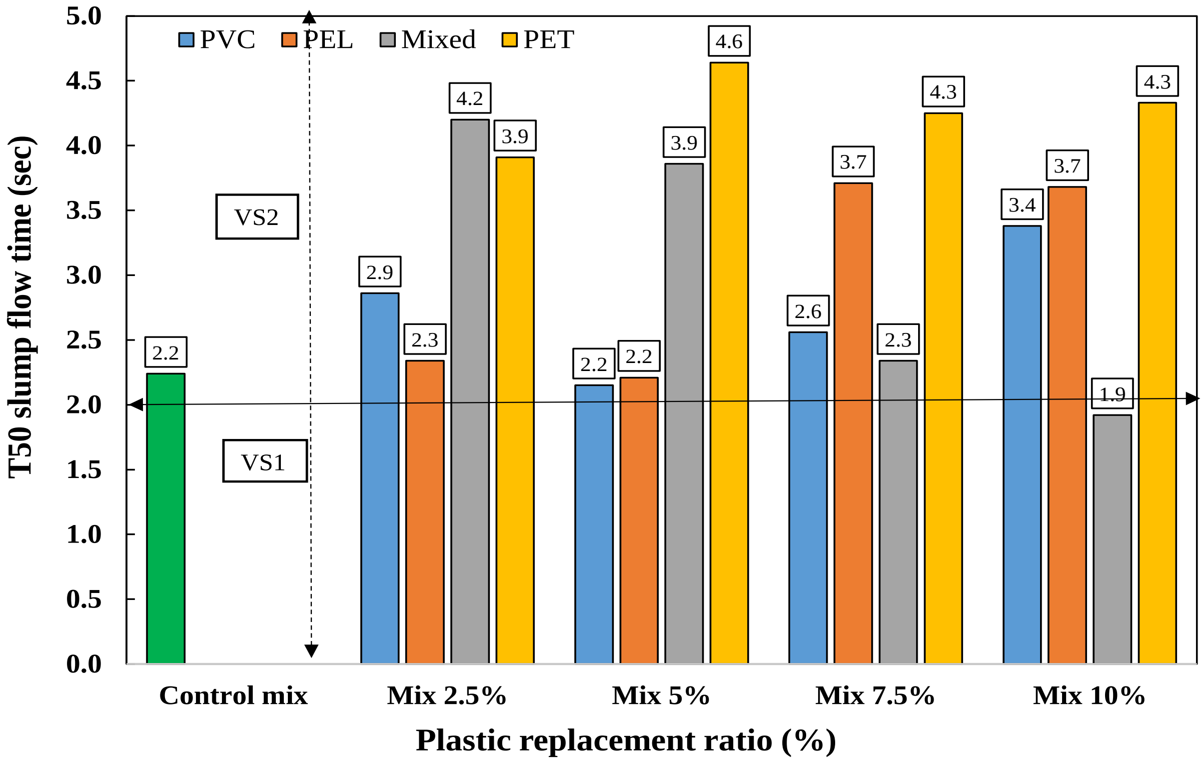


Fig. 7 T50 Flow Time for Different Concrete Mixtures.

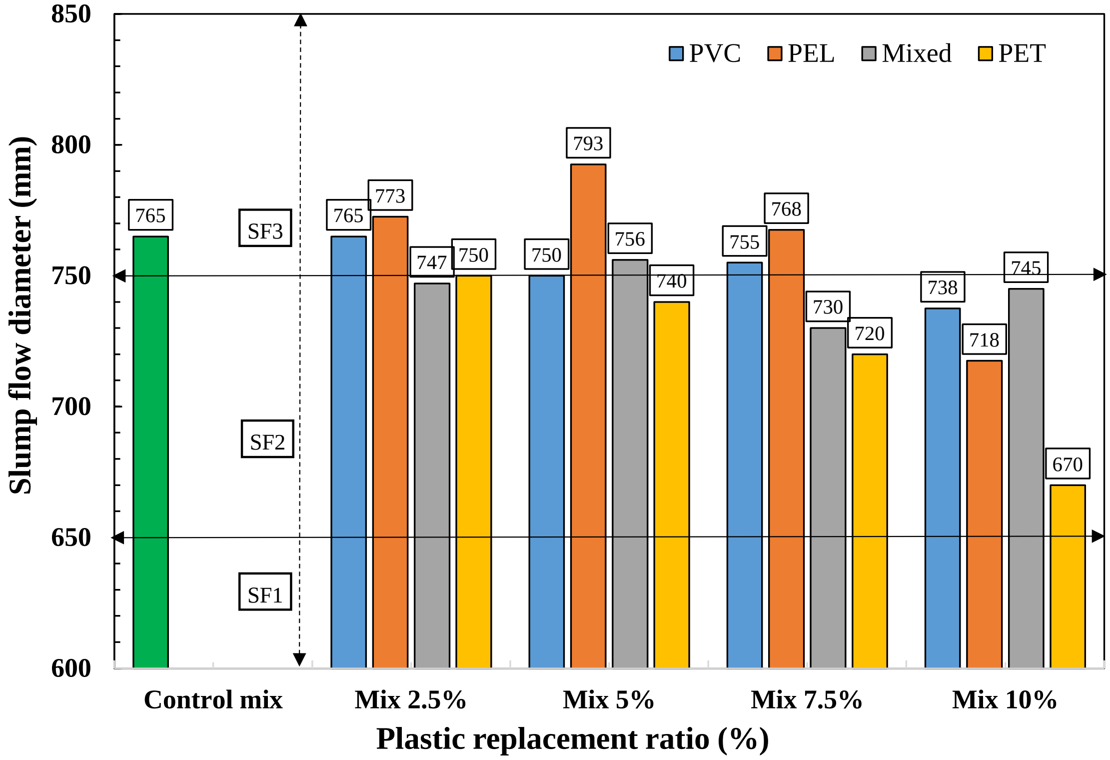


Fig. 8 Slump Flow Diameter for Different Concrete Mixtures.

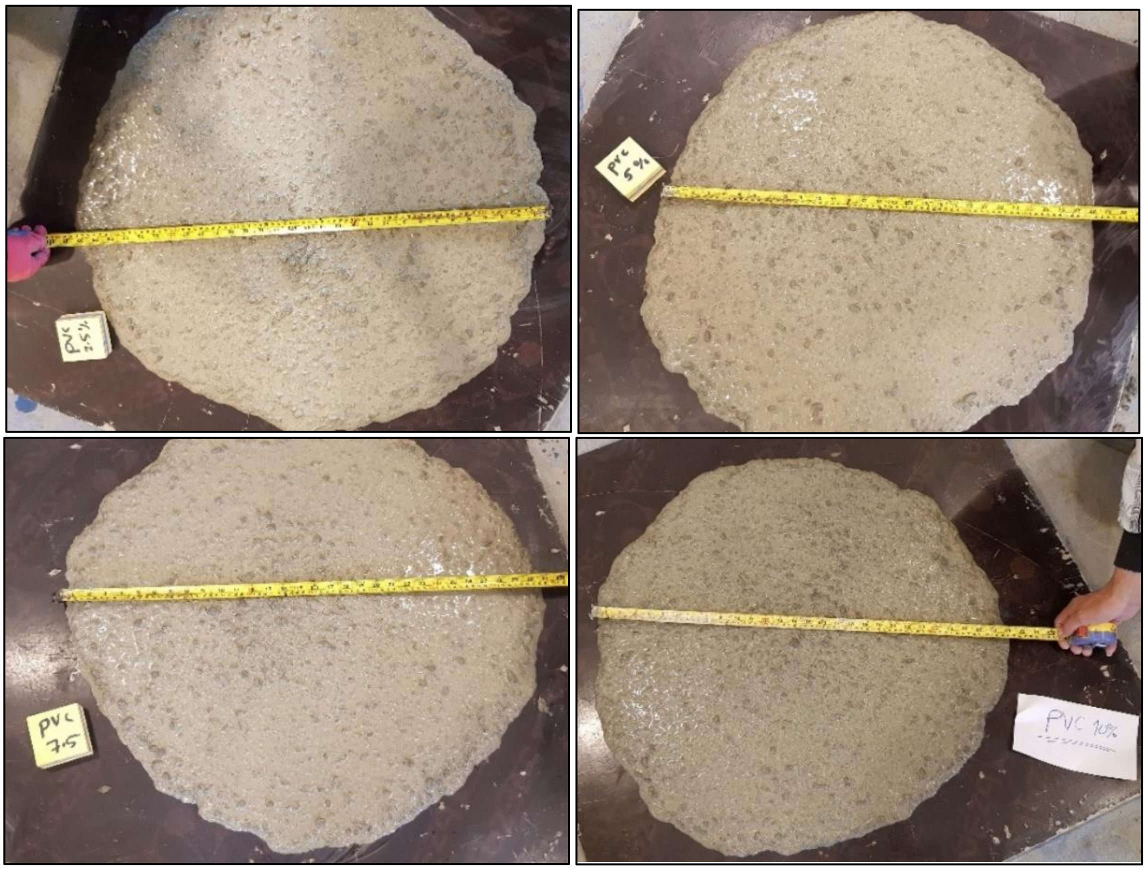


Fig. 9 Slump flow diameter for concrete containing PVC aggregate.

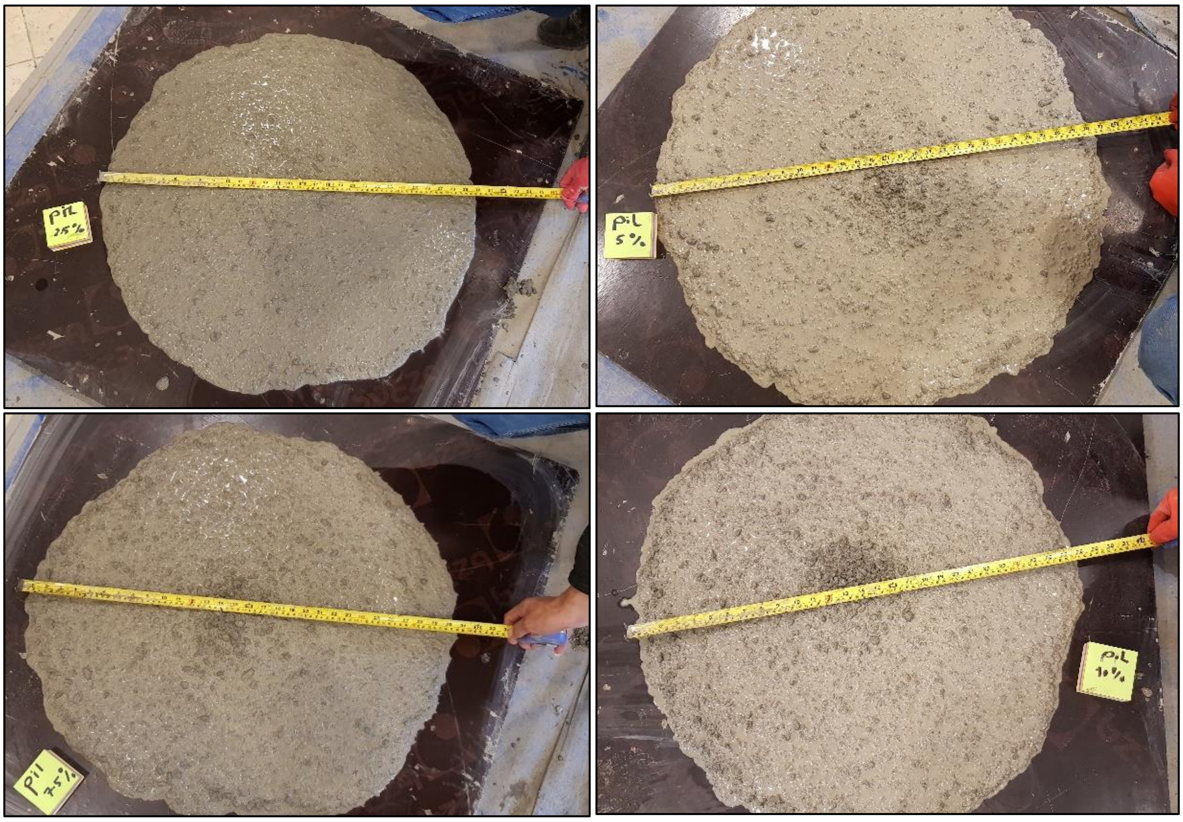


Fig. 10 Slump flow diameter for concrete containing different percentages of PEL aggregate.

Fig. 11 Slump flow test result for concrete containing Mixed plastic.

Fig. 12 Slump flow test result for concrete containing PET aggregate

3.2 V-funnel test

Fig. 13 shows the results of the V-funnel test for different concrete mixtures. The V- funnel time for the control concrete and PA concrete with PA not larger than 5% are classified according to VS2/VF2. Hamzeh [14] confirmed that the V-funnel time slightly increased with increasing PVC addition. The value increased to 18.3 sec on using 10% PVC aggregate, with little blocking effect during the concrete flow. It can be found that SCC containing PEL aggregate had very unstable properties; the same result was also obtained by Hilal et al. [17] and Faraj et al. [18] when they realized that a systematic relationship could not be observed between PEL replacement and V-funnel time. On replacing 5 and 10%, a relatively lower time was observed compared to the control sample (12.9 sec); however, for 2.5 and 7.5%, the measured time was higher (15.2 and 19.7, respectively). No blocking was observed for this concrete. In general, adding both Mixed and PET aggregates negatively impacted the V- funnel time, especially at higher plastic contents; however, the action of PET aggregate was the worst mainly because of the particles' flakiness effect. Concrete containing Mixed plastic aggregated up to 7.5% and PET aggregated up to 5% fall within the VS2/VF2 class limits; otherwise, the mixture falls outside the EFNRAC range [1]. The same results were obtained by Mermerdaş et al. [13] and Sakin [11]. The test results also showed that the concrete was blocked in the V-funnel tube due to the PET aggregate's sharp and flaky shape.

3.3 L-box test

Figs. (14- 16) show the L-box height ratio, T20 L-box time, and T40 L-box time for SCC containing different types of PA, respectively. The control sample had the following results: H2/H1, T20, and T40 of 0.95, 1.6 sec, and 3.7 sec, respectively. For SCCs with PVC aggregate, the high ratio was considered in the PA2 class and was almost stable, up to 7.5% of PVC. On using 10% PVC aggregate, H2/H1 decreased to 0.89, but no blocking was observed. L-box height was well reduced due to replacing fine aggregate with 7.5% or 10% PET aggregate, mainly because of the flakiness effect of PET particles. Results also showed that the T20 increased with increasing PVC ratio, but the results are very close, which was also true for T40, but the difference in the time was much higher. The mixture with 5% PEL aggregate had the maximum value of 1, and that with 10% aggregate had the lowest value of 0.93 (PA2 class), and no blocking occurred during the test. The T20 change was unstable for this type of plastic. The same results were obtained by Faraj et al. [18] for mixtures with 2.5% and 7.5% PEL aggregate; the time was moderately more significant than that of the control mixture. For Mixed plastic, H2/H1 was higher for all replacements compared to the control sample ranging from 0.95 to 0.97 (classified as PA2 class). After concrete settlement, all mixtures caused little blocking during testing without influencing the L- box high ratio. The plastic's irregular shape and sharp edge increased well for both T20 and T40 and was the highest for Mix-10% with 2.7 and 6.5 sec, respectively. For SCCs with PET plastic, as confirmed by Sadrmomtazi et al. [10] and Hama and Hilal [12], the L- box high ratio was considered in the PA2 class only for concrete mixture with 2.5% and 5% PET aggregate with H2/H1 of 0.94, and 0.95, respectively. With increasing PA content, the filling ability and the concrete flow were highly decreased and caused blocking inside the L- box apparatus changing the classification for both mixtures to PA1- class with an H2/H1 value of 0.58 and 0.56, respectively (see Fig. 17). However, the results obtained by Aswatama et al. [15] were opposite, stating that H2/H1 increased with increasing PET ratio; this was due to using irregular PET having finer particles with 96% passing sieve 2.38. The T20 was comparable to the control mixture up to 5% PET aggregate; however, the value was twice the control mixture for mixtures containing 7.5% and 10% plastic aggregate. T40 for all mixtures containing PET aggregate was higher than that of the control, and increased with increasing the replacement ratio, but the maximum value was for 7.5% PET.

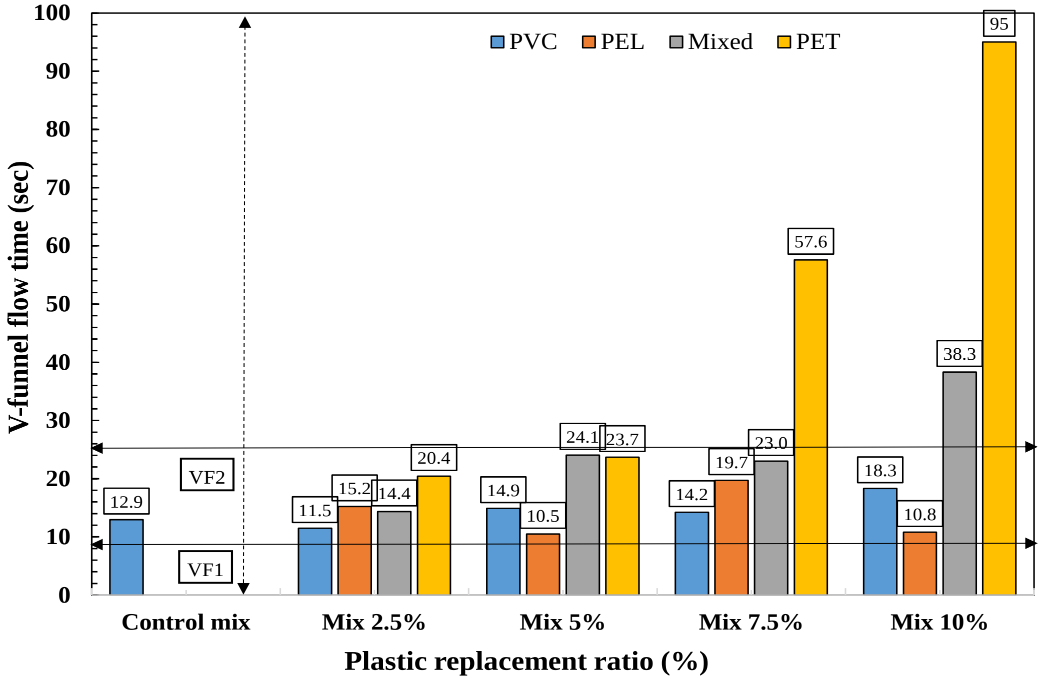


Fig. 13 V-Funnel Flow Time for Different Concrete Mixtures.

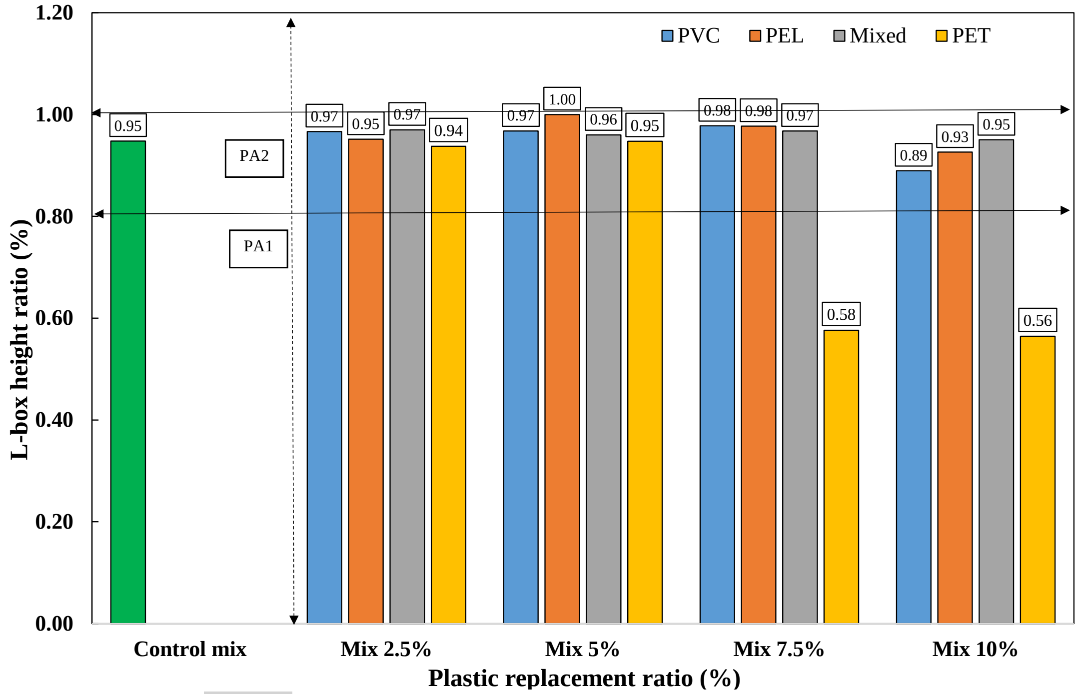


Fig. 14 L-box height ratio for different concrete mixtures.

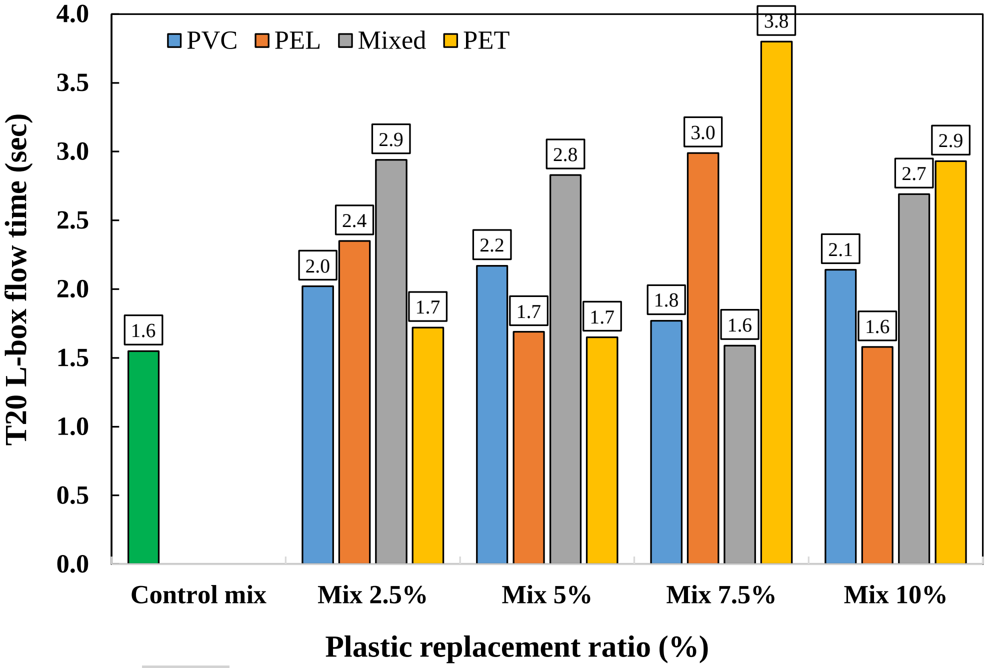


Fig. 15 T20 L-box flow time for different concrete mixtures.

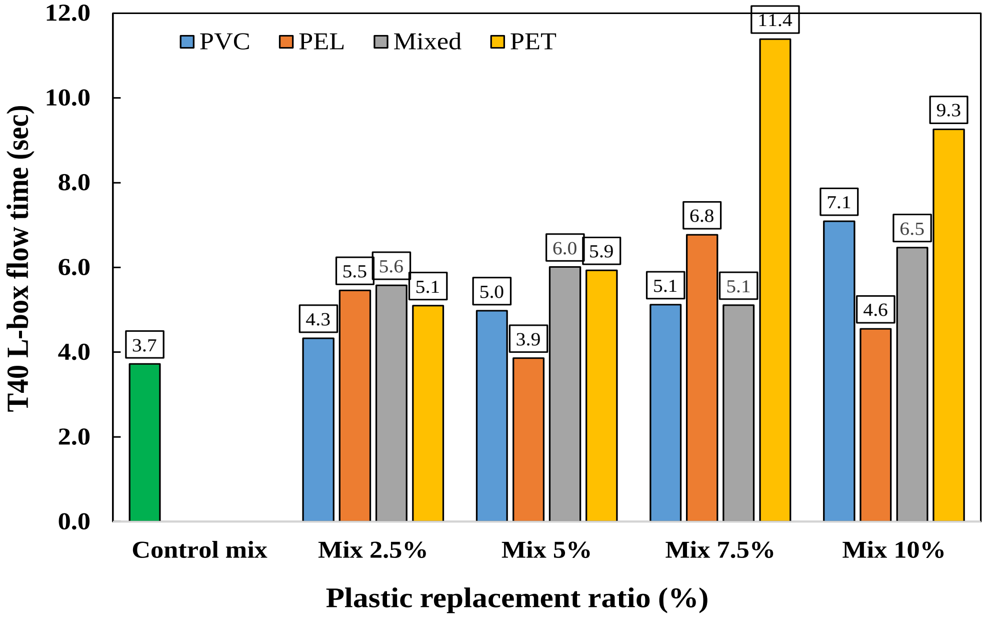


Fig. 16 T40 L-box flow time for different concrete mixtures.

Fig. 17 L-box test result for concrete with different percentages of PET plastic replacement.

3.4 Compressive strength

Fig. 18 shows a variation of compressive strength with different PA volumes. A degradation of compressive strength can be found with increasing PA in the mixture. The lowest strength loss was for the mixture containing PVC aggregate, followed by the mixture containing PET aggregate. The lower strength loss of the mixture containing PVC aggregate could be attributed to the smaller-sized particles (see Fig. 2) embedded and distributed well inside the hardened cement paste structure. There was no difference in the strength value on replacing sand with 2.5% PVC, Mixed, and PET aggregates. Up to 5% plastic aggregate content, the highest strength loss was for the mixture containing PEL aggregate, while for larger ratios, this loss was for the mixture containing Mixed aggregate, reaching 33.6%. Compressive strength for a concrete mixture containing PVC aggregate was reduced by 7, 7.1, 7.5, and 12.2% using 2.5, 5, 7.5, and 10% PVC aggregate, respectively. Fractured concrete indicated a uniform distribution of PA particles (as shown in Fig. 19). The gradual decrease in compressive strength values with increasing PVC percentages can be attributed to the weak bond between the surface of the plastic waste and cement paste due to the non-absorbent properties of the plastic, which led to restricting the water movement and increasing voids [14,37]. For concrete mixture with PEL aggregate, the non-absorbent and smooth surface of the plastic significantly decreased the compressive strength, in which the decrease ratio was 14.4, 20.9, 22.8, and 27.1% for 2.5, 5, 7.5, and 10% respectively, higher than that of the concrete mixture containing PVC aggregate. A relatively high strength loss can be found for a concrete mixture containing PEL aggregate at low PA ratios of 2.5% and 5% compared with other mixtures. Observing fractured concrete indicated that most plastic particles have migrated to the surface of the concrete in the mold due to the plastic's lightweight (as shown in Fig. 19). Following a concrete mixture containing PVC aggregate, a mixture with PET aggregate had the lowest compressive strength loss. A similar trend for PET had been observed by other researchers [10,11,13,15] for different percentages and different shapes. However, the decrease percentage was much higher for Mixed plastic compared to PET plastic with 7.4,15.6,27, and 33.6% compared with 6.8,10.3,16.8, and 18.5% by using 2.5, 5, 7.5, and 10% plastic aggregate, respectively. The relatively high strength loss on using 10% Mixed aggregate indicated the vital action of irregular particle's shape effect on the residual compressive strength (see Fig. 19).

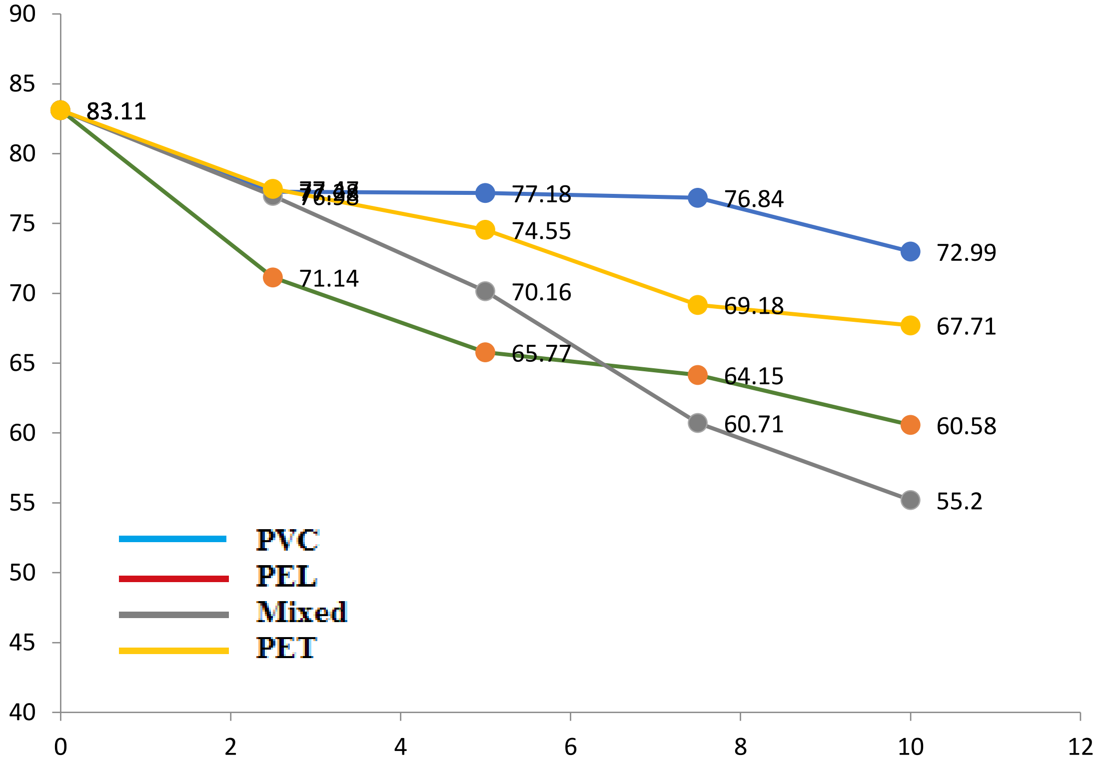


Fig. 18 Variation of compressive strength with the plastic aggregate ratio

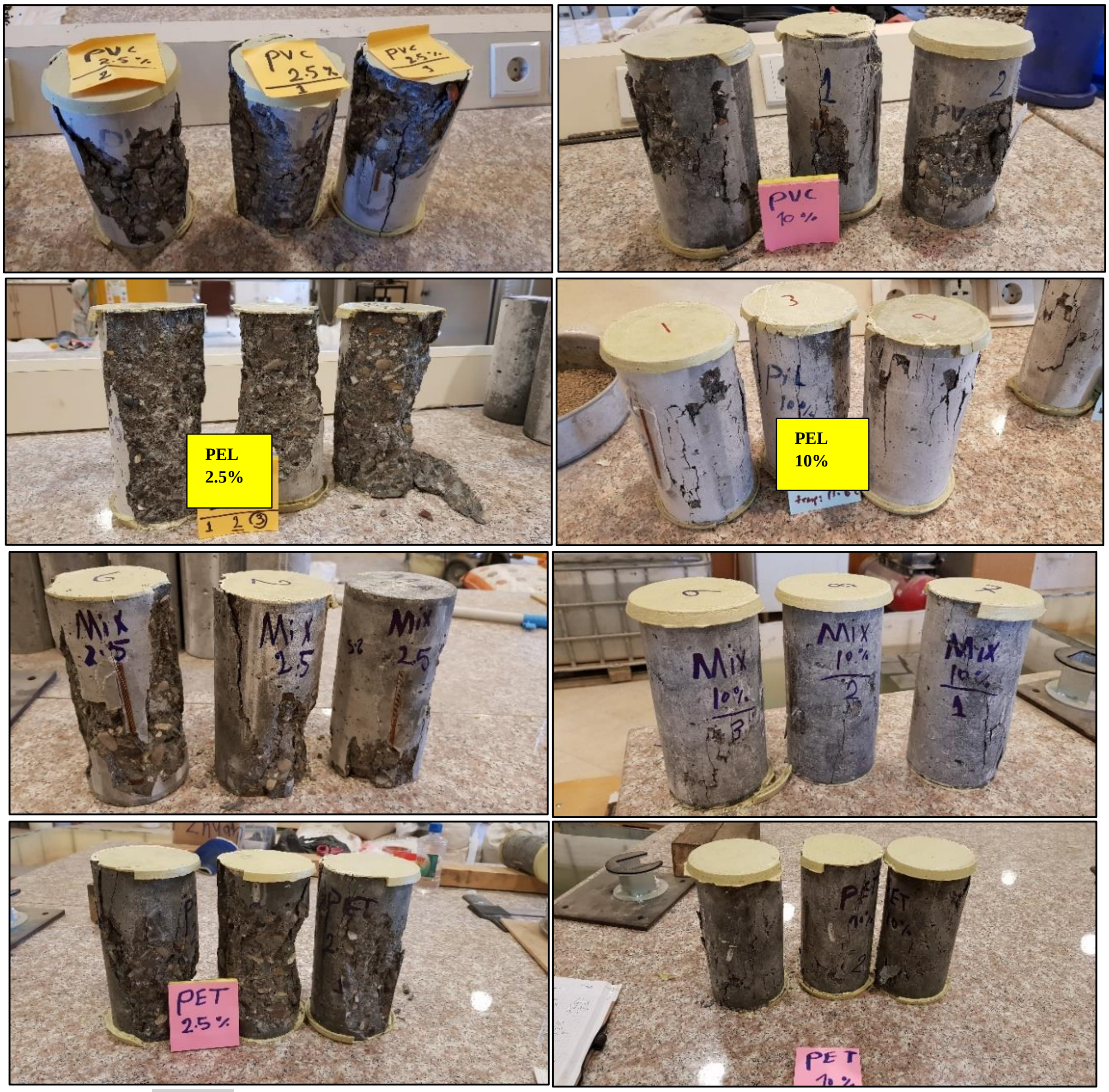


Fig. 19 Concrete samples with PET plastic after compressive strength test

4. CONCLUSION

From the present experimental study, the following conclusions are drawn:

1- Changing the PA geometry influenced different properties of fresh SCC; namely flowability, compact ability, and passing ability represented by slump flow, V-funnel, and L-box tests.

2- Up to 7.5% plastic aggregate content, PVC, and PEL samples were classified in SF3 class. On the other hand, for Mixed and PET plastic, this ratio was restricted to 2.5%. The action of PEL aggregate was the best among all PAs in terms of T50 flow time and slump flow diameter.

3- All PVC and PEL plastic were in the range of EFNARC classification (classified in VS2/PA2 class) and with no blocking in V-funnel and L-box test for all samples.

4- Concrete containing Mixed plastic aggregate up to 7.5% and PET aggregate up to 5% fall within limits of VS2/VF2 class; otherwise, the mixture falls out of the EFNRAC range.

5- The best PA replacement regarding all fresh property results was PVC confirming all requirements for a successful SCC concrete and causing no blocking or segregation. Thus, 10% was selected as the optimum percentage.

6- The worse plastic was PET plastic. The mixture with 7.5% required 57.6 sec to be fully discharged from the V-funnel apparatus and caused blocking inside the L-box with very low H2/H1, equaled 0.58, besides segregation and bleeding during the slump test. Thus, more than 5% was not recommended when using PET plastic in SCC.

7- Besides segregation and bleeding during the slump flow test and migrating of PA to the concrete surface, a systematic relationship cannot be observed between PEL replacement and T50 or V-funnel time. Thus

2.5% was indicated as the optimum percentage for PEL plastic in SCC.

8- Degradation of compressive strength can be found with increasing PA in the mixture. The lowest strength loss was for the mixture containing PVC aggregate, with 12.2% for 10%, while the highest strength loss was for the mixture containing mixed aggregate reaching 33.6%.

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