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Research Article

Analysis of Mechanical Properties of Concrete using Plastic Granules as Coarse Aggregates

Mahesh Chandra Paliwal[1],S.S. Kushwaha[2]
[1]*PhD Scholar, Civil Engineering, Rabindranath Tagore University, Bhopal (M.P.), India*
[2]*Assistant Professor, Civil Engineering, Rabindranath Tagore University, Bhopal (M.P.), India*

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ABSTRACT

This study presents the development and application of mathematical models to analyze the mechanical properties of concrete incorporating waste plastic granules. Specifically, the research focuses on compressive strength and split tensile strength of concrete mixtures where Low-Density Polyethylene (LDPE) granules are used as a partial replacement for natural coarse aggregates. LDPE waste, sourced from post-consumer plastic, was introduced in varying proportions of 0%, 20%, 30%, and 40% by volume. The study aims to evaluate the influence of these substitutions on the mechanical performance of concrete and to develop predictive models for strength characteristics. The results contribute to the sustainable management of plastic waste and provide insights into its potential for use in eco-friendly concrete production.

Keywords: Low-Density Polyethylene (LDPE) Granules,Plastic Waste,Mechanical Properties,Fine Aggregates,Plastic Granule Aggregates, Coarse Aggregates, Eco-friendly Concrete Production

1. INTRODUCTION

The rapid growth in plastic consumption has led to a significant increase in plastic waste, posing severe environmental challenges worldwide. Among the various types of plastics, Low-Density Polyethylene (LDPE) is widely used in packaging and is often discarded after a single use, contributing to the growing burden of non-biodegradable waste (Hopewell et al., 2009). Conventional disposal methods, such as landfilling and incineration, are not sustainable in the long term due to their adverse environmental impacts (Rujnić-Sokele & Pilipović, 2017). In parallel, the construction industry faces increasing pressure to adopt more sustainable practices by incorporating alternative materials in concrete production. The partial replacement of natural aggregates with recycled waste materials has emerged as a promising strategy to reduce the environmental footprint of concrete while conserving natural resources(Saikia & Brito, 2012).

This study explores the feasibility of using waste LDPE granules as a partial substitute for coarse aggregates in concrete. The primary objective is to assess the influence of LDPE content on the mechanical properties of concrete, particularly compressive strength and split tensile strength. By introducing LDPE in varying proportions—0%, 20%, 30%, and 40%, this research aims to evaluate its effects on concrete performance and develop mathematical models that predict strength behavior. The integration of waste plastics into concrete not only provides a sustainable outlet for plastic waste but also opens new avenues for environmentally responsible construction materials.

2. OBJECTIVE OF THE STUDY

This study examines how adding plastic granules with different densities to concrete affects the material's mechanical and environmental qualities. Among the particular objectives are:

1. Assessing the workability, tensile strength, and compressive strength of concrete that contains plastic granules made of LDP.

2. Calculating how recycling plastic waste into building materials benefits the environment.

3. Too the optimal proportions of plastic aggregates to improve the performance of concrete.

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4. Developing mathematical models to model and forecast how plastic-modified concrete will behave in different scenarios.

5. Suggestions the application of plastic granules in building to encourage environmentally friendly methods.

3. LITRATURE REVIEW

- Impact of Plastic Granule Density Variations on Mechanical Properties

- **Compressive Strength**

Zhang and Wang (2024) studied how different concentrations of plastic granules in concrete impacted its compressive strength. They found that higher percentages of plastic granules led to reduced compressive strengths. However, optimizing the particle size distribution could minimize the effect; thus, there is a possibility for designing customized concretes. Gupta et al. (2023) also investigated the compressive strength of SCC that incorporated plastic debris. Their discovery that SCC containing plastic debris has a compressive strength comparable to that of regular concrete provides support for using plastic trash as a partial replacement for regular aggregates.

Li et al. (2018) studied how varying plastic granule concentrations influenced the mechanical properties of concrete in a related study. The authors noted that even though the compressive strength was lowered, adding plastic granules enhanced the flexural strength at the same time. Plastic grains, they reasoned, may increase concrete's ductility and crack resistance, which would explain their results. The study highlights the compromises that plastic-modified concrete makes when deciding how to rank its mechanical attributes, such as compressive strength.

- **Spilit Tensile Strength**

Recent studies have focused on plastic granules' effect on concrete tensile strength. Zhang and Wang et al.(2023), studied FRC with varying densities of plastic granules. Their work indicates that moderate plastic concentrations improve the tensile strength of fiber reinforced concrete (FRC), meaning plastic waste and fiber reinforcement complement each other in enhancing concrete quality. Another investigation on the tensile behavior of plastic-treated concrete under extreme environmental conditions was conducted by Liu et al. (2023). Relative to the conventional concrete, they found that plastic granule-filled concrete exhibited better retention of tensile strength and resistance to environmental degradation, highlighting its possibility for use in durable infrastructure in challenging environments.

Kahn et al. (2019) tested the tensile properties of lightweight aggregate concrete (LWAC) by varying densities of plastic trash. Their finding disclosed that plastic granules usage increases tensile strength in LWAC, which can help prevent cracking and ultimately guarantees structural soundness of the concrete. The significance of tensile strength is highlighted by this very fact with respect to plastic-modified concrete.

3. MATERIALS & METHODS

3.1 Materials

The first process was to locate all of the raw materials required. These included glass powder, plastic granules, cement, and fine and coarse aggregates. All the components were carefully sourced and prepared to meet the demands of the experimental setup. This preparation ensured consistency and reliability in subsequent testing and analysis.

3.2 Mix Preparation:

In certain concrete mixtures, glass powder was utilized in lieu of some of the cement. In other mixes, plastic granules were used to partly replace coarse pebbles. Their respective contributions and the effects of their combined impact on the performance of the concrete were assessed by cyclically changing the replacement ratios. To achieve uniformity in every mix design, this step demanded accurate measuring and mixing.

3.3 Test & Method

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3.3.1 Test of Mechanical Properties: There was an extensive analysis of the amended concrete's mechanical characteristics. The tests included:

- **Test of Compressive Strength-** One important parameter which expresses the general capacity of concrete in resisting load is its compressive strength. Cube molds with typical dimensions of 150 mm x 150 mm x 150 mm were constructed for the experiment. The air bubbles trapped within the mixture of concrete were expelled out while it was compacted with great care before piling into these molds. The samples after molding were immersed in water for curing seven and twenty-eight days respectively. After the curing process was finished, the compressive strength was measured using a compression testing machine. When the load was gradually increased till failure, the maximum load was recorded. To determine the compressive strength, the following equation was subsequently used:

Compressive Strength = Maximum Load (N) / Cross-Sectional Area (mm^2)

Figure 1: Test analysis of Compressive Strength

- **Test of Split Tensile Strength -** Important among concrete's properties is its tensile strength, which is essentially its resistance to cracking under tension. The aforementioned attribute was determined by conducting this split tensile strength test in accordance with the guidelines of the ASTM C496 standards.

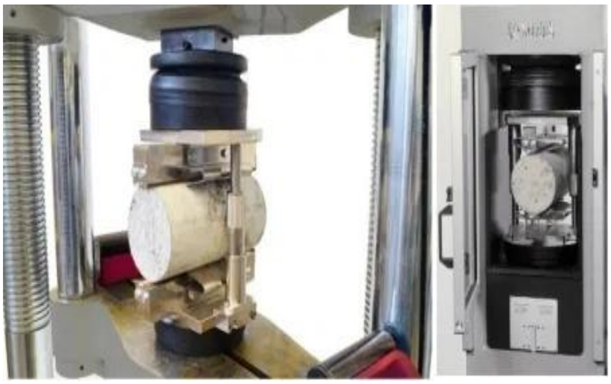

Figure 2: Split Tensile Strength Testing

4. RESULTS & DISCUSSION

4.1 Experimental Investigations and Correlation Models

- Experimental investigations were carried out on concrete mixes with a target strength of 20 MPa. The concrete was cast using 53-grade cement, river sand with a fineness modulus of 2.27, and a water-to-cement ratio ranging from 0.45 to 0.55. Table 1 summarizes the experimental results, showing how varying the percentage of plastic

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granules and glass powder affects concrete properties. Increasing the percentage of plastic granules decreases the strength of concrete.

Table 1: Results of experimental investigations

S. No.	Mixes with Variation in Glass Powder	Split Tensile Strength (MPa)	Slump (mm)	Compressive Strength (MPa)	Cement	Glass Powder	% Plastic Granules
1	M11	5.10	97	19.1	0.95	0.05	0
2	M12	4.60	95	19.3	0.90	0.10	0
3	M13	4.30	94	19.8	0.85	0.15	0
4	M21	4.59	93	18.6	0.95	0.05	12
5	M22	4.14	91	18.9	0.90	0.10	12
6	M23	3.87	88	19.4	0.85	0.15	12
7	M31	4.13	89	18.4	0.95	0.50	18
8	M32	3.73	87	18.7	0.90	0.10	18
9	M33	3.48	84	19.3	0.85	0.15	18
10	M41	3.72	86	18.1	0.95	0.50	24
11	M42	3.35	83	18.7	0.90	0.10	24
12	M43	3.13	82	19.1	0.85	0.15	24
13	M51	3.35	82	17.9	0.95	0.50	30
14	M52	3.02	80	18.3	0.90	0.10	30
15	M53	2.82	77	18.6	0.85	0.15	30
16	M61	3.01	79	17.6	0.95	0.50	36
17	M62	2.72	77	18.2	0.90	0.10	36
18	M63	2.54	74	18.5	0.85	0.15	36
19	M71	2.71	76	17.1	0.95	0.50	42
20	M72	2.44	73	17.8	0.90	0.10	42
21	M73	2.29	72	18.0	0.85	0.15	42
22	M81	2.44	73	17.0	0.95	0.50	48
23	M82	2.20	70	17.4	0.90	0.10	48
24	M83	2.06	67	17.9	0.85	0.15	48
25	M91	2.20	68	16.8	0.95	0.50	54
26	M92	1.98	65	17.4	0.90	0.10	54
27	M93	1.85	63	17.7	0.85	0.15	54
28	M101	1.98	64	16.2	0.95	0.50	60

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29	M102	1.78	62	16.9	0.90	0.10	60
30	M103	1.67	60	17.3	0.85	0.15	60

Using the experimental data, correlation models were developed to evaluate compressive strength and split tensile strength. The following relationships were derived:

Compressive Strength = S in MPa,

Split Tensile Strength = T in MPa,

and Percentage of Plastic Granules = P %

From the regression analysis of the data following relations are obtained for evaluating the compressive strength through the Percentage of plastic Granules. Figure 3 represents the curve plotted between compressive strength (S) and Plastic Granules (P).

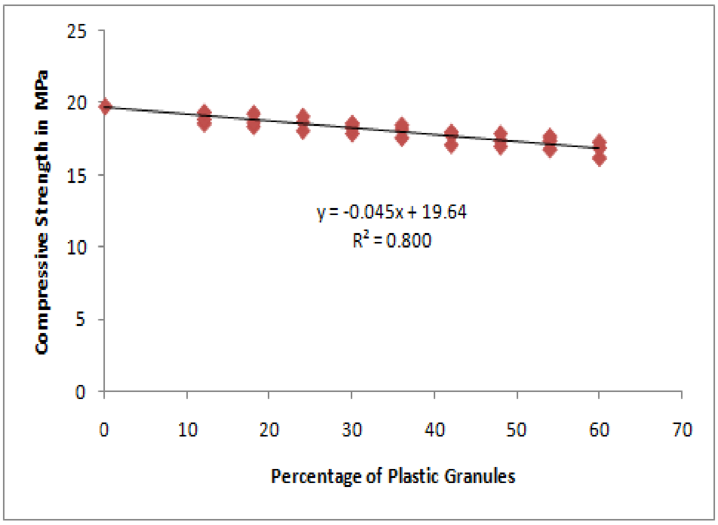

Figure 3: Relation between S and P

Hence, relation obtained is:-

$$\mathbf{S = -0.045\ P + 19.64 \ ...eqn.\ (1)}$$

$$\mathbf{R^2 = 0.800}$$

This eqn. 1 is useful for calculating compressive strength of a concrete through by putting % of Plastic Granules. In Figure 4 values of Tensile strength were plotted against Plastic Granules to obtain a relation between T and P.

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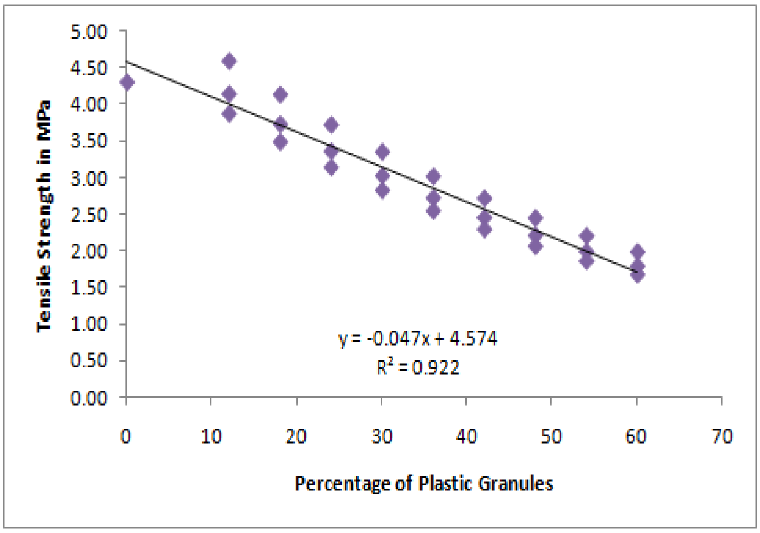

Figure 4: Relation between T and P

Hence, relation between tensile strength and plastic granules has been obtained as:-

$$T = -0.047\ P + 4.574 \quad \text{....eqn. (2)}$$

$$R^2 = 0.922$$

Now, eqn. 2 is useful for calculating tensile strength of a concrete through by knowing % of Plastic Granules.

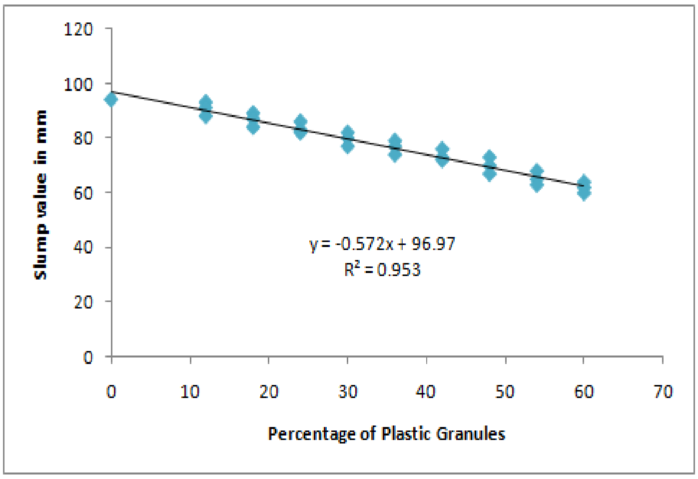

Figure 5 :Relation between W and P

Hence, relation between Slump value and plastic granules has been obtained as:-

$$W = -0.572\ P + 96.97 \quad \text{...eqn. (3)}$$

$$R^2 = 0.953$$

Now, eqn. 3 is useful for calculating Slump value of a concrete through by knowing % of Plastic Granules.

The experimental results reveal that increasing the percentage of plastic granules negatively impacts the compressive strength and split tensile strength of concrete. This decrease is attributed to the lower density and weaker bond between plastic granules and the cement matrix compared to conventional aggregates . Additionally, plastic granules reduce the workability of concrete, which can complicate the mixing and placing processes.

The inclusion of glass powder, however, demonstrates a positive effect on the compressive strength of concrete. This improvement can be linked to the pozzolanic reaction between glass powder and cement, which enhances the strength properties. Despite this, the workability of concrete decreases as the percentage of glass powder increases, similar to the effect of plastic granules..

These findings are consistent with previous research that highlights the dual impact of incorporating waste materials in concrete. While such materials can enhance certain properties, they also pose challenges, particularly related to workability and overall strength.

5. CONCLUSIONS

5.1 Conclusions

The major findings and contributions of this study can be summarized as follows:

- Density Polyethylene (LDPE) granules were successfully incorporated as partial replacements for coarse aggregates in concrete, promoting a sustainable approach to plastic waste management.
- Compressive and split tensile strengths decreased with increasing LDPE content. A 20% replacement level demonstrated an acceptable balance between performance and sustainability, making it suitable for non-structural applications. Concrete with 20% LDPE showed the most promising results in terms of strength retention.Replacement levels beyond 30% led to significant reductions in mechanical performance.
- Predictive models were developed to estimate compressive and tensile strengths based on LDPE content. These models can aid in the design and optimization of eco-concrete mixes incorporating plastic waste.
- The approach supports resource conservation by reducing the use of natural aggregates. It also contributes to environmental protection through plastic waste reuse.
- Compressive Strength (S): Decreases with the increase in the percentage of plastic granules. The developed model S=−0.045P+19.64S = -0.045P + 19.64S=−0.045P+19.64 can be used to estimate compressive strength based on the plastic granule content.
- Split Tensile Strength (T): Also decreases with the percentage of plastic granules. The relationship T=−0.047P+4.574T = -0.047P + 4.574T=−0.047P+4.574 provides a method for predicting tensile strength.
- Workability (W): Shows a significant reduction with higher plastic granule content. The equation W=−0.572P+96.97W = -0.572P + 96.97W=−0.572P+96.97 helps estimate workability.

5.2 Recommendations For Future Work:

- Investigate surface treatment methods to enhance bonding between LDPE and the cement matrix.
- Assess the long-term durability, water absorption, and thermal resistance of LDPE-modified concrete.
- Explore the integration of other types of plastic waste for comparative analysis.

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