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SUSTAINABLE CONCRETE PRODUCTION: EXPLORING RECYCLED WASTE MATERIALS AND PERFORMANCE IN LABORATORY ENVIRONMENTS

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ABSTRACT

This study focuses on sustainable concrete production in the construction industry, addressing the significant waste generated through the lens of "The Construction and Demolition Waste Rules and Regulation, 2016" set by "The Bureau of Indian Standards." The study's threefold objectives are to support regulatory initiatives by exploring recycled materials in compliance with regulations, enhance waste processing efficiency for sustainability, and contribute to broader sustainable objectives emphasizing the 3Rs (reduce, reuse, recycle).

Keywords: *Sustainable concrete production, Construction waste, Recycled materials, Recycled coarse aggregate, Recycled glass powder, Marble dust.*

1. INTRODUCTION AND BACKGROUND

The management of construction and demolition waste (C&DW) is increasingly becoming a focal point for policymakers in India and across the globe.

According to a report [1] published by the Centre for Science and Environment (CSE), a nonprofit organization based in Delhi, India, as of August 25, 2020, the country recycles only 1% of its construction and demolition (C&D) waste. Despite an annual estimated generation of 150 million tons of C&D waste, the official recycling capacity is a mere 6,500 tons per day, which accounts for just approximately 1%. Globally, building waste production of 2 to 3 billion tons per year is estimated, of which 30-40 % is concrete [2].

Concrete, as a cornerstone of modern construction, has long been renowned for its durability and versatility. Yet, the conventional methods of concrete production are associated with substantial carbon emissions and a high demand for finite natural resources. To address these ecological and resource-driven concerns, the construction industry is under increasing pressure to adopt more sustainable practices. One promising avenue for achieving this goal is the integration of waste materials derived from construction demolition (C&DW), recycled glass, and marble dust into concrete production processes.

Various research endeavors have shown encouraging findings in substituting traditional concrete constituents with waste and recycled materials i.e., Recycled Coarse Aggregate (RCA) from Construction and Demolition Waste (C&DW), Waste Marble Powder/Dust (WMP/D), and Recycled Glass Powder (RGP). It demonstrates the potential of integrating these materials as partial or full replacements for conventional concrete production components such as cement, natural aggregate, and coarse aggregate.

Recycled fine aggregates improve RAC strengths without adverse effects, while recycled coarse aggregates decrease strengths. Initial separation is crucial for quality assurance. Demolition waste as fine aggregate enhances durability and mechanical properties, with a 20% replacement level proving effective. However, demolished aggregate concrete is up to 20% weaker than standard concrete, with an optimal replacement range of 25% to 50% for high-strength outcomes [3 – 6].

Recycled waste glass enhances concrete strength and sustainability. It can replace fine aggregates up to 100%, serving as a lightweight filler. Concrete with 30% Recycled Coarse Aggregates (RCA) and 10% Glass Powder (GP) demonstrates superior strength compared to standard concrete. Strategic replacement of cement or fine aggregate with glass powder improves compressive strength, with optimal levels around 10%. Utilizing Recycled Glass Powder (RGP) as a cement substitute up to 10% supports sustainability goals by reducing cement consumption. Quality control ensures stability and performance [7 – 10].

The integration of waste glass and marble in concrete increases density, water absorption, acid resistance, and dry shrinkage compared to standard concrete. Partially substituting cement with Waste Marble Dust (WMD) significantly reduces costs but results in decreased compressive and flexural strength [11 – 14].

The fresh properties of concrete, including workability, setting time, and consistency, are crucial during mixing and placement. Evaluating how the inclusion of waste materials impacts these properties is essential to prevent any hindrance in the practical use of concrete. Therefore, the successful incorporation of waste materials relies on a thorough understanding of their effects on both fresh and hardened concrete properties.

Despite numerous studies in this field, there remains a gap in research adopting a comprehensive approach that utilizes all three types of waste and recycled materials simultaneously. Therefore, this study aims to fill this gap by examining the influence of incorporating construction demolition waste, recycled glass, and marble dust in the production of environmentally sustainable concrete. With a focus on these alternative materials, the research delves into the intricacies of sustainable concrete production. Given the escalating environmental concerns and the imperative for resource conservation, this investigation seeks to uncover the potential benefits, challenges, and transformative impact of these unconventional components in the construction industry.

This study builds upon the groundwork laid by Dutt et al. [15], aiming to validate the suitability of conventional concrete materials as control benchmarks for this laboratory investigation.

2. METHOD

A systematic approach to evaluate the fresh and hardened properties of concrete made up of partial replacement of Ordinary Portland Cement (OPC) with Waste Marble Powder (WMP);

Sand (Fine Aggregate) with Recycled Glass Powder (RGP) and Coarse Aggregate with Concrete and Demolition Waste (C&DW) was employed, steps indicated below:

2.1 Literature Review

A comprehensive literature review was conducted to explore the feasibility of partially substituting waste and recycled materials (i.e., WMP, RGP, and C&DW) to support the production of environmentally friendly and cost-effective concrete**.**

2.2 Testing Properties in Study Scope

The fresh properties of concrete in its initial state were examined to evaluate its workability and durability through the slump cone test, while comprehensive strength was studied to assess the hardened properties.

2.3 Material Selection

The materials chosen for creating control concrete include Grade 43 Ordinary Portland Cement, coarse aggregates in sizes of both 10mm and 20mm and fine aggregate with particles larger than 4.75mm [15]. Test materials, namely Waste Management Powder (WMP) and Recycled Glass Powder (RGP), were obtained from a nearby supplier. Construction and Demolition Waste (C&DW) was directly sourced from a nearby demolition site. Water, readily available in the laboratory, was used as the primary source. Figure 1 depicts these testing materials.

Waste Marble Powder (WMP)/Marble Dust | Recycled Glass Powder (RGP) | Construction and Demolition Waste (C&DW)

Figure 1: Materials used for Test Concrete Mix (Author's Property)

2.4 Testing Equipment

The consistency of fresh concrete before setting was measured using the slump cone apparatus, while UTM was utilized to assess the comprehensive strength of specimens after setting for 3, 14, and 28 days. Figure 2 illustrates the equipment utilized for this study.

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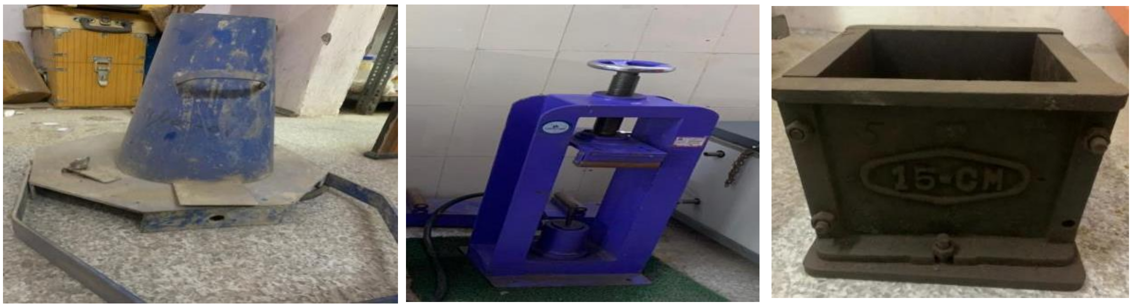

Slump Cone Apparatus | Universal Testing Machine (UTM) | Specimen Cube

Figure 2: Equipment used for assessing concrete mix properties (Author's Property)

2.5 Laboratory Setup

Balaji Scientific Laboratories (BSL), located in Faridabad, Haryana, was selected as the optimal venue for conducting tests on fresh and hardened concrete properties.

2.6 Preparation of Recycled Coarse Aggregate from Construction and Demolition Waste

The initial construction and demolition waste (C&DW) underwent crushing with a crusher to decrease its size, and the resulting crushed material underwent screening to obtain recycled coarse aggregate (RCA) with a size of 20mm.

2.7 Experimental Design and Testing Techniques

A comprehensive assessment of fresh and hardened concrete properties was conducted in December 2023. Testing methods were adjusted to conform with the procedures outlined in the IS Codes [16 - 17] as follows:

2.7.1 Concrete Mix Proportion

➢ **Design Stipulations:**
- Grade of Concrete: M-25
- Max. size of coarse aggregate (mm): 20
- Required workability (slump): 25 – 50
- Exposure Conditions: Moderate
- Q.C. Supervision: Good
- Minimum Cement Content in Kg [41]: 300
- Max. Water Cement Ratio [42]: 0.50

➢ **Concrete Mix Ratio (per m^3 of Concrete)**
- Total Volume: 1 m^3
- Volume of Cement: 0.117 m^3
- Volume of Water: 0.178 m^3
- Volume of all Aggregates: 0.705 m^3
- Ratio (Kg/m^3):

Water	Cement	Sand (Fine Aggregate)	Coarse Aggregate
178.0	370.0	730.0	1108.2

2.7.2 Specimen Strengths and Composition

To evaluate the sustainability of testing materials, two types of concrete specimens of Grade M25 were created: control (C) and test (T), each with varying strengths and compositions as outlined in Table 1. 09 sets were prepared for each specimen. In the testing specimens, a portion of the control materials was substituted by weight according to the percentages specified in Table 1 and replacements were made as below:

- OPC with WMP
- Sand with RGP
- Coarse Aggregate with RCA

Materials	Water-Cement Ratio	Control	Test				
		C 1	T 1	T 2	T 3	T 4	T 5
OPC		11.239	10.1151	11.239	11.239	11.239	11.239
Coarse Aggregate		33.66	33.661	33.661	25.245	23.562	21.879
Sand		22.183	22.183	17.746	22.183	22.183	22.183
WMP	0.48	-	1.124 (10%)	-	-	-	-
RGP		-	-	4.437 (20%)	-	-	-
RCA		-	-		8.415 (25%)	10.10 (30%)	11.78 (35%)
Total Concrete Mix Weight / Specimen Set		**67.082**					

Table 1: Substituted Weight Percentages in Specimens: Partial Replacement of Control Materials (Author's Property)

2.7.3 Mixing and Specimen Preparation

The preparation of mixing and concrete (M25) specimens followed the prescribed procedure outlined in the Indian standard [17]. The raw materials for the control specimen, including coarse and fine aggregates, and cement, were initially dry-mixed in a tilted drum-type mixer for approximately 30 seconds. Subsequently, two-thirds of the required water was introduced, and the mixing process continued for an additional two minutes. Following this, the remaining one-third of the water was added, and mixing persisted for an additional 3–4 minutes before assessing the fresh properties of the concrete mixes. A similar process was followed for preparing testing specimens. Specimens were then cast for compressive evaluation (150 mm cubes). After 24 hours, the samples were de-molded and underwent curing in a curing tank until the testing phase. Figure 3 illustrates the specimen mixing process, while Figure 4 showcases a sample of the de-molded cube.

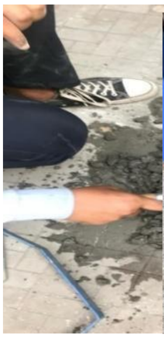

Figure 3: Specimen Mixing Process **Figure 4: Demolded Cube (Author's property)**

2.7.4 *Testing Techniques*

➢ **Slump Test for Freshen Properties:**

The test [18] was employed to measure the "slump" or deformation of a cone-shaped sample of concrete under its own weight. Figure 5 below depicts the slump cone test.

Figure 5: Slump Cone Test (Author's property)

➢ **Cube Test for Harden Properties:**

In the context of concrete, a compressive strength test was executed to measure compressive forces until failure occurs on cube-shaped specimens. 09 subsets were prepared for each specimen (i.e., control and tests).

A set of three subsets for each specimen experienced compressive axial force at a controlled rate, adhering to the recommended limits. The concrete failure occurred on Day 3 for one group, while the remaining six subsets underwent the same process and failed on Day 14 and Day 28. Figure 6 depicts a sample undergoing compressive strength testing using a Universal Testing Machine (UTM).

Figure 6: Compressive Strength Testing (Author's property)

2.8 Compliance Assessment

The obtained results were then compared with the specifications outlined in the Indian Standard Code to determine compliance.

2.9 Interpretation

The findings were analyzed to assess the viability of partially substituting conventional concrete production materials with waste and recycled materials, aiming to promote sustainable and environmentally friendly concrete production.

2.10 Reporting

A thorough report (#20231102006) was assembled, meticulously outlining the outcomes derived from the conducted experiments.

3 RESULTS:

3.1 Workability

Figure 7 illustrates the outcome of the slump test, done with slump cone equipment with dimensions of 150 mm height.

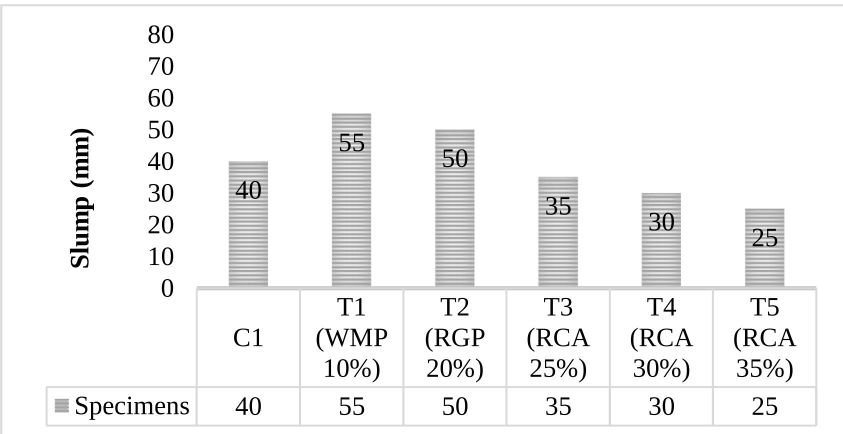

Figure 7: Slump Test Results of Control and Test Specimens (Author's property, C/O Balaji Scientific Laboratories (BSL))

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3.2 Compressive Strength

Target Strength, calculated as below:

$f'_{ck} = f_{ck} + 1.65\ s$[1]

f'_{ck}: target mean compressive strength at 28 days in N/mm^2; f_{ck}: characteristic compressive strength of concrete at 28 days in N/mm^2; s: value of standard deviation in N/mm^2; and 1.65 represents the tolerance factor.

$f'_{ck} = 25 + (1.65 \times 4) = \mathbf{31.6\ N/mm^2}$

Figure 8 illustrates the overall comparison for the resulting average compressive strengths, while Figure 9 depicts a comparison between the individual test specimen and the control specimen with a water/cement ratio of 0.48 on Day 3, Day 14, and Day 28, respectively.

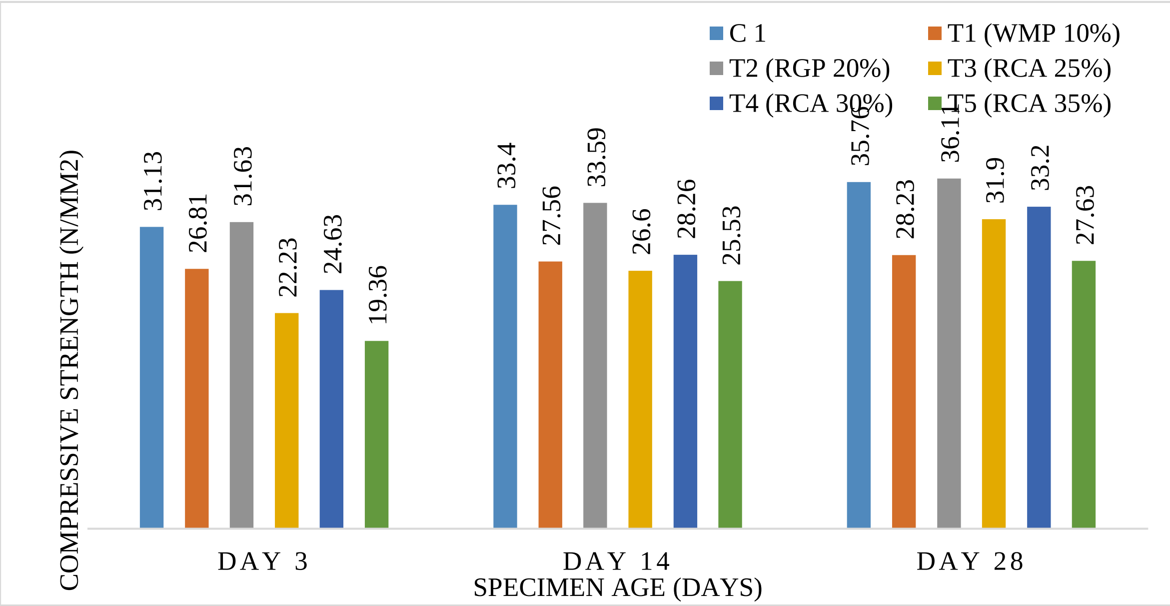
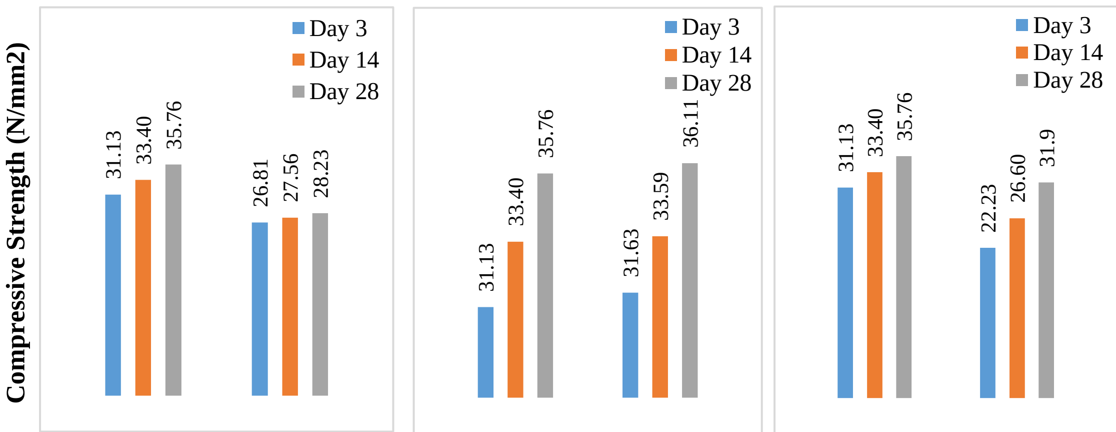


Figure 8: Average Compressive Strength Summary of Control and Test Specimens (Author's property, C/O Balaji Scientific Laboratories (BSL))



[a] Per IS 10262 (2009): Guidelines for concrete mix design proportioning, clause 3.2.1.2, A-3 and B-3 based on the grade of concrete i.e., M 10 and M 15 – 3.5; M 20 and M 25 – 4.0; and M30, M 35, M40, M 45, M 50 and M 55 – 5.0.

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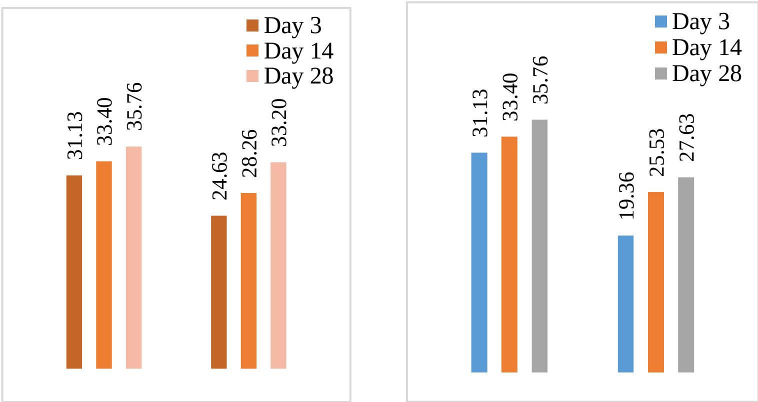

Figure 9: Average Compressive Strength of Control and Individual Test Specimens (Author's property, C/O Balaji Scientific Laboratories (BSL))

4 CONCLUSIONS

In this study, evidence is presented to support the use of recycled glass powder, waste marble powder, and recycled coarse aggregate as viable materials for the production of sustainable and environmentally friendly concrete.

➢ In laboratory tests, the initial workability level was assessed as low with a standard water-cement ratio of 0.48, thereby suggesting a requirement for adjustments in water content, the utilization of superplasticizers, or the incorporation of Viscosity-Modifying Admixtures.
- Upon substitution of OPC with 10% WMP in (T1) and Sand with 20% RGP in (T2), a notable enhancement in workability is observed. The improvement is approximately 37.5% in the case of T1 and 25% in the case of T2. Specifically, the workability increased from 40 (C1) to 55 (T1) and 50 (T2).
- T3, T4, and T5 demonstrate a comparable range of low workability, albeit lower than C1, T1, and T2.

➢ The hardened properties of concrete mix have shown comparable results in laboratory assessment, against the set targeted compressive strength of 31.6 N/mm².
- The test specimen (T1) with a 10% replacement of OPC with WMP demonstrates a compressive strength of 28.2 N/mm² on Day 28, closely approaching the targeted strength. This suggests a sustainable alternative for replacing OPC with WMP.
- The test specimen (T2), which involved a 20% replacement of sand with RGP, attained a higher compressive strength of 36.1 N/mm² on Day 28, surpassing the target. This once again underscores the feasibility of replacing sand with RGP.
- Test specimens T3, T4, and T5 exhibited compressive strengths of 31.9 N/mm², 33.2 N/mm², and 27.6 N/mm², respectively, on Day 28. This indicates that a 25% replacement of coarse aggregate with RCA demonstrates the capability to achieve the targeted compressive strength. However, an increase in the replacement percentage initially led to an increase, followed by a sharp decrease in compressive strength. Specifically, a 35% replacement resulted in a strength lower than anticipated, making it an unsuitable percentage for replacement. This supports the suitability of 25% and 30% as replacement options.

- OPC is more expensive due to the extra processing needed for OPC clinker production, but the financial impact can be alleviated by incorporating WMP, making it more economically viable.
- The manufacturing of OPC cement results in the emission of CO2, diminishing its environmental friendliness. Consequently, substituting a portion of OPC with WMP promotes the eco-friendliness of concrete production.
- C&DW in concrete production shall further promote sustainability by recycling and reusing waste materials as RCA, reducing the environmental impact associated with traditional disposal methods, and contributing to the efficient use of resources in the construction industry.
- Another viable practice of reusing glass waste reduces the environmental impact associated with glass disposal. Partial replacement for Sand with RGP, hence contributing to the overall sustainability of concrete production. This approach not only minimizes the demand for raw materials but also provides an eco-friendly solution for managing glass waste in the construction industry.

Therefore, the study illustrates the advantages of integrating waste materials such as waste marble dust, glass powder, and demolition waste for achieving sustainable concrete production.

5 DISCUSSIONS

- Using waste products presents a compelling opportunity to recycle and repurpose materials that would otherwise end up in landfills.
- By diverting these waste materials from disposal sites, we can simultaneously reduce the burden on landfill capacity and diminish the negative environmental impacts of waste accumulation.
- The waste-to-resource approach not only reduces the environmental footprint of the marble industry but also explores new avenues for optimizing concrete performance.
- A higher slump generally suggests higher workability, indicating that the concrete is more fluid and easier to place and compact.
- Compressive strength property is vital in determining the suitability of concrete for various construction applications, ensuring it can bear the weight and stress imposed on it in real-world scenarios.

6 FUTURE SCOPE AND RECOMMENDATIONS

- Conducting tests on fresh properties, such as the Compaction Factor Test, is crucial for evaluating the workability of freshly blended concrete to estimate the ease with which concrete can be compacted and consolidated, offering valuable insights into its uniformity and capability to effectively fill molds or formwork.
- Additional non-destructive tests (i.e., Rebound Hammer, Ultrasonic Pulse Velocity, etc.) to evaluate the hardened properties of concrete are pivotal for the long-term performance of concrete structures. Any degradation in these properties can have a substantial impact on the service life and maintenance requirements of concrete components.

Therefore, a thorough evaluation of these properties is imperative to ascertain the structural integrity and longevity of concrete structures constructed using these unconventional materials.

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ABBREVIATIONS

- OPC: Ordinary Portland Cement
- WMP: Waste Marble Powder
- RGP: Recycled Glass Powder
- C&DW: Construction and Demolition Waste
- RCA: Recycled Coarse Aggregate