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Influence of Waste PET Bottle Particles and Steel Fibers on Fresh Properties of Concrete

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ABSTRACT. *Fiber-reinforced concrete containing wastes is trending nowadays due to its better performance and modified mechanical properties when compared to conventional concrete. Those wastes include artificial and natural fibers which are low density, lightweight, environment-friendly, and cost-friendly as well. Steel fibers along with waste PET (Polyethylene terephthalate) bottle particles with varying percentages are used to study the combined effect on concrete. Fresh properties of concrete strongly depend on the dynamic and mechanical properties of concrete. So, it is important to determine the fresh concrete's workability for easy handling and pouring. The study aims to determine the effect of steel fibers and waste PET bottle particles with different percentages on the properties of fresh concrete. Pozzolanic material and admixture are used to enhance the workability of concrete. In this study, three combinations are made by keeping the constant percentage of steel fibers i.e. 2% by volume, and varying percentages of PET bottle particles. Plain concrete (PC) is designed for the strength of 30MPa and slump, fresh density, and compaction factor tests were conducted for examining the fresh concrete properties. The concrete's workability is checked by doing a slump cone test, compaction factor test, and fresh density, then results are compared with PC. The results showed that by adding steel fibers (SFs) and washed PET bottle particles, the value of the slump decreased by 18.2% for the mixture containing 5% PET particles, 41% for the mixture containing 10% PET particles, and 59% for the mixture containing 15% PET particles when compared with PC.*
Keywords: steel fibers, waste PET bottle particles, workability, compaction factor, fresh density, slump cone test

1. INTRODUCTION

With the growing age, the utilization of concrete is growing day by day. This can be due to the increase in urbanization rate in many developing countries and even undeveloped countries. The most widely used construction material is concrete and it is the backbone of the construction industry [1]. Besides its abundant utilization, concrete has adverse ecological effects and there is always a need to reduce the impacts on the environment due to concrete. Sustainable material is always needed to reduce the cement content of concrete, reducing air pollution due to less carbon dioxide (CO_2) emission into the air. Concrete is brittle in nature; it is stronger in the compression and weak in tension [2][3]. Artificial fibers gained popularity due to their less cost, eco-friendly nature, and lightweight. They also have good physical properties when compared to plain concrete (PC). The use of waste natural fibers or artificial fibers leads to the reduction of the workability of concrete [4]. The fresh concrete's workability is directly related to the strength parameters of concrete. By the incorporation of short discrete fibers in concrete, workability is minimized to some extent as compared with conventional concrete [5].

The workability reduces when we add different types of fibers to concrete. To increase the steel fiber-reinforced concrete's (SFRC) workability and stability, superplasticizers can also be used in the concrete mix. The accelerated stiffening and decreased workability of fresh concrete would be the disadvantage of SFRC due to the SFs addition, thereby excess vibration required to make the SFRC workable, so increasing the construction labor and construction time [6]. The addition of PET particles in concrete also reduces the slump, resulting in stiffness, and reducing workability. The characteristics of FRC increase or decrease depending on fiber content percentage. It was noted that workability was affected by higher percentage of fiber [7]. The slump cone test is performed at construction site and in the laboratory for the determination of the workability of fresh concrete [8][9]. The slump of concrete determines its workability. The material with a high stump value is considered more workable and vice versa. Artificial fibers and other artificial raw materials greatly impact the workability of concrete. So, workability is controlled by these substituents of concrete and by the water-to-cement ratio (w/c). Reduction in the water-to-cement ratio caused a reduction in workability. To meet the flaw, different plasticizers and super-plasticizers are used [10]. These admixtures help to enhance the workability of concrete.

Many researchers reported the effect of artificial waste like waste PET bottle particles and steel fibers on the properties of concrete [11] [12] [13]. Steel fiber is a natural fiber and waste PET bottles can be used to enhance the mechanical as well as dynamic properties of concrete. It was observed that by the usage of steel fibers up to 0.5% by volume affects the impact resistance reached 1.5 and 1.8 times the initial crack and the ultimate strength of the ordinary concrete [15], and by using hooked shapes up to 1% by volume of concrete, the impact resistance reached 3.9 and 2.4 times the initial crack and the ultimate impact strength of high strength concrete [16]. The combined effect of both steel fiber and waste PET bottle particles may have better properties than using them solely. Few studies show the combined effect of steel fiber and waste PET bottle particles [11].

A wide range of studies is available on the workability of artificial hybrid fiber-reinforced concrete. The hardened properties of concrete play an important role in workability. So, there is a need to explore the effect of steel fibers and waste PET particles on the workability of concrete. The waste disposal issue and the high cost of construction can be solved. [17]. For this purpose, mixtures containing steel fibers are prepared, and waste PET bottle particles are replaced with sand. Pozzolanic material is used to increase the properties as the workability decreases by adding these materials to concrete [6]. So, silica fume powder is partially replaced with cement, and polycarboxylate is used to tackle this disadvantage. A slump cone test is performed to check the workability of the mixtures and PC. The lower value of the slump may cause difficulty in handling and pouring. It may also tend to deviate from the required strength properties. This study may help to understand the workability of PC and mixtures. It may also help to explore the behavior of steel fibers and waste PET bottle particles when used with concrete and their effect on the fresh concrete's workability.

2. METHODOLOGY

2.1. Raw Ingredients

Ordinary Portland cement (OPC), Margalla crush, and locally available sand as written in table 2 were used to prepare PC. For the preparation of mixtures, steel fiber of length of 40mm and diameter of 0.8 having an aspect ratio of 50, waste PET bottle particles with a maximum size of 7mm, silica fume powder (white) is added 2% by the replacement of cement, and 1% polycarboxylate liquid is also added by volume of concrete. The percentage of steel fibers is 2% by volume of concrete, and the waste PET bottle particles are varying as 5%, 10%, and 15% by the replacement of sand. Tap water is used to prepare PC and mixtures. PC and all mixtures are prepared with a water-to-cement ratio (w/c) of 0.47. The steel fibers and waste-washed PET bottle particles are shown in figure 1 which is used for the preparation of concrete, while table 1 shows the sieving details of PET particles and table 2 shows the physical properties of coarse aggregate and fine aggregate.

a) b)

Fig-1: a) Washed dried waste PET Bottle Particles b) Steel fibers

Table-1: Sieving of PET bottle particles

Sieve Size	Percentage remaining on the sieve
7.00 mm	5
4.75 mm	12.5
2.36 mm	67.5
1.18 mm	15

Table-2: Physical Properties of Coarse aggregate and Sand

Parameters	Margalla Crush	Parameters	Sand
Water Absorption (%)	1.32	Specific gravity	2.65
Specific gravity	2.83	Natural water content (%)	2
Bulk density (kg/m^3)	1508	Maximum dry density (g/cm^3)	1.66
Voids	45.56	Minimum dry density (g/cm^3)	1.34
Impact value	16.50	Maximum void ratio	0.970
Crushing Value	29.80	Minimum void ratio	0.590

2.2. Mix Design and Concrete Preparation

To prepare plain concrete, the ratio for mix design for the cement, sand, and aggregates was kept as 1, 1.3, and 2.3 respectively. PC and mixtures are prepared with a water-to-cement ratio (w/c) of 0.47. As there is no such standard procedure till now for mixing. So, the layers method is adopted for the mixing of ingredients. A step-wise increment of water was adopted to avoid bleeding. For the preparation of PC, all ingredients were added to a concrete mixer, and the mixer was allowed to rotate for three minutes. All materials were added in a mixer in such a way that they may mix efficiently. To prepare mixtures, one-third of the aggregate was spread in the mixer in a layer followed by one-third of steel fiber and waste PET bottle particles. Then one-third of the sand was poured and spread with the help of a spade followed by one-third of the cement. All layers were thoroughly spread to attain a homogeneous mix. The same procedure was adopted for the whole ingredients in each mixture. One-third of the water was added to the mixer and then the mixer was allowed to mix. The rest of the water was added in increments during the rotation of the concrete mixer to make mixtures workable. Table 3 shows the mix design ratio and the ingredients used in the concrete mix.

Table-3: Mixtures combination and mix design ratio

Concrete Mix	Binder Material		Fine Aggregate		CA (kg/m^3)	Water (kg/m^3)	Steel Fibers*** (kg/m^3)	Polycar-boxylate*** (kg/m^3)
	Cement (kg/m^3)	Silica Fume* (kg/m^3)	Sand (kg/m^3)	PET Particles** (kg/m^3)				
PC	2221.66	-	2886.66	-	5108.33	1065	-	-
S1	2178.33	43.33	2742.33	143.33	5108.33	1065	216.66	111.66
S2	2178.33	43.33	2598	288.33	5108.33	1065	216.66	111.66
S3	2178.33	43.33	2453	431.66	5108.33	1065	216.66	111.66

Note: * partially replaced with cement, ** partially replaced with sand, *** added by volume of concrete

2.3. Tests

The tests conducted is explained in detail along with the standards used for the testing.

2.3.1. Slump Test

A slump cone test is performed to determine the workability of concrete. This test is done at the laboratory before pouring concrete into molds by using ASTM standard C143/C143M-15a.

2.3.2. Compaction Factor Test

The compaction factor test is conducted by using BS 1881-103. The compaction factor of PC and all three mixtures are measured.

2.4.3. Fresh Density Test

The fresh density of concrete is measured by using ASTM C138. By using this standard fresh density of PC and mixtures are determined.

3. RESULTS AND ANALYSIS

3.1. Influence of Waste PET Particles and Steel Fibers on Slump of Fresh Concrete

The slump of the PC and all the mixtures are measured. The value of the slump for PC is 110 mm. It can be noted that S1, S2, and S3 have 90mm,65mm, and 45mm slumps as shown in the third column of table 3. The common thing is that all these three mixtures have steel fiber of 40 mm lengths with 0.8 diameters having an aspect ratio of 50 but different percentages of PET bottle particles i.e. 5%, 10%, and 15%. There was a gradual decrease in slump value for S1, S2, and S3 when compared with plain concrete (PC). The slump of concrete having 15% PET particle content is shown in figure 2.

Fig-2: Slump of concrete having 15% PET particles content

The concrete pouring and transporting depends upon the workability of fresh concrete. In this regard, water to cement ratio plays an important role. If the concrete does not meet the required w/c, it may cause a reduction in slump value. The less slump value shows less workability of concrete and vice versa. All mixtures are less workable than PC because all mixtures have less value of slump as compared to PC. The less value of slump is due to the incorporation of steel fibers and PET particles which lowers the density of concrete. The orientation of steel fibers did not affect the workability. S3 has a 45mm slump, so it is more difficult to handle and transport.

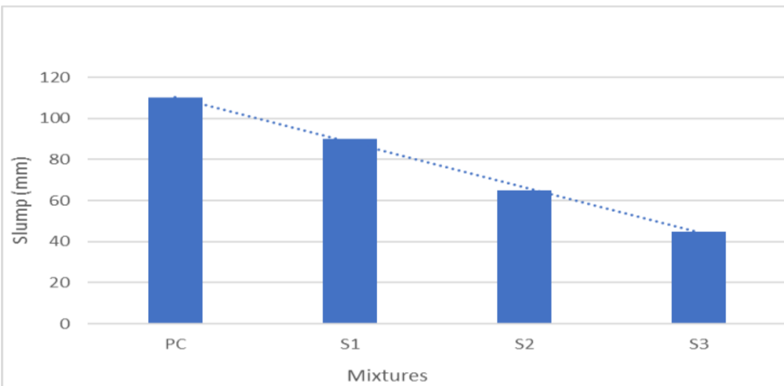

Fig-3: Slump of PC and mixtures

The slump is decreasing as we add more PET particles. The workability is decreasing due to the combined effect of steel fibers and PET bottle particles. This is due to the low density of PET particles, which reduces the workability of mixers. Figure 3 shows the slump values of PC and mixtures i.e. S1, S2, and S3, while table 4 shows the slump of the mixtures, and their fresh density and compaction factor values.

It can be seen from figure 3 that the slump values of the mixtures are decreasing when compared with PC. This is due to the presence of low-density PET particles, by increasing the content of PET particles, the slump decreases and vice versa.

Table-4: Showing slump, compaction factor, and fresh density of fresh concrete

Sr. No	**Samples**	**Slump (mm)**	**Compaction Factor**		**Fresh Density (kg/m$^{3)}$**
			Value	**Workability**	
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1	PC	110	0.90	Plastic	2304
2	S1	90	0.88	Stiff Plastic	2288
3	S2	65	0.82	Stiff Plastic	2254
4	S3	45	0.80	Stiff	2222

3.2. Effect of Waste PET Particles and Steel Fibers on Compaction Factor of Fresh Concrete

The compaction factor and the workability of PC and mixtures are given in the fourth and fifth columns of table 4. It was observed that the PC showed a 0.90 value for the compaction factor, while S1, S2, and S3 showed 0.88, 0.82, and 0.80, respectively. The values of the compaction factor decrease as we compare PC and mixtures. The plastic and stiff workability of PC and S3 can be seen, while S2 and S3 show stiff plastic workability as shown in the fifth column of table 4. It was observed that by adding PET particle content, the compaction factor reduces, as they are low-density particles that reduce the compaction factor.

Fig-4: Compaction Factor of PC and mixtures

Many studies have shown a similar change in the PC when varying types of fibers and particles are added. Adding varying types of fibers and particles makes PC less dense, which results in low workability and makes it difficult for the pour. Figure 4 shows the compaction factor values for PC and mixtures i.e. S1, S2, and S3. Figure 4 shows the compaction factor values for PC and mixtures.

3.3 Fresh Density of concrete having Waste PET Particles and Steel Fibers

The fresh densities of mixtures and PC are determined and are given in the sixth column of table 3. The observed densities of PC, S1, S2 and S3 are 2304 kg/m^3, 2288 kg/m^3, 2254 kg/ and 2222 kg/m^3, respectively. It was noted that the addition of PET particle content reduces density, and a decreasing trend was seen when we compare all mixtures with PC. Previous studies have also shown the same trend. Adding different types of material can lead to low-density concrete compared with PC. The fresh density is also decreasing due to the addition of low-density PET particles. The increment in PET particle content makes the concrete less workable and less pourable. Figure 5 shows the fresh densities of PC and mixtures.

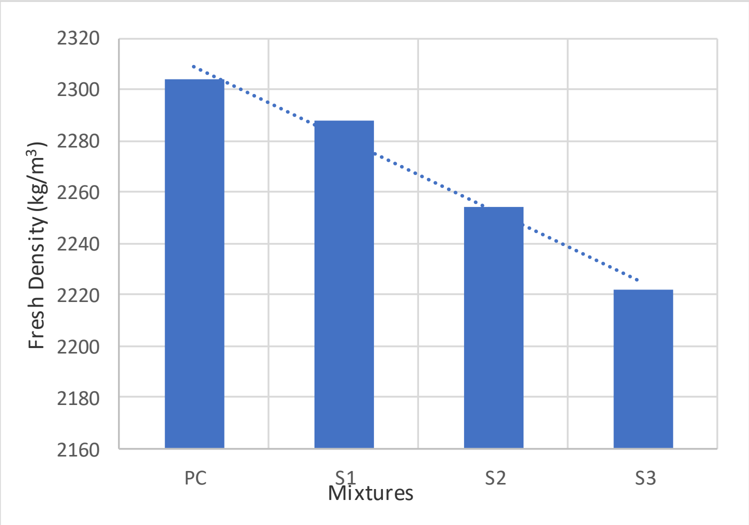

Figure 5: Fresh density of PC and mixtures

4. CONCLUSION

The effect of waste PET bottle particles and steel fiber is determined in terms of fresh concrete's workability. For this purpose, a slump cone test is performed on PC and mixtures. The steel fiber is added 2% and PET bottle particles are taken as 5%, 10%, and 15% with the partial replacement of sand. After conducting this study following conclusions are made.

- Addition of steel fibers and waste PET particles reduces the workability of fresh concrete. The slump is 18.2% decreased for the mixture that contains 5% PET particles, 41% decreased for the mixture that contains 10% PET particles, and 59% decreased for the mixture that contains 15% PET particles when compared with PC.

- There is a decrease in the compaction factor, and fresh density of concrete mixes containing 5%, 10% and 15%. The mixers having 15% PET particle content showed the minimum values, while the mixture containing 5% PET particles showed good compaction factor and fresh density values.

- Concrete containing 5% PET bottle particles is easy to handle and pour, some pozzolanic material and admixtures enhance the concrete's workability.

Concrete containing 5% PET bottle particles has shown more strength and good workability. Environment pollution can be controlled by utilizing wastes in concrete and it also enhances the concrete's properties when compared with plain concrete (PC).

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