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INVESTIGATION ON MECHANICAL BEHAVIOUR OF PLASTIC WASTE (LDPE) IMPREGNATED CONCRETE

R.Darwin[1], **S.Usha**[2]
[1] *PG Student, Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi - 626005, Autonomous Institution-Affiliated to Anna University, Chennai*
[2] *Assistant Professor, Department of Civil Engineering, Mepco Schlenk Engineering College Sivakasi - 626005, Autonomous Institution-Affiliated to Anna University, Chennai*

Abstract— Environmental concerns due to the over-exploitation of sand have led to restrictions on extraction of sand across India. Thus, the construction industry has huge demand for a suitable environmentally friendly alternative to sand. On the other hand, recycling of waste plastic is rarely done in India, with nearly 40% left in landfill. The dumping of these plastic materials, which degrade at extremely low rates, will lead to high negative impacts in the society. These plastic wastes will persist in the environment for very longer period, which is a long-term environmental concern. In order to solve both these problems, processing the waste and using it as a partial replacement of sand can be done. As there is strength degradation observed in various previous studies of plastic incorporation in concrete, Rise Husk Ash (RHA) and Silica Fume (SF) are replaced for cement to enhance the strength. Keeping the RHA and SF proportion to be constant, the maximum amount of plastic waste that can be replaced for sand is found out. This paper mainly focuses on the mechanical behaviour of the plastic impregnated concrete. The result concludes that the maximum amount of plastic that can be partially replaced for sand in concrete is 30%. Beyond that, the concrete will not satisfy the minimum requirements of the codal provisions.

Keywords— Silica Fume, Rice Husk Ash, LDPE, Plastic Waste, Impregnated.

I. INTRODUCTION

All In 2014, India reached 280 Mt of cement manufacturing [1]. Due to the growing economic nature, high population and rising living standards, the need for concrete construction boomed, which initiated the extremely high internal demand for cement. This made India to export only small volumes of cement [2]. Mass extraction of sand by river dredging is a serious problem in India for a long period and is mainly due to the construction demand. In 2011, the high court ruling has virtually eliminated sand-dredging [3] which is the main reason for the increased demand for sand in India. The reports of Indian central pollution control board states that approximately more than 15,000 tons of plastic waste is land filled every day in India [4]. Non-biodegradable plastic waste is inert and breaks down very slowly once buried in landfill. A study concludes that the plastic recycling also yields by-products such as polyethylene terephthalate (PET), which still requires land filling. Thus, the recycling of plastic is also not a proper method for complete disposal of plastic waste. Thus, the solution to these problems will be partial replacement of plastic waste for fine aggregate, which would otherwise remain as waste in landfill. This action will not only encourage the collection and use of waste but also acts as the alternative source of fine material.

Al-Manaseer and Dalal [5] initiated the research on plastic aggregate substitution in concrete and its effect on compressive strength. They explored the cylinder strength for different water to binder ratios by increasing the proportion of waste plastic particles. They concluded that compressive strength reduced with an increase in plastic aggregate. This loss in strength is attributed to the poor bonding between the cement paste and plastic.

Saikia and de Brito [6] tested concrete by mixing plastic waste in three different size and shape: 1) large particles of length 10–20 mm; 2) shredded flaky fine particles of length 2–5 mm; and 3) cylindrical pellet shaped particles of length 3 mm. Each of these was partially replaced for sand and tests were carried out. The replacements range is 0% to 15%. Increasing the replacement ratio reduced the concrete's compressive strength. They concluded that the reason for the reduction in compressive strength is due to the lack of interaction between the cement paste and PET aggregate. They also concluded that the interfacial transition zone of the concrete containing PET is weaker than interfacial transition zone of standard concrete.

Albano et al. [7] studied the compressive strength of the concrete by using irregularly shaped PET particles having size between 2.6 mm and 11.4 mm. The replacement quantities are 10% and 20% and the two different w/c ratios considered for the study is 0.50 and 0.60. The study concluded that there is a reduction in the compressive strength with the increase in the plastic proportion. This also implies that the plastic particles act as defects in the concrete's internal structure. The research concludes that the concrete containing larger plastic particles were weaker when compared to concrete containing smaller PET particles. They observed that there is a formation of honeycomb of cavities and pores, which is mainly due to the low workability.

Frigione [8] investigated the mechanical behaviour of the concrete by using the granulated PET. In this study, the PET is graded very similarly to the siliceous sand and it is replaced for sand in the mix. The observations concluded that the compressive strength of the mix decreased and for the replacement ratio of 5%, the reduction was less than 2%. The results shows that it is favourable when compared with the results obtained by Saikia and de Brito [6], which stated that there is 12% loss for the replacement of 5% sand by larger plastic pellets. This indicates that the use of plastic may lead to decrease in compressive strength due to the poorer bond with the surrounding matrix. But this loss can be limited by proper mix design and correct choice of plastic.

The usage of mixture of PET and polystyrene as the replacement for sand is studied by Ismail and Al-Hashmi [9]. As plastic is a hydrophobic material, there is a decrease in bonding strength between the surface of the cement paste and waste plastic, which resulted in the reduction in compressive strength. As plastic acts as hindrance to the movement of the water required for hydration of cement, the compressive strength got reduced even worse.

Albano et al. [7] experimented and demonstrated that both higher replacement percentages, and larger particles, can cause relatively high reductions in the tensile strength, which is mainly attributed to the increase in voids present in the concrete. This statement is supported by Frigione [8], where 5% volume replacement of sand by using granulated PET resulted in a 2% loss in tensile strength.

Saikia and de Brito [6] found that the plastic introduction in concrete mix not only reduced the compressive strength but also reduces the tensile strength of the concrete. The loss in strength is directly proportional to the amount of plastic waste in the concrete. The loss of tensile strength was mainly due to the smooth surface of the plastic particles. This smooth surface results in weakening of the bond between the cement paste and plastic particles. Microscopic studies of the failed specimens clearly depicted that the failure is mainly due to the de bonding of the plastic-concrete interface.

The influence of curing conditions for plastic waste impregnated concrete on its mechanical performance was experimented by Ferreira et al. [10].The research concluded that the curing conditions do not have any dominant effect on performance of the concrete, which is mainly dependent on percentage replacement.

Safi et al. [11] investigated the use of waste plastic bags in the self compacting mortar. Replacement of 0–50% was tested and the strength reduction is related to the percentage replacement.

At 30% replacement, strength reduction of 15% was observed at 28 days. The strength reduction is mainly attributed to poor bond between the plastic and surrounding cement paste. Majority of the research in the literature supports this conclusion.

Choi et al. [12] heated the PET fragments of size 5–15 mm and created rounded aggregate particles. Replacement of all the large aggregate with the heated PET particles resulted in strength reduction of 42% at 28 days. An improvement in workability is observed due to the round shapes of the PET particles. Hassani et al. [13] investigated the mechanical behaviour of concrete by replacing coarse aggregate with plastic up to 20% by volume. They observed a reduction in strength as in the previous literature. Batayneh et al. [14] proposed to use ground glass and plastic as replacement materials, which depicted moderate reduction in strength of about 13% in a 20% aggregate replacement mix.

In addition to waste plastic materials, many other materials have been trialed as the replacement materials in concrete mixes. Some of them are recycled cable rubber used in electric cables [15], polystyrene waste [16, 17], and scrap rubber obtained from tiers [18, 19]. In addition to aggregate and sand alternatives, Gesoglu et al. [20] replaced 5–25% of cement with plastic waste powder and observed a linear reduction in compressive strength with increasing the cement replacement. Many review papers reported by Siddique et al. [21], Saikia and de Brito [22] and Sharma and Bansal [23] clearly showed the variables associated with implementing plastic as an replacement for aggregate, which demonstrated the key factors to be considered for replacing plastic as a replacement for aggregates. The key challenge for plastic replacement in this paper is to minimize this loss in strength as far as possible.

Eshan mohseni et al. [24] investigated about the incorporation of Rise Husk Ash as a partial replacement for cement and observed an enhanced mechanical behaviour. B. Chatveera et al. [25] studied the durability properties of concrete by partially replacing its cement quantity with Rise Husk Ash. They observed an enhancement in the mechanical as well as durability behaviour of the concrete. A. Safwan et al [26] added silica fume in various percentages from 0% to 25% and their mechanical as well as durability properties are studied. They conclude that the addition of silica fume enhanced both the mechanical as well as durability properties.

The literature study of several papers summarizes a common fact that the addition of plastic waste in the concrete in any form reduces the compressive strength of the concrete mainly due to the lack of bonding between plastic waste and cement paste. In this paper, silica fume and rise husk ash of constant percentage is partially replaced in cement to compensate this strength reduction due to addition of plastic waste.

II. MATERIALS

A. Cement

The cement used in the project is commercially available Ordinary Portland Cement (OPC) of 53 grade confirmed to IS: 12269-1987. As plastic addition reduces the compressive strength, the cement is the main material to be added for binding action in the concrete.

B. Fine Aggregate

Natural River sand is used for concrete mixing. The size of river sand below 4.75 mm confirming to zone II (IS 383-1970) should be used. The Laboratory tests were carried out for fine aggregate in order to determine its physical properties. These tests should be done according to IS: 2386 (Part III).

C. Coarse Aggregate

Coarse aggregate used in this research consists of crushed stone of size 12.5 mm and below. Laboratory tests were done on coarse aggregate to determine the different physical properties based on IS: 383-1970.

D. Plastic Waste

The plastic waste to be added in the concrete is LDPE waste. LDPE represents Low Density Poly. As LDPE plastic waste is produced in large quantity than any other type of plastic waste, the implementation of LDPE plastic waste in concrete has significant positive impacts in the society.

E. Rise Husk Ash

The rise husk ash to be added in concrete is replaced for cement in a constant proportion of 20%. The rise husk is obtained in large quantity and it is burnt into ash.

F. Silica Fume

Silica Fume is used as partial replacement in concrete for cement. This increases the durability of reinforced concrete and reduces cement usage. However, the high specific surface area and low bulk density of Silica Fume offer challenges in its application and transport. It can be added maximum of up to 10%, beyond that the workability will decrease.

Table1. Properties Of silica Fume

Property	Requirements
Appearance	White and soft
Specific Gravity	2.2-2.3
Particle size	Less than 1µm
Bulk density	130 kg/ m3 – 600 kg/ m3

G. Super-Plasticizer

Super Plasticizer used for this project is Ceraplast 300. It is a dark brown liquid based on Naphthalene which mixes readily with water and therefore disperses evenly. This ultimately reduces the water demand for required workability, and it also minimizes segregation and bleeding.

Table2. Properties of Ceraplast 300

Physical properties	Limits
Air entrainment	Approx.1%
Chloride content	Nil
Color	Brown
Dosage	0.3% to 1.5%
Ph	~8
Specific gravity	1.2

III. METHODOLOGY

A. Mix Proportion

The plastic waste is added in concrete mix in powder form. The plastic waste is replaced for fine aggregate in five different proportions. The Silica Fume and Rise Husk Ash are added in the mix in order to compensate the strength loss due to plastic waste addition. The Silica Fume and Rise Husk Ash are replaced for cement in constant percentage of 10% and 20% respectively in all the mix. The specimens S1, S2, S3, S4, S5 and S6 shows the mixes for 0%, 10%, 20%, 30%, 40 and 50% of plastic replacement for fine aggregate respectively. The mix proportion of each and every specimen is shown in table 3.

Table3. Mix proportion

Specimen	FA (Kg)	CA (Kg)	Cement: RHA: SF (80:20:10) kg	LDPE (Kg)
S1	2.24	4.81	1.22:0.37:0.19	-
S2	2.05	4.81	0.854:0.37:0.19	0.08
S3	1.79	4.81	0.854:0.37:0.19	0.16
S4	1.57	4.81	0.854:0.37:0.19	0.24
S5	1.35	4.81	0.854:0.37:0.19	0.32
S6	1.12	4.81	0.854:0.37:0.19	0.40

B. Compressive Strength Test

The cube mould of size 150x150x150 mm is taken. The mould should be cleaned well in order to achieve accuracy. The mix is made using proper proportions and is filled into the mould. The filling of mix is done properly by placing it in 3 layers with proper damping. Then the cube is demoulded from the mould after 1 day and is subjected to curing in curing tank for 7 days, 14, days, 21 days and 28 days. Then the cured cubes are taken out and subjected to compressive strength test in UTM by applying a gradually increasing load. The load at which the concrete fails is noted. This gives the compressive strength of the specimen. For each proportion, three specimens are subjected to compressive strength testing and average is taken as the compressive strength of the corresponding specimen.

C. Split Tensile Strength

The mix is done for various proportions, and it is casted in to the cylinder mould. It is then placed in the UTM along the diameter. The load is applied gradually, and the load at which it fails is noted. The split tensile strength of the concrete is calculated as per the formula given in the clause 8.1 of IS 5816: 1999

IV. RESULTS AND DISCUSSIONS

3.1. Compressive Strength Test

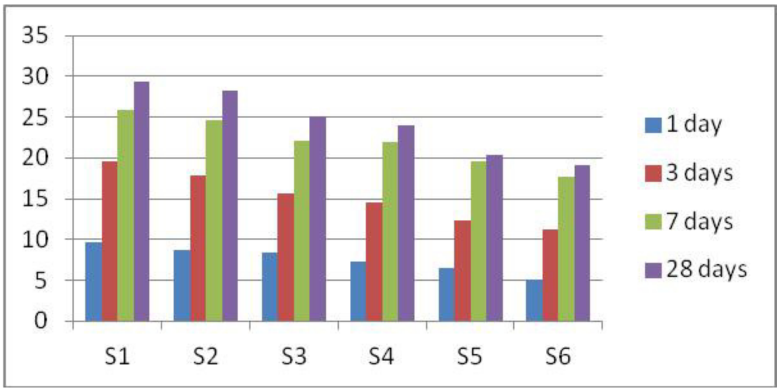
The cubes which are cured for 1 day, 3 days, 7 days and 28 days are to be tested for compressive strength, and the results are tabulated as in Table 4. Also the casted cube specimen and testing of the specimen are shown in Figure 1 and Figure 2.


Figure1. Casted cube


Figure2. Testing of cube

Table4. Compressive strength of cubes

Specimen	Compressive strength after Curing period, N/mm^2			
	1 day	3 days	7 days	28 days
S1	9.69	19.56	25.95	29.42
S2	8.68	17.91	24.66	28.26
S3	8.43	15.61	22.13	25.14
S4	7.34	14.52	21.87	23.97
S5	6.51	12.36	19.64	20.43
S6	5.11	11.25	17.65	19.05



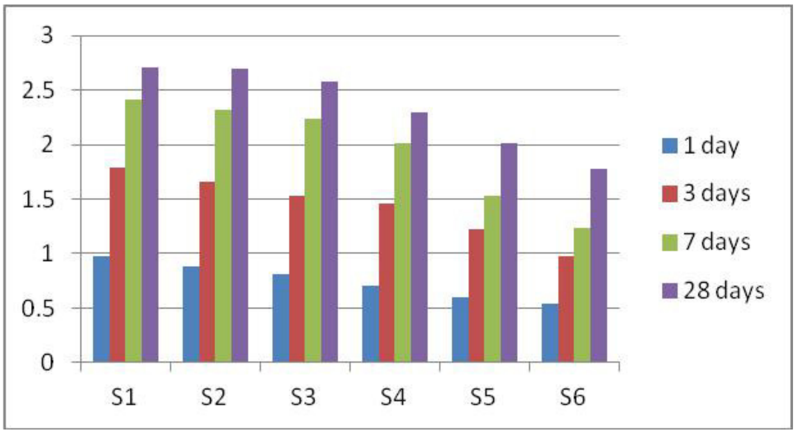
The table shows that the addition of Plastic waste (LDPE) of about 30% along with the RHA and SF satisfies the compressive strength, according to the codal provision. Plastic waste along decrease the compressive strength of the concrete cubes, RHA and SF enhance the initial and final strength of the concrete cubes.

3.2. Split tensile test

The cylinders which are casted using various proportions are tested and the results are depicted in the table given below.

Table5. Split Tensile Strength of Cylinders

Specimen	Tensile strength after Curing period, N/mm^2			
	1 day	3 days	7 days	28 days
S1	0.97	1.79	2.41	2.71
S2	0.88	1.66	2.32	2.69
S3	0.81	1.53	2.23	2.58
S4	0.71	1.46	2.01	2.29
S5	0.60	1.22	1.53	2.01
S6	0.54	0.97	1.24	1.78



The split tensile strength test shows that the addition of RHA and SF with the Plastic Waste (LDPE) increases the tensile strength of the cube. The split tensile strength decreases without RHA and SF due to the poor bonding of LDPE and the Cement matrix.

V. CONCLUSION

The following conclusions were made from the experimental works carried out in the study,

- The recycling of plastic will also yield several harmful by-products, which are very difficult to dispose. Hence, using this plastic waste in concrete will be a definite solution to the problem of plastic waste disposal.
- The reduction in compressive strength and split tensile strength is observed for the increase in the percentage of plastic waste.
- The maximum percentage of plastic waste that can be incorporated as a replacement for sand is 30%
- To compensate the strength loss RHA and SF are added, both increase the strength to a greater extent due to the micro structure of both the wastes (RHA and SF)
- Due to the closely packed micro structure of RHA and SF, the concrete is closely packed by reducing the porous structure which increases the durability of concrete.
- The plastic waste has the smooth surface, which is the main reason for the reduction in both the compressive strength and the tensile strength of the concrete.
- Due to the density of LDPE is low, the weight of the concrete specimen decreased about 10% - 30% when compared with the control mix.

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