



Properties of Sustainable Self- Compacting Concrete Containing PET Waste Plastic with Various Cement Replacement Materials

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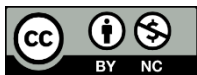
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ABSTRACT

This main aim of this study is evaluating wide range of fresh and hardened properties of sustainable self-compacting concrete containing various types of Cement Replacement Materials with optimum contents of Polyethylene Terephthalate PET waste plastic as fibers and fine aggregate replacement. This is to evaluate effect of the two forms of PET and to determine the best CRMs could be used with sustainable SCC. such as limestone, glass powder and fly ash with high replacement rate of 70% by weight of cement were used while fourth one (kaolin) was used with replacement rate of 20%. PET fibers were added to SCC with an aspect ratio of 24.4 and 0.7% volume fraction whereas fine aggregate partially replaced by 4% of waste plastic. Four reference mixtures contained FA, LP, GP and KA only, same four mixtures contained 0.7% PET fibers by volume, and the other same four mixtures contained 4% PET fine aggregate by volume. The obtained results all tested fresh properties, which include slump flow, T500, L-Box and segregation resistance were within the limits of the specification reported in EFNERC guidelines. Further, the forms PET have an adverse effect fresh properties of SCC. As for hardened properties (compressive strength, splitting tensile strength, flexural strength and impact strength). Further, this produced type of SCC showed a range of compressive strength (15.2-31.64 MPa) at 28 days. It can be from the current study the best CRMs to be used in SCC containing PET wastes was FA in terms of most tested properties.

1. Introduction

The evolution of concrete production in recent years has resulted in an invention of new types of sustainable concrete. Such concrete kinds are commonly used in the construction of healthy, safe and secure concrete structures that can withstand different types of loads. Self-compacting concrete SCC is a relatively new type of concrete that can eliminate most of internal voids, boost durability, and reduce bleeding (Al-Hadithi, Noaman, & Mosleh, 2019). Furthermore, due to compaction by its own weight, SCC can be considered a material that is cost-effective in reducing the cost and durations of vibration and production.

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The American Concrete Institute (ACI) (2007) defines SCC as very flowable, non-segregating concrete that can spread into place, fill the formwork, and encase the reinforcement without the need for mechanical consolidation (Alyhya, 2016). It first developed in Japan in 1980s and was made up mostly of the same materials as conventionally vibrated concrete. However, the composition of the concrete clearly differs. SCC requires a higher proportion of ultra-fine materials as well as the incorporation of chemical additives, especially an effective high range water reducer (Dehwah, 2012). It is known that in order to obtain a successful fresh SCC, three main requirements should be achieved (EFNARC, 2002): good flowing ability or filling ability, good passing ability and good segregation resistance. This can be done using three methods (Badry, 2015): i) Limiting aggregate content, ii) Reducing water-powder ratio and iii) Using of high quantity of superplasticizer.

The mix design approach of SCC with low cement and total binder contents may be of significant interest since it may meet both self-consolidation and environmental friendly requirements. Due to its excellent durability and ease of placing, SCC is a sustainable material that can speed construction processes (Figueiras, Nunes, Coutinho, & Figueiras, 2009). The cement industry is one of the sources of carbon dioxide emissions into the atmosphere, in addition to the combustion of fossil fuels and deforestation. Cement manufacture is an energy-intensive and highly polluting process that gives about 5–8 % to overall carbon dioxide (CO₂) emissions (Ibrahim, 2021).

Nevertheless, pollution due to plastic waste has become one of the world's most important environmental issues. Over the last few decades, massive amounts of non-biodegradable trash, particularly waste plastics (WP), have demonstrated that they pose major environmental issues; in addition, they are regarded as one of the most dangerous causes of pollution. Plastic trash reuse is critical to sustainable solid waste management. Plastic waste management aids in the conservation of finite natural resources, the reduction of pollution to the environment, and the conservation and recycling of energy production processes (Al-Hadithi & Hilal, 2016). The globe produces almost 6.5 billion tons of waste plastic each year (Almeshal, Tayeh, Alyousef, Alabduljabbar, & Mohamed, 2020).

The effects of adding many types of CRMs and waste plastic on the properties of SCC were investigated by many scientists and researchers. The world is currently looking for sustainability that focuses on producing environmentally friendly building materials in order to reduce CO₂ emissions into the atmosphere. Providing a clean and healthy environment, not only for humans, but for all living beings on earth, reducing the use of energy resources (Faraj, Ali, Sherwani, Hassan, & Karim, 2020).

(Tejaswi, Rao, Vidya, & Renuka, 2015) looked into the feasibility of producing environmentally kind, conventionally viable concrete using various percentages of glass waste (10, 20, 30, 40, and 50% by weight) instead of cement and sand. They claimed that these substitutes can effectively aid in reducing the cement industry's carbon dioxide emissions. The highest residual strength, after exposed to high temperature, was seen with 20% replacement, and it was virtually as strong as the reference concrete mix, they noted. (Anwar, 2016) (previous study showed that glass waste can be used successfully as partial replacement of cement in developing the concrete strength due to its pozzolanic nature. (Vanjare & Mahure, 2012) investigated the fresh and mechanical properties of mixes SCC incorporating glass powder as a partial cement replacement of (5, 10, and 15) % by weight. They concluded that the rheological and mechanical properties decreased with increasing the glass content. The use of LP and FA at high levels of cement replacement has been extensively studied in producing SCC.

(Khatib, 2008) studied the effect of FA, as cement replacement material, on the properties of SCC with replacement ratios (20, 40, 60, 80)%. The results showed that FA can be used in large proportions in the production of SCC, in addition to an improvement in workability in terms of slump flow within the specifications of EFNARC. As for the absorption, high values are obtained with the increase in the amount of fly ash, but it did not exceed 2%.

(Siddique, 2011) studied the properties of SCC containing FA class F, with replacement ratios from 15 to 30%. SCC showed compressive strength of (30-35) MPa and tensile strength (1.5-2.4) MPa. (El-Chabib & Syed, 2013) examines the possibility of using an alternative cement substitute in SCC mixtures such as FA with different ratios (10, 20, 30, 50)%. It was observed that the percentages of FA (10 and 20) % increases slump flow to 555-595 mm while at the percentages (30 and 50) %, the rate of increase is slower.

(Ahmed & Babikir, 2020) investigates the reduction of cement content by using alternative materials for cement, such as LP, and the replacement ratios were up to 15%. Fresh properties and compressive strength tests were carried out. The results indicated that most of the prepared mixtures achieved the required workability, but with increasing the replacement ratios, the compressive strength decreased. (Beeralingegowda & Gundakalle, 2013) proved that the use of LP in SCC is effective up to 20% of the cement and even boosting its workability. (Uysal & Yilmaz, 2011) used LP and marble powder MP at different ratios in SCC while maintaining the same ratio of water to binder 33%.

The results showed that it is possible to these mineral admixtures successfully in SCC. It had a positive effect on the workability because an improvement in the fresh properties was noted. However, few studies were found in the literature dealing with the use of KA at high levels of cement replacement. When (Azeredo & Diniz, 2013) looked into the possibilities of utilizing this industrial waste in SCC, they found that doing so had a considerable positive impact on the environment.

In term of using waste plastic in SCC, (Sadromtazi, Dolati-Milehsara, Lotfi-Omran, & Sadeghi-Nik, 2016) reported that the use PET of a partial substitute for natural aggregates (that pass through a sieve 4.75mm) lead to a decrease compressive , flexural strength and ultrasonic pulse velocity(UPV) of SCC. (Kim, Yi, Kim, Kim, & Song, 2010) studies showed that the use of recycled plastic fibers in normal concrete NC as well as self-compacting concrete SCC increased durability and impact strength. (Ismail & Al-Hashmi, 2008) found that, as the percentage of waste plastic (consists of 80% polyethylene and 20% polystyrene) increases, the bulk density decreases and the workability increases. (Safi, Saidi, Aboutaleb, & Maallem, 2013) showed that the use of recycled waste plastic PET can be used as fine aggregate replacement sand. The sand is replaced with plastic in various amounts. Mortars with 50% plastic waste perform better than other waste proportions.

(Asmaa S Hussien, 2022) explained that adding modified and treated PET fibers to SCC leads to an increase in the mechanical properties compressive (strength, tensile, flexural, impact strength, porosity and less absorption). The optimal fiber content in this study was 0.7%. It was also found that there is a slight decrease in SCC fresh properties. (Mahmoud Khashaa, 2019) studied the production and improvement of SCC mixes using waste materials such as limestone powder and plastic waste PET. The optimum values for limestone, PET and superplasticizer were 20.1%, 2.4%, 1.16 % respectively. They found that the use of plastic waste, replacing it as part of the fine aggregate, had a negative effect when the replacement rate was high, but the presence of fillers (LP) in the mixtures helped reduce this negative effect.

From the above literature reviewed, it can be concluded that the use of high level of cement replacement by natural and byproduct waste materials in SCC becomes a traditional way in conventional SCC. Further, the use of waste plastic with different forms in SCC has increased considerably. However, there is lack of information about the best type these waste to be successfully used in SCC containing waste plastic. Accordingly, the current study is designed to discover both the impact of using PET wastes at optimum content of two different forms (PET fibers and PET fines) as well as to determine the best CRMs to be used in combination with plastic waste in a sustainable SCC type.

2. Experimental program

2.1 Materials

The materials used in this study to produce SCC mixtures are: cement C, coarse C.A and fine aggregate F.A, Polyethylene Terephthalate PET as fibers and as fine aggregate, fly ash FA, limestone powder LP, glass powder GP and kaolin KA.

Ordinary Portland cement (CEM I) was used for preparing and casting SCC samples throughout the experimental work. Chemical and physical properties of this type of cement were tested and they were identical to Iraqi specification IQS NO. 5, 2019(Specifications, No.5 , 2019) Coarse aggregate: with maximum size of 10 mm and bulk density of 2668 kg/m³ was used while the fine aggregate maximum size was 4.75 mm with bulk density of 2600kg/m³. Specific gravity for coarse and fine aggregate were 2.65, 2.62 g/cm³ respectively. The test results showed that the fine and coarse aggregate to the Limit of Iraqi Specifications No.45/1984(specification, No.45/1984) Particle size distributions of fine aggregate and PET (F.A) are displayed in Fig. 2

Fly ash FA class F with specific gravity of 2.1g/cm³ was used. Natural limestone powder LP (Calcium carbonate) with specific gravity of 2.7g/cm³ was also used. Discarded broken window glass, which is available locally and is leftover, was used to produce glass powder GP with a specific gravity of 2.11g/cm³. Kaolin, also known as kaolinite, with specific gravity of 2.58 g/cm³ was used; it is a soft, white, naturally occurring clay mineral. All the used above CRMs have particles size less than 75µm. Table 1 shows the chemical compositions of cement and CRMs used while Fig.3 shows photographs of these materials.

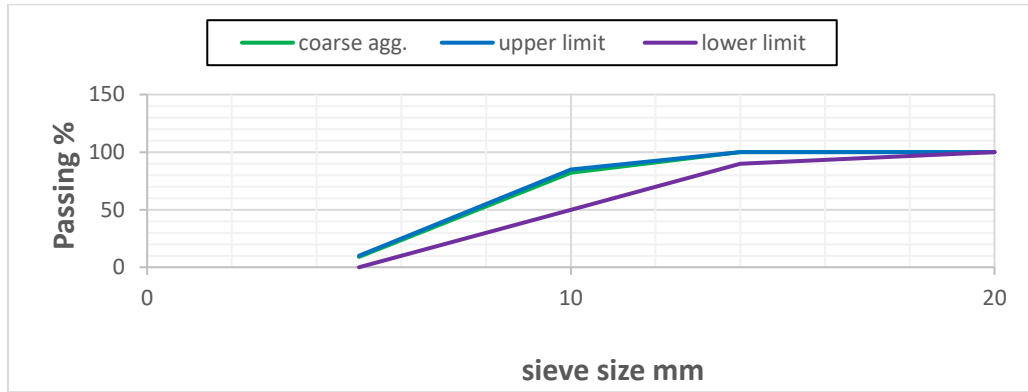


Fig.1 Particle size distribution of coarse aggregate.

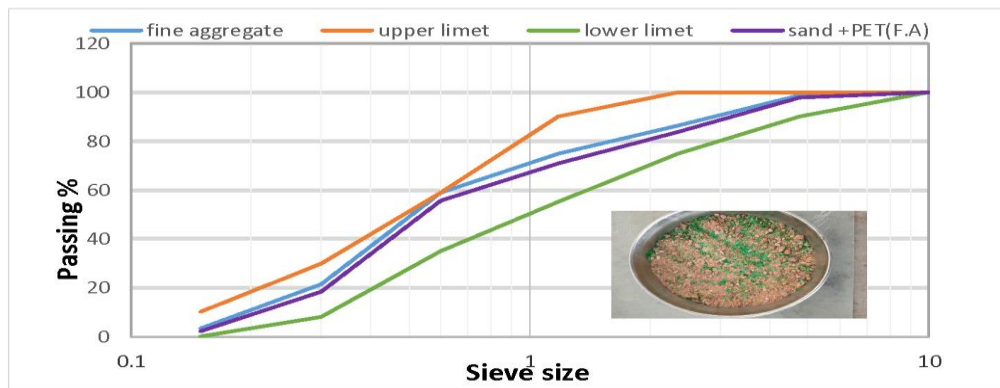


Fig.2 Particle size distribution of fine aggregate and PET (F.A).

Table 1- chemical composition of cement and other CRMs used

Main oxides %	SiO ₂	Al ₂ O ₃	CaO	Fe ₂ O ₃	CaCO ₃	L.O.I %
C	20.06	4.80	62.95	3.35	--	2.3
FA	47.68	27.73	5.11	18.32	--	3.71
LP	10.5	4.5	42	2.1	98.9	42.1
GP	96.40	0.66	1.52	1.09	--	0.5
KA	50	30.7	0.2	1.8	--	11.9



Fig .3 CRMs used in production of SCC mixes

In this study, PET plastic waste was used, which they are soft drink bottles. They were used both as fibers and as fine aggregate partial replacement. First, soft drink bottles were collected, then these bottles were cleaned in order to get rid of dirt. Then the bottles are cut up and the top and bottom of the bottles are removed with the help of scissors. Next, the plastic sheets were then divided into 4 mm wide strips using a paper shredder; the fibers were then cut using customized scissors to provide the necessary length of the PET fibers (length of 30 mm and thickness of 0.3mm). Paper shredder was also used to prepare fine PET particles with a size less than 4.75mm. Fig.4 explains the method used to make PET fibers and PET fines and their final forms whereas Table 2 shows the physical characteristics of waste plastic as fibers.



Fig .4 Method used to make PET fibers and PET fines

Table 2- Physical characteristics of waste plastic as fibers

Color	Length mm	Width mm	Thickness mm	l/d	Density kg/m ³	Water absorption %	Tensile strength MPa	Modulus of elasticity MPa
Green	30	4	0.3	24.4	1370	nil	105	0.57

5.52 kg/m³ of aqueous solution of epsilon (i21) type F was used as super-plasticizer SP to maintain the required fresh properties of the produced SCC for all designed mixes.

2.2 Mixing procedure and mix design

It is expected that the use of PET fibers or PET fines in SCC might affect the fresh properties. Since there is not any unified process or standard method for mixing of SCC, many attempts have been made to reach the appropriate mixing procedures. In this study, according to previous study the following steps were followed in order to prepare SCC mixtures containing fibers and fine aggregate: i) fine and coarse aggregates were added and placed in a rotating mixer for two minutes, after which cement and filler are added ii) before addition, the cement and filler were mixed for two

minutes in order to ensure their homogeneity iii) After that, during the rotation of the mixer, the process of adding fibers or fine aggregate takes place when the ingredients are dry and before adding water and SP, the process of adding is done gradually to avoid pelleting and irregular spreading that occurs in the concrete iv) Part of the mixing water is added to the SP and then gradually poured the mixer left to rotate for additional two minutes in order to homogenize the materials.

After completing the mixing process, each mixture is tested immediately to check its fresh properties. For successful mixtures, three cubes of 100 mm, three cylinders of 100 x200mm, three prismatic of (100x100x400) mm and three disks of 150x65 mm were cast. After casting, the samples were left in the laboratory for after 48 hours in a sealed condition. The samples then were de-molded and were kept in water treatment tank until the age of the test.

Twelve sustainable SCC mixtures were designed with three groups as shown in Table 3. The first group contained CRMs only (FA, LP, GP and KA) with a replacement rate of 70% except that for KA which was only 20%. It should be highlighted here that it was not being able to obtain successfully fresh SCC mix for KA replacement beyond this rate. Optimum contents of PET fibers and PET fines were adopted for the second and third groups respectively (Hussien & Mohammed, 2023; Majid & Mohammed, 2023). The water and SP contents were fixed for all tested mixtures to be 160 and 5.52 kg/m³ respectively. This will allow evaluating the influence of PET additions in both cases (fibers and fines). Table 3 lists the mix design of the produced sustainable SCC mixes.

Table 3 - Mix design and proportions of self-compacting concrete mixes in kg/m³

Group No.	Mix Title	C	F.A	C.A	W	w/b%	SP	GP	LP	KA	FA	PET F.A	PET Fi
1	SCC-FA	138	850	770	160	1.1	5.52	...	...	...	322	...	...
	SCC-LP	138	850	770	160	1.1	5.52	...	322	...	...	...	...
	SCC-GP	138	850	770	160	1.1	5.52	322	...	...	...	...	...
	SCC-KA	368	850	770	160	1.1	5.52	...	...	92	...	...	...
2	SCC-FA-0.7%Fi	138	850	770	160	1.1	5.52	...	...	...	322	...	9.52
	SCC-LP-0.7%Fi	138	850	770	160	1.1	5.52	...	322	...	...	...	9.52
	SCC-GP-0.7%Fi	138	850	770	160	1.1	5.52	322	.....	.....	...	...	9.52
	SCC-KA-0.7%Fi	368	850	770	160	1.1	5.52	...	.....	92	...	...	9.52
3	SCC-FA-0.4%F.A	138	832	770	160	1.1	5.52	...	...	...	322	18	...
	SCC-LP-0.4%F.A	138	832	770	160	1.1	5.52	....	322	...	...	18	...
	SCC-GP-0.4%F.A	138	832	770	160	1.1	5.52	322	...	...	...	18	...
	SCC-KA-0.4%F.A	368	832	770	160	1.1	5.52	...	...	92	...	18	...

C cement, C.A: coarse aggregate, F.A: fine aggregate, SP: Superplasticizer, FA: fly ash, GP: Glass powder, LP: Limestone powder. KA: Kaolin, W: Water, w/b: water to binder ratio, F.A: Fine aggregate (PET), Fi: fibers (PET).

2.3 Testing procedures

In this study, the fresh properties tests of SCC (slump flow, T50, L-Box and segregation resistance) were carried out in according to the recommendations of EFRANC guidelines [4]. As for hardened properties, the compressive strength test was carried out using 10 mm cubes at ages of 7, 14, 28 days. The test was carried out using a testing machine (EIE – Digital), 2000 KN, capacity at a loading rate of (3) KN/s. The compressive strength is calculated by taking the average of three cubes according to BS-EN12390-3(Standard, 2009). The splitting tensile strength test was conducted at the age of 28 days. The average result of three cylinders with dimensions (diameter x length) 100X200mm were calculated in according to the requirements of ASTM C496-11(A. ASTM, 2011). Three prisms with dimensions of 100x100x400 mm were tested using two point load to calculate the modulus of rupture according

to in ASTM C78 standard (C. ASTM, 2010). In order to calculate the impact strength of concrete, cylindrical disks with a height of 65mm and diameter of 150mm. The number of blows required to cause first crack was recorded and the test was continued to record the number of blows required to cause a complete fracture of the specimen. The photographs in Fig.5 represent the all conducted tests in this study. Fresh properties and compressive strength were evaluated for all SCC mixtures while the rest of the properties (splitting strength, flexural strength and impact strength), were studied independently for the mixtures containing waste plastic PET only.



Fig .5 Tests of fresh and hardened properties of SCC

3. Results and discussion

3.1 Fresh properties

3.1.1 Slump flow and T500

The results explained the effect of PET as fibers and as fine aggregate on slump flow diameter test are shown in Fig. 6 and Fig.7 respectively.

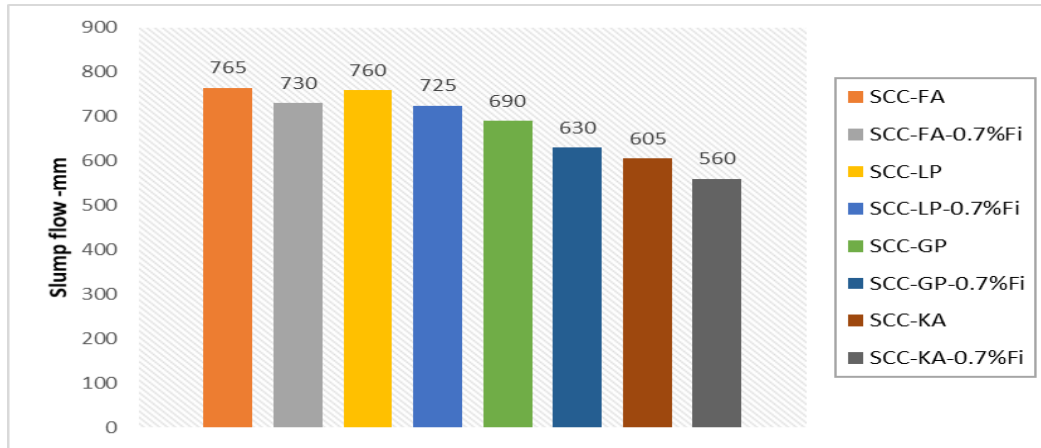


Fig.6 Effect of PET fibers on slump flow diameter

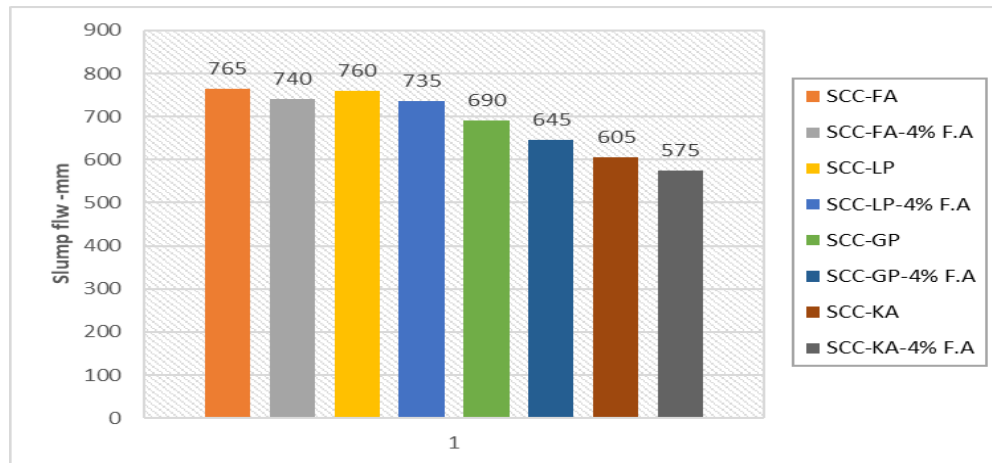


Fig.7 Effect of PET fine aggregate on slump flow diameter

Slump flow diameter results were in the range of (560-730) mm for the addition of PET fibers. As for the replacement of sand with fine PET particles, the results of slump flow values were from (575 to 735) mm. Results demonstrated that all the measured flow diameter were within the limitations of the EFNARC guideline (EFNARC, 2002). According to this guideline, the tested SCC mixtures SCC-FA and SCC-LP can be characterized as SF3, SF2 for SCC-FA-0.7% Fi, SCC-LP-0.7% Fi, and SCC-GP, SF1 for SCC-GP-0.7% Fi, SCC-KA, and SCC-KA-0.7% Fi. For the replacement of PET fine aggregate (SCC-FA-4%F.A and SCC-LP-4%F.A, as SF2, SCC-GP-4%F.A and SCC-KA-4%F.A as SF1). The results also reveal that the additions of PET as fibers and as fine aggregate replacement at optimum contents reduces the slump flow slightly for all used CRMs. For regular addition of PET fibers in SCC (Al-Hadithi & Hilal, 2016) concluded that there was a negative effect when adding these types of fibers to and the reason for this decrease might be due to the tendency of these fibers to undergo agglomeration inside the mix and hence reduces the spreading of concrete. (Baali, Belagraa, Chikouche, & Zeghichi, 2021) It was found that the incorporation of plastic fibers had a negative effect on the slump flow diameter hence reduces the spreading of self-compacting concrete mixes.

However, the sustainable SCC mix containing 70% FA exhibited less reduction ratio due to the use of waste plastic in two cases. This behavior may be attributed to surface texture and shape of fly ash particles as compared to other used CRMs. Due to the better smoothness and circularity of fly ash particles, fly ash has been utilized to increase the flow diameter of SCC as stated by (Xie, Liu, Yin, & Zhou, 2002).

The values of T500 for the tested four references SCC mixes (with CRMs only) and those containing PET fibers and PET fines are shown in Fig 8, and 9.

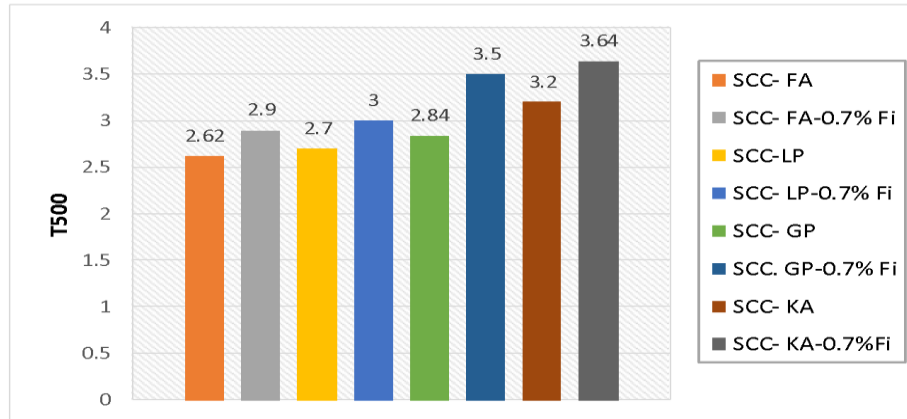


Fig.8 Effect of PET fibers on flow time of SCC mixes

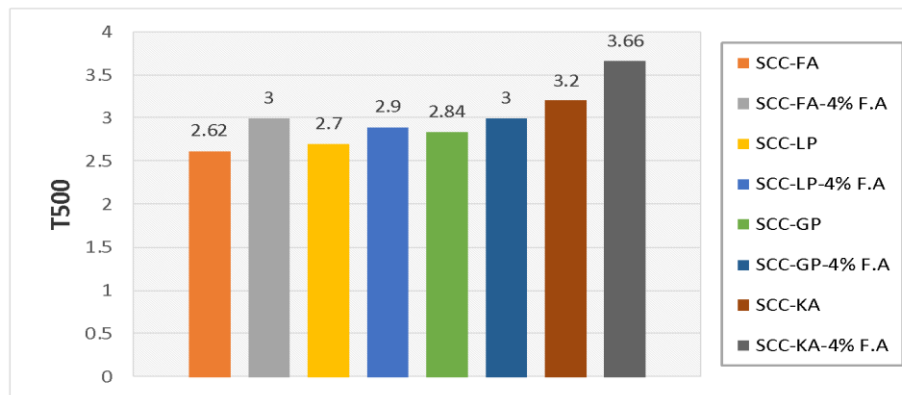


Fig.9 Effect of PET fine aggregate on flow time of SCC mixes

The obtained results revealed that the addition of PET as fibers and fine aggregate to the SCC mixture resulted in an increase of the time to reach 500 mm flow (T500) significantly as compared to reference mixes. However, they stayed in the range of 2-5 mm as stated by European guidelines EFNARC (EFNARC, 2002). The maximum flow time T500 was recorded for SCC mixture containing kaolin and PET fine aggregate (3.66 sec). However, the use of both FA and LP at replacement level of 70% decreases this effect considerably. In general, it was observed that mixtures with PET fibers had a lower time than mixes with PET fine aggregate. This might be because PET fibers have a lesser surface area than PET particles, which allows the mixture to flow quickly.

3.1.2 L-Box

The blocking ratios of H_2/H_1 obtained from the L-Box for the tested reference SCC mixtures and those containing PET fibers and PET fines at optimum contents are shown in Figs. 10 and 11. The results in Fig.10 confirmed that the blocking ratio decreased below the limit specified by EFNARC specifications (0.8 Minimum)(EFNARC, 2002). This is for the mixes containing PET fibers for both GP and KA replacements fibers indicating a lower passing ability while they remained above this limit for the other two mixes. It is worth to note that the use of waste plastic as fine aggregate was better than using them as fibers in term of L-Box test as shown in Fig.11. A slight decrease in the passing ability was observed when compared with the reference mixtures that contain fillers only. The long length of PET fibers as compared to fine PET might be the cause to prevent the mix from passing through the reinforcing steel bars of L-box. The use of 70% FA and 70% LP as partial replacements of cement showed better performances in this aspect

also.(Hama & Hilal, 2017) the size and content of the used plastic waste also had an impact on the L-box height ratio. The L-box height ratio decreases as waste plastic is added.

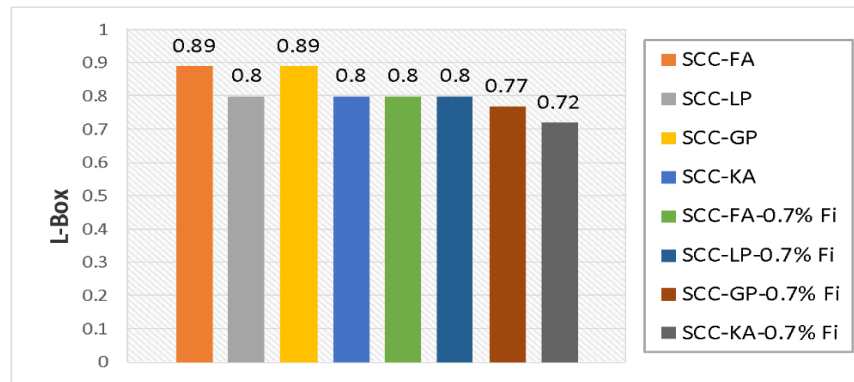


Fig .10 Effect of PET fibers on L-Box of SCC mixes

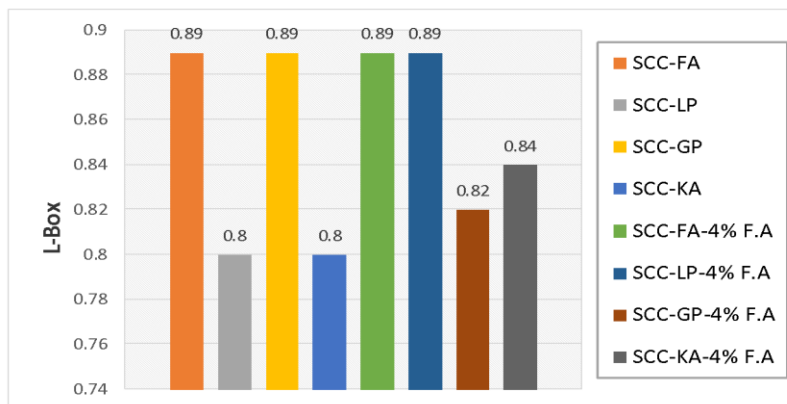


Fig.11 Effect of PET fine aggregate L-Box of SCC mixes

3.1.3 Segregation resistance (SI index)

The results of the segregation resistance test are shown in Fig 12 and 13.

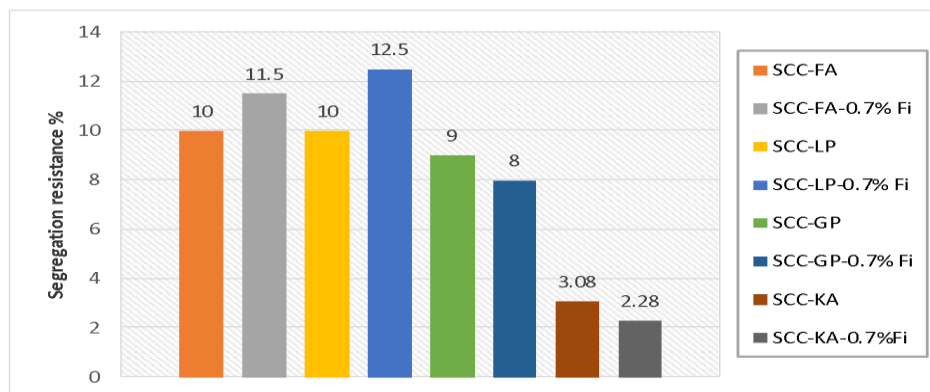


Fig .12 Effect of PET fibers on segregation resistance of SCC mixes

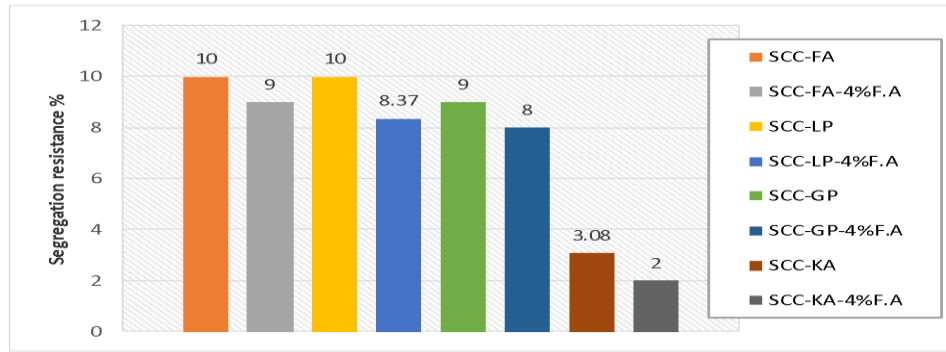


Fig .13 Effect of PET fine aggregate on segregation resistance of SCC mixes

The results from the two figs 12 and 13 revealed that all produced SCC mixtures had segregation indices lower than 15%. The experimental results illustrate gradual decrease in all values of segregation indices as compared to reference mixes. The reason for this decline may be due to an increase in the viscosity of the mix that contributed to segregate lower. The minimum segregation index SI was 2% in mixture containing kaolin and fibers.(Hilal & Hadzima-Nyarko, 2021) concluded that the segregation index reduced by the addition of waste plastic for all mixtures

The segregation index values were in the range (10.3-2) %for the addition of fibers, and the replacement of sand with fine PET particles results in segregation index values between (12.5-2.28) %.

3.2 Hardened properties

3.2.1 Compressive strength

Figs. 14 and 15 show the effect of PET as fibers and as fine aggregate on compressive strength of self-compacting concrete SCC.

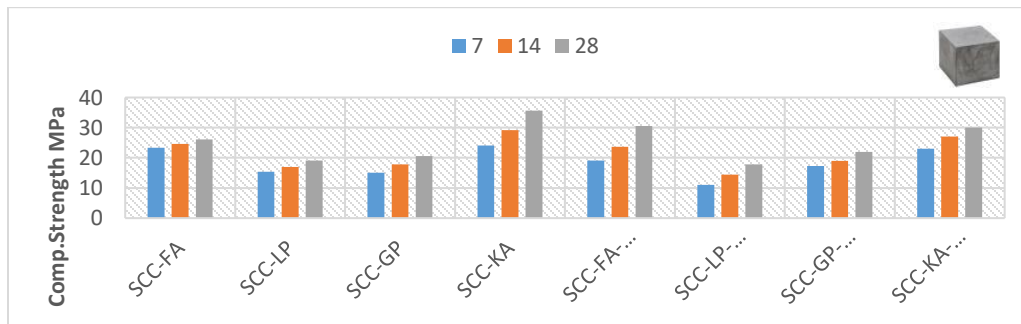


Fig.14 Effect of PET fibers and filler on compressive strength of SCC mixes

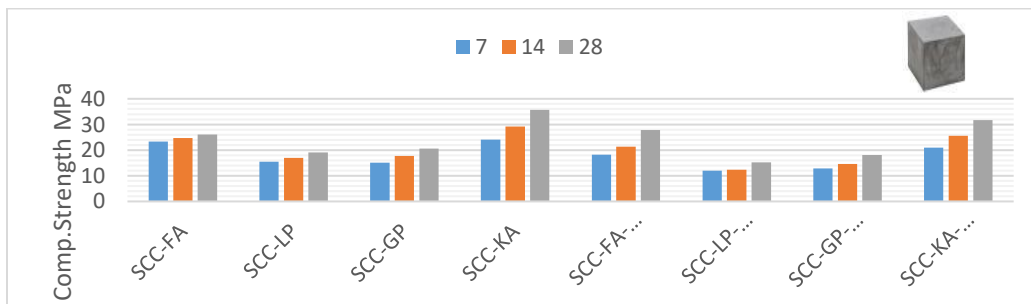



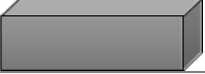
Fig.15 Effect of PET fine aggregate and filler on compressive strength of SCC mixes

The experimental results in Figs. 14 and 15 illustrate a decrease in all values in comparison with the four reference mixes at all ages. Further, the use of PET as fibers was better than PET fines. The maximum compressive strength achieved when using plastic waste either as fibers or fine aggregate was (30.60 MPa) for FA high replacement rate of 70% by weight of cement. It was observed that there were slight increases in compressive strength values when adding PET fibers and PET fine aggregate as a substitute for sand in SCC mixtures that contain fillers such as limestone, glass and kaolin. However, the notable increase in the strength for SCC containing KA might be attributed to the high cement content for this mix. In addition to the FA pozzolanic nature, the reason for this increase can be attributed to the ability of FA to ensure a good distribution of PET within the microstructure of SCC. This might lead to an increase in homogeneity and a decrease in voids formation according to (Gu & Ozbakkaloglu, 2016). In particular, PET in both forms was used at optimum contents.

3.2.2 Splitting tensile and flexural strengths

The splitting tensile and flexural strengths' values of SCC containing PET as fibers and fine aggregate after 28 days of water curing, as an average of three samples, are shown in Table 4.

Table 4 - Effect of PET as fibers and fine aggregate on splitting tensile strength of SCC mixes

Mix title	Splitting strength MPa 	Flexural strength MPa 
SCC-FA-0.7%Fi	3.56	3.94
SCC-LP-0.7%Fi	1.16	2.45
SCC-GP-0.7%Fi	2.26	3.18
SCC-KA-0.7%Fi	2.89	3.84
SCC-FA-4%F.A	2.81	3.09
SCC-LP-4%F.A	1.17	2.14
SCC-GP-4%F.A	1.16	2.85
SCC-KA-4%F.A	2.52	2.69

In general, it was observed that the tensile strength values of SCC mixtures containing PET fibers were greater than those containing PET fines. The weakening of the bond between the cement paste and the surface of the waste plastic particles with high surface area might be responsible for this behavior. (Ghorpade & Rao, 2018) also indicated that the tensile strength of SCC can increase by adding PET fibers. However, the recorded value of the results show that the tensile strength of concrete mixes increased to their maximum values with the addition of fly ash 70% by weight of cement as compared to other CRMs. They were 3.56 and 2.81 MPa for the mixes using this type of filler and PET as fibers and fines. The increases of the tensile strength values of SCC containing KA and PET in the two forms as compared to those containing GP and LP might be as result of high cement content in this type of concrete.

The results in Table 4 also show that the flexural strength of SCC mixes exhibited the same trend as compared to tensile strength but with higher values. The max achieved value was for SCC containing FA replacement with PET fibers at optimum content (3.94 MPa). This can be due to the same above mentioned reasons as well as the hydrophobic properties of plastic, which may prevent cement from full hydration in the vicinity of their surfaces. For the addition of PET fines in SCC, (Rai, Rushad, Kr, & Duggal, 2012) concluded from their research that adding plastic as fine aggregate reduces flexural strength of conventional concrete.

3.2.3 Impact strength

Table 5 illustrated detailed results of the number of blows required to make the initial and final cracks and the relevant impact strength for three SCC disks samples at 28 days. The impact energy at first crack and final failure was calculated as in Eq.1.

$$EI = N * m * g * h \dots\dots\dots\text{Eq.1}$$

Where: EI= Impact energy (N. m). g = Gravity acceleration (m/s²). h = Height of drop hammer (m). m = Mass of the drop hammer (kg). N = Number of blows.

Table 5 - Number of blows to cause first crack and failure with energy measured

Mix title	No. of blows (1 st crack)	Impact Energy (1 st crack N .m)	No. of blows (at failure)	Impact Energy (at failure N .m)
SCC-FA-0.7% Fi	158	3222	181	3692
SCC-LP-0.7% Fi	117	2387	166	3386
SCC-GP-0.7% Fi	110	2244	168	3427
SCC-KA-0.7% Fi	150	3060	173	3529
SCC-FA-4% F.A	185	3774	194	3957
SCC- LP-4% F.A	114	2325	122	2489
SCC-GP-4% F.A	125	2550	139	2835
SCC-KA-4% F.A	156	3264	185	3773

In general, the addition of plastic based fibers to SCC increases impact strength significantly. This indicates that any type of plastic, i.e recycled CFRP fibers , have the ability to absorb more energy, which causes failure according to (Mastali, Dalvand, & Sattarifard, 2017). However, in term of PET forms, PET fines in the current study showed better performance as compared to PET fibers in this aspect. The results obtained in Table 5 demonstrated that the use of PET fines at optimum content exhibited the highest numbers of blows to cause the first crack for SCC containing 70% FA followed by the same mix containing PET fibers (185 and 158 blows respectively).

Recently, it was explored by (Al-Tayeb, Aisheh, Qaidi, & Tayeh, 2022) that the use of plastic waste PW up to 20% can lead to clear improvements in impact behavior of conventional type of concrete. Replacing the cement 20% KA also resulted in an increase in the number of blows and impact strength mixtures containing plastic waste as fibers and partially replacing fine aggregate in place of sand. This may be due to the pozzolanic behavior of FA as compared to other used CRMs at high level (70% GP and 70% LP) and the high cement content for the SCC with 20% KA replacement. At failure, the best impact performances were achieved in SCC mixture containing 70% FA and PET fines at optimum content.

4. Conclusions

In this current research study, the effect of using waste plastic as fibers and fine aggregate in sustainable type of SCC containing various types of cement alternative materials such as (limestone, fly ash, glass powder and kaolin) on the fresh and hardened properties were experimentally evaluated. Accordingly, the following main conclusions and findings can be drawn:

1. Slight negative impact in the fresh properties of SCC incorporating high levels of CRMs, such as 70% of FA, GP, LP and 20% KA, were observed due to the additions of waste plastic PET as fibers and as fine aggregate replacement at optimum contents. However, the replacement of cement by 70% FA reduced these negative impacts significantly.
2. For the produce sustainable SCC, the impact of using PET as fine aggregate replacement at optimum content on the test fresh properties, such as slump flow, T500, L-box and SI, was greater than their use as PET fibers at optimum content.
3. The maximum achieved compressive strength when using waste plastic either as fibers or fine aggregate was recorded for SCC mixture with FA at high replacement rate of 70% by weight of cement. However, slight increases in compressive strength values were observed that there is when adding PET fibers and PET fine aggregate as a substitute for sand in SCC mixtures that contain fillers limestone, glass powder and kaolin.
4. Tensile and flexural strength behaviors, the sustainable SCC mixtures containing PET fibers shown a best performance as compare those containing PET fines. The best cement replacement materials used in this aspect is the fly ash in both cases.
5. Due to the use of PET as fines at optimum content in SCC mixtures containing 70% FA, substantial increase and improvement in the number of blows (to cause both first crack and final failure) and the impact resistance of SCC at both cases were recorded. However, it was followed by the same mixture with PET fibers at optimum content.

6. Based on most of tested properties in this study, the best CRMs to be used in sustainable SCC contain waste plastic PET was the FA as compared to others (GP, LP and KA).

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