

Development Of Innovative Interlocking Block Design by Recycled Plastic Waste for Sustainable Construction

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Abstract—The increasing consciousness of the environment among people worldwide has resulted in research on alternative construction materials, especially those that produce minimal waste output. The production of stackable blocks from recycled plastic waste as a green construction process is the focus of this research. Recycling plastic not only enhances traditional construction materials but also reduces the damage plastic waste causes to the earth. The interlocking block system with interlocking blocks is designed to be long-lasting, durable, and easy to install with different ratios of recovered plastic waste as a binder and filler. The mechanical and physical properties of the blocks were determined through testing through shear strength, water absorption, and lifespan. Composed of recycled plastic waste, the blocks are much stronger and less susceptible to water, thus, ideal for different building applications. The research is based on the premise that recovered plastic waste can substitute sustainable construction materials. The results explain how effectively waste can be recycled in the construction industry, thus, eliminating waste and directing the circular economy.

Index Terms—Recycled Plastic Waste, Interlocking Blocks, Sustainable Construction, Eco-friendly Materials, Waste Recycling

I. INTRODUCTION

Bricks have long been an essential building material in India, where brick-making is a traditional industry, primarily located in rural areas. With rapid urbanization and an increasing demand for construction materials, brick kilns have expanded to meet the growing needs of the construction sector. However, this expansion has raised serious environmental and health concerns. Locally, the pollution generated by brick-making activities harms human health, animals, and plant life, while globally, these operations contribute to environmental pollution,

including global warming and climate change (Batayneh et al., 2007). Additionally, extreme weather conditions, such as frost, can lead to the degradation of brick surfaces, further diminishing their lifespan and utility.

As environmental concerns escalate, alternative construction materials are being explored. One promising option is Cellular Light Weight Concrete (CLC) blocks, which serve as a sustainable alternative to traditional red bricks. CLC blocks, produced with a mixture of cement, fly ash, and water, along with a pre-formed stable foam, offer significant environmental benefits. Unlike traditional red bricks, the production of CLC blocks consumes less energy and emits no pollutants, making it an environmentally friendly building material (Bhupendra S. S. and Vanita A., 2014). Furthermore, the process of adding foam creates millions of tiny voids, giving the concrete its lightweight and insulating properties. Studies have shown that the compressive strength of CLC blocks is comparable to or even exceeds that of conventional clay bricks, providing a robust, sustainable alternative for construction (Batayneh et al., 2007).

In addition to the widespread adoption of CLC technology, the growing issue of plastic waste has prompted researchers to explore its incorporation into construction materials. The rapid rise in solid plastic waste in India, compounded by the country's large population, presents a significant environmental challenge. With a population exceeding 170 million, India is one of the largest producers of solid waste globally, much of which remains uncollected and is discarded in open spaces and residential areas (Bioenergy Consult, 2016). Recycling plastic waste into construction materials can mitigate waste accumulation, reduce environmental pollution, and provide cost-effective alternatives to conventional building materials (Dhir and Csetenyi, 2003). Recent

research has highlighted the potential of using recycled plastic in concrete to improve its properties. For example, Batayneh et al. (2007) demonstrated that incorporating plastic particles into concrete could reduce strength properties, with 20% plastic replacement causing a sharp reduction in compressive strength. However, lower percentages of plastic, such as 5%, showed more moderate reductions. This suggests that the inclusion of waste plastic in concrete requires careful optimization to balance strength and environmental benefits. Furthermore, the use of waste plastics addresses the growing problem of non-biodegradable waste, which has a significant adverse impact on the environment.

The primary goal of this research is to develop and study the mechanical properties of lightweight interlocking blocks made from plastic waste. By comparing these blocks to conventional ones, the study aims to assess their potential as a viable and sustainable alternative in construction. Additionally, the research will explore various mix proportions and the effects of different plastic waste additions on the density and strength of the blocks.

II. LITERATURE REVIEW

The rising emphasis on sustainability in construction has led to increased research into using recycled materials, with particular focus on integrating plastic waste into lightweight concrete blocks and other building components.

Several studies have explored the impact of incorporating plastic waste into concrete production. Jain et al. (2023) conducted an experimental study to evaluate the potential of using plastic waste in the production of composite construction materials. They found that while the inclusion of plastic resulted in a decrease in compressive strength, it contributed to the reduction of environmental pollution by utilizing waste materials (Jain et al., 2023) [1]. Similarly, Mohan (2022) demonstrated that semi-automated machines could efficiently process plastic waste to create sustainable construction materials, leading to a reduction in resource consumption and pollution (Mohan, 2022) [2].

Choi et al. (2009) evaluated the use of fine plastic aggregate in concrete. They found that plastic aggregate could replace traditional aggregates, leading to a reduction in the overall weight of the concrete,

while still maintaining adequate structural integrity (Choi et al., 2009) [3]. Additionally, Basha et al. (2020) investigated the mechanical and thermal properties of lightweight recycled plastic aggregate concrete, noting that the inclusion of plastic improved the thermal insulation properties of the concrete, making it suitable for energy-efficient building applications (Basha et al., 2020) [5].

The physical properties of concrete containing plastic waste have also been a major focus. Pradha and Saranya (2023) studied the use of recycled plastic in foam concrete, observing that foam concrete blocks are effective in saving resources such as cement and energy, while also reducing the environmental footprint (Pradha and Saranya, 2023) [4]. Their findings support the idea that foam concrete, incorporating recycled plastic, is a sustainable alternative to traditional blocks.

Belmokaddem et al. (2020) further examined the physical properties of concrete containing recycled plastic, revealing that the incorporation of plastic waste caused a reduction in the compressive strength, but the reduction was less significant when using smaller-sized plastic aggregates (Belmokaddem et al., 2020) [6]. This study highlights the importance of controlling the size of recycled plastic to mitigate the negative impact on concrete strength.

Several studies have addressed the impact of plastic waste on the strength and durability of concrete. Kim et al. (2010) found that concrete mixed with recycled PET (Polyethylene Terephthalate) fibers showed improved fracture toughness, although the compressive strength decreased with increasing plastic content (Kim et al., 2010) [11]. Similarly, Naik et al. (1996) explored the use of post-consumer plastic wastes in cement-based composites, highlighting the importance of managing plastic content to maintain the desired mechanical properties (Naik et al., 1996) [12].

Aziz and Abdullah (2020) reviewed several studies on the use of recycled plastic in concrete, concluding that although plastic waste decreases the strength of concrete, it offers significant environmental benefits by reducing waste accumulation and contributing to the sustainability of the construction industry (Aziz and Abdullah, 2020) [19].

The environmental benefits of using plastic waste in concrete production are significant. According to Pacheco-Torgal et al. (2012), the recycling of waste

plastic into concrete not only reduces the environmental impact of plastic waste but also promotes the reduction of carbon footprints in construction (Pacheco-Torgal et al., 2012) [13]. This is particularly relevant in regions where plastic waste is abundant but recycling facilities are lacking. Rauniyar et al. (2024) also pointed out that plastic waste can be used effectively in the production of composite bricks, thereby alleviating the environmental burden caused by the improper disposal of plastic (Rauniyar et al., 2024) [3].

Furthermore, Olofinnade et al. (2021) highlighted the role of recycled plastic in sustainable construction, noting that plastic waste can replace conventional building materials in applications such as non-load-bearing walls, which significantly reduces resource consumption and waste generation (Olofinnade et al., 2021) [20].

In addition to the environmental benefits, the economic advantages of using recycled plastic in construction materials cannot be overlooked. Duraiswamy et al. (2025) explored the economic feasibility of using recycled plastic in concrete production and found that while the initial costs of processing plastic may be higher, long-term savings are achieved through the reduction of material costs and waste management expenses (Duraiswamy et al., 2025) [7]. Moreover, the use of recycled plastic in construction can also lead to cost reductions in materials such as cement, sand, and aggregates, which are typically expensive and energy-intensive to produce.

Sathvik et al. (2024) discussed the potential for using plastic waste to produce lightweight and durable concrete blocks, which can be used in a variety of construction applications, including partitions and non-load-bearing walls. They emphasized that these blocks offer a practical solution for the growing demand for low-cost construction materials, particularly in regions facing a housing crisis (Sathvik et al., 2024) [6].

Using recycled plastic waste in construction, especially in lightweight concrete blocks, offers a smart solution for both waste management and sustainable building. While adding plastic may slightly reduce compressive strength, it brings key benefits like lowering material costs, cutting plastic pollution, and improving insulation. With more research, the balance between strength and

sustainability can be improved to suit different construction needs.

III. PROPOSED METHODOLOGY AND DESIGN

1. Existing Methods

Existing methods for utilizing plastic waste in construction materials primarily focus on its incorporation as a partial replacement for fine or coarse aggregates in concrete mixes. In these methods, shredded or granulated plastic is blended with conventional concrete ingredients to produce lightweight concrete or blocks. Some approaches also involve melting and molding plastic to form bricks or interlocking blocks, while others use plastic fibers to improve ductility and reduce cracking. These techniques often aim to reduce the environmental burden of plastic waste while maintaining acceptable mechanical properties for non-structural and light structural applications. However, challenges such as reduced bond strength, long-term durability, and optimal mix design remain areas of active investigation.

2. Data Used

The experimental investigation utilized six different mix proportions of foam concrete, incorporating varying percentages of fly ash and recycled thermoplastic waste. Ordinary Portland Cement (OPC 53 grade) served as the primary binder, while fly ash was used to enhance workability and reduce cement content. A protein-based foaming agent was employed to achieve the desired lightweight characteristics of the concrete. Thermoplastic waste, processed into small chips, was added in proportions of 0%, 5%, 10%, 12.5%, and 15% by volume as a partial replacement for fine aggregate. Key parameters such as compressive strength, water absorption, and density were recorded at 7 and 28 days of curing to evaluate the mechanical and durability performance of the interlocking blocks.

3. Methodology

➤ Experimental Investigations

This section presents the experimental methodology and results pertaining to foam concrete incorporating fly ash and thermoplastic waste. Six mix designs were studied, with fly ash replacing cement at 20% and 30%, and thermoplastic polypropylene waste replacing fine aggregates at 5% and 10%. The aim was

to assess the impact of these substitutions on the mechanical and physical properties of foam concrete, using Ordinary Portland Cement (OPC), Class F fly ash, a protein-based foaming agent, and potable water.

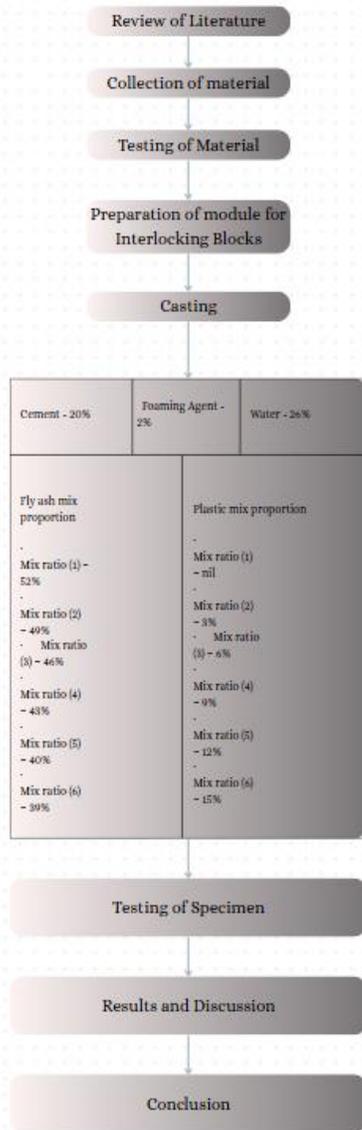


Fig 1: Methodology Flowchart

➤ *Materials*

Cement used was OPC 53 grade with a specific gravity of 3.15 and standard consistency of 31%. Fly ash (Class F) with a specific gravity of 2.2 was utilized for partial cement replacement. Fine aggregate was natural river sand (Zone II, IS: 383-2016) with a fineness modulus of 2.45 and specific gravity of 2.63.

The thermoplastic waste comprised crushed polypropylene particles (≤ 4.75 mm, specific gravity 0.92), used as fine aggregate substitute. A protein-based foaming agent with a dilution ratio of 1:30 was used to introduce air-voids, producing a foam density of 75–80 kg/m³. All mixes maintained a constant water-cement ratio of 0.45.

➤ *Mix Proportions*

Six different foam concrete mixes were prepared. The control mix (FC0) contained no replacements. Mixes FC1 to FC5 included 20–30% fly ash and 5–10% thermoplastic waste, as shown in Table 1.

Table I Mix Proportions of Foam Concrete

Mix ID	Cement (%)	Fly Ash (%)	Fine Aggregate (%)	Plastic Waste (%)	W/C Ratio	Foam Volume (%)
FC0	100	0	100	0	0.45	25
FC1	80	20	95	5	0.45	25
FC2	80	20	90	10	0.45	25
FC3	70	30	95	5	0.45	25
FC4	70	30	90	10	0.45	25
FC5	100	0	90	10	0.45	25

➤ *Casting and Curing*

All mixes were prepared using a rotary drum mixer and cast into 150 mm × 150 mm × 150 mm cube moulds. Each mix had 9 cubes—3 each tested at 7, 14, and 28 days of curing in potable water. Specimens were demoulded after 24 hours.

➤ *Workability*

Workability was evaluated using the slump cone method. Foam concrete exhibited moderate workability, with slump values ranging from 65 mm to 85 mm depending on mix composition (Table 2). Higher plastic content generally led to lower slump due to irregular particle shape and surface texture.

Table II Slump Values for Fresh Concrete

Mix ID	Slump (mm)
FC0	85
FC1	78
FC2	70
FC3	75
FC4	65
FC5	68

➤ *Fresh Density*

The fresh density of each mix was measured immediately after mixing. Table 3 summarizes the results, showing a decline in density with increasing fly ash and plastic content.

Table III Fresh Density of Foam Concrete

Mix ID	Density (kg/m ³)
FC0	1880
FC1	1825
FC2	1770
FC3	1805
FC4	1745
FC5	1785

➤ *Water Absorption*

Water absorption was determined on 28-day oven-dried specimens submerged in water for 24 hours. Table 4 indicates a marginal increase in water absorption with plastic addition, attributed to increased porosity.

Table IV Water Absorption

Mix ID	Absorption (%)
FC0	6.8
FC1	7.4
FC2	8.1
FC3	7.6
FC4	8.5
FC5	8.3

➤ *Compressive Strength*

Compressive strength tests were conducted at 7, 14, and 28 days. Results are presented in Table 5. Strength declined with higher levels of replacement, although all mixes maintained acceptable structural performance for non-load bearing applications.

Table V Compressive Strength Results

Mix ID	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
FC0	16.5	21.2	26.8
FC1	15.2	19.5	24.1
FC2	14.0	17.8	22.3
FC3	13.8	17.2	21.5
FC4	12.4	15.6	19.4
FC5	13.2	16.4	20.7

Observations

- Workability and density decreased with increasing fly ash and plastic content.
- Water absorption slightly increased due to enhanced porosity.
- Compressive strength values remained within usable limits, with FC1 and FC2 performing best among the modified mixes.

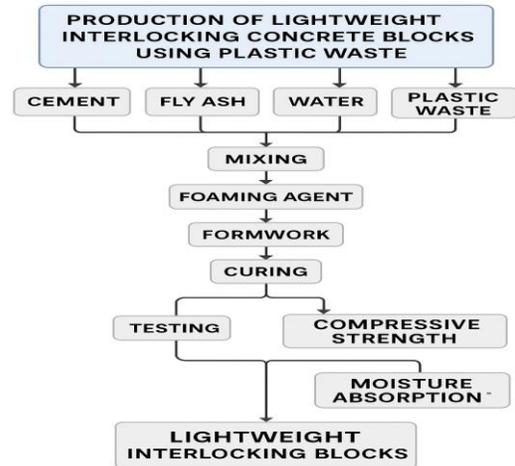


Fig 2: System Architecture Workflow

4. *Mix Design Methodology*

The mix design for foam concrete was developed based on target density, desired compressive strength, and the proportioning of air-entrained volume. The adopted methodology integrates guidelines from IS 10262:2019 (for conventional concrete), with necessary adjustments for lightweight foam concrete. A target density of 1800 ± 50 kg/m³ was maintained across all mixes.

Design Parameters

- Grade of Concrete: Equivalent to 15–25 MPa compressive strength
- Target Wet Density: 1800 kg/m³
- Cement: OPC 53 Grade
- Cementitious Material: OPC replaced partially by Class F fly ash (0%, 20%, 30%)
- Fine Aggregate: River sand (Zone II) with partial replacement by thermoplastic waste (0%, 5%, 10%)
- Water-Cement Ratio: 0.45 (fixed)
- Foaming Agent: Protein-based, diluted 1:30 with water
- Foam Volume: Approx. 25% of total mix volume

Proportioning Strategy

The mix proportions were derived by adjusting the binder and aggregate content to compensate for air-void volume introduced by the foam. A fixed foam volume ensured consistency across batches. The basic control mix (FC0) was designed with no replacements. Modified mixes (FC1–FC5) substituted fly ash and thermoplastic waste in varying ratios, as detailed in Table 6.

Table VI Final Mix Design per m³ of Foam Concrete

Mix ID	Cement (kg)	Fly Ash (kg)	Sand (kg)	Plastic Waste (kg)	Water (kg)	Foam (litres)
FC0	350	0	1150	0	157.5	250
FC1	280	70	1090	60	157.5	250
FC2	280	70	1035	115	157.5	250
FC3	245	105	1090	60	157.5	250
FC4	245	105	1035	115	157.5	250
FC5	350	0	1035	115	157.5	250

Note: Foam volume was calculated based on laboratory-generated foamed slurry with a bulk density of 75–80 kg/m³, added post mixing of mortar matrix.

Observations During Mixing

- All mixes exhibited uniform foam dispersion with stable air-void structure.
- Plastic particles were evenly distributed using a gradual dry mixing method prior to foam addition.
- No segregation or bleeding was observed during pouring and casting.

IV. RESULTS AND DISCUSSION

4.1 General

The experimental study was conducted to evaluate the mechanical and durability performance of interlocking lightweight concrete blocks developed with partial replacement of fly ash by waste plastic. The study primarily focused on assessing the compressive strength at 7 and 28 days and water absorption capacity after 28 days. A series of concrete blocks with varying plastic content (0%, 3%, 6%, 9%, 12%, and 15%) were prepared, cured, and tested to understand the effect of plastic incorporation on strength and water absorption.

4.2 Test on Specimens

The following tests were conducted to evaluate the performance of the interlocking blocks:

- Compressive Strength Test
- Water Absorption Test

4.2.1 Compressive Strength Test

The compressive strength test was conducted on interlocking blocks after 7 and 28 days of water curing. A Compression Testing Machine (CTM) with uniform axial loading was used until the specimen failed. The compressive strength values were then computed using the standard formula.

Compressive Strength after 7 Days of Curing

Table VII Compressive Strength of Interlocking Blocks (7 Days Curing)

S. No.	Plastic Content (%)	Sample 1 (N/mm ²)	Sample 2 (N/mm ²)	Sample 3 (N/mm ²)	Average Strength (N/mm ²)
1	0%	1.30	1.20	1.25	1.25
2	3%	1.65	1.44	1.42	1.50
3	6%	2.07	1.86	2.07	2.01
4	9%	2.27	2.30	2.20	2.26
5	12%	2.69	2.48	2.65	2.60
6	15%	3.10	2.89	3.31	3.10

The results show a clear enhancement in compressive strength with increasing plastic content. At 15% replacement, the strength improved significantly to 3.10 N/mm² compared to 1.25 N/mm² in the control specimen. This improvement could be attributed to the denser microstructure induced by plastic particles, enhancing the load-bearing capacity.

Compressive Strength after 28 Days of Curing

Table VIII Compressive Strength of Interlocking Blocks (28 Days Curing)

S. No.	Plastic Content (%)	Sample 1 (N/mm ²)	Sample 2 (N/mm ²)	Sample 3 (N/mm ²)	Average Strength (N/mm ²)
1	0%	3.10	2.89	3.31	3.10
2	3%	2.80	2.89	3.15	2.94
3	6%	2.82	2.89	3.04	3.04
4	9%	3.26	3.20	3.04	3.18
5	12%	3.47	3.29	3.47	3.40
6	15%	4.13	4.34	4.30	4.27

At 28 days, all specimens showed significant strength gains due to continued hydration. The compressive strength increased steadily with higher plastic content. The 15% plastic replacement yielded the highest average strength of 4.27 N/mm². The results confirm that thermoplastic particles act as fillers and enhance strength by reducing internal voids and improving particle packing.

4.2.2 Water Absorption Test

Water absorption is a critical parameter for evaluating the durability of masonry units. The test was conducted after 28 days of curing. Specimens were weighed before and after oven drying, and the percentage of water absorbed was calculated using the formula:

$$\text{Water Absorption (\%)} = \frac{W2 - W1}{W1} \times 100$$

Where,

W1 = Wet weight of block = 6566 g

W2 = Dry weight of block = 6205 g

$$\begin{aligned} \text{Water Absorption (\%)} &= \frac{6205 - 6566}{6566} \times 100 \\ &= 5.49\% \end{aligned}$$

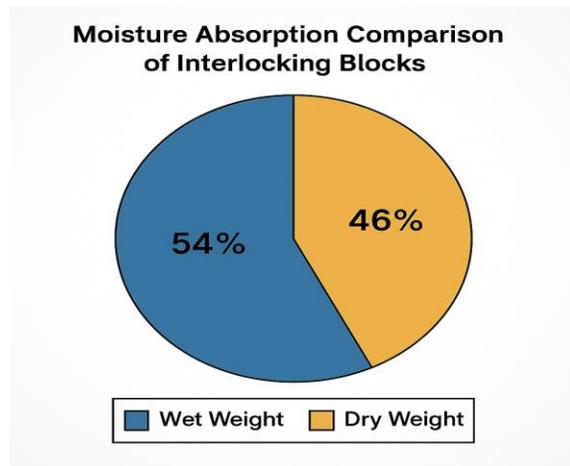


Fig 3: Moisture Absorption Comparison of Interlocking Blocks

The interlocking blocks exhibited a water absorption percentage of 5.49%, which is well within the permissible limit of 7%. This indicates that the blocks possess adequate impermeability and can resist moisture ingress. The presence of plastic helped in reducing the porosity of the matrix, which directly contributed to lower water absorption.

4.3 Overall Interpretation

The experimental results clearly demonstrate that the incorporation of waste plastic improves both strength and durability properties of interlocking blocks. Strength development is significantly enhanced at higher plastic content, particularly at 12% and 15%, where the blocks not only meet but surpass minimum structural requirements for non-load bearing applications. Simultaneously, water absorption values remained well within limits, validating the applicability of these blocks in practical construction scenarios.

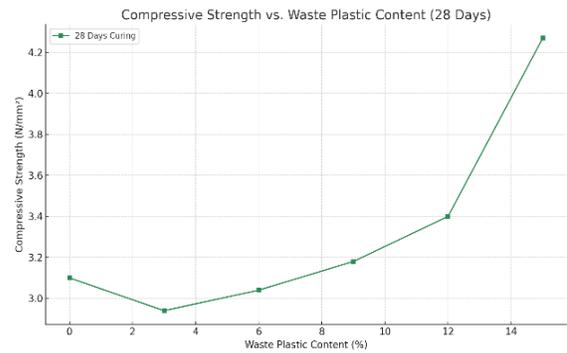


Fig 4: Summary Graph – Compressive Strength vs. Plastic Content 28 days

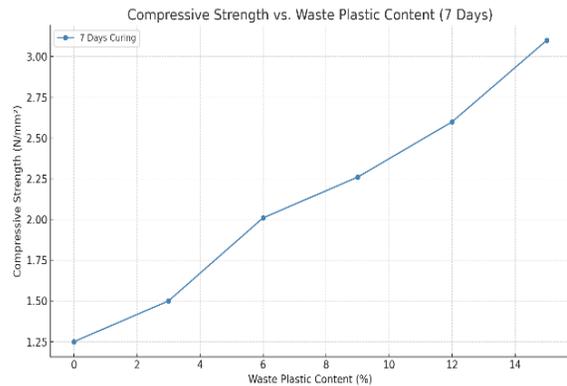


Fig 5: Summary Graph – Compressive Strength vs. Plastic Content 7days

Discussion

The compressive strength test results at both 7 and 28 days of curing demonstrate a noticeable enhancement in strength with the incremental addition of waste plastic as a partial replacement for fly ash. At 7 days, the strength increased from 1.25 N/mm² to 3.10 N/mm² as plastic content rose to 15%, showing a substantial improvement. By 28 days, the strength

further increased to 4.27 N/mm², indicating that longer curing durations contribute to better hydration and stronger internal bonding. The improved performance can be attributed to the plastic particles filling voids within the matrix, which enhances compactness and contributes to the material's load-bearing capacity, making it viable for use in structural or semi-structural masonry elements.

The water absorption test after 28 days showed a value of 5.5%, which is well within the standard permissible limits for masonry blocks. This relatively low absorption suggests a dense and well-bonded microstructure. The hydrophobic nature of plastic reduces pore connectivity and capillary action, leading to lower moisture uptake. These results suggest that integrating up to 15% plastic waste not only boosts mechanical properties but also contributes to enhanced durability. Therefore, plastic waste-modified foam concrete blocks can serve as an environmentally responsible and technically sound alternative in the production of interlocking units.

V. CONCLUSION

The experimental investigation demonstrated that incorporating waste plastic as a partial replacement for fly ash in lightweight interlocking blocks significantly improves their mechanical and durability characteristics. Compressive strength results indicated a progressive increase with higher plastic content, achieving a peak strength of 4.27 N/mm² at 15% plastic replacement after 28 days of curing. This suggests that waste plastic not only contributes to strength gain but also enhances internal bonding and material densification.

Furthermore, the water absorption value was measured at 5.5%, well within the permissible limits, confirming the blocks' suitability for construction applications in terms of moisture resistance and long-term durability. The successful use of thermoplastic waste in interlocking blocks not only addresses environmental concerns related to plastic disposal but also promotes sustainable material utilization in civil infrastructure. Based on the findings, it can be concluded that up to 15% plastic replacement offers an optimum balance between strength, absorption, and sustainability, making it a viable solution for eco-friendly building practices.

VI. FUTURE SCOPE

The study opens new avenues for sustainable construction by integrating waste plastic into interlocking block production. Future research can focus on long-term durability tests such as thermal resistance, freeze-thaw cycles, and chemical attack to validate performance under extreme environmental conditions. Additionally, exploring the use of mixed plastic types, higher plastic replacement percentages, or hybrid additives like fibers or geopolymer binders could further enhance the mechanical properties and environmental benefits of the blocks.

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