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Experimental Study of the Structural Behavior of Reinforced Concrete with Processed Demolition Waste

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Abstract: Before 2009, recycled construction materials in India were mostly thrown away in open areas, which caused harm to the environment. To solve this issue, the Indian government set up the country's first recycling plant for construction and demolition waste in Jahangirpuri, Delhi. These plants break down old building materials into smaller pieces that can be reused for things like footpaths and tiles. Studies have shown that adding just 1% fiber (by the weight of cement) to concrete made with recycled materials can give it strength similar to normal concrete made with new materials. It also improves how well the concrete holds up under tension and bending. Although this type of concrete costs about 5.91% more to make, it cracks less and lasts longer, making it a more durable and eco-friendly option.

Keywords: *Recycled Aggregates, Construction Waste, Fiber Reinforcement, Concrete Strength.*

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I. INTRODUCTION

The construction industry generates millions of tones of construction and demolition (C&D) waste each year. Much of this waste contains materials that are potentially reusable, but without proper handling, they become a burden on the environment and society [5]. Recycling C&D waste plays a crucial role in transforming what would otherwise be discarded into valuable resources, thereby promoting sustainable development [12].

The Environmental Protection Agency defines C&D waste as material generated during the construction, renovation, or demolition of buildings, roads, and other infrastructure, as well as debris resulting from natural disasters [5]. One of the key aspects in the production of concrete is the mix design, which involves selecting appropriate materials and determining their proportions to achieve the required strength, workability, and durability at the lowest possible cost.

Recycled aggregates are derived from processed construction and demolition debris and can serve as a substitute for natural aggregates in concrete mixes [12]. This paper investigates the use of recycled aggregates in combination with steel fibers and their effect on the mechanical performance of concrete. Specifically, it examines compressive strength, split tensile strength, and flexural strength, which are essential for assessing concrete's structural capabilities [11].

The study aims to assess whether this composite approach can deliver a more sustainable, durable, and cost-effective alternative to conventional concrete. Furthermore, it explores how steel fiber reinforcement influences workability, crack resistance, and overall performance of recycled aggregate concrete, helping to address common issues associated with recycled construction materials [3].

II. LITERATURE REVIEW

As concerns over environmental sustainability and resource depletion intensify, the construction industry is exploring alternatives to traditional concrete production. One such alternative is the use of recycled aggregates (RA), derived from construction and demolition (C&D) waste.

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While promising, the application of RA in concrete presents challenges that impact its mechanical performance.

- *Use of Recycled Aggregates in Concrete:*

Recycled aggregates are produced by processing C&D waste materials, including old concrete, masonry, and other construction debris. Studies indicate that concrete made with RA generally exhibits lower mechanical properties compared to that made with natural aggregates. This is primarily due to the presence of old mortar, impurities, and the porous nature of the recycled aggregates, which can lead to increased water absorption and reduced compressive strength [1][2]. However, research suggests that the properties of recycled aggregate concrete (RAC) can be enhanced by optimizing the mix design, employing appropriate processing techniques, or incorporating additives. For instance, pre-soaking recycled aggregates before mixing can mitigate the negative impact on compressive strength [3], and washing the aggregates helps reduce impurities, leading to improved strength characteristics [4].

- *Incorporation of Steel Fibers in Concrete:*

Steel fibers are widely recognized for their ability to enhance the mechanical properties of concrete. Their addition improves tensile strength, ductility, and resistance to cracking by acting as crack-bridging agents, absorbing stress, and enhancing the post-cracking behavior of concrete [5]. Steel fibers are particularly effective in improving the flexural strength and impact resistance of concrete [6]. Research has shown that the inclusion of steel fibers significantly improves the performance of concrete under tensile and flexural loads. Moreover, the addition of fibers increases the resistance of concrete to shrinkage and thermal cracking. However, the impact of steel fibers on concrete's compressive strength remains a subject of debate, as some studies indicate that the improvement is marginal or negligible compared to tensile and flexural strength [7].

- *Synergistic Effect of Recycled Aggregates and Steel Fibers:*

Several studies have explored the combined use of recycled aggregates and steel fibers in concrete. The introduction of fibers in RAC has been found to offset some of the inherent weaknesses of recycled aggregates. For example, the addition of steel fibers can improve the workability and durability of concrete made with recycled aggregates, enhancing the interfacial bond between the recycled aggregates and the cement matrix [8]. In a study by Idir et al., the mechanical properties of RAC with varying steel fiber contents were evaluated, and results showed a significant increase in flexural and tensile strength. The fibers bridged cracks and minimized shrinkage, improving the overall durability of the concrete [9]. Similarly, a recent study by Sabir et al. investigated the effects of fiber-reinforced RAC and concluded that the addition of fibers increased resistance to cracking, reduced shrinkage, and improved load-carrying capacity. While a slight reduction in compressive strength was observed with higher fiber content, the overall durability and post-cracking performance were significantly improved [10].

- *Economic and Environmental Considerations:*

In addition to the technical benefits, the combination of recycled aggregates and steel fibers offers economic and environmental advantages. The use of recycled aggregates reduces the need for natural aggregates, which are increasingly scarce and costly [11]. Moreover, recycling construction waste helps reduce landfill burden, contributing to environmental conservation. The incorporation of steel fibers, though adding some cost to the mix, can offer cost benefits in the long run. As steel fibers enhance durability and reduce maintenance costs, they can contribute to the longevity of structures, offsetting the initial higher material costs [12].

III. METHODOLOGY AND ANALYSIS

This section outlines the methodology followed for preparing the concrete mix, conducting tests, and determining the appropriate proportions of the materials involved. The concrete mix design is prepared using the Design Mix Method, which is based on a systematic approach to determine the ingredient proportions to achieve the desired concrete strength.

- *Concrete Mix Proportioning*

Grade of Concrete : M25

The target strength for the mix is determined using the following formula:

$$\mathbf{F_m = fck + 1.65 \times S}$$

Where:

F_m = Target mean compressive strength at 28 days

fck = Characteristic compressive strength at 28 days

S = Standard deviation (for M25, S=4)

For M25 grade concrete, the target mean compressive strength is calculated, where fck = 25MPa and S=4 resulting in the following target strength:

$$F_m = 25+1.65\times4=31.6\text{MPa}$$

- *Water-Cement Ratio Selection:*

Based on IS 456-2000, the maximum water-cement ratio for moderate exposure conditions is 0.50. Considering the use of 43-grade cement, we adopt a water-cement ratio of 0.45, which is less than 0.50 and therefore acceptable.

- *Water Content Selection:*

From Table 2 of IS 10262-2009, for a 25mm to 50mm slump range, the maximum water content is 186 liters. The estimated water content for the 25mm–50mm slump range is considered as 186 liters.

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- *Cement Content Calculation:*

Given the selected water-cement ratio of 0.45, the cement content is calculated as follows:

- *Cement Content*

0.45186=413kg/m3

According to **IS 456-2000**, the minimum cement content for moderate exposure conditions is 300 kg/m³. Since the calculated value is 413 kg/m³, it satisfies the requirement.

- *Proportion of Coarse Aggregate and Fine Aggregate:*

From Table 3 of IS 10262:2009, for a water-cement ratio of 0.50, the volume of coarse aggregate is 0.60, and the volume of fine aggregate (Zone I) is 0.40. For a water-cement ratio of 0.45, the volume of coarse aggregate is modified to 0.61, and the volume of fine aggregate is adjusted to 0.39.

Thus, the mix proportions for M25 grade concrete are as follows:

Cement: 413 kg

Fine Aggregate (FA): 520.38 kg

Coarse Aggregate (CA): 1331.4 kg

Water-Cement Ratio: 0.45

Mix Proportion: 1:1.26:3.17 (Cement: FA : CA), with a water-cement ratio of 0.45. 3.5 Testing of Materials

Various tests were performed to ensure the quality and suitability of materials used in the concrete mix. *Testing of Cement:*

- ✓ *Fineness Test:*

Cement was sieved on a 90-micron sieve to determine the proportion of cement particles larger than 90 microns.

- ✓ *Consistency Test:*

Conducted to determine the standard consistency of the cement paste.

- ✓ *Soundness Test:*

To check for any expansion or cracking in the cement after setting.

- ✓ *Initial Setting Time Test:*

To measure the time taken for the cement paste to start setting.

- ✓ *Specific Gravity Test:*

To measure the density of the cement.

- *Testing of Fine Aggregate (Sand):*

- ✓ *Sieve Analysis:*

To determine the grading of the fine aggregate.

- ✓ *Bulking Test:*

To measure the bulking of the sand under varying moisture conditions.

- ✓ *Specific Gravity Test:*

To determine the density of the fine aggregate.

- *Testing of Coarse Aggregate:*

Specific Gravity Test: To measure the density of the coarse aggregate.

- ➢ *Adjustment of Water-Cement Ratio with Recycled Aggregate:*

Recycled aggregates typically have a higher capacity to absorb water compared to natural aggregates, which can negatively impact both the water-cement ratio and the overall workability of the concrete mix. To address this challenge, the recycled aggregates are soaked in water prior to mixing. This pre-soaking process saturates the aggregates, ensuring that they do not draw excess water from the mix during preparation. As a result, the intended water-cement ratio is preserved, and the concrete maintains its desired workability and consistency [1].

- ➢ *Addition of Fibers:*

Polypropylene fibers are delicate and may bend or break if introduced too early in the mixing process. To preserve their integrity and ensure even distribution, these fibers are typically added after the coarse and fine aggregates have been mixed, but before the cement is incorporated. This method helps maintain the fibers' reinforcing properties throughout the mix [1].

- ➢ *Materials Used:*

The concrete mix was prepared using the following materials:

- Ordinary Portland Cement (OPC) of 43-grade quality [1]
- Fine aggregate consisting of river coarse sand [2]
- Fresh coarse aggregates with particle sizes of 10 mm and 20 mm [3]
- Recycled coarse aggregates, also sized 10 mm and 20 mm, sourced from construction and demolition waste [4]
- Steel fibers measuring 3.5 cm in length and 0.8 mm in diameter for reinforcement purposes [5]
- Monofilament polypropylene fibers used as secondary reinforcement [6]

- ➢ *Testing of Materials:*

Various tests were performed to ensure the quality and suitability of materials used in the concrete mix.

- ➢ *Testing of Cement:*

- *Fineness Test:*

The cement was passed through a 90-micron sieve to assess the percentage of particles exceeding this size, which indicates the fineness of the cement [1].

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- *Consistency Test:*

This test was performed to establish the standard consistency of the cement paste, defining the water content needed to achieve a certain flow or stiffness [2].

- *Soundness Test:*

Conducted to evaluate the cement's potential to undergo undesirable expansion or cracking after setting, ensuring stability in hardened concrete [3].

- *Initial Setting Time Test:*

This test measured the duration required for the cement paste to begin hardening after mixing with water [4].

- *Specific Gravity Test:*

Used to determine the density of the cement, which affects the mix design and concrete properties [5].

Fig 1 Soundness Test

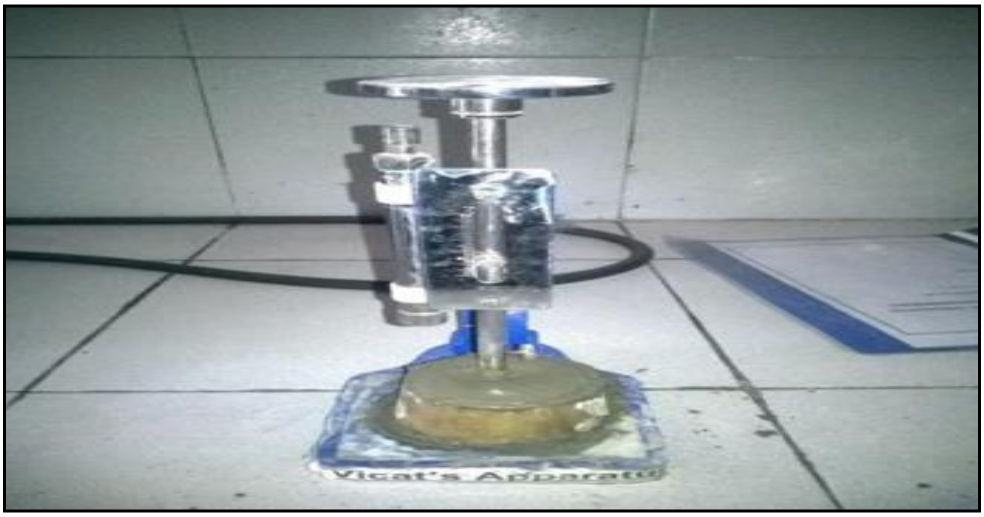

Fig 2 Consistency of Cement

➢ *Testing of Fine Aggregate (Sand):*

- *Sieve Analysis:*

Carried out to classify the particle size distribution of the sand, essential for understanding its grading and suitability for concrete production [6].

- *Bulking Test:*

Performed to quantify the increase in volume of sand due to moisture content, which influences mix proportions [7].

- *Specific Gravity Test:*

Conducted to find the density of the fine aggregate, an important parameter in mix design calculations [8].

➢ *Testing of Coarse Aggregate:*

- *Specific Gravity Test:*

To measure the density of the coarse aggregate.

➢ *Fineness Test of Cement*

The fineness of cement is measured by sieving it through a 90-micron sieve. The proportion of cement particles larger than 90 microns is determined. The following procedure is followed:

- Agitate the sample of cement by shaking it in a stoppered jar for 2 minutes to disperse agglomerates. Stir gently with a dry rod to distribute fines throughout the cement.

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- Attach a pan under the sieve to collect the cement passing through.
- Weigh approximately 10 grams of cement and place it on the sieve.
- Agitate the sieve until no more fine particles pass through.
- Weigh the residue and express its mass as a percentage of the initial amount placed on the sieve.
- This process is repeated twice to ensure accuracy.

IV. RESULTS AND DISCUSSION

The research demonstrated that substituting natural aggregates with recycled aggregates (RA) initially caused a reduction in compressive strength at 25% and 50% replacement levels, primarily due to the inferior strength characteristics of RA. Although steel fibers were incorporated into the mix, their amounts were insufficient to fully counteract this decline. However, at higher replacement levels of 75% and 100%, the compressive strength showed signs of improvement, with the full replacement mix achieving strength comparable to the conventional concrete. It was also observed that decreasing the fiber content led to a consistent drop in compressive strength.

In terms of flexural strength, improvements were recorded across all levels of RA replacement. This enhancement is attributed to the crack-bridging action of the fibers, which helped compensate for the increased micro-cracking induced by the recycled aggregates. Split tensile strength showed little variation when only RA was used but increased noticeably with the addition of fibers.

The best mechanical performance was achieved at 100% RA replacement combined with a total fiber content of 1% by weight of cement, consisting of 75% steel fibers and 25% polypropylene fibers, indicating a promising approach to improve the sustainability and durability of concrete mixes containing recycled aggregates.

Comparison of cost of concrete made from fresh aggregate and recycled aggregate with fiber:

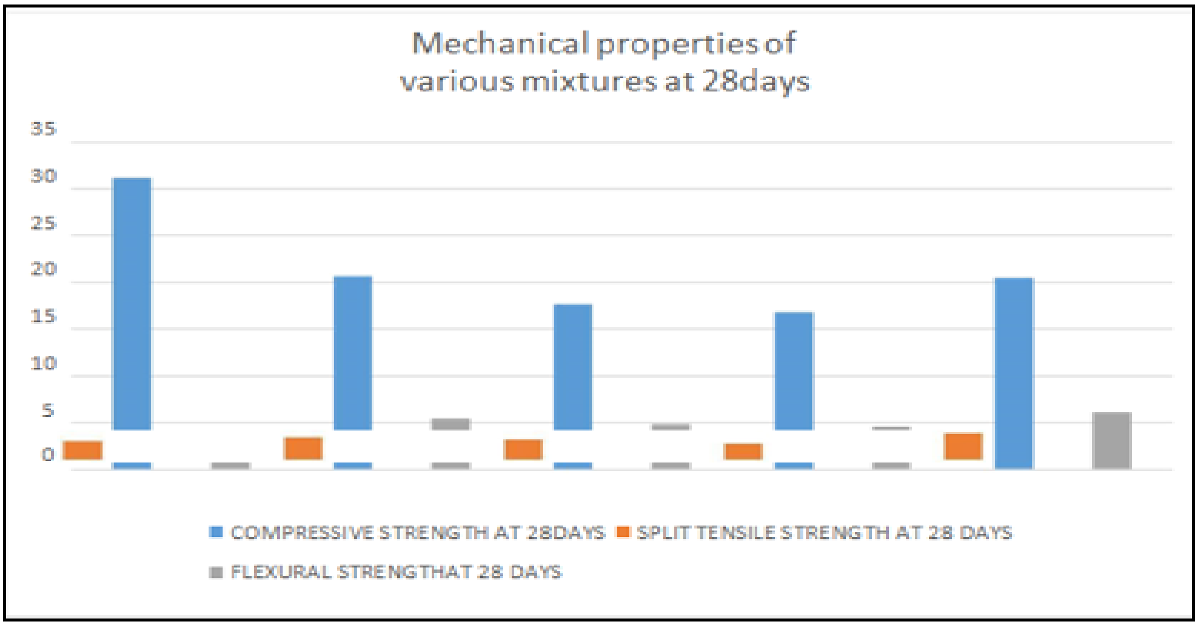

Fig 3 Mechanical Properties of Various Mixtures at 28 days.

Table 1 Cost of 1m³ Fresh Aggregate Concrete

S.no	Particulars	Quantity	Rate	Cost (Rs.)
1	Cement	413 KG	362.5 per 50 KG	2696.89
2	Fine aggregate	520.38KG	0.94 paisa per KG	489.16
3	Coarse aggregate	1331.4KG	0.94 paisa per KG	1230.46
Total cost			**4416.51**	

Table 2 Cost of 1m³ Recycled Aggregate Concrete with PPF and SF

S.no	Particulars	Quantity	Rate	Cost (RS.)
1	Cement	413 KG	362.5 per 50 KG	2696.89
2	Fine aggregate	520.38KG	0.94 Paisa perKG	489.16
3	Recycled coarse aggregate	1331.4KG	0.66 Paise per KG	863.94
4	PPF	1.04KG	336 RS.	349.44
5	SF	3.09KG	90 per kg	278.1
Total cost			**4677.53**	

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- Rate of 1m3 fresh aggregate concrete = Rs. 4416.51
- Rate of 1m3 concrete from recycled aggregate along with SF & PPF = Rs. 4677.53
- **Difference of Rate** = (Rs. 4677.53- Rs. 4416.51) = **Rs. 261.02**
- Percentage of Difference of Rate **= 5.91 %**

V. CONCLUSIONS

This research underscores the promising use of recycled waste glass as a partial substitute for fine aggregates in concrete production. Incorporating waste glass can enhance concrete's mechanical performance, including compressive strength and durability, while also advancing sustainability by lowering dependence on natural aggregate sources and reducing construction waste. Properly managing factors like particle size, replacement levels, and curing conditions is essential for maximizing the benefits of recycled glass in concrete. This method presents an effective strategy to address waste disposal issues in construction, supporting both environmental protection and improved material performance in sustainable building practices.

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