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THE EFFECTS OF STEEL AND PET FIBERS ON THE PROPERTIES OF FRESH AND HARDENED SELF-COMPACTING CONCRETE

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ABSTRACT

Self-compacting concrete (SCC) due to several economical and technical advantages is increasingly used in construction industry. It can be improved on strength behavior when the fibers are added. Although the workability as a significant factor for this concrete must be maintained. This investigation experimentally evaluated the effects of steel and PET (polyethylene terephthalate) fibers separately on the properties of either fresh or hardened SCC. Fresh properties of concrete have been investigated by slump flow, V-funnel and L-box tests. Hardended properties were tested for compressive strength, splitting tensile strength, flexural strength, shrinkage and ultrasonic pulse velocity (UPV) tests. The results showed that 30 Kg/m^3 Steel and 3 Kg/m^3 PET fibers can be considered as suitable contents regarding to fresh and hardened properties of SCC. However, the addition of PET fibers have caused a slight decrease in compressive strength.

Keywords: Self-compacting concrete; engineering properties of concrete; steel fibers; PET fibers.

1. INTRODUCTION

SCC is one of the newest types of high-performance concrete which does not need to use an internal or external compaction, pass from the dense network reinforcement which make it different from ordinary concrete. Another characteristics of SCC is its high viscosity and stability that is due to using more fillers and cementitious materials. Increasing the cementitious materials and fillers in SCC, it will increase the brittleness of concrete matrix and more early-age cracking of SCC (due to plastic shrinkage, as well as thermal stress) and more drying shrinkage, comparing to normal concrete. Considering the successful

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experience of using fibers in concretes during the past years to improve these shortcomings of concretes, the use of fibers is a good idea to promote the ductility and to reduce early-age cracking of SCC [1-5]. Beside due to the presence of fibers which reduces the workability parameters of fresh concrete, maintaining the fresh properties of SCC within the desire range, limit the content of fibers used in SCCs [6-8]. The use of fiber-reinforced concrete (FRC) has been increased in building structures because majority of using fibers in concrete show improvement on toughness, compressive strength, flexural strength, tensile strength, impact strength as well as the failure mode of the concrete [6,9-12].

The use of steel fibers has become popular in FRC, specially their structural application is considered. In some cases, using steel fibers could be more effective than the classic method of reinforcing the concrete with bars, such as below [13-15]:

- Thin sections: due to a small cover of concrete and geometric complications, the use of bars is not possible and the use of fibers with a high volume percentage could be considered as a good replacement.
- Elements which are under severe loading, heavy loads and large displacements (such as the interior cover of tunnels and explosion resistant structures): In such structures, fibers act as additional reinforcements.

PET has been used increasingly in recent years (especially use as PET bottles) [16,17]. Burying or burning a great amount of these disposable materials does a lot of harm to the environment [18]. Nowadays, researchers have investigated many effects of plastic waste on mortar and concrete [19-21], especially as mortar and concrete fiber reinforcement. Pereira de Oliveira and Castro-Gomes [22] investigated the effect of PET fiber on cement-lime mortar. The results indicated that, the PET fiber incorporation did not significantly change the magnitude of the mortar compressive strength. Whereas, significantly improved the flexural strength of mortar with a major improvement in mortar toughness. A study by Foti [23] exploring the effect of PET fibers on the ordinary concrete. The test results showed that, the addition of PET fibers decreased the compressive strength of plain concrete. Similar conclusion has been reported by Kim et al [24]. In both studies, good results in terms of increased ductility of the fiber-reinforcement concrete had been obtained.

Based on experiments of other authors, limited works have been done on SCCs containing PET fibers. Therefore, the effects of PET fiber on characteristics of fresh and hardened SCC were considered and were compared with SCC including steel fiber and without fiber.

2. EXPERIMENTAL PROGRAM

2.1 Materials

In this study, the coarse and fine aggregates were crushed. Nominal maximum size and water absorbtion of coarse aggregate (CA) were 12 mm and 0.86 respectively and water absorbtion of fine aggregate (FA) was 1.93.

In this research type II portland cement conforming the requirements of ASTM which produced at Hegmatan factory was used with specific gravity of 3.15 gr/cm^{3}` and Blaine fineness of 2900 gr/cm^{3}. Also, silica fume (SF) which produced at Ferro Alloy Azna factory with specific gravity 2.12 gr/cm^{3} was used. The chemical compositions of these binders are presented in Table 1. Also, quarry waste stone powder (QWSP) with specific gravity 2.7 gr/cm^3 was used.

Table 1: Chemical properties of binders

Chemical composition (%)	Cement	Silica fume
CaO	63.24	0.49
SiO_2	21.54	95.10
Al_2O_3	4.95	1.32
Fe_2O_3	3.82	0.87
MgO	1.55	0.97
SO_3	2.43	0.10
Na_2O	0.61	0.57
K_2O	0.30	0.35

Polycarboxylicether based high range water reducer (HRWR) namely Glenium51 with density between 1.06 and 1.08 gr/cm^3 (at 20℃) was used to improve the workability of fresh concrete.

In this study two types of steel and PET fibers were used, Figure 3. Which PET fibers were formed by cutting of PET bottles. Steel fibers (S-F) dimensions were of 50 mm length with a diameter of 1 mm and they had a tensile strength and specific gravity of 1000 MPa and 7.85 gr/cm^3 respectively. PET fibers (PET-F) dimensions were approximately 2 mm width, 0.5 mm thickness and 35 mm length and they had a specific gravity of 1.34 gr/cm^3.

(a) (b)

Figure 3. PET (a) and steel (b) fibers used in this study

2.2 Mix proportions

In this research, 10% of cementitiouse material was incorporated with silica fume and water to total cementitiouse materials ratio (w/cm) of 0.40 was considered. The cementitiouse materials content was kept at 450 kg/m^3.

SCC mixture without fiber (Control mixture) was made based on the recommendation given by EFNARC committee [25], with high passing ability in crossing the bars, great stability against segregation and bleeding (despite of adding fibers in different mixtures, the desired factors of regulation were maintained). Considering the use of crushed sand and gravel and their negative effects on flow properties, increasing the superplasticizer additive dosage required. The mixtures properties are shown in Table 2.

Table 2: Mixture proportion

Mix ID	Water (kg/m^3)	Cement (kg/m^3)	SF (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	QWSP (kg/m^3)	HRWR (kg/m^3)	S-F (kg/m^3)	PET-F (kg/m^3)
Control	180	400	50	657	904	250	4.41	0	0
Steel30	180	400	50	657	904	250	6.50	30	0
Steel40	180	400	50	657	904	250	6.95	40	0
Steel50	180	400	50	657	904	250	7.52	50	0
PET3	180	400	50	657	904	250	4.80	0	3
PET4	180	400	50	657	904	250	5.12	0	4
PET5	180	400	50	657	904	250	5.38	0	5

According to Table 2, the amounts of 30, 40 and 50 kg/m^3 steel fibers and 3, 4 and 5 kg/m^3 PET fibers were added to the control mixture. Then, the effects of these amounts of fibers on the workability of fresh concrete were investigated. Finally, hardened concrete tests were carried out on the mixtures which had suitable fresh concrete properties.

Mixing of SCCs containing fibers were performed in two different ways by other researchers. Some of them, first mixed fibers with aggregates then added cement and water [26,27]. But some others, first made SCCs without fibers and then added the fibers to the mixture [6,8]. In this study, the second method was used. The fine and coarse aggregates and quarry waste stone powder were first mixed in mixer for 30 second, then one-third mixing water was added into mixer and after 1 min mixing, the mixer was turned off and cement and silica fume were added into mixer. After that, the mixer was started and the rest of mixing water along with superplasticizer were added into running mixer in a gradual manner. After 3 min mixing, the fibers were added into running mixer gradually. Finally after 3 min, the fresh self-compacting concrete tests and molding specimens were performed.

After casting, All the specimens were kept in the laboratory room for 24 hr. The test specimens were then remolded and moist cured at 24±2 ℃ until the age of tests.

2.3 Fresh concrete tests

In this investigation, slump flow, T_{50}, V-funnel and L-box tests were performed according to the procedure recommended by EFNARC committee [25]. Slump flow test has been proposed to assess filling ability of concrete in the absence of obstructions. Slump flow is not a suitable factor to exactly indicate the fresh properties of SCC. But, if the slump flow is kept within a desirable range, it is possible to evaluate the requirements of SCC. All SCC mixtures with slump flow values between 650 and 800 mm were proposed in the present study. The visual stability index (VSI) was used in relation to slump flow test as the simplest well known method to detect stability. According to this index, self-compatibility of concrete is scaled into four groups between 0 (highly stable) and 3 (highly unstable). After removing the slump cone, the segregation resistance of SCC can be inspected visually by measuring a coarse aggregate pile or the thickness of cement paste extended beyond the coarse aggregate. Generally, a VSI from 1 (stable matrix) to 0 has been regarded as acceptable. Viscosity can be evaluated by the T_{50} or V-funnel times. The L-box is utilized to determine passing ability of SCC when flowing through confined or reinforced areas. The workablity limits suggested by EFNARC committee are presented in Table 3.

Table 3: Slump flow, viscosity and passing ability limits with respect to EFNARC [25]

Method	Unit	Typical range values	
		Min	Max
Slump flow	cm	65	80
t_{50} Slump flow	s	2	5
V-funnel	s	6	12
L-box	H1/H2	0.8	1

2.4 Hardened concrete tests

The experiments carried out in the hardened phase consist of: compressive strength, splitting tensile strength, flexural strength, and shrinkage.

Compressive strength was studied on three 100 mm cube at curing ages of 3, 7, 14, 28, 42 and 90 days in accordance with ASTM C39 at the rate of loading was 0.25 MPa/s. Splitting tensile strength was studied on three 150×300 mm cylindrical at curing ages of 3,7, 14, 28, 42 and 90 days. This test was performed according to procedure recommended by ASTM C 496 and the rate of loading was 1.2MPa/s. Flexural strength tests were carried out on three prismatic specimens 100×100×500 mm at curing ages of 28 and 90 days. This test was performed according to procedure recommended by ASTM C 78 and the rate of loading was 1MPa/min.

Shrinkage tests were investigated on three prismatic specimens 70×70×280 mm at ages of 3, 7, 28 and 90 days in accordance with ASTM C 157. After demolding, the test specimens were kept in laboratory room until the age of testing.

The ultrasonic pulse velocity test was conducted according to ASTM C 597 on three 100 mm cube at curing ages of 14, 28, 42 and 90 days.

3. RESULT AND DISCUSSION

3.1 Fresh concrete results

The fresh properties of all SCC mixtures were studied and results of these tests were shown in Table 4.

Table 4: Fresh concrete test results

Mix ID	Slump flow (mm)	VSI	T_{50} (sec)	V-funnel (sec)	Blocking ratio
Control	67	0	1.8	5	1
Steel30	65	1	4	10	0.81
Steel40	63	2	9	23	0.68
Steel50	61	3	15	40	0.55
PET3	68	1	2.4	6	0.91
PET4	65	3	4.9	15.3	0.78
PET5	61	3	8.5	19	0.7

As metioned earlier, the viscosity of SCCs, as dicated by T_{50} measurements of slump flow test and V-funnel test. The results demonstrated that Steel40, Steel50, PET4 and PET5 mixtures had not suitable viscosity, seemed to be affecred by fiber inclusion, giving longer slump flow time (T_{50}) and V-funnel test and poienting out to a less flowing concrete. The L-box test showed that the passing ability of these four SCCs mixtures decreased and in Steel40, Steel50 and PET5 mixtures, the considerable blockage were observed. Also, In the all of above mixtures, the significant segragation and bleeding were observed. So, as the contents of fibers increased, the workability decreased.

Although, the addition of 30 kg/m^3 steel fibers and 3 kg/m^3 PET fibers had caused a slight decreas in workability parameters, the results of the fresh concrete properties of these mixtures were maintained within the desirable ranges. Also, visual inspection of fersh concrete did not dictate any segregation and bleeding in Steel and PET mixtures.

3.2 Hardened concrete results

Based on fresh concrete tests results, the maximum permitted amounts of steel fibers and PET fibers were found to be 30 kg/m^3 and 3 kg/m^3 respectively in order to preserve the workability of SCCs. Hence, for hardened concrete tests, steel30 and PET3 mixtures along with Control mixture were considered.

3.2.1 Compressive strength

The results of compressive strength test were shown in Figure 4. It can be observed that the compressive strength of all mixtures increased by the age of concrete. Moreover, the addition of steel fibers to concrete enhanced the compressive strength, but the inclusion of PET fibers reduced the compressive strength in all concrete ages. For example at the age of 28 day, The presence of steel fiber caused an improvement in the compressive strength of SCC up to 9.6%, whereas, the PET fiber had caused a decrease down to 6.9%.

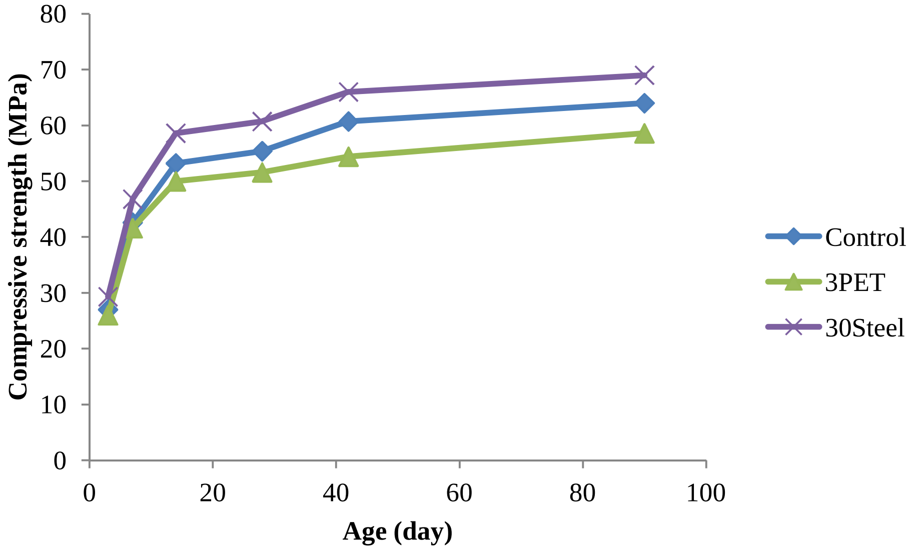

Figure 4. Compressive strength of control, steel and PET mixtures

In all ages, the most important observation during testing was the change of the failure mode of the concrete as the fibers were included in SCC. Specially, this event in the mix containing steel fiber was more clear. The failure mode changed from sudden failure into a more ductile failure. This due to the strong bond between fibers and the concrete, and the effect of fibers in preventing concrete from sudden explosive failure.

3.2.2 Splitting tensile strength

The results of splitting tensile strength were shown in Figure 5.

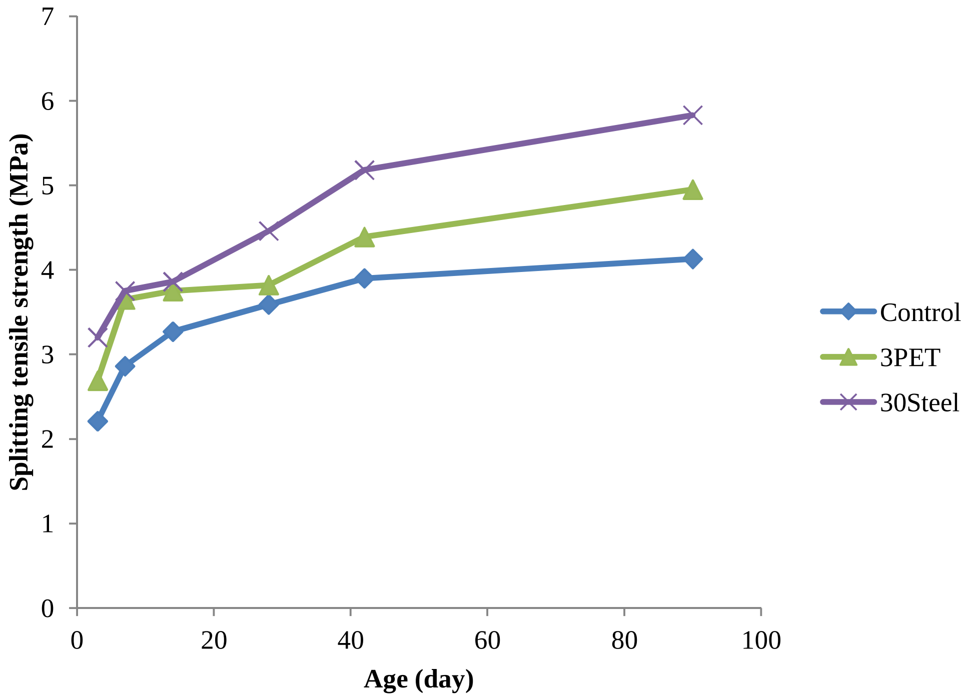

Figure 5. Splitting tensile strength of all mixtures

The results indicate that presence of both steel and PET fibers increased the splitting tensile strength in all ages, however the increasing rate in steel concrete mixture was found to be higher. This behavior can be explained that steel fibers have higher tensile strength than PET fibers and the bond between steel fibers and concrete is higher than bond between PET fibers and concrete (due to physical properties of steel fibers such as: strong surface and two ends hooked).

Moreover, in both concretes containing fibers, the failure mode changed from sudden explosive failure into ductile failure and the test cylinders did not completely split in two separate halves at failure due to the inclusion of fibers. This event could be due to strong bond between fibers and concrete.

The splitting tensile strength of SCC mixtures versus cylindrical compressive strength was presented in Figure 6. It should be noted that the 100 mm cube compressive strength was converted to cylindrical strength by applying suitable conversation factor [28]. Accordingly, it can be seen that splitting tensile strength values of all SCC mixture lie in the range of bound value suggested by CEB-FIP [29] code for normal concrete.

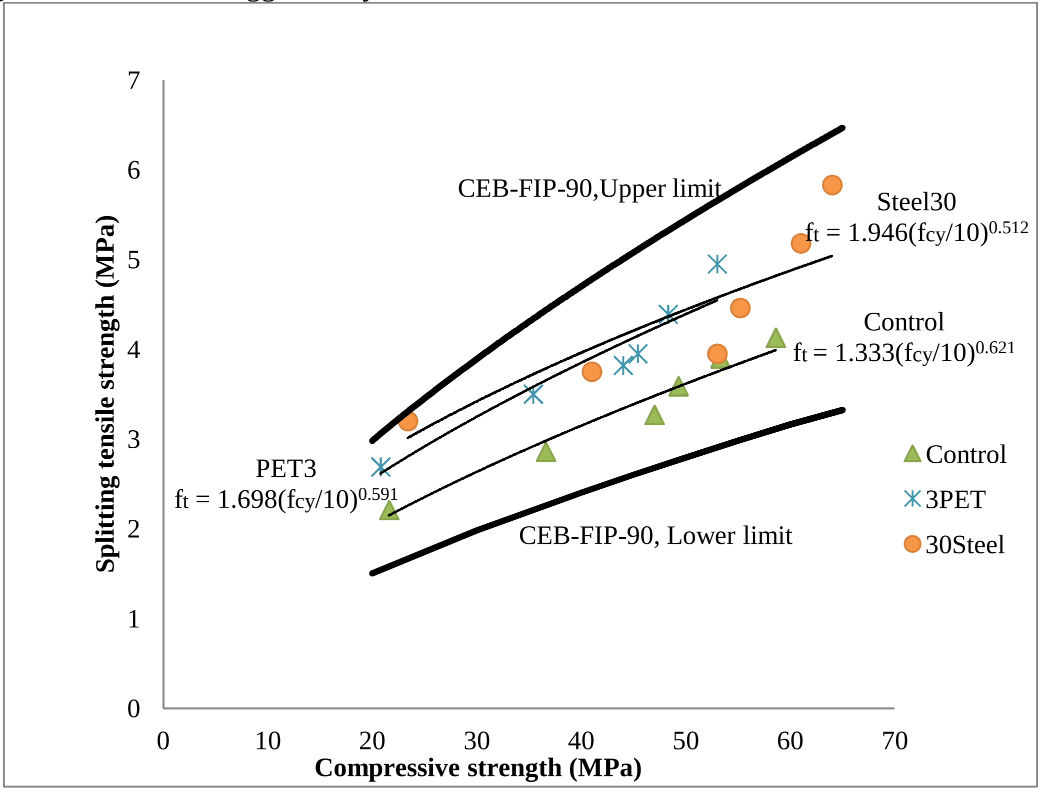

Figure 6. Variation splitting tensile strength vs. compressive strength

3.2.3 Flexural strength

The results of flextural strength test were shown in Figure 7.

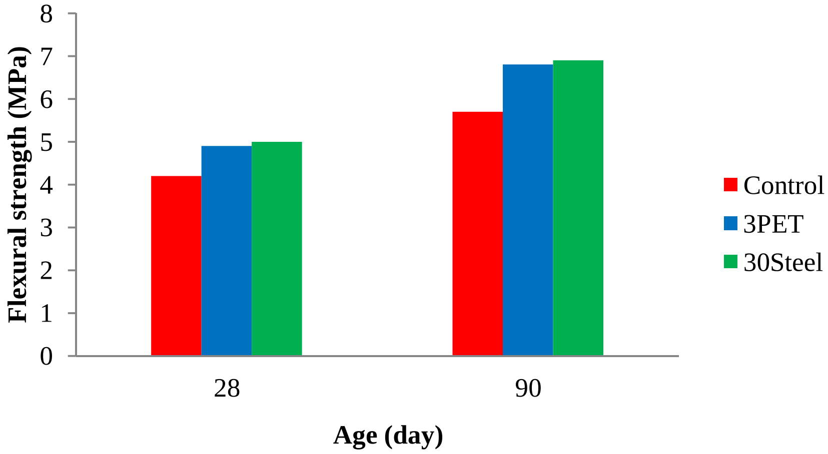

Figure 7. Flexural strength of all mixtures

The obtained results showed the effectiveness of both steel and PET fibers in improving the flexural behavior of concrete, where the performance of concrete containing steel fibers was slightly better. This test, like splitting tensile strength, in both concrete containing fibers, the failure mode changed from sudden explosive failure into ductile failure and the test specimens did not completely split two separate halves at failure due to the inclusion of fibers.

3.2.4 Shrinkage

The results of shrinkage test were shown in Figure 8.

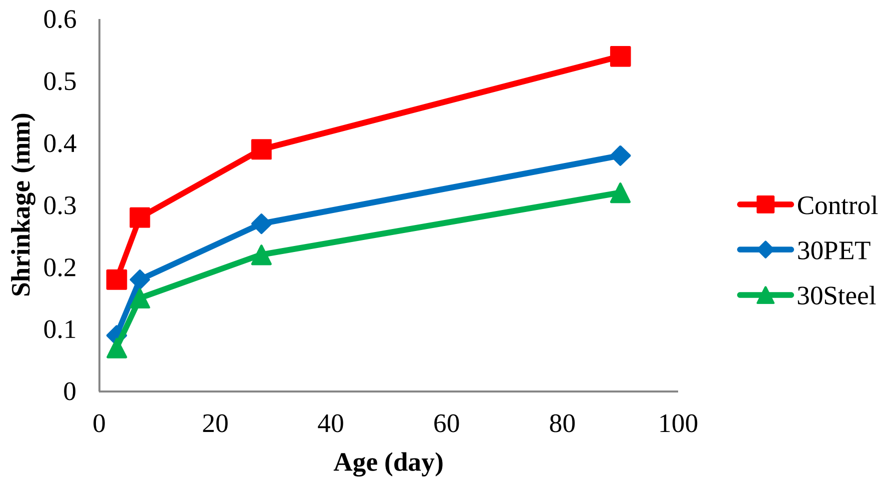

Figure 8. Shrinkage measurements of all mixtures

As can be observed that presence of steel and PET fibers decrease the amount of shrinkage. Although, concrete containing steel fibers showed a better performance. These improvements on shrinkage behavior could be due to strong bond between fibers and concrete which reduces the shrinkage enhancement.

In the other words, after occurrence of microcracks in the concrete matrix (because of shrinkage), the stresses are transferred from matrix to fibers in the cracked parts of the concrete matrix and considering to long-term resistance of fibers, the fibers are able to withstand greater tensile strain and they prevent the crack propagation and the localization of microcracks into macrocracks, so the shrinkage are decreased.

3.2.5 Ultra pulse velocity (UPV)

The ultrasonic pulse velocity (UPV) method was applied to characterize the uniformity of fiber reinforced SCC. Figure 9. presents the UPV values of all SCC mixtures at different curing ages.

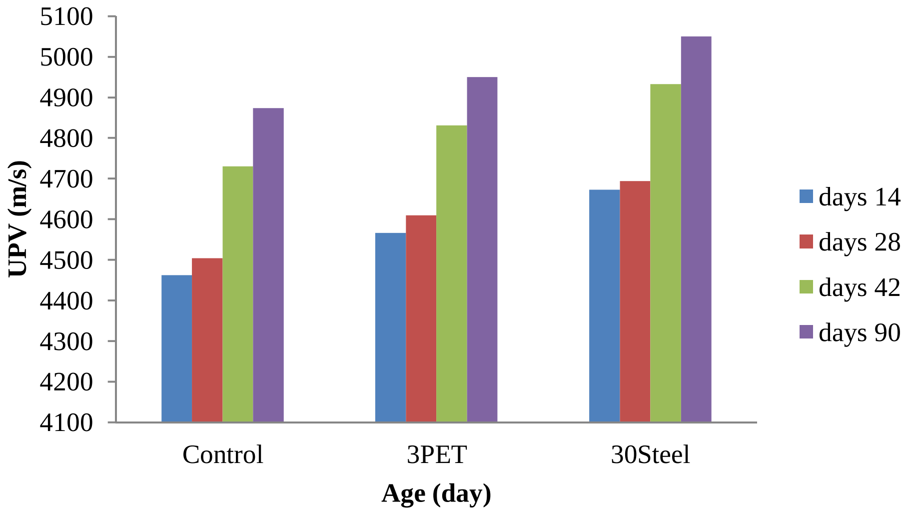

Figure 9. UPV of SCC mixtures at different curing ages

However, a slight increase was observed in the UPV of SCCs containing fibers, but it was not significant. So, UPV did not seem to be affected by using of fibers. This observation is in agreement with the results found in other studies [26,30]. The negligible variation in the UPV test results can be as an indication of the uniformity of concrete matrix in all mixes. Also, it was clear from Figure 9, that, as hydration continued, the UPVs increase for all SCC mixtures.

4. CONCLUSION

Based on the results of this experimental study, the following conclusions can be drawn:

1. Considering to fresh concrete tests, the amounts of 30 kg/m^3 steel fibers and 3 kg/m^3 PET fibers can be regarded as the most appropriate amounts of fibers which added to SCC mixtures.

2. The addition of steel fibers decreased the flow ability in slump flow test, increased the flow time in slump flow (T_{50}) and V-funnel tests and decreased the passing ability in L-box test, but these results were not significant about SCC containing PET fibers.

3. Steel concrete had the most compressive strength in all ages, whereas PET fibers had caused a decrease in compressive strength.

4. Steel and PET concretes had more splitting tensile strength than Control concrete in all ages and SCC containing steel fibers had the best performance.

5. The presence of both steel and PET fibers caused an improvement in the flexural strength of SCC up to 20% and 18% respectively.

6. In compressive strength, splitting tensile strength and flexural strength tests, the failure mode of the concrete changed from sudden failure into a more ductile failure as fibers used in SCCs.

7. In fiber reinforced concrete, better performance was observed in decreasing drying

shrinkage and SCC containing steel fibers had the best performance.

7. The UPV test of the SCC mixtures showed to be unaffected by the steel and PET fibers inclusion.

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