International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 12 | Dec 2020 www.irjet.net p-ISSN: 2395-0072

Use of Recycled Plastic in Concrete as Replacement of Fine Aggregate

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Abstract-*The growing contamination of water bodies, air and soil has raised issues regarding severe problems of disposal of plastic waste. Due to lack of functioning of solid waste management systems, only a small amount of it undergoes recycling which often results in hazards to human health, animals, marine life and ecological disturbance. One of the highest demanding materials in construction industry is the natural sand, which has been hugely exploited from the river beds in recent years. This has not only created the ecological problems but also encountered the problems like scarcity of sand, rise in the cost of sand, and hence tightening of regulations on sand mining. To overcome these problems, use of plastic waste as an alternative to the natural sand can be a sustainable solution. Many researchers had done research using plastic waste as replacement for aggregate with respect to the strength properties of concrete. This paper presents the investigation on strength and durability properties of concrete using recycled plastic waste in the granular form as a replacement to the sand (fine aggregate). The results of the study indicate that the concrete so developed satisfies the IS code provisions with regard to the strength and durability properties by incorporating the recycled plastic and also possible to lower down the cost.*

***Index Terms*- Concrete, scarcity of sand, plastic utilization, durability.**

1. INTRODUCTION-

Every year, India generates 15 million tonnes of plastic waste. Due to lack of functioning of solid waste management systems, only 25% of it undergoes recycling. This leads to burden on the landfills.(1) According to the recently published report on United Nations Environment Programme, the world produces 400 million tonnes single-use plastic (SUP) waste annually (47 per cent of the total plastic waste). It is estimated that only 9% of the plastic is getting recycled worldwide. Interestingly, almost 60 % of the total plastic waste generated in India gets recycled while the remaining escapes into the environment.(2) According to a British science journal report, plastics can cause a wide variety of adverse effects to people and the environment. Chemicals in plastics are absorbed by human bodies, and some of these can change the structure of hormones.(3)

Almost 200 different species of animals are known to ingest plastic debris. It is observed that if an animal consumes plastic, it can clog its stomach.(4) According to a study published in Environmental Science and Technology, micro-plastic contamination in soil is threatening the growth of earthworms.(5) In a research paper published in the journal Nature Communications, over 8 million tonnes of plastic enter the oceans every year. By 2050, the number of plastic entities would be equal to the number of fish in the sea, according to a study. (7)One of the ways to dispose the plastic waste is reduction of its volume by burning. But burning plastics is not a viable alternative as it generates harmful toxic gases. Plastic toxins in dumps and from litter can seep into the ground water, which people drink every day.

At this juncture, it becomes essential to have robust and stringent waste management tool to substantially improve the situation. For utilization of plastic waste, several investigations and researches are going on. One of such ways is to utilize plastic waste in construction industry in different processes. (8) India has the world's third largest construction business after China and the US. Malls, houses, offices and flyovers have sprung all over. At present, higher speed of construction is required to meet the increasing demands of the construction industry so as start functioning of the important infrastructure projects at the early stage in view of the progress of the country. Irrespective of location, scale or type, concrete is the base of all the construction activity in the nation. In fact, concrete is the second most consumed material after water, with nearly three tonnes used annually for each person on the planet.(9) But the construction sector, mostly real estate, constantly complains of acute shortage of natural sand. The demand for sand has surged to a point where riverbeds and beaches around the world are being stripped bare. India is importing river sand to satiate the growing demand of its construction industry and to keep soaring sand prices in check. But imports alone will not suffice without effective implementation of regulations and promotion of

alternative construction materials.(10) Due to such restrictions put by government on mining of river sands, in recent years use of "artificially crushed stone sand" or "manufactured sand" is being done on major scale. However, as manufactured sand generally contains large proportion of micro fine particles due to its production process, it affects the strength and workability of the concrete. (11)

The issues regarding the threats to the ecology due to the plastic waste and irresponsible sand mining have to be considered seriously. The above discussions have made it necessary to study the feasibility of replacement of sand with the recycled plastic in concrete. This research focuses on strength and durability properties of concrete with recycled plastic. The results of performance of concrete with plastic aggregate with regard to its workability, compressive strength and durability (water permeability) are assessed and the results indicated that the concrete so produced just satisfies the IS Code provisions.

2. LITERATURE REVIEW

Raghtate A. (12)carried out the research work and studied the effect of using plastic in concrete on its properties namely compressive strength and split tensile strength. The study was carried out by adding varying percentages of pieces of polyethylene bags in 0.2%, 0.4%, 0.6%, 0.8% and 1%. Increase in the percentage of plastic impacted the compressive strength, but the rate of reduction of strength was found to be lowered. A reduction of 20% compressive strength with 1% plastic was observed. Furthermore, split tensile strength was found to be increased to a little extent, when plastic was added to the concrete. The researcher concluded that, increase in percentage of plastic in concrete improves its tensile strength but affects the compressive strength.

Mahesh M. *et al* (13) carried out investigation on utilizing polyethylene plastic in the form of fibers in the concrete. The study was carried out with varying percentages of plastic fibers in the concrete as 2%, 4% and 6%. The concrete specimens were cured for 7, 14 and 28 days and tested for compressive strength and split tensile strength. The test results found that there was reduction in the compressive strength and split tensile strength of concrete as the percentage of plastic fibers increased, but the rate of reduction of strength was low. Reduction in the self weight of concrete was observed. It has been concluded that using plastic fibers in concrete can cause 5%-10% effect on mechanical properties of the concrete.

Tamang L. *et al* (14) The investigators performed detailed study to examine effects on the mechanical properties of concrete due to utilization of plastic as coarse aggregate. The plastic aggregate were prepared by melting the plastic at 150-1800^{o}C, allowing setting and crushing it to the required size. Compressive strength of concrete with 20% plastic aggregate had high compressive strength but 2% lower than that of nominal concrete. The test results of split tensile strength indicated that concrete with 15% plastic aggregate had high tensile strength but 30% lower than that of nominal concrete. From the study, it was concluded that using plastic aggregate, the compressive strength of concrete remained intact but the tensile strength gets affected severely.

Chien C. *et al* (15) The research was based on the study of properties of concrete using HDPE plastic fine aggregate. In the workability test, results showed that increase in the percentage of HDPE plastic fine aggregate in concrete reduces its workability. The split tensile strength test and compressive strength test performed on cylindrical specimens of 100mm (diameter) x 200mm (height) and slab of 305mmX305mmX25mm found that beyond 10% replacement of fine aggregate with HDPE plastic aggregate, the workability reduced significantly but the compressive strength and heat absorption of the concrete improved.

Mathews P. *et al* (16)The researchers carried out investigation of effects on the mechanical properties of concrete when natural coarse aggregate (NCA) was replaced with plastic coarse aggregate (PCA). The workability test results have shown that the workability of concrete with 20% PCA is higher than that of nominal concrete, due to absence of water absorption by the PCA. The concrete specimens with varying percentages of replacement of NCA with PCA tested for compressive strength found that a 22% percentage replacement of NCA with PCA gave significant improvement in the compressive strength of the concrete.

Das S. *et al*(17) The aim of the research was to investigate the effect of using plastic waste as fine aggregate on the mechanical properties of the concrete. The plastic was grinded and used as replacement of fine aggregate in the concrete in varying percentages 2%,4%,6%,8% and 10%.An ACI mix of M28 was used to determine mechanical properties of concrete e.g. compressive strength, tensile strength, post-heating compressive strength are determined by performing various tests. The results found that the optimum percentage of replacement of fine aggregate with plastic aggregate in concrete was 6%. The mechanical properties of concrete improved upto 6% replacement of fine aggregate with plastic aggregate, further increase in the plastic aggregate led to reduction in the strength.

Youcef G. *et al*(18) The research paper is based on the study of using waste plastic bags as replacement of fine

aggregate in the concrete. The concrete specimens with percentage of plastic aggregate as 10%, 20%, 30% and 40% were tested for compressive strength, flexural strength and ultrasonic pulse velocity. The results of test found that the workability improved when plastic aggregate was used. The ultrasonic pulse velocity results have shown that the density of concrete reduced due to smooth surface of plastic aggregate which reduces bondage of grains in the concrete. The authors concluded that there was significant loss in the mechanical properties of the concrete with plastic aggregate.

Manikandan P. *et al* (19)The investigation was carried out on utilizing scrapped plastic as fine aggregate and crushed plastic as coarse aggregate in concrete and studying effects on the properties of concrete. The concrete specimen with 5%, 7% and 9% replacement of fine aggregate and coarse aggregate with the plastic waste tested for compressive strength. The results have shown that there was significant improvement in the compressive strength of concrete with increasing percentage of plastic in it. The conclusion stated that concrete with scrapped plastic as fine aggregate showed compressive strength more than concrete with crushed plastic as coarse aggregate.

Amalu R. *et al* (20)The research was based on use of waste plastic as an alternative to fine aggregate in the concrete. The percentage replacement of fine aggregate with recycled plastic waste varied from 10% to 25%. The concrete specimens were tested for workability, compressive strength and flexural strength. The results of these tests found that the compressive strength and flexural strength of the concrete specimen reduced with increase in the percentage replacement of the fine aggregate with recycled plastic waste. But due to less absorption of water, workability of concrete found to be improving with the increase in the plastic aggregate.

Lakshami R. *et al* (21)The researchers carried out experimental study on performance of M20 concrete with addition of E plastic waste as coarse aggregate in the concrete. The percentage replacement of coarse aggregate with E plastic waste varied from 0% to 30%.there was no significant reduction in the compressive strength and flexural strength of the concrete upto 20% waste plastic replacement in the concrete. The ultrasonic pulse velocity test performed on concrete specimens with E plastic waste and fly ash found that the results of test after 7 & 14 days had small deviations from specified limits but test results after 28 days were within acceptable limits. It was concluded that the addition of fly ash in the concrete with E plastic waste found good strength development properties.

Shyam S. *et al* (22)The investigators studied the utilization of HDPE plastic powder as replacement of M sand in the concrete. The strength and durability properties of concrete with 5, 10, 15 and 20% replacement of M sand with plastic in powder form were determined. The workability, compressive strength, flexural strength and tensile strength of concrete found reduced with increase in HDPE plastic powder. Also, the density of concrete reduced with the increasing percentage of HDPE plastic powder.

Rai B. *et al* (23)The researchers studied mechanical properties of concrete utilizing flakes of waste plastic with varying percentages in it. The concrete mix with and without plasticizer was tested for workability, compressive strength and flexural strength. In case of concrete mix without plasticizer, it was found that workability reduced with increase in flakes of plastic waste and concrete with plasticizer showed less deviation in workability. The flexural strength of concrete varied irrelevantly with addition of plasticizer in it. Maximum reduction of strength of concrete with flakes of waste plastic was about 15%.

A. Research Gaps

From the literature review following gaps in the research works are identified:

- The researchers have given importance only to the strength properties of concrete using plastic as an alternative to aggregate. Also, no emphasis is given on the durability properties of concrete.
- Use of plastics in granular form in different grading is not reported in the literature.

Thus, in order to bridge this gap, in the present research work use of waste plastic was thought for developing a concrete of minimum M20 grade to assess the strength and durability properties as per IS specifications.

B. Objectives

The objectives of the research are stated below:

- To determine the desirable content of waste plastic (i.e. densely graded granular form) by varying its content in the range of 7.5% to 12.5% to replace the fine aggregate content (crushed sand) for development of M20 grade concrete.
- To develop M20 grade concrete by replacing fine aggregate with desirable content of waste plastic in densely graded granular form.

- To study workability, strength and durability properties of developed concrete.

3. EXPERIMENTAL PROGRAM

Thirty cubes of M20 grade with three different percentages of plastic grade A and plastic grade B (0%, 7.5%, 10%& 12.5%) were cast and cured for 28 days as recommended by IS 10262:1982.

A. Materials-

a. *Cement*- The cement used in concrete mix design was ordinary Portland cement (OPC) of grade 53. The physical properties of the cement were determined in laboratory using standard methods in IS 4031: 1968 are given in Table 1:

Table 1- Physical properties of cement

Physical Property	Test Results
Consistency	31%
Specific Gravity	3.15
Initial Setting Time	165 min.
Final Setting Time	250 min.
Soundness	1.5mm
Compressive strength at 28 days	56N/mm^2

b. *Aggregate*: The physical properties of coarse aggregate and fine aggregate as determined in the laboratory are given in Table-2:

Table 2- Physical properties of aggregate

Physical Property	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.73	2.76
Water Absorption	1.59%	1.45%
Fineness Modulus	5.61	4.4
Grading of Aggregate (Confirming to IS 383:1970)	< 20 mm	Zone II

c. Water: Potable water was used for preparation of all the concrete mixes.

Table 4 - Mix Proportion

Material	**Control mix**	**Mix 1A**	**Mix 1B**	**Mix 2A**	**Mix 2B**	**Mix 3A**	**Mix 3B**
Cement(kg/m^3)	350	350	350	350	350	350	350
Water (kg/m^3)	190	190	190	190	190	190	190
Fine Aggregate(kg/m^3)	785.25	726.36	726.36	706.73	706.73	687.57	687.57
Coarse Aggregate (kg/m^3)	1212	1212	1212	1212	1212	1212	1212
Plastic Grade A (kg/m^3)	-	16.836	7.216	22.268	9.543	28.242	12.10
Plastic Grade B (kg/m^3)	-	8.125	18.96	10.747	25.07	13.63	31.80
% Replacement	0	7.5	7.5	10	10	12.5	12.5

d. Plastic Granules: Low density polyethylene (LDPE) plastic granules of two different grades were used as replacement of fine aggregate in concrete. The results from testing of physical properties of plastic granules are given below in Table-3:

Table 3- Physical properties of Plastic Granules

Physical Property	Plastic A	Plastic B
Specific Gravity	1.11	1.25
Grain Size	1.18mm-2.30mm	2.40mm-3.80mm

For providing better grading of plastic, these two plastics were mixed in the proportion of 70:30 and 30:70 to form Plastic Grade A & Plastic Grade B respectively.

B. Concrete Mix Design: The concrete mix was prepared and tested according to the guidelines of IS10262: 1982 and IS456:2000. Thirty cubes of M20 grade concrete were cast with three different percentages of plastic grades in the form of cubes having dimensions 150mmX150mmX150mm and cured for 28 days. Six cubes were cast with normal control mix of concrete. The details of materials quantities (proportions) as obtained in the mix design process are given in Table-4.

Table 5 –Proportion of plastic granules in mix					
Designation	% Replacement of FA with Plastic	Plastic grade A		Plastic grade B	
		%	Weight (kg)	%	Weight (kg)
Mix1A	7.5	70	16.836	30	8.125
Mix1B	7.5	30	7.216	70	18.96
Mix2A	10	70	22.268	30	10.747
Mix2B	10	30	9.543	70	25.07
Mix3A	12.5	70	28.242	30	13.63
Mix 3B	12.5	30	12.10	70	31.80

4. PRELIMINARY TRIALS

Compressive strength of trial mixes -

Trials were carried out on control mix to get desired workability and compressive strength. After correcting the water content for water absorption, the desired workability of mix was attained. Also, to attain desired compressive strength, trials were done.

Determination of desirable content of plastic granules-

To determine desirable content of plastic granules, trials with different percentages of plastic granules were carried out. From these trials, a range of 7.5% to 12.5% replacement of FA was found satisfactory. Control mix with replacement of FA as 7.5%, 10% and 12.5% with two grades of plastic was cast into cubes.

Types of Mixes-

Following table Table-5 gives details about each mix and its plastic proportion.

Mixes with these proportions were prepared and cast into moulds of cube size 150mmX150mmX150mm. These cubes were removed from moulds after 24 hours and kept in water for curing for 28 days period.

Tests on concrete-

1.Workability- Workability gives idea about the ease of placement of concrete. According to guidelines by IS 456:2000, slump cone test was used for determination of workability of concrete mixes.

2. Compressive Strength- The concrete cubes were cured for 28 days and then tested under CTM. Three cubes of each mix were tested and average of the values is considered as compressive strength of the mix.

3. Durability- The most accurate way of testing for all important durability is the water permeability test. The relationship between permeability and durability allows the durability of a mix to be determined by testing the permeability of the mix in question. For determination of durability of mixes, water permeability test was performed confirming to DIN 1048-Part 5.

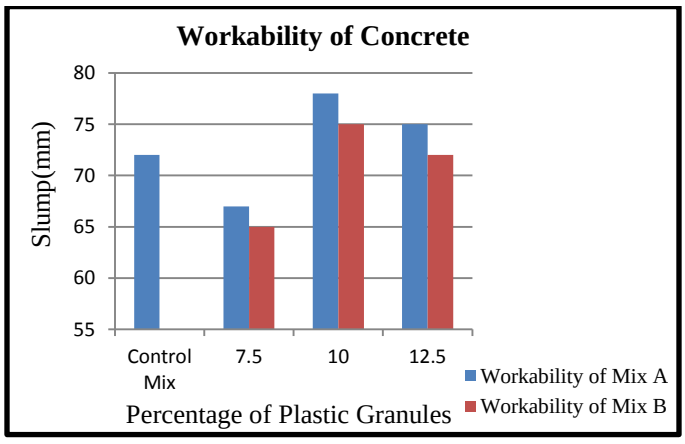
5. RESULT & DISCUSSION

The results of various tests performed on concrete cubes prepared with desirable content of plastic granules are presented in the following sections :

Workability of concrete –The results of slump cone test are presented in Figure -1. The mixes Mix2A and Mix2B with slump values of 78mm and 75mm provided desired workability i.e. 75mm-100mm. The results of concrete mixes Mix 1A &Mix 3B with slump values of 67mm & 72 mm deviated 21% and 10% from results of control mix. The workability of the concrete is found increasing with increase in the percentage of replacement of fine aggregate with plastic granules. Due to hydrophobic property of plastic, there is less absorption of water.

While comparing the workability with control mix, the concrete mixes with 10% plastic deviated only 6.5%; Whereas the mixes with 7.5% &12.5% replacement with plastic found significant deviation.

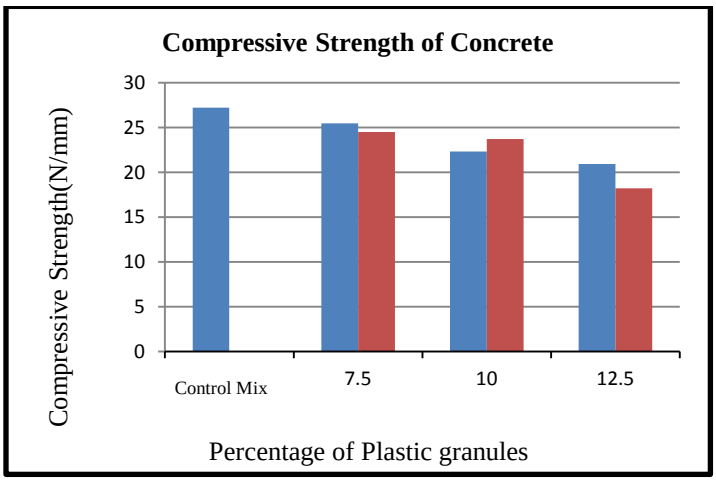
FIGURE-1



Compressive Strength of Concrete – The compressive strength test found that mixes Mix 1A & Mix 1B performed better than other mixes with 25.45N/mm² & 24.5 N/mm² respectively. The strength of control mix was 27.2N/mm², and results of all the concrete mixes with plastic remained below this. Mix2A and Mix2B found with only 15%reduction in the compressive strength when comparing with the control mix. Increasing percentage

replacement of F.A. with plastic granules reduced the compressive strength of the concrete. The graph of compressive strength test results of concrete is presented in Figure 2:

FIGURE-2



Durability of Concrete- From the workability and compressive strength test, we found that concrete specimens with 10% replacement of FA by plastic grade perform better as compared to other specimens. So the specimens of Mix 2A and Mix 2B are tested for water permeability.

Water permeability test

The results obtained from water permeability test of specimens are presented in Table-6:

Table 6-Depth of Penetration of water into concrete	
Designation	Depth of Penetration (mm)
Control Mix	12
Mix 2A	27
Mix 2B	34

The water permeability test results found that the addition of plastic granules in the concrete reduced the denseness of concrete. Although the results found that concrete with plastic exceeded the standard depth of penetration value, concrete Mix 2A showed better resistance to penetration of water. Mix2A has depth of penetration +2mm more than that of standard value i.e. 25mm.

6. CONCLUSIONS

From the experimental research work carried out for developing the concrete by utilizing plastic granules to replace FA, the following conclusions can be drawn:

- The workability of concrete is found to be improved by 7% when compared with control mix by replacing 10% of the fine aggregate by plastic granules.
- The compressive strength reduces by increasing the percentage of plastic granules in it. The mixes 2A and 2B with 10% replacement of fine aggregate showed better results. The compressive strength of the mixes is found to be less by 15% when compared with the strength of control mix.
- Comparing the durability of mixes with 10% replacement of fine aggregate by plastic granules and control mix, Mix 2A is found to have good resistance to the penetration of water through it. The grading of Plastic grade A was the same as that of fine aggregate used in control mix.

7. FUTURE SCOPE

- As it is found that grading of plastic granules improves the properties of concrete, there needs a rigorous work on improvement of grading of plastic granules making it equivalent to grading of fine aggregate.
- For improving the denseness of the concrete, use of mineral admixtures like fly ash, silica fume can be a better option. This can lead to better durability qualities of the concrete with plastic.

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