



## EVALUATE THE INFLUENCE OF STEEL FIBERS ON THE STRENGTH OF CONCRETE USING PLASTIC WASTE AS FINE AGGREGATES

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### Abstract

*The plastic existence in abundance and its low biodegradability affect the environment. In recent years, researchers have tested numerous recycling techniques. However, each has its demerits. One such technique is recycling plastic as aggregates in concrete. It improves the concrete thermal insulation but depreciates its compressive and tensile strength, which is its core property in the construction industry. The objective of this research work is to efficiently utilize the plastic aggregate in concrete without deteriorating its strength with the use of steel fibers. In total eight concrete mix configurations were studied in this research. The result discussion includes compressive strength, split tensile test, and toughness index. The steel fiber used in the concrete mix with recycled plastic as fine aggregates improved the concrete strength. Its effects increase with an increase in % vol replacement of plastic aggregates with fine aggregates from 5 to 20.*

**Keywords:** Concrete; compressive strength; tensile strength; recycled plastic granules; steel fibers

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### I. Introduction

Since the 1960s the global production of plastics has amplified twentyfold, reaching 322 million tons in 2015 [X]. In the next twenty years, it is expected to amplify twofold again (COM 2018). This phenomenal growth is due to its high strength to weight ratio, longevity, and low cost. Due to the increase in the use of plastic products,

*Samiullah Qazi et al*

the volume of plastic waste is also increasing. Like other waste, plastic waste has also a hazardous effect on the environment [XXVIII], which needs to be disposed of. According to a survey published on the national geographic website [XIX], “in the last six decades, a whopping 91% of plastic isn't recycled i.e., 6.3 billion metric tons out of the 8.3 billion metric tons that have been produced has become plastic waste. The vast majority—79 percent—is accumulating in landfills or sloughing off in the natural environment as litter. Meaning: at some point, much of it ends up in the oceans, the final sink”. Plastic biodegradation requires thousands of years [XX, IV]. Saikia and Brito [XIX] stated that waste plastics decrease soil permeability and fertility. Incineration can also be used as a disposal method because of its high calorific value. However, its burning pollutes the air due to the release of poisonous gases, including dioxins [XIV]. Apart from that, recycling plastic waste as aggregates in concrete appears the best solution due to its ecological and economic benefits. According to Sharma R, Bansal PP [XXVI], in Europe alone the aggregates demand per annum is 3 billion tons (€20 billion). This demand is fulfilled by up to 90% of the processing of natural resources, and 10% from recycled aggregates. Therefore, plastic waste use as aggregate in concrete will reduce the depletion of natural resources to a good amount. Numerous researchers have worked on recycling of plastic as aggregate in concrete, such as waste plastic flakes [XXI], plastic coarse aggregate (PCA) [XXIV], high-density polyethylene waste (HDPE) [XVIII], polyethylene terephthalate particles (PET) [XIV, II], PET waste [XI], shredded fibers of polythene bags [IV], PET bottle fibers [XI], polyvinyl chloride (PVC) pipe [XV], and granulated plastic waste [XIII]. The plastic aggregates (PA) due to their inherent low thermal conductivity, high heat capacity, and high toughness improve some concrete properties [XXIV]. As the unit weight of plastic aggregate is significantly lighter than that of natural aggregates, therefore it reduces the overall density of concrete [XXIII]. This lightweight concrete use can reduce the buildings' dead weight, which lowers the seismic risk, and is supportive in the design of an earthquake-resistant building [XIV]. However, the PA addition in concrete also has some detrimental effects on its mechanical behavior and workability [XXIII]. The partial replacement of PA with NA in concrete always lowers its strength and modulus of elasticity [II, XXVI]. The concrete compressive strength along with its density reduces with an increase in the volumetric replacement of plastic with sand [XVII]. This phenomenon is attributed to the weak bond between the plastic and surrounding matrix and excess in the water-cement ratio due to the hyperbolic plastic surface instigating an increase in voids [XXVIII]. All failure modes in concrete are a consequence of tensile failure [IX] and improving the tensile strength is a method to lessen the reduction in compressive strength. The steel fibers are used in concrete to improve its mechanical performance and limit crack propagation. Researchers [VIII, III] have recorded an improvement in concrete tensile strength, flexural strength, and relaxation, with the partial replacement of coarse aggregates with steel fibers.

The main objective of this research work is to retain the compressive strength of concrete with the use of steel fiber while efficiently disposing of recycled plastic as fine aggregates in concrete. The test results discussed in this research are concrete compressive, tensile strength, and toughness index.

## II. Experimental work

In this research, the recycled plastic granules (RPG) manufactured by recycling of polythene bags by a local plastic recycling factory were used (Fig. 1). The type 1 Portland cement used had normal consistency of 28%, initial setting time of 75 min, final setting time of 196 min (ASTM C187), the specific gravity of 3.01 (ASTM C77), fineness of 92% (ASTM C184), and compressive strength of  $23 \pm 0.4$  MPa (ASTM C109). The particle size distribution of fine and coarse aggregates used is shown in Fig. 2. Its fineness modulus was 2.8 (ASTM C136/C136M-14). The coarse aggregates with a maximum size of 0.75 inches were used. The hooked shape steel fibers of 65mm length and 0.5mm diameter were used (Fig. 1). The material properties evaluated using ASTM standards procedures are listed in Table 1.



(a) Recycled plastic granules

(b) Steel fibers

Fig. 1 Materials used as partial replacement of sand and coarse aggregates

**Table 1: Material properties**

Materials	Cement	Natural Quartz	Sand	Recycled plastic granules	Steel Fibers
Specific gravity	3.01	2.76	2.47	1	7.9
Water absorption	--	3.7	1.01	--	--

To identify an optimum plastic aggregate concrete mix, eight concrete mixes were evaluated in this research. The control specimen mix design ratio was 1: 2.77: 3.74 by weight with targeted strength of 20.7 MPa (3000 psi). This particular strength was selected because normally the strength recommended in the field is at least 13.8 MPa (2000 psi) for construction in a low seismic zone and 20.7 MPa (3000) psi in a high seismic zone according to BCP 2007 [V]. The mixed design details are listed in Table 2. Twelve 6" \* 12" concrete cylinder specimens per each configuration were prepared. In total ninety-six concrete cylinder specimens were tested. All the specimens were cured for 28 days before testing. Six out of twelve concrete cylinders per each



with sand (PC20), as compared to normal concrete (NC). This decrease in strength is attributed to the weak bond of pet particles with texture [XXII], apart from its lesser strength as compared to natural aggregates. The pet particle due to its inherent weak adhesion hinders the bond between cement paste and natural aggregates. This leads to the formation of weak interfacial transition zones [XXVI], through which the cracks initiate in specimens under lesser induced loading. The 1.5 wt% replacement of steel fibers with coarse aggregates limited the compressive strength deterioration to a great extent, credited to the good mechanical properties of steel fibers. The increase in compressive strength recorded in steel fiber concrete (SC) compared to normal concrete (NC) was 19%. However, the same improvement rate was not observed in the case of concrete with pet particles. The improvement in compressive strength of SPC10, SPC15, and SPC20 as compared to PC10, PC15 and PC20 was 7%, 12%, and 18%, respectively (% compared to control specimen NC). Therefore, the influence of steel fibers in concrete was higher in one with a higher vol% replacement of plastic granules with sand.

**Table 3: Concrete cylinder uniaxial compressive and split tensile test results**

Specimens	$f_c^*$ (MPa)	St. Div. (MPa)	Strength Gain (%)	$f_t^*$ (MPa)	St. Div. (MPa)	Strength Gain (%)
NC	18.99	0.38	--	1.85	0.12	--
PC10	15.7	0.16	-17%	1.29	0.14	-30%
PC15	13.78	0.18	-27%	1.18	0.17	-36%
PC20	11.71	0.64	-38%	1.02	0.5	-45%
SC	22.6	0.33	+19%	2.17	0.2	+17%
SPC10	17.09	0.34	-10%	1.7	0.13	-8%
SPC15	16.14	0.32	-15%	1.59	0.18	-14%
SPC20	15.1	0.64	-20%	1.4	0.3	-24%

\* $f_c$ : Compressive strength;  $f_t$ : Split tensile strength

Six specimens per each concrete mix were subjected to the split cylinder test with a UTM machine, according to the ASTM C496 standard. Test results are depicted in Table 3 & Fig. 4. The specimen split tensile strength decreased with the increase of recycled plastic granules (RPG) and increased with the induction of steel fibers. The 20 vol% replacement of RPG with sand reduced the overall strength by 45% in comparison to the control specimen. The decrease in tensile strength is much higher than in the case of compressive strength. This behavior is attributed to the weak interfacial bonding between the plastic aggregate and cement paste. The steel fibers replacement with coarse aggregates in all mixes improved their performance by almost 22%. According to Kang J. [XVI], “The ratio between the tensile and compressive strength can give information on the toughness behavior of the concrete specimen”. Concrete of higher toughness displays its higher ratio [XXIV]. The tensile/compressive strength ratios are presented in Table 4. The RPG induction reduced the specimen

toughness index whereas steel fiber addition in concrete mix regained/improved the specimen toughness index compared to the control specimen (NC).

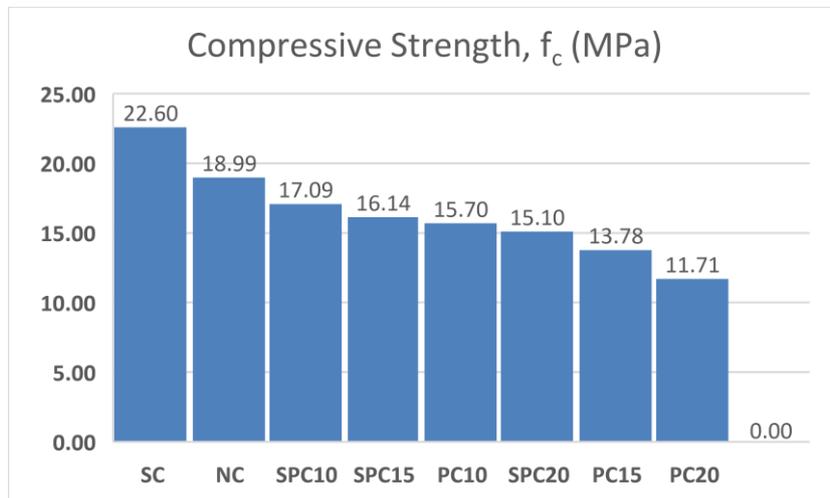


Fig. 3 Compressive Strength after 28 days curing

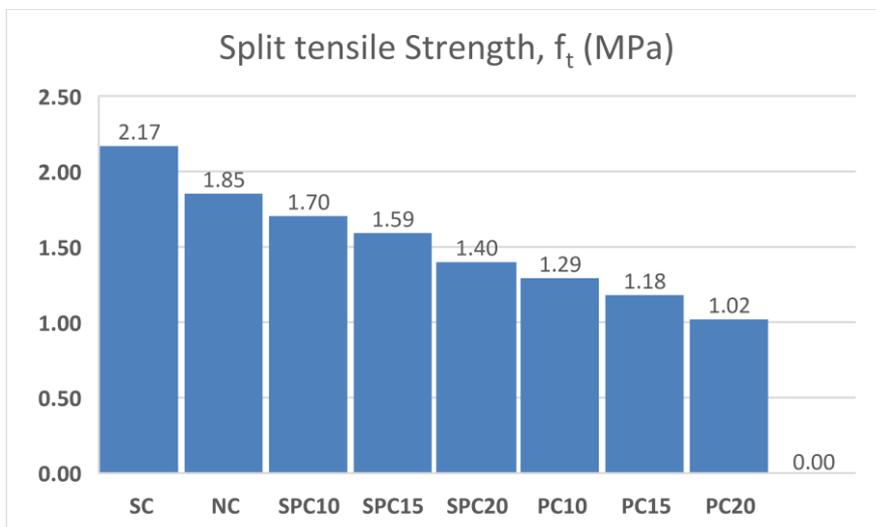


Fig. 4 Split Tensile Strength after 28 days curing

**Table 4: Specimen Tensile and compression strength ratio**

Specimens	NC	PC10	PC15	PC20	SC	SPC10
Toughness (TS/CS)	0.098	0.082	0.086	0.087	0.096	0.100

#### **IV. Conclusions**

This study investigated the behavior of normal concrete modified by partial replacement of sand with recycled plastic granule and coarse aggregates with steel fibers as an additive. The recycled plastic granules were obtained from the recycling of polythene bags. For this purpose, compressive and split tensile tests were performed on specimens cured for 28 days. In total eight concrete mixes were used to examine the effect of these variables on concrete mechanical properties. Based on the test specimen experimental data evaluation, the following conclusions are made:

- The partial replacement of sand with plastic granules in a normal concrete mixture reduces its split tensile and compressive strength. The deterioration increase with an increase in vol% partial replacement and is owed to the poor adhesion between the cement paste and plastic granules.
- The partial replacement of coarse aggregates with steel fibers yields positive results. It increases concrete compressive and tensile strength.
- The effectiveness of partial replacement steel fiber with coarse aggregate in concrete in terms of strength, was not prominent in concrete with recycled plastic granule as compared to normal concrete. The weak interfacial bonding between the plastic aggregate and the surrounding matrix also affected its efficiency.

#### **Conflict of Interest:**

There was no relevant conflict of interest in this paper

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