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Characterization of Concrete Incorporating Waste Polythene Bags Fibers

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Abstract

In an attempt to create environmental friendly concrete, an investigation was carried out to determine the effects of adding non-biodegradable plastic fibers obtained from shredded waste polythene terephthalate bags on fresh and hardened properties of concrete. A pre-defined concrete mix was adopted with water to cement ratio of 0.45. Concrete mixtures were produced by adding 0.5% to 1.5% waste polythene fibers by weight of cement while keeping all other fractions the same. The size of the fibers was kept as 2cm × 3cm. Large size was selected because smaller polythene fibers would break very easily. Various tests performed on the fresh and hardened concrete show that the addition of plastic fibers changes fresh-state, physical and mechanical properties of concrete. The addition of plastics fibers increases in the workability of fresh concrete. However, plastic fibers reduce the density of hardened concrete and increase porosity and water absorption. Furthermore, on addition of these fibers reduction in the mechanical properties of concrete was observed. The addition of 1.5% fibers caused a reduction of 9.7%, 6.9% and 12.4% in split tensile strength, compressive strength and flexural strength of concrete respectively. Based on the experimental results it might be argued that the various concrete strength parameters decrease on addition of fibers but this reduction may be considered small compared to the benefits of its environmental friendly nature. Such concrete may be initially used in the non-structural applications such as barriers, curb stones, concrete blocks, and floor tiles.

Key Words: Polythene, Bags, Fibers, Environment, Concrete

1. Introduction

Plastic is considered to be one of the most versatile materials which act as raw material for the production of various beneficial products being used around the world on a daily basis. It is reported that around 4% of the world's oil production is utilized as raw material for plastic production [1]. Although these products might be very useful, their usefulness gets shadowed by the non-biodegradable and toxic nature of plastics. Plastics contain various toxic substances like di-ethylhexyl-phthalate (DEHP), poly halogenated compounds and heavy metals [2], [3]. As plastics require thousands of years to degrade, their proper disposal has become a serious concern [4]. Some researchers have proposed that plastics, in the form of fibers, can be used in concrete manufacturing as a mean of safe disposal [5]–[9].

In previous studies various types of materials have been incorporated in concrete to improve the engineering properties of concrete like resins, fibers, rubber, slag, ashes etc. [10]–[16]. It has been reported that the extent of effect depend on various factors including the interaction between cement and these additives and their proportion [17]–[22].Furthermore, the effect of addition of these materials may yield positive as well as negative effects on engineering parameters of concrete [23].

As plastics are one of the most abundantly used materials, plastic-fibers have been used as an additive in concrete alone and in combination with other additives [22], [24]. Literature reports contradictory results regarding the incorporation of plastic fibers in concrete. On one hand, it has been reported that plastic fibers can increase concrete's compressive strength when added up to certain content [5]. An increase of up to 13% was reported by Ochi et. al. on adding 1% fibers [25]. However, the strength starts decreasing on increasing the fibers content. A similar study carried out by Kim et. al. reported that the compressive strength decreases on adding plastic fibers to concrete. A reduction of up to 9% was reported [26]. This change in behavior was attributed to the type of material (modulus of elasticity of plastic fibers) and processing of the plastic fibers by Borg. et. al. [6]. Similar studies carried out on long term strength gains by adding plastic fibers in concrete reported that although slight increase in strength is observed at 28 days, the strength reduces afterwards due to degradation of plastics in alkaline environment [27], [28].

Similarly, investigations on flexural strength of concrete incorporating plastic fibers were also carried out by several researchers. Four-point flexural tests carried on plastic fibers reinforced concrete specimens showed remarkable increase in the post-cracking residual strength and toughness [25], [27]. Hence, the addition of plastics may have conflicting effects on engineering properties of concrete, however, the reported negative values are not that high, which can be called alarming. Therefore, plastic has seen its real life application in Japan in the construction of roads, bridge piers, tunnel lining and underground storage tanks etc. [25].

Apart from compressive and flexural strength parameters, the suitability of concrete in seismic regions is also very important. Owing to the lightweight nature, plastics may be incorporated for production of light weight concrete by replacing aggregates with plastics. Such lightweight concrete may be very helpful in highly seismic prone regions [29]–[34]. Furthermore, the addition of plastic fibers enhances the ductility of concrete, which is desirable against seismic deformations [25], [27]. For such performance, bond of plastic fibers with concrete matrix is very important. In a study it was found that embossed fibers provide better bond strength as compared to crimped and straight fibers. Similar findings were also reported by Kim et. al. [26]. Apart from improving the seismic behavior, strong bond between plastic fibers and concrete may enhance the concrete's resistance to plastic shrinkage and subsequently reduce cracking in concrete at early stages.

Although several studies have reported moderately positive impact of the use of plastic fibers on concrete's mechanical properties, there are a few reports which state negative impact as well. The use of waste materials in concrete may reduce the strength parameters but as their use in concrete is an environmental friendly move, such applications might be recommended. In this study, plastic fibers obtained from locally produced polythene bags have been incorporated in concrete and their effects on various fresh and hardened properties of concrete has been investigated.

2. Materials and Experimental Method

2.1 Materials Selection and Preparation

Ordinary Portland cement (ASTM C-150 [35]) and locally available Sargodha Crush (coarse aggregate) and Chenab Sand (fine aggregate) were used to produce concrete. Gradation of coarse and fine aggregates was carried out following ASTM C136 [37]. Gradation curves are shown in Fig. 1 and Fig. 2. The fineness modulus of coarse aggregates was 4.5% and that of fine aggregates was 4.9% (as determined from gradation process). The consistency of cement paste was determined following ASTM C187 [36]. The value was around 35%.

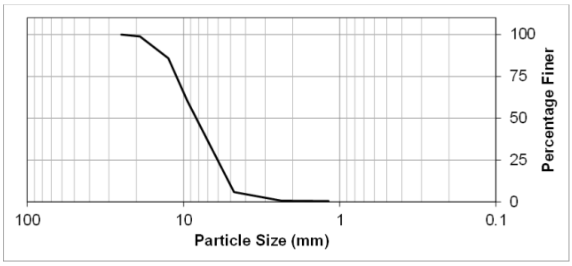

Fig.1: Gradation curve of coarse aggregates (Sargodha crush)

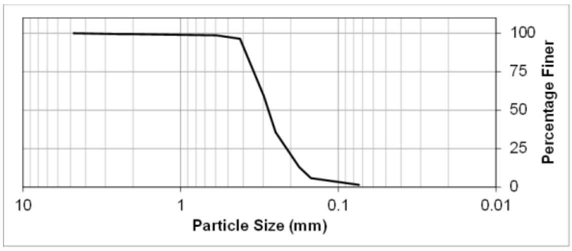

Fig. 2: Gradation curve of fine aggregates (Chanab Sand)

Apart from regular constituents, plastic bag fibers were also used in concrete. The waste plastic bags were collected from various dumping locations to collect a blend of different types of materials used in the industry to produce plastic bags. Further, these bags were cut into pieces which were 2cm × 3cm in size. The larger size was maintained as smaller polythene fibers are too weak to withstand stresses developed in concrete. Previous studies have reported smaller fiber sizes of up to 0.05 – 2mm diameter [5] as well as larger fiber sizes of 3cm to 5cm [6]. As most of the polythene bags used in Pakistan are 15 µm in thickness, the strength contributed by them was expected to be very less. Therefore, large size of 2cm × 3cm was selected. Bigger fibers may crumble during mixing stage and provide better strength than smaller fibers.

2.2 Concrete Mix Procedure

Various constituents were mixed in the proportion of 1:1.5:3 with water to cement ratio of 0.45. The water cement ratio was selected based on workability requirements as reported in previous study [38]. Ordinary tap water (fit for drinking purposes) was used to produce the concrete mixture. Plastic fibers (obtained after manually shredding the waste plastic bags) were incorporated in various dosages ranging from 0.5% to 1.5% by weight of cement. The details of the concrete mixes are presented in **Table-1**. All concrete constituents were initially mixed in dry state and later water was added to produce the mixture using concrete shear mixer of 0.5m^3 capacity. Plastic fibers were gradually added at the final stage of mixing to avoid coagulation of fibers.

Table 1: Concrete mix proportions

Mix No.	Description	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Plastic Fibers (kg)
1	Control	10	15	30	4.5	0
2	0.5% Plastic Fibers	10	15	30	4.5	0.05
3	1.0% Plastic Fibers	10	15	30	4.5	0.1
4	1.5% Plastic Fibers	10	15	30	4.5	0.15

2.3 Test procedure

An important parameter of concrete is the ease of use during fresh state (workability). On adding various additives, the workability might be improved or negatively affected. Slump value test and compacting factor test were performed to investigate concrete's workability. ASTM C143 was used to perform the tests [39] (**Fig. 3**). In order to access the physical properties of concrete, density of concrete, air voids determination and sorptivity various tests were carried out using ASTM C642 [40] and ASTM C1585 [41]. For this purpose, cylindrical disk specimen were retrieved from the 150mm diameter concrete cylinders by cutting 50mm and 100mm thick concrete cylinder slices. These samples were oven dried at 110 ºC for 24 hours after initial mass measurements. Afterwards, the samples were air dried to around 20-25 ºC for measuring the mass. Later on these samples were taken through another drying cycle of 24 hours and the mass was measure again. Further, the samples were immersed in water for 48 hours at 21 ºC. Their mass was measured again after making them surface dry. The samples were then boiled in water for 5 hours and the mass was measured again. Finally, the samples were suspended in water for measuring apparent mass. Density and water absorption was calculated at each stage of this test.

Furthermore, various tests were performed related to the mechanical properties of the concrete. These tests included compressive strength test (ASTM C39 [42]), flexural strength test (ASTM C78 [43]) and split tensile strength test (ASTM C496 [44]). Direct shear test was also performed on the prism samples. **Fig. 5** presents the experimental setup of the shear test. The bottom supports and loading points were both 190mm apart. The central portion had an overlapping zone of 20mm, and the load was applied at the mid-point of this 20mm zone. Due to the concentration of shear forces on that zone, the shear cracks were expected to originate in that portion. Hence, the load determined by this method would be very close to the actual shear strength. Concrete cylinders with 150mm diameter were used for compressive and split cylinder tensile tests. Prisms of size 100 × 100 × 400mm were used for flexural and direct shear test. The details of specimen types and tests performed are presented in **Table-2**.

3. Results and Discussion

3.1 Fresh Concrete Properties

Slump Value Test

Slump test was performed to determine the effect of plastic fibers on the workability of concrete. It was observed that on adding plastic fibers the slump value of concrete increased, as shown in **Fig. 6**. A moderate 8% increase in slump was observed on adding 0.5% plastic fibers while 28% increase in slump value was observed on adding 1.5% plastic fibers. The increase in the slump value may be attributed to the smooth surface of plastic fibers (as compared to sand particles) which helps in creating zones of lesser friction for inter-particle movements and also retard early cement reaction by preventing the cement particles getting in contact with aggregates[38], [45].Another reason reported in literature for improved workability is the non-absorptive characteristic of plastic fibers [46].Similar results were reported by other researchers as well [38], [46], [47]. Safi et. al. (2013) reported that on adding 20% waste plastic fibers (by weight of sand), the slump may increase to around 25% [38].

Compacting Factor Test

Compacting factor test was also performed on fresh concrete incorporating different dosages of plastic fibers. It was observed that on adding waste plastic fibers, the compacting factor value reduces which is analogous to the slump value test results. Fig. 7 shows the effect of plastic fibers on compacting factor value of concrete. It was observed that on adding 0.5% waste plastic fibers, the compacting factor value reduces by around 8.5% and on adding 1.5% fibers the compacting factor value reduces by around 15%. Bhogayata et. al. (2012) reported similar results stating that on adding 1.2% plastic fibers the compacting factor decrease by about 21%. The trend is similar to the test results as obtained in this study. It was also reported that the effect of plastic fibers on workability is dependent on the size and cutting techniques used to produce plastic fibers [47].

3.2 Hardened Concrete Properties

Tests were performed to characterize concrete based on strength and other hardened properties. Water absorption, bulk density, permeable air voids were determined as per ASTM C462 [40].

Table 2: Test Matrix

No.	Type of Specimen	Test Performed	Test Specification
1	Cylinder (150 × 300mm)	Compressive Strength	ASTM C39-05
2	Cylinder (150 × 300mm)	Split Tensile Strength	ASTM C496-11
3	Prism (100 × 100 × 400mm)	Flexural Strength Test	ASTM C78-16
4	Prism (100 × 100 × 400mm)	Shear Strength Test	Generic
5	Disk (150 × 50mm)	Sorptivity Test	ASTM C1585- 13
6	Disk (150 × 100mm)	Density Water Absorption Air Voids	ASTM C642-13

(a) Compacting Factor Test (b) Concrete Slump Test

Fig. 3: Workability tests on concrete (a) compacting factor test (b) slump test

(a) Cylinders for compression and split tensile tests (b) Prisms for flexural and direct shear tests

(c) Disks for physical properties tests (d) Flexural test on concrete

Fig. 4: Various concrete specimens for testing

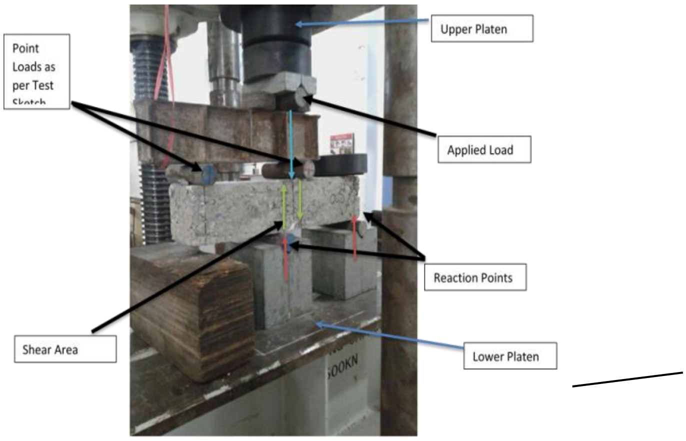

Fig. 5: Schematic figure of direct shear test on concrete prisms

Water Absorption

The results of water absorption before and after boiling in water test are presented in **Fig. 8**. It can be observed that on adding waste plastic fibers the water absorption increases. At 0.5% fibers dosage an increase of about 3.5% was observed before boiling and about 9.6 % after boiling. For 1.5% fiber dosage, water absorption increased by about 25% before boiling. The increase in water absorption may be attributed to increased porosity which may have increased due to the disturbances at fibres-matrix contact zone due to damaged fibers. Increase in the water absorption after adding plastic fibers have also been reported by other researchers as well [6], [48].

Fig.9 shows the results of bulk density tests. It was observed that on adding 0.5% fibers the bulk density of concrete at dry state, after immersion and after boiling reduced by 1.1%, 0.9% and 0.6%, respectively. Similarly, on adding 1.5% fibers, dry state bulk density, bulk density after immersion and bulk density after boiling reduced by 8.5%, 7.3% and 6.2% respectively. The reduction in bulk density values after addition of plastic fibers is logical and has also been reported by several other researchers. Safi et. al. (2013) reported a reduction of 9.5% on adding 10% waste plastic fibers while Yang et. al. (2015) reported a reduction of 3% in the bulk density of concrete incorporating 10% plastic fibers [38], [46]. The reduction of bulk density may be attributed to the weight ratio of conventional concrete constituents (cement, sand and aggregate) and plastic fibers which are comparatively very light. This observation has already been verified by various researchers [24], [45], [49].

Fig. 10 shows the increase in permeable air voids in concrete incorporating various dosages of waste plastic fibers. It was observed that on adding 0.5% and 1.5% plastic fibers the permeable air voids increase by about 5% and 32%, respectively. The increase in the air voids may be attributed to the crumbling of plastic fibers which would entrap more air than the concrete without fibers or concrete with lesser amount of fiber. Fig. 11 shows the sorptivity test results for concrete incorporating various dosages of waste plastic fibers. Analogous to the water absorption test, the sorptivity value also increases on addition of waste plastic fibers.

Compressive Strength

Concrete compressive strength was determined at various ages (7, 14, 21 and 28 days) for concrete prepared with 0.5%, 1.0% and 1.5% waste plastic fiber dosages. It was observed that the compressive strength reduces on addition of waste plastic fibers (WPF). As compared to regular concrete, after 28 days, average decreased in compressive strength was 5.75%, 6.36% and 6.58% for 0.5%, 1.0% and 1.5% plastic fibers, respectively () (**fig. 12**). The decreasing trend in compressive strength of WPF concrete is parallel to the results reported by several previous studies [47], [50], [51].

It was reported that on addition of 10% fibers by weight of sand, the compressive strength was reduced by 6.6% [38]. The may be due to insufficient homogeneity of concrete owing to the weak bond between the plastic and cementations particles [51]. Furthermore, the reduced strength may also be attributed to the lower strength of plastic fibers [38].

Tensile Strength

Split cylinder tensile strength results of concrete incorporating different dosages of waste plastic fibers are presented in **Fig. 13**. It was observed that tensile strength of concrete decreases on addition of waste plastic fibers, similar to compressive strength. The average decrease in split tensile strength at 28 days was observed as 6.34%, 8.58% and 9.7% at 0.5%, 1% and 1.5% plastic fibers dosage, respectively. This may be attributed to weak fiber-cement matrix interface [46].

Flexural Strength

Fig. 14 shows the results of four-point flexural strength tests performed on concrete prisms. It was observed that at 28 days curing age, the reduction in flexural strength of concrete was 4.6%, 7.2% and 12.4% for 0.5%, 1.0% and 1.5% waste plastic fiber dosages, respectively. The reduction in concrete flexural strength was also reported by several other researchers [22], [38], [45], [50]. A reduction of about 19% was reported by Safi et. al. (2013) at 28 days, after adding 10% plastic fibers in concrete by weight of sand [38].

Direct Shear Strength

Fig. 15 shows the effect of waste plastic fibers on shear strength of concrete at different dosages. It was observed that the average shear strength of concrete incorporating 0.5%, 1.0% and 1.5% waste plastic fibers reduced by approximately 31%, 39% and 45%, respectively.

4. Conclusions

Main aim of this study was to characterize the concrete incorporating different dosages of waste plastic fibers to create an environment friendly concrete mix. The prime benefit would be safe disposal of toxic plastic waste which may become hazardous if dumped in open landfills. Three dosages of waste polythene fragments (2cm × 3cm in size) including 0.5%, 1.0% and 1.5% were added to concrete mix. Fresh and hardened state properties of concrete were determined. Hardened state properties included both physical and mechanical parameters.

On adding WPF, workability improved. This was evident both from the slump and compacting factor test. For 1.5% dosage, slump value increased by 28%, while the compacting factor was reduced by 15%. Thus, concrete incorporating WPF may be suitable for narrow spaces where high workability is needed. All physical parameters exhibited negative trend on addition of WPF. On adding 1.5% WPF, density was reduced by 8.5% in dry state and 6.2% after boiling. Similarly, water absorption and air voids for 1.5% WPF increased by 25% and 32%, respectively. Similar results were reported by other researchers.

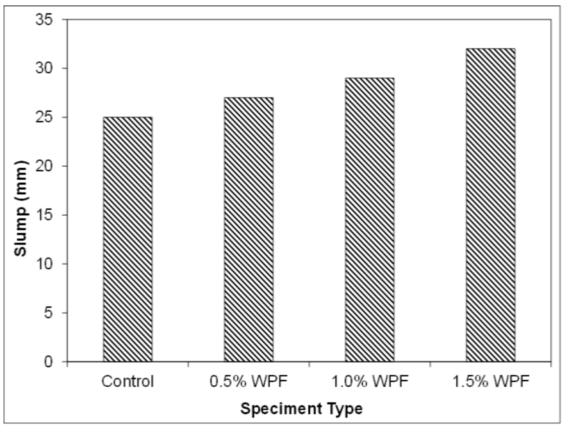

Fig. 6: Effect of plastic fibers dosage on slump value of concrete

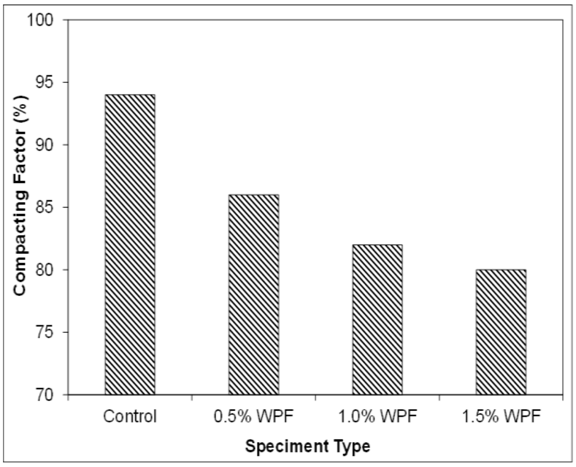

Fig.7: Effect of plastic fibers dosage on compacting factor value

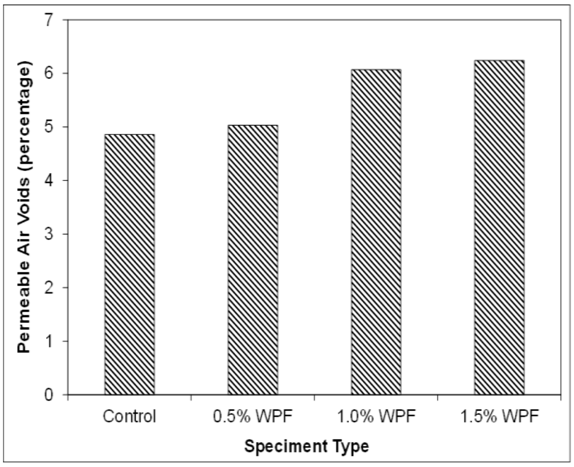

Fig.10: Permeable air voids in concrete incorporating plastic fibers

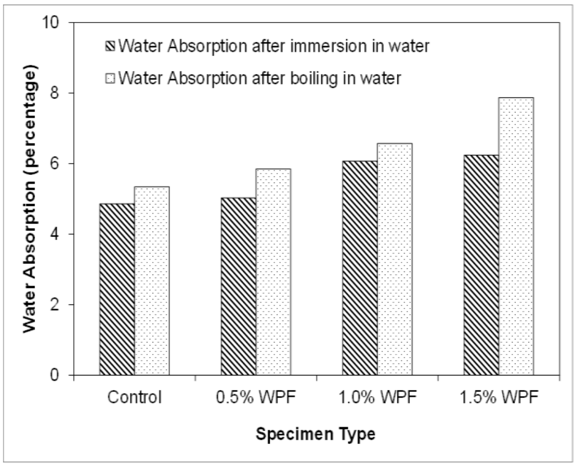

Fig.8: Water absorption test on concrete incorporating WPF

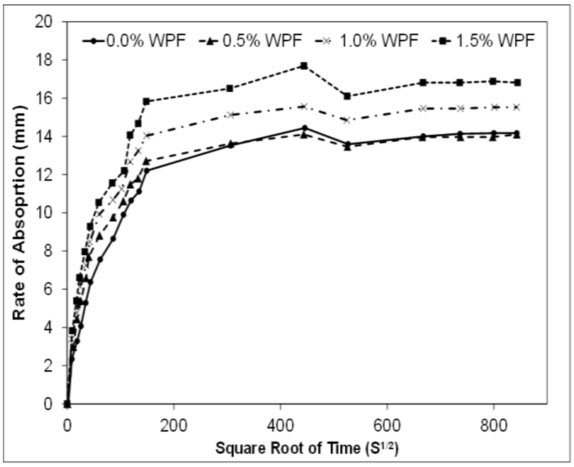

Fig.11: Sorptivity test results for concrete incorporating waste plastic fibers

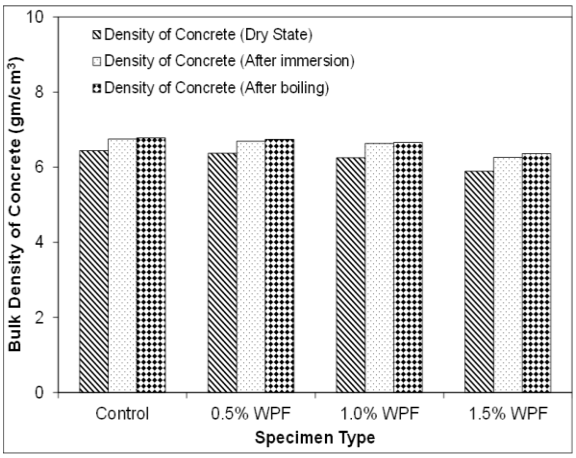

Fig.9: Bulk density of concrete (dry state, after immersion in water and after boiling)

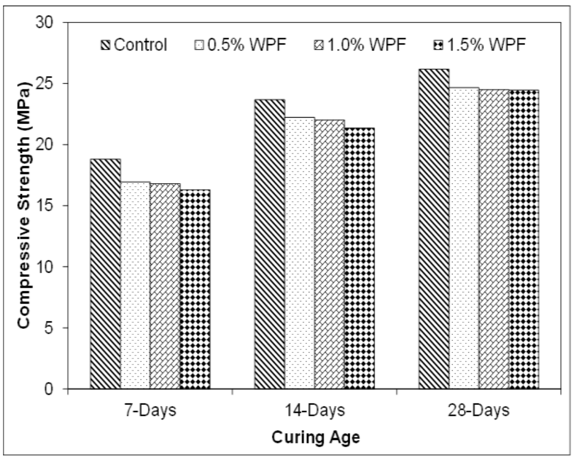

Fig. 12: Effect of waste plastic fibers on compressive strength of concrete

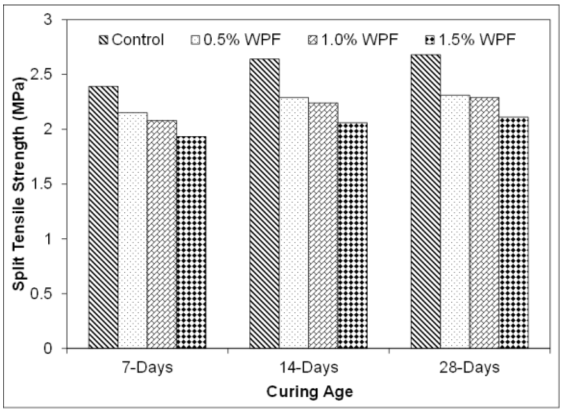

Fig.13: Effect of waste plastic fibers on tensile strength of concrete

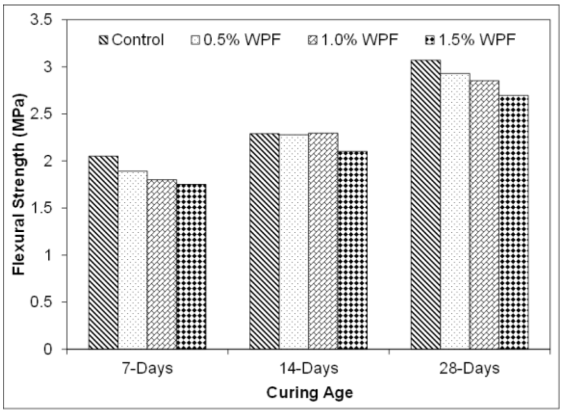

Fig.14: Effect of waste plastic fibers on flexural strength of concrete

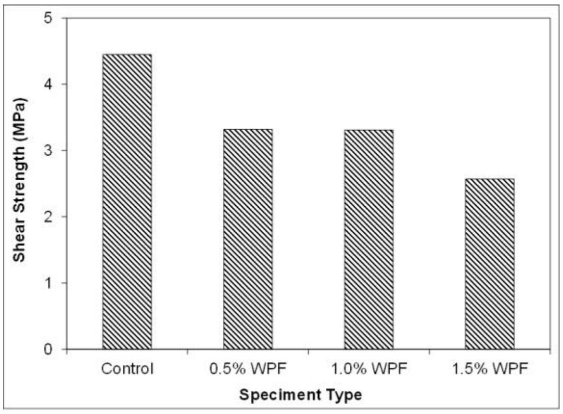

Fig. 15: Effect of waste plastic fibers on shear strength of concrete

Compressive strength tests and flexural strength tests also exhibited negative trends. On adding 0.5% fibers the compressive, tensile and flexure strength values were dropped by about 5.75%, 6.34% and 4.6% respectively. Similarly, the reduction in these values was observed to be 6.58%, 9.7% and 12.4% on addition of 1.5% WPF. For most of the mechanical strength properties the reduction was around 10% or less. However, the direct shear strength test showed drastic reduction. At 0.5% WPF dosage the strength reduced by 31% and at 1.5% dosage the strength was reduced by about 45%.

Based on the results it can be concluded that waste plastic fibers obtained from polythene bags may be incorporated in concrete for safe disposal without significantly compromising on the major strength parameters of concrete including compressive and flexural strength. Such concrete may be recommended for use in non-structural application like barriers, curb stones, pavements etc.

5. References

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