INFLUENCE OF SILICA FUME, STEEL, AND POLYPROPYLENE FIBERS ON MECHANICAL PROPERTIES OF PLASTIC CONCRETE

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Abstract. Recently many researchers have introduced the concept of using waste plastic in concrete to save natural resources and control environmental pollution. Because the strength of concrete decreases when plastic is used to partially substitute coarse aggregates, such concrete cannot be used for structural purposes. The goal of this research is to see how silica fume, stainless steel fibers, and polypropylene fibers affect the mechanical properties of plastic waste concrete to improve its strength and durability. Normal control mix was prepared for the comparison of results with plastic waste concrete In plastic concrete, the proportion of coarse aggregates replaced by plastic aggregates was kept constant (20 %). Cement was replaced with silica fume by weight and fibers (steel and polypropylene) were added by volume of concrete. The addition of silica fume and fibers in mixes was optimum based on the literature review. When compared to the control mix, the split tensile, compressive, and flexural strength of plastic concrete with 20% replacement decreased by 50%, 16.29 %, and 33.25 %, respectively. By incorporating silica fume and steel fibers split tensile, compressive, and flexural strength of plastic concrete was reduced only by 4.72%, 4.56 %, and 1.376 %, respectively. Polypropylene fibers and silica fume improved the tensile, compressive, and flexural strength of plastic concrete by 86.18%, 69.75%, and 97.93% respectively. The mechanical properties were enhanced with the inclusion of steel fibers, polypropylene fibers, and silica fume. Hence, it is concluded that plastic concrete can be used for structural elements by adding some additional constituents to it.

Keywords- Mechanical properties, Plastic concrete, Polypropylene, Steel fiber

1 Introduction

The use of various types of plastics is a challenge to protect the environment. Currently, different types of plastic are used worldwide. However, the advantages of using plastic are outweighed by its negative environmental impact. In developing countries, improper disposal of plastic waste can be a chief cause of health problems and pollution. The reuse of plastic waste in concrete manufacturing is a feasible way to control its bad impacts on the environment. Many researchers have utilized plastic waste in their studies as a replacement material for coarse aggregate.

Zeeshan Ullah [1] has researched concrete containing plastic waste up to replacement ratios of 15% and 20% with conventional aggregate concrete. The results revealed that with the inclusion of plastic waste aggregates in concrete there is a significant decrease in mechanical properties due to poor interlocking. The tensile and compressive strength was reduced by 32.4% – 23.5% at a 20% replacement ratio. Prasanna et al [2] has investigated the effect of using broken E-waste as a coarse aggregate substitute on concrete strength. It was determined that using more than a 20% replacement ratio of E-waste as coarse aggregate would be unsuitable because it would reduce the compressive strength of concrete by 33.7 %. Khawar Ali [3] has evaluated the mechanical properties of plastic waste concrete containing silica fume and observed the thermal behavior against elevated temperatures. The Optimum result was obtained with 20% sand replacement and cement with plastic fine aggregate (PFA) and silica fume respectively. The compressive and tensile strengths were improved by incorporating silica fume in PFA concrete. Manjunath [4] has replaced both coarse and fine aggregates with waste particles. At 20% replacement of coarse and fine aggregates split tensile, compressive, and flexural strength decreased by 22.44%, 52.98%, and 42.52% respectively. Zeeshan Ahmad [5] has utilized shredded electronic waste along with micro-synthetic fibers with a 30 % replacement ratio of coarse aggregates in concrete. The inclusion of 0.75 % fibrous material raised the compressive and tensile strengths by 30% and 75%, respectively.

Adewumi john [6] reviewed the engineering properties of recycled plastic waste. There was a reduction in strength by using plastic waste in concrete but still can be used in many engineering applications like temporary structures, concrete pavements, etc., Ramadevi [7] prepared concrete by using grounded PET bottle flakes for fine aggregates with the replacement of 1%,,2%,4%, and 6%. The compressive and tensile strengths were increased and it was concluded that PET bottle fibers can be used to substitute fine aggregates up to an extent of 2%. Liliana Ávila Córdoba [8]casted concrete specimens containing PET particles. The PET bottles were recycled to obtain PET flakes and were used in the ratio of 1, 2.5, and, 5% by volume and in three different sizes 0.5, 1.5, and 3mm. It was observed that with the increase in the size of PET particles, Young's modulus decreases whereas the smaller size of PET particles and lower concentration improve compressive strength and strain.

According to the above literature review, the use of plastic waste aggregates in concrete results in a decrease in strength properties. As a result, additives may be required to achieve good strength properties when using plastic concrete. The current study aims to improve the mechanical properties of plastic-containing concrete by using silica fume as a partial substitute for cement and different types of fibers

2 Methodology

The current study's goal is to enhance the mechanical strengths of concrete that contains waste plastic using silica fume, steel, and polypropylene fibers. For this purpose, four types of mixes are prepared with mix IDS M1, M2, M3, and M4. The M1 mix represents natural coarse aggregate (NCA) concrete which acts as a control mix for comparison of results. The M2 mix represents plastic concrete in which natural coarse aggregates are partially replaced by plastic coarse aggregates (PCA). The M3 represents a plastic concrete mix in which cement and NCA are partially replaced by silica fume (SF) and PCA respectively along with the inclusion of stainless-steel fibers (SSF). M4 mix contains polypropylene fiber (PPF) by volume, SF, and PCA as a partial replacement of cement and NCA respectively. A total of 24 cylindrical specimens (150 mm x 300 mm) six for each mix type are prepared for split tensile and compressive strength determination. Similarly, for modulus of rupture, 12 beam specimens (100mmx100mmx400mm) are prepared, three for each mix. All the samples are tested in a compression testing machine having a capacity of 3000KN.

3 Experimental program

3.1 Constituents

As adhesives in this study, silica fume and Portland cement (OPC) are used. The coarse aggregates are taken from Margallah quarries. The river bed sand from Lawrancepur having a maximum size of 4.75mm is used as fine aggregates. The plastic aggregates are mainly prepared from a scrap of TV, LCD, computer monitors, computer keyboards, etc. For the present study, plastic waste was obtained from the local market in processed form with a maximum size of 20 mm. The maximum size of natural coarse aggregate is kept as 20mm. Gradation curves for both fine and coarse aggregates are shown in Figure 1 . Potable water is used to mix all ingredients. The steel and polypropylene fibers are used to enhance strength properties. The properties of natural coarse aggregates (NCA), Plastic coarse aggregates (PCA), and fine aggregates are enlisted in Table 1. Figure 2 shows plastic aggregates, silica fume, and fiber types.

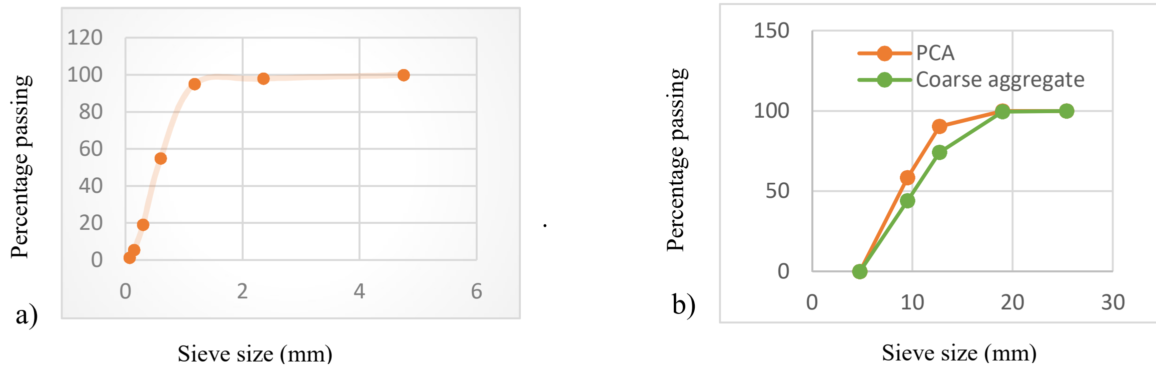


Figure 1: a) Gradation curve for sand b) Gradation curve for NCA and PCA

Table 1: Aggregate properties

Properties	**NCA**	**PCA**	**SAND**
Max aggregate size(mm)	20	19	4.75
Min aggregate size(mm)	4.75	4.75	-
Specific gravity	2.68	1.06	2.64

a) Silica fume and Plastic aggregate

b) Steel and polypropylene fibers

Figure 2: a) Plastic aggregate and silica fume b) Steel and polypropylene fibers

3.2 Mix design

The concrete mix is designed in a 1:1.68:3.20 ratio. The four mix types are prepared. Table 2 depicts the details of ingredients for mixes. The optimum values of PCA, silica fume, and steel and polypropylene fibers are taken from the previous studies. Therefore, the coarse aggregates were replaced with plastic aggregates at 20% [4, 9, 10], silica fume (SF) was replaced at 20% with OPC [3]; while steel and polypropylene fibers are used in the ranges of 0.75% and 0.5% respectively [11-13][12, 14, 15] by volume of concrete to enhance strength properties.

Table 2: Details of mix types and their proportions

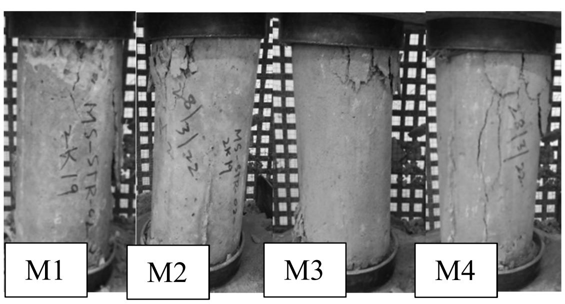
Mix ID	Fiber type	PCA (%)	Fiber (%)	Silica Fume (%)	OPC kg/m^3	Sand kg/m^3	NCA kg/m^3	PCA kg/m^3	Silica Fume kg/m^3	Fiber kg/m^3	Water kg/m^3	Plasticizer kg/m^3
M1	-	-	-	-	392	661	1256	0	0	0	176	4.6
M2	-	20%	-	-	392	661	1004.8	62.88	0	0	176	4.1
M3	SSF	20%	0.75%	20%	313.6	661	1004.8	62.88	55.25	58.95	176	4.9
M4	PPF	20%	0.5%	20%	313.6	661	1004.8	62.88	55.25	4.55	176	4.9

3.3 Mix preparation and casting

A concrete mixer of capacity 0.15m^3 is used to prepare all mixes. In the first step, all dry concrete ingredients (sand, cement, NCA, PCA, and SF) are placed in a mixer and half of the required water is added to mix it for 3 to 4 minutes to produce a homogeneous mixture. After that, fibers are added to the addition of remaining water and allowed to mix for another five minutes. Super plasticizerzer is added to achieve slump within 100-120 mm range mm. After concrete preparation, following proper compaction, cylinders (150 mm x 300 mm) and beams (100mmx100mmx400mm) were casted for compressive, tensile, and flexural strengths.

3.4 Curing and testing

After 24 hours of casting, all samples are de-molded and placed in a water tank to cure for 28 days at room temperature. When the testing age is reached, the samples are air-dried and prepared for testing. The compressive and tensile strengths of cylindrical concrete specimens are determined using a compression testing machine for each mix type conforming to ASTMC39 [16] and ASTMC496 [17] respectively. For flexural strength/modulus of rupture, beams are tested by central point loading confirming to ASTM C293 [18].See Figure 3 failure modes in compression, flexural and tension for all mixes.



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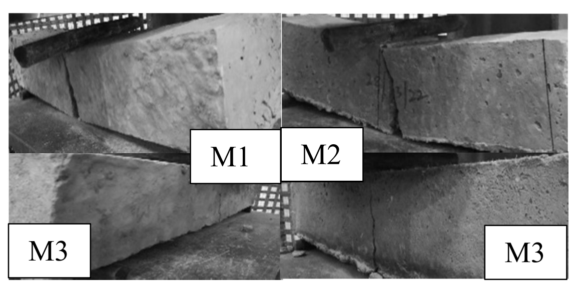

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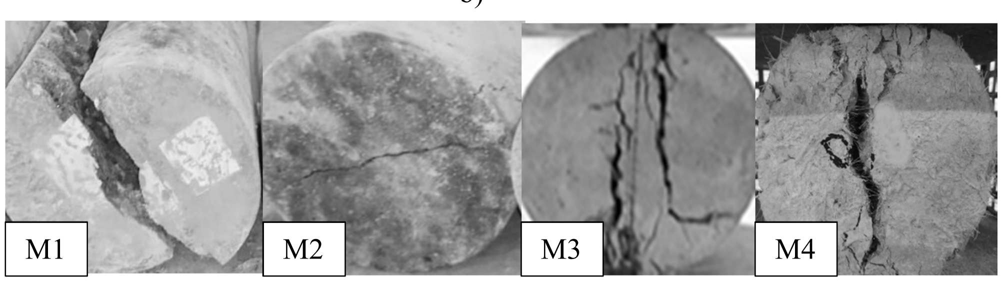

c)

Figure 3:a)Failure modes in compression b)Failure modes in flexural c)Failure modes in tension

4 Results and Discussions

4.1 Compressive strength

Three cylindrical samples for each mix type were tested for average compressive strength determination. Figure 4 shows the variation of compressive strength for each mix type (M1, M2, M3, and M4). For controlled mix M1, compressive strength of 2715 psi is obtained. With the partial substitution of coarse aggregates with plastic waste aggregates in mix type M2, the compressive strength was reduced by 16.293%. Plastic aggregate's smooth texture causes poor adhesion with cement paste, resulting in a decrease in strength. For mix type M3 in which cement is partially replaced by silica fume and steel fibers are added by volume along with the incorporation of plastic aggregates, the compressive strength was decreased by 4.56% as compared to the control mix. Similarly for mix M4 in which polypropylene fibers are induced instead of steel fibers, the compressive strength was decreased by 4.9% to the control mix. The packing and pozzolanic action of silica fume, as well as the bridging and interlocking effect of steel and polypropylene fibers, are the primary causes of the increase in compressive strength.

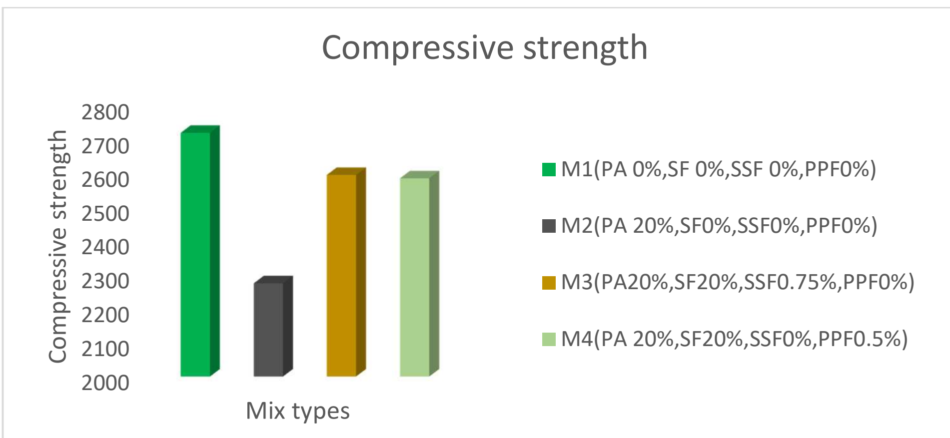

Figure 4: The Comparison of compressive strength results

4.2 Splitting tensile strength

Twelve cylindrical specimens, three for each mix type, were tested in a compression testing machine to determine the average splitting tensile strength. For the control mix, the tensile strength comes out to be 275psi. Tensile strength for Mix type M2 is 50% less as compared to control mix M1. This decrease in tensile strength is brought on by the flimsy adhesiveness or bond among cementitious material and plastic aggregates. With the inclusion of silica fume and steel fibers, the strength of plastic concrete improves by 90.54% (i.e. M3 mix). However, it was increased by 86.18% with the incorporation of, silica fume, and polypropylene fibers (i.e. M4 mix). Figure 5 shows the tensile strengths of all mixes. The ability of fibers to reduce small cracks in the concrete matrix accounts for the majority of the increase in tensile strength. When the splitting occurred and continued, the load was gradually supported by the fibers by acting as a conduit for stress transfer from the matrix to the fibers. The stress transfer caused the tensile capacity to rise.

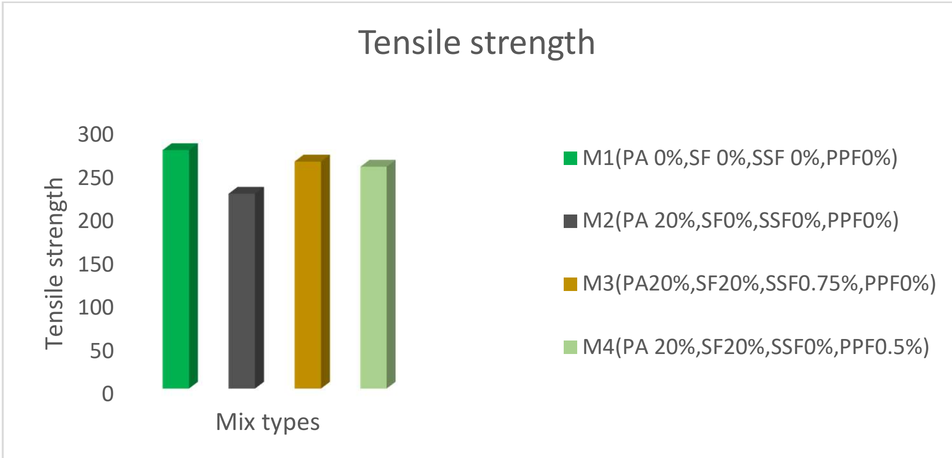

Figure 5: The comparison of split tensile strength results

4.3 Modulus of rupture

The casted prisms were subjected to central point loading for each mix type. The flexural strength was decreased with the addition of plastic waste (M2 mix) due to PCA's smooth surface texture and the cement paste's poor interfacial binding, or adhesiveness; however, it improved with the incorporation of silica fume, steel, and polypropylene fibers (i.e. M3 and M4 mixes). For control mix M1, the flexural strength is 436psi. For mix M2 it decreased by 33.25%. Mix M3 and M4 improved the flexural strength of plastic concrete by 95.86% and 97.93% respectively. Figure 6 shows flexural strength results. The improved fiber-matrix bond may be responsible for the increase in flexural strength. The main reason for the increase could be the fibers that cross the crack in the tension half of the reinforced beam.

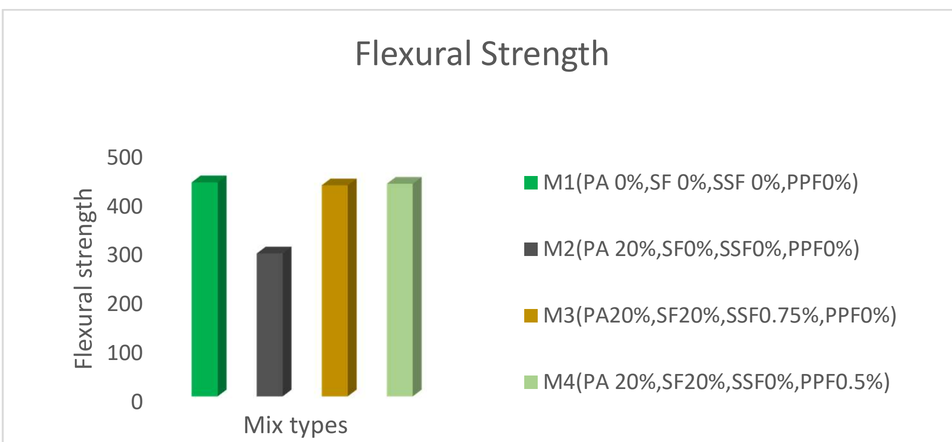

Figure 6: The comparison of flexural strength test results

5 Conclusions

The current study leads to the following conclusions:

1 When plastic waste is mixed into concrete, the compressive, tensile, and flexural strength decrease by 16.29 %, 50 %, and 33.25 %, respectively because the of hydrophobic nature of plastic aggregates and poor bonding between cement matrix and PCA.

2 By adding silica fume the compactness of the matrix increased due to the pozzolanic and filling effects of SF as a result the mechanical properties of plastic concrete increased significantly.
3 The SSF and PPF fibers significantly enhanced the tensile and flexural strength due to crack arrest ability and the crack bridging mechanism.

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