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Performance of Plastic Waste as a Sustainable Alternative to Fine Aggregate in Concrete

Karan R. Meshram[1] and Mayuri Chandak[2]
[1]P.G. Student, Department of Civil Engineering Priyadarshani College of Engineering, Nagpur, India
Email: meshramkaran18@gmail.com
[2]Assistant Professor, Department of Civil Engineering Priyadarshani College of Engineering, Nagpur, India
Email: mayuri.chandak@pcenagur.edu.in

***Abstract*— In this experimental study, discarded plastics serve as an interim replacement material for high-quality aggregates within cement mixtures. Our objective involves identifying the optimal proportion of recycled plastics incorporated into cement mixtures for enhancing their strength without compromising performance metrics. An inventive project to lessen the impact of plastic waste on the environment is the substitution of waste plastic granules for fine aggregate. In this experiment, we varied the amount of waste plastic 0%, 20%, 25%, 30%, and 35% to substitute the fine aggregate in M-25 grade concrete for the purpose of determine its effective content based on strength parameters. Our study examined both the fluidity of freshly poured concrete and its tensile strength after hardening. The findings demonstrated that the amount of waste granules aggregate in the concrete mix raised, degree of workability lower down. A gradual raises of waste plastic granules trigger a slight increase in flexural strength but a decline in compressive resistance as related to regular concrete with no waste plastic (0%). However, it was discovered that the concrete achieved notable strength properties at effective waste plastic contents of 20% and 25%. A 2% of silica fume mineral admixture is subsequently used in the replacement concrete based on the compressive strength result. As a result, the compressive strength was marginally higher than it would have been without the admixture.**

***Index Terms*— High density polyethene (HDPE), Concrete, Silica fume, Replacement, Waste plastic, Compressive strength, Flexure strength.**

I. INTRODUCTION

Recently, tectonic growth in plastic manufacture globally is observed, projected at around forty trillion metric tonnes across all territories as of twenty-two years hence. India plays an important role in contributing globally to plastic pollution by producing approximately 90 million tons of plastics each year. Studies indicate that roughly 20 million metric tonnes of plastics flow into our ecosystems annually. Based on research conducted in 2024, approximately three percent of data was analyzed. Approximately five percent of global plastic output is discarded annually. A rise in worldwide plastic consumption leads to substantial production of plastic debris. Plastics remain intact indefinitely within earth's soils and aquatic environments due to their chemical stability. Plastic incinerating emits toxins such as dioxins, furans, mercury, and PCBs into the air, posing risks not only to humans but also to plants. Therefore, in order to prevent significant harm to our sustainable environment, a practical approach for recycling and repurposing HDPE plastic need to be desired. Additionally, because

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excessive sand mining significantly degrades riverbed characteristics, the scarcity of traditional fine aggregate, such as river and, has become a major concern.

Cement fuses sand, water, and aggregate to create concrete, which has been used to construct buildings and infrastructure worldwide. However, due to its importance in modern construction, a number of changes have occurred with cement regarding the advancement of technology, concerns about sustainability, and increasing demand. In this light, understanding qualities, traits, and production processes of cement is very important for successful and efficient construction of structures using it. Emphasis will be placed on the usage of OPC 33-grade cement. Sand consists of particles made up of various elements such as organic materials, minerals, and rocks larger in size compared to silt yet smaller than pebbles. A crucial component in numerous engineering projects involving building materials like concrete production. Sand can be discovered across various places like dunes, riverbanks, coastlines, and arid regions. Sand extraction leads to significant environmental degradation through soil depletion and biodiversity decline. Transforming plastic waste into granules is essential for some economies to reduce the amount of polymer debris waste dumped into landfills as well as oceans. The procedure involved to manufacture polymer granules includes breaking down plastic waste into tiny granules or pellets, mainly utilizing high-density polyethylene (HDPE) material. Plastic waste granules are made by a number of processes, including collection, sorting, cleaning, and processing. Plastic debris undergoes cleaning before being cut into tiny fragments via machinery designed for this purpose. Plastic waste granules are between 1.2 and 2 mm in size. Plastic waste is being used as a partly alternate for nature sand addresses two critical concerns simultaneously for minimizing plastic disposal issues and conserving natural resources. To test the strength properties, cubic shape unit specimens were made for the Compressive load test and rectangular beam shape specimens were made for the flexural load test. The specimens incorporated waste plastic granules as a partly substitute for fine aggerate at level of 20%, 25%, 30%, and 40%. And also, the concrete mixture was modified by introducing silica fume at 2% of the cement weight in other concrete sample with same mix proportions.

II. Literature Review

Akshay A Tayde et al. (2024) It was elucidated that incorporating waste plastic into bituminous concrete for road construction is an advantageous method to enhance the durability of flexible pavements. They used different proportions of plastic granular such as 5%, 8%, 10%, 12% and 15%. Their tests included assessing the material's density relative to water content, its susceptibility to tearing under pressure, evaluating how much force it can withstand before breaking, estimating its capacity to take up shock without deforming permanently, estimating what percentage of mixtures provides excellent strength while maintaining flexibility against humidity changes and heat exposure, assuring propriety for environments such as those found in countries like India where conditions vary widely [1]. Muktta Narayan Shrestha et al. (2024) The natural sand is partly substitute with plastic waste which is a size of 5-7 mm. They make the M-20 grade of concrete by adding in various percentage of plastic waste as 2%, 4% and 6%. The result demonstrates that rising plastic waste in concrete lead to a decline in both compressive load strength and specimen weight. The silica and addition additive were added in same plastic mix concrete and then a noticeable enhancement in compression performance was observed as earlier mix [2]. Srinivas Halemani et al. (2023) Studies indicate that using recycled plastic instead of sand improves concrete's strength and durability significantly. they use of different amounts of the plastic waste from 5 to 25 percent of total fine aggregating materials directly affects the workability of concrete. As the proportion of substitution rises due to more plastic being incorporated into the mixture, its compressive strength diminishes after curing for twenty-eight days. For concrete mix designs with 5% replacement of plastic waste, it can be expected that the compressive strength will generally be around 1% demote that of an equivalent concrete mix without plastic waste, due largely to the lower strength of the bond formed by the plastic and binder material, the lack of any adhesion. Research indicates that as more plastics enter the concrete mixture, its compressive strength tends to diminish. However, at lower amounts of replacement of up to 5 -10%, this does not significantly impact the overall structural performance of concrete [3]. Babatunde, O.Ya et al. (2022) The researchers studied the application of Polyethylene Terephthalate (PET) plastic partly substituted by fine aggregate in plain cement concrete. They determined various parameter including concrete workability, compressive capability, flexural strength, and moisture absorption aspect by adding various percentages of waste crush granule as of 10%, 20% and 30%. This study compares with control concrete; a little improvement in compressive as well as flexural performance was observed at 10% replacement and further increasing the plastic percentage these properties was decreases its value [4]. Suryakanta Panigrahi et al. (2021) The researchers studied the waste polymer granules used as substitute of coarse aggregate for producing the plain cement concrete.

They demonstrate the compressive performance and split tensile capacity by substituting coarse aggregate of 10%, 20%, and 30% of plastic granules of size as 5-7 mm. The study showed that when more plastic waste was present in the plain cement concrete mix, its compressive as well as split tensile performance diminished relative to standard mix. The finding shows that strength has reaches to 80% when 30% of the plastic granules were used as a replacement [5]. Faran Ahmad et al. (2021) conducted out investigation on utilizing the electronic plastic waste by subsisting the coarse material. It was acquired from the multiple electronics equipment such as keyboards, TVs, computers, mouse, LCDs, monitors etc, which ribboning into small pieces. A research project was conducted by mixing various proportions of e-plastic, specifically 10%, 20%, 30%, 40%, and 50%. This study shows the result as the abrasion value growing with greater percentage of electronic waste into plain concrete comparing with control mix concrete. A tectonic deplete in crushing strength and modulus of rupture is distinguished at 52.7% and 39.4% specifically for a 50% substitute [6]. Dhanagar Gayatri et al. (2020) conducted out the research work and evaluated the effect of plastic granule in plain cement concrete parameter including workability of concrete as well as compressive strength. They used two type of plastic grade such as plastic grade A and plastic grade B and those are differentiated by only grain size. The study was conducted out by adding various percentage of plastic granules in 7.5%, 10% and 12.5%. The workability was found to rise by 7% as the 10 percentage of plastic granule increased with respect to the standard mix. The crushing strength lower down 15 % with increased the 10 percentage of polymer waste granules with respect to the standard mix. Durability of concrete with 10% interchanging sand by plastic waste reveals good resistance to the penetration of water [7]. D. RamaDevi et al. (2020) The experimenter accomplished the detailed evaluation of characteristic parameter of plain cement concrete by employing polymer debris granule as replacement of nature sand. They used plastic cover and plastic bottle in their research and each of them was 0.4%. They compared the outcome of crushing strength, tensile strength and modulus of rupture for plastic cover plain cement concrete, polymer bottle concrete with conventional concrete. This experiment reveals that the crushing strength was diminish as polymer granule added and tensile strength and modulus of rupture was evolved by inserting plastic waste granules in concrete [8]. Darsh Panchal et al. (2020) The probation was rested on the probe of properties of plain cement concrete with the application of polymer debris granules as partly substitution of nature fine aggregate. This experiment assesses impact of incorporating recycled plastic granules on concrete's bulk density, weight and compressive strength of plain concrete. They used 4% and 8% of recycled plastic granules as substitute of nature sand to produce light weight concrete. The workability of 8 % of concrete was decline as reference to conventional mix and crushing strength of these mix was slightly declined but it is acceptable [9]. Hargovind Shukla et al. (2019) This research carried out the work by using polymer debris granules as partly substitute of natural sand to produce the plain cement concrete. This investigation was carried out by adding various percentage of plastic waste as 10%, 20%, 40% and 60% for developing the M-25 grade concrete by using 0.5 w/c ratio. The result of this research shows that the modulus of rupture, tensile strength and also crushing strength was escalated by rising percentage of plastic granule up to 40% in plain cement concrete with respect to standard mix [10]. Manjunath Itagi et al. (2019) This experimental study the work by using waste plastic fiber at various percentage such as 0.5%, 1%, 1.5%, 2%, 2.5% and 3% of cement. The effect of plastic fiber was studied taken together as compression & tension zone and dispersed in tension zone. The result shows by addition of fiber in the concrete, the strength was effectively increased and enhancement was more at first crack stage than at the ultimate load level. This study also shows that the occurrence off cracks in fiber reinforced concrete was decline compared to that in ordinary concrete [11].

III. Experimental Program

The following experimental program was studied the strength behavior of M-25 grade of concrete. The specimens were cast for different weight percentage of plastic waste (0%, 20%, 25%, 30% and 35%) partially substituting fine aggregate by conforming to IS:10262-2019. Here, the fundamental material characteristics including particle size analysis, relative density, consistency of cement, initial and fine setting time were conducted.

A. Material properties

Cement

Grade 43 UltraTech cement (OPC) was employed in preparing cube specimens for compression testing and beam specimens for flexural evaluation. The laboratory cement test by confirming to IS: 4031-1988 was conducted to determine its physical parameters. The specific gravity cement was evaluated by pycnometer meter apparatus and consistency, initial and final setting time was evaluated by using Vicat apparatus and there finding are summarized in Table I.

TABLE I. PHYSICAL PARAMETER OF A CEMENT

Physical parameter	Test Result
Compressive strength at 28 days	56 N/mm^2
Consistency	31%
Initial Setting Time	30 min
Final Setting Time	540 min
Specific gravity	3.15

Aggregates

The laboratory test of fine aggregate as well as coarse aggregate was conducted to evaluate its physical parameter. Grading of Aggregate, Fineness Modulus, specific gravity and also density are among the parameters that these tests assist in determining. are listed below in Table II

TABLE II: PHYSICAL PARAMETERS OF FINE AND COARSE AGGREGATE

Physical Property	Coarse Aggregate	Fine Aggregate
Specific gravity	2.72	2.74
Density (kg/m3)	1636.10	1725.33
Fineness Modulus	5.52	4.3
Grading of Aggregate (Confirming to IS 383:1970)	< 20 mm	Zone II

Water

Water used in this experiment is conforms to IS: 3025 (part 22, 23). These regulations guarantee that there are no contaminants in the water that could compromise the performance and setting characteristics of the plain cement concrete. The water is deemed appropriate for mixing and curing processes if it satisfies these requirements. Maintaining consistency, dependability, and durability in the concrete produced depends on water quality.

Waste Plastic Granules

High density polyethylene (HDPE) polymer plastic was acquired from different places and pulverised using mechanical bladed mill, then grinded particles were separated by sieve apparatus and those grinded particle in the size of 1.23-2.3 mm. Plastic granule as shown in Figure 1 was used as partly substituted of fine aggregate in concrete. The testing results of different properties of waste granule are listed below in Table III.

TABLE III. PHYSICAL PROPERTIES OF A PLASTIC GRANULE

Physical Property	Plastic Granule
Specific gravity	1.3
Grain Size	1.23 - 2.3 mm
Density	700 kg/m^3

Figure 1: Grinded Plastic waste

B. Mix Design

The specimens were cast for different weight percentage of plastic waste (0%, 20%, 25%, 30% and 35%) partially substituting fine aggregate by conforming to IS:10262-2019. The standard M-25 grade concrete mix was made following IS 456-2000 guidelines. The specimens in cubic form, each measuring 150 mm on all sides, were fabricated with and without silica fume to test compressive strength using various ratios of plastic concrete. Additionally, the specimens of beam as rectangular form of length 500 mm and width and height 100 mm were fabricated for the flexural strength evaluation. The entire set of specimens was fabricated using uniform 0.5 w/c ratio and those are compared with control mix concrete. The mix proportion is displayed in Table IV.

TABLE IV. MIX PROPORTIONS FOR 1M^3 OF CONCRETE WITH VARIOUS PLASTIC PERCENTAGE

Materials	0%	20%	25%	30%	35%
Water (kg)	210.5	210.5	210.5	210.5	210.5
Cement (kg)	421.1	421.1	421.1	421.1	421.1
Coarse Aggregate (kg)	1094.94	1094.94	1094.94	1094.94	1094.94
Fine Aggregate (kg)	622.8	498.2	467.1	435.9	404.8
Plastic (kg)	-	124.5	155.7	186.8	217.9

IV. RESULTS AND DISCUSSIONS

The finding from multiple tests conducted on concrete cubes and beams prepared with different content of plastic granules are presented in the following:

A. Workability Test

The slump cone test shown in Figure 2 and result was shown in given Figure 3. It was observed that the degree of workability lower down by raising the plastic granules in the plain cement concrete as compared with conventional concrete, but it is acceptable as per the IS 7320:1974.

Figure 2: Slump Test

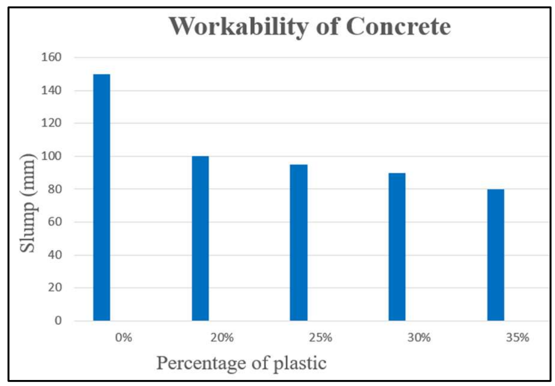


Figure 3: Graph for Slump vs % of Plastic

B. Flexural Strength Test

The specimens of beam as rectangular form of length 500 mm and width and height 100 mm was used for transverse rupture strength test shown in Figure 4. It was casted at different percentage of plastic replacement for 7 day and 28 day curing ages. The mean strength of trio of specimen was taken as the flexural strength value of various samples. The finding showed that a slightly raised in flexural strength of concrete with raising in plastic granules related to flexural strength of standard concrete, as illustrated in Figure 5

Figure 4: Flexural strength test

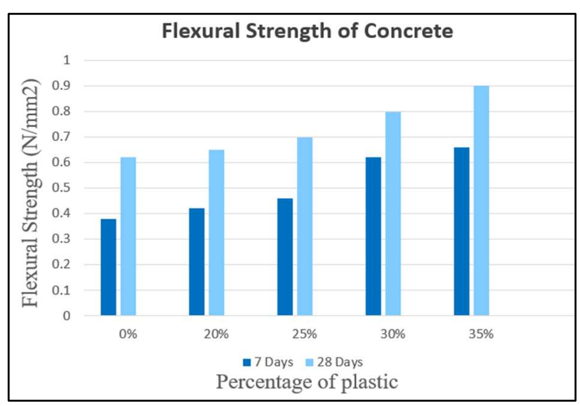
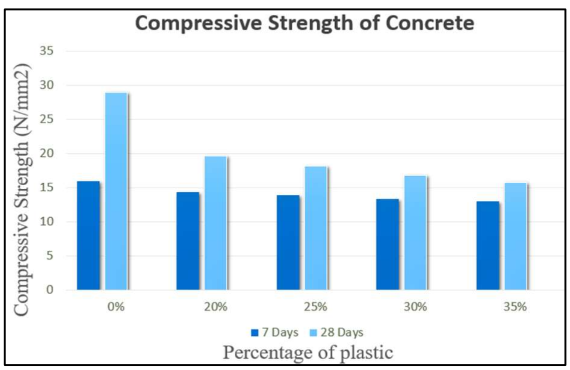


Figure 5: Flexural strength and varying % of plastic

C. Compressive Strength Test

The specimens in cubic form, each measuring 150 mm on all sides was used for compression strength test shown in Figure 6. It was casted at different percentage of plastic replacement for 7 day and 28 day curing ages by using both in the presence and absence of silica fume admixture in plain concrete. The mean strength of trio of specimen was defined as the compressive strength of various samples. The finding showed that the crushing strength of specimen lower down as raising of plastic granule compared to conventional concrete, as illustrated in Figure 7. After adding the silica fume (2% of cement) to that concrete mix, the result observed was that the crushing performance was increased as related to previous concrete results, and its results are shown in the given Figure 8.

Figure 6: Compressive Strength Test



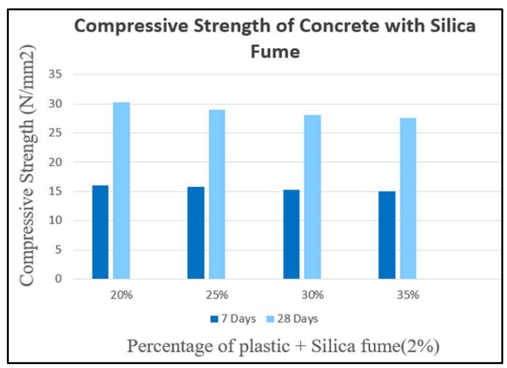


Figure 7: Compressive strength and varying % of plastic Figure 8: Compressive strength and varying % of plastic + Silica fume (2%)

V. CONCLUSION

This experimental study work conducted out for developing the M-25 grade concrete by utilizing waste plastic to substitute the fine aggregate. The research concludes that by utilizing the waste plastic in concrete hold the promise to maintain the strength for general work and best solution for disposing the waste plastic as the biggest environmental concern in the world. This research support significantly to both infrastructure development and environmental sustainability efforts by recommending for the reuse of waste plastic in construction. From this research work following conclusion were drawn: The degree of workability lower down as the plastic substitution in the concrete was raised as compared to the control mix displayed in Figure 3. The compressive performance of concrete lower down with a raising in plastic granules in plain concrete compared to conventional mix, as illustrated in Figure 7. After adding the silica fume (2% of cement) admixture to plastic content concrete mix, the result observed was that the compressive strength was increased as related to without admixture plastic content concrete are shown in Figure 8. The flexural performance of concrete slightly improved with the addition of more plastic granule in concrete compared to flexural performance of conventional mix are displayed in Figure 5.

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