Stallion Journal for Multidisciplinary Associated Research Studies
ISSN (Online): 2583-3340
Volume-5 Issue-2 || April 2026 || PP. 58-64 https://doi.org/10.55544/sjmars.5.2.8

Compressive Strength Improvement of Concrete Incorporating Recycled Marble Aggregates: Case Study of Herat City

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www.sjmars.com || Vol. 5 No. 2 (2026): April Issue

Date of Submission: 13-04-2026	**Date of Acceptance:** 16-04-2026	**Date of Publication:** 28-04-2026

ABSTRACT

The research analyzes the mechanical performance of concrete by integrating recycled marble aggregates from Herat City, Afghanistan, into concrete components while focusing on the enhancement of compressive strength of concrete. Specific standard laboratory tests are applied to the normal and marble aggregates, including Aggregate Impact Value (AIV), bulk density, specific gravity (SG), water absorption, and fine modulus, which are conducted in accordance with the ACI code to evaluate their physical properties. Nine different concrete mix designs are designed with different combinations of marble as fine and coarse aggregates, along with normal aggregates, to evaluate their compressive strength. The compressive strength of samples is tested at 7, 14, and 28 standard days. The results show that while marble concrete cylinders generally show lower performance than normal samples, the combination sample in which marble is used as coarse aggregate and normal aggregate is used as fine aggregate can significantly enhance the compressive strength of concrete. Overall, the findings indicate that coarse marble aggregate can be used for sustainable construction while maintaining acceptable structural performance.

Keywords- Concrete, Marble, Mix-design, Compressive Strength, Aggregate, Material, Cement.

I. INTRODUCTION

Over time, material science has been a significant branch of engineering. Innovation is the basis of this field. With the advent of new technology, scientists and researchers try to discover new things to make a revolution in the construction industry. Concrete is one of the most import material that human discovered yet. This material is used widely in contemporary structures throughout the world. With abundant sources like normal aggregate and cement and easy flexibility in shape, it becomes one of the useful materials in construction.

Enhancing the workability of the concrete for different purposes is the most considerable thing in construction engineering. The compressive strength of concrete is the key factor in concrete mix-design and concrete usage. In this research, we aim to enhance the concrete compressive strength by changing its components. Marble, as a new component, is used in different mix designs to check its effects on the concrete compressive strength. Currently, marble is extensively utilized in construction, resulting in a rise in the trash generated from it [1].

The processing of marble for different applications generates approximately 30% of waste due to its irregular shape (Aliabdo et al., 2014). It is a type of solid waste material that can be utilized in the preparation of concrete as a filler material, fine aggregates, or cement. Studies in Engineering and Exact Sciences, Curitiba, application of marble waste as a resource will not only reduce the environmental impacts of disposing of marble waste but also conserve natural resources, thereby paving the way for recycling [2].

Nowadays, concrete is used as an engineering material in almost all construction categories, including residential and high-rise buildings, and other infrastructure. The main components of concrete are cement, water, and aggregates, accounting for approximately 70–80 % of the total concrete volume. Approximately 12.6 billion t of concrete are used worldwide, consuming 1.6 billion t of cement, 10 billion t of aggregates, and 1 billion t of mixing water [4]. Binici et al. [3] research shows 100% of the natural coarse aggregates in concrete were replaced by waste marble while keeping the water-to-cement ratio steady at 0.4 by weight. It was noted that the smooth surface texture and reduced absorption of water of the marble waste made the concrete mixes containing it more workable than the control mixes. Marble waste aggregates were used in place of traditional coarse aggregates in research by Hebhoub et al [5].

Recycled marble from Herat can be used to produce structural concrete with equal or higher compressive strength than conventional mixes if replacement levels are optimized. As guidance, 10–40% fine marble (as sand), 25–70% coarse marble (as gravel), or 5–15% marble fines/fillers in RAC are the most promising ranges. Local testing with Herat marble and aggregates is still essential to fix exact percentages and ensure durability under Herat's environmental conditions.

II. METHODOLOGY

Improving engineering performance and addressing environmental challenges associated with construction materials is the main focus of this study. From this perspective, this research is focused on conducting a comprehensive evaluation of the properties of concrete produced by incorporating recycled marble aggregates as a partial replacement for natural coarse aggregates.

The study investigates the influence of varying replacement levels of natural aggregates with marble aggregates on the compressive strength and overall performance of concrete. In addition, the work examines how the inclusion of marble waste affects key engineering properties such as workability, density, and structural integrity. Through controlled mix design and laboratory testing, the research aims to determine the optimal proportion at which marble aggregates can be effectively utilized without compromising the strength requirements of concrete.

2.1. Experimental methodology

This research is primarily experimental, and concrete mixes will be designed with:

- Normal aggregate
- Marble
- Combined marble and normal aggregates

Tests will include:

- Compressive strength
- AIV (Aggregate Impact Value)
- Water absorption
- Bulk Density
- Specific Gravity
- Fine Modulus

Samples will be tested at:

- 7 days
- 14 days
- 28 days

Different strength classes (30 MPa) will be evaluated.

2.1.1. Concrete Specimen Preparation and Dimensions

Concrete specimens used for the compressive strength test were prepared in the form of cylindrical molds in accordance with the requirements of ASTM International. Each cylinder had a diameter of 150 mm and a height of 300 mm, maintaining a standard height-to-diameter ratio of 2:1 to ensure uniform stress distribution during testing.

The molds were properly cleaned and oiled before casting to prevent adhesion of concrete to the mold surface. Fresh concrete was placed in the molds in three equal layers, and each layer was compacted using a standard tamping rod to eliminate air voids and achieve proper compaction.

After casting, the specimens were covered to prevent moisture loss and were kept at room temperature for 24 hours. Subsequently, the cylinders were demolded and cured in water under controlled laboratory conditions until the time of testing.

For each concrete mix (gravel, marble, and combined aggregate), a minimum of three specimens were prepared and tested at curing ages of 7, 14, and 28 days to evaluate the development of compressive strength over time.

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III. RESULTS AND DISCUSSION

During the design stage, certain tests are conducted on normal and marble aggregates to improve the accuracy of each mix-design sample. These tests are performed in accordance with the ACI [6] code norms. These tests are standard tests required for concrete mix design and include: AIV (Aggregate Impact Value), Bulk Density, Specific Gravity, Water Absorption, and Water Content. To understand and compare the results of each test on the normal and marble samples, some graphs and figures are provided in each section.

3.1. AIV Test Result

Aggregate Impact Value (AIV) is normally done to evaluate the toughness and resistance of aggregates to sudden impact or shock. AIV provides a relative measure of an aggregate's toughness and resistance to impact, distinct from its resistance to slow-compression loads (ACV) [7]. The test aims to measure how resistant the aggregate is under load impact. This is significant for road, pavement, and concrete structures for the selection of stronger aggregates. A lower AIV value indicates a stronger aggregate; in contrast, a higher AIV value indicates a weaker aggregate. Concrete strength depends heavily on aggregate quality. This factor impacts concrete durability and compressive strength of concrete. Figure 1 shows the AIV results on the marble and the normal aggregate.

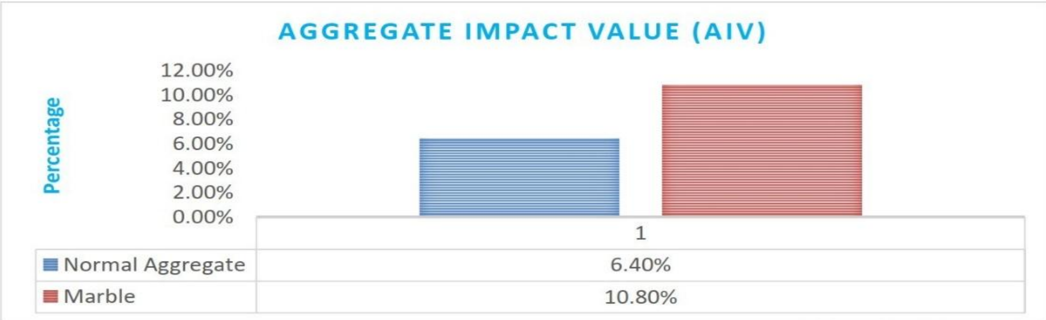

Figure 1: Comparative AIV results of normal aggregates and marble aggregates

The Aggregate Impact Value is calculated using:

$$\mathbf{AIV\ (\%) = (W2/W1) \times 100}$$

Where:
W1 = Original weight of oven-dried aggregate sample
W2 = Weight of fines passing 2.36 mm sieve after impact

According to Figure 1, the AIV result of the normal aggregate is 6.40%, and marble is 10.80% this shows that the marble strength is weaker than normal aggregate. Since marble is softer than normal aggregate, this result is logical.

3.2. Bulk Density Test Result

Bulk density is used to determine the weight of aggregate to fill a given volume. Since the mix design is based on ACI, this value is significant for calculating the quantity of aggregates per cubic meter. This affects the workability, cement requirements, and the strength and durability. Higher bulk density means fewer voids and requires less cement paste. On the other hand, lower bulk density indicates more voids and needs more cement paste. The formula below is used to calculate this value:

$$\mathbf{Bulk\ Density = V/\ W}$$

Where:
W = Weight of aggregates (kg)
V = Volume of container (m^3 or L)

Figure 2: Comparative bulk density results of normal aggregates and marble aggregates

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The bulk density of the normal aggregate is 2.186% higher than that of the marble sample, which is a slight difference.

3.3 Specific Gravity (SG)

Specific Gravity is the ratio of the density (or unit weight) of the aggregate to the density of water at a specified temperature. This test is crucial for concrete mix design for all samples. The SG is used to convert the weight to volume. The formula below is used to determine the specific gravity of the samples.

$$\textbf{Specific Gravity (SG)} = W_{SSD} - W_{submerged} / W_{dry}$$

Where:
W_{dry} = Oven-dry weight of aggregate
W_{SSD} = Saturated Surface Dry weight
$W_{submerged}$ = Weight of aggregate in water

Figure 3 shows the comparative specific gravity of coarse and fine aggregates of normal and marble, along with the Portland Cement.

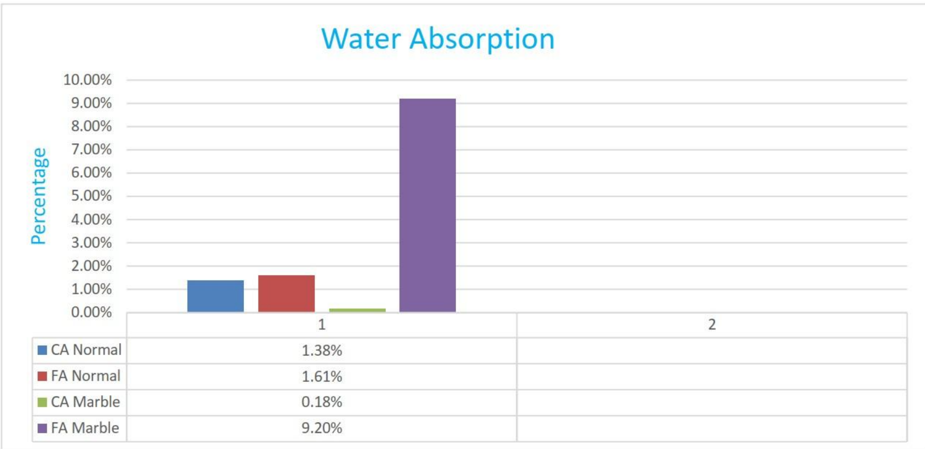

Figure 3: Comparative specific gravity SG results of normal and marble aggregates and Portland Cement

According to Figure 3, Portland Cement has the highest SG, 3.12. The normal coarse aggregate has an SG of 2.76, and the marble coarse aggregate has an SG of 2.56. The marble fine aggregate has the lowest SG, 2.12.

3.4 Water Absorption (WA) Test Results

Water absorption is another physical key property for designing concrete mixes. This shows how much water can be absorbed by aggregate during the concrete mixture in the laboratory. This characteristic is the most significant thing for determining the water-cement ratio. The concrete compressive strength depends on the water-cement ratio. Because the wrong ratio can reduce the compressive strength of concrete. Higher water absorption requires much more water than cement. Figure 4 indicates the water absorption of coarse and fine natural and marble aggregates.

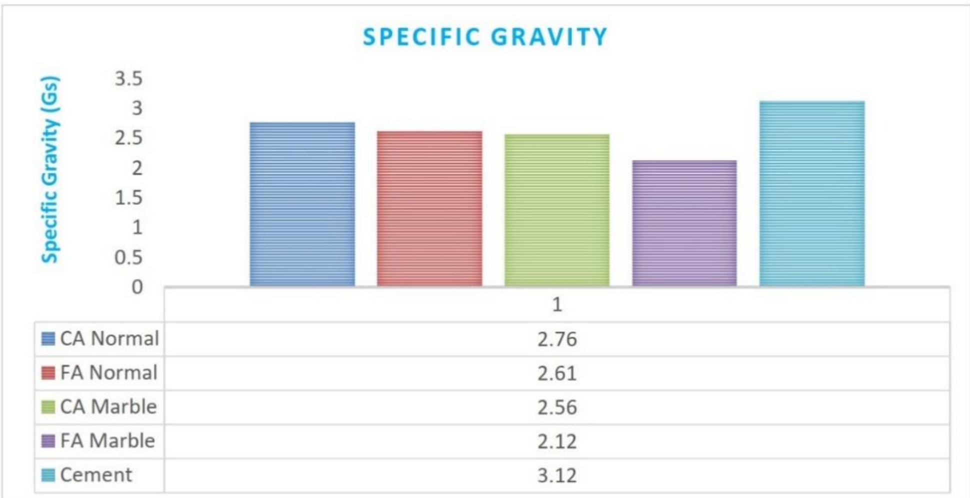

Figure 4: Comparative water absorption results of normal aggregates and marble aggregates

According to Figure 4, the marble fine aggregate with 9.20% water absorption has a high water absorption. The marble coarse aggregate has the lowest 0.18% WA, which is almost negligible and a good characteristic for concrete design. In contrast, fine marble aggregate consumes much water during the concrete mixture. The fine marble aggregate becomes a paste state after absorbing water, as shown in Figure 5.

Figure 5: Marble exhibits a plastic (paste-like) consistency after water absorption

3.5 Compressive Strength of the Samples

The samples are tested under the automatic concrete compressive machine in the range of 7, 14, and 28 days. Figure 6 indicates the compressive strength results of all samples over the time range.

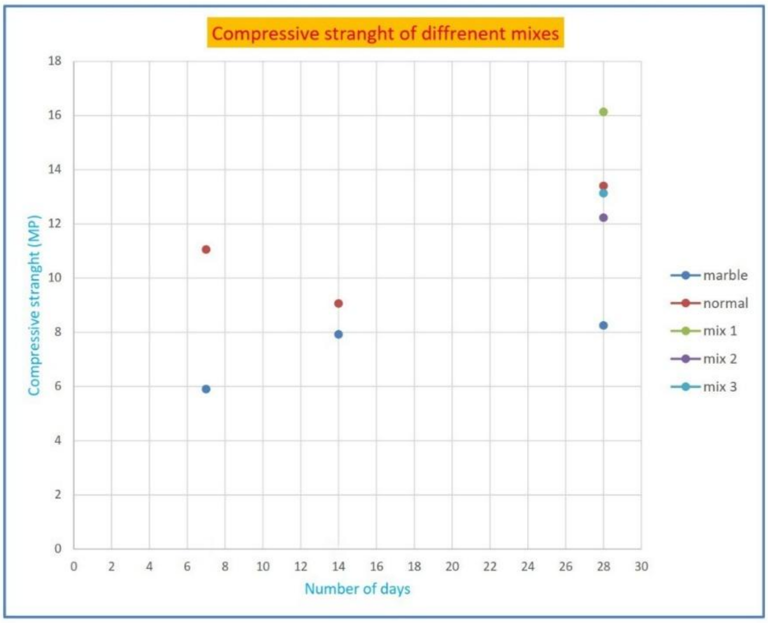

Figure 6: Comparison chart of compressive strength of concrete mixes over time

Table 1: Compressive strength of concrete mixes over time, along with average weight

Samples		Days		Average Weight (Kg)
	7	14	28	
Normal Mix Compressive Strength (MPa)	9.06	11.05	13.4	14.1
Marble Mix Compressive Strength (MPa)	5.9	7.92	8.25	13.68
Mix Type 1 Compressive Strength (MPa)			16.13	14.15
Mix Type 2 Compressive Strength (MPa)			12.23	13
Mix Type 3 Compressive Strength (MPa)			13.13	13.9

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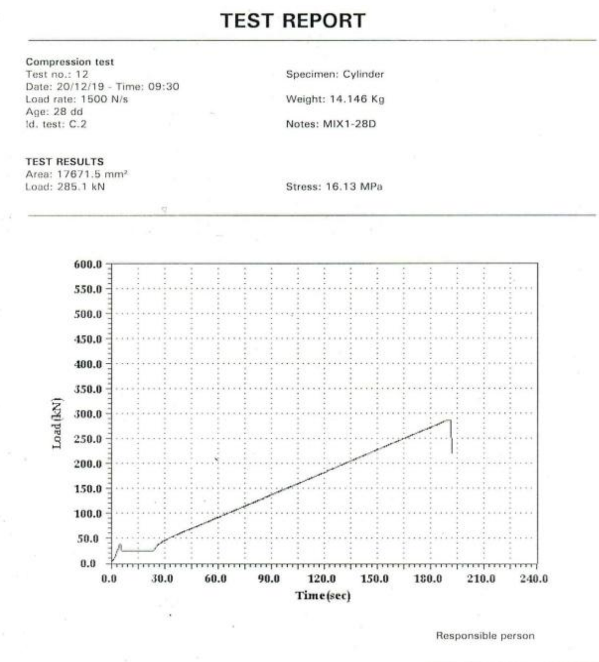
According to Figure 6 and Table 1, Mix Type 2 has the lightest weight among the other mixes (13 Kg). Marble mix has a lighter weight, since marble has a lower bulk density than common aggregates. This means that using marble aggregate in concrete design reduces the concrete weight. The compressive strength of the marble mix over 7, 14, and 28 days is lower than 10 MPa due to the marble fine aggregate. Fine marble reduces the cement viscosity in the concrete mix. Marble mostly contains $CaCO_3$ (calcium carbonate) that does not react with cement hydration products. Figure 7 shows the marble standard concrete cylinder (D = 15 cm, H = 30 cm) under the compressive machine.

Figure 7: Marble concrete cylinders under compressive machine

Mix Type 1, normal aggregate is used as fine aggregate and marble as coarse aggregate, has the highest compressive strength (16.13 MPa). This shows, integration of marble coarse aggregate in the concrete mix improves concrete compressive strength remarkably.



TEST REPORT

Compression test
Test no.: 12
Date: 20/12/19 - Time: 09:30
Load rate: 1500 N/s
Age: 28 dd
Id. test: C.2

Specimen: Cylinder
Weight: 14.146 Kg
Notes: MIX1-28D

TEST RESULTS
Area: 17671.5 mm²
Load: 285.1 kN

Stress: 16.13 MPa

Responsible person

Figure 8: The test report of Mix Type 1 (28 days)

IV. CONCLUSION

To sum up, marble is one of the abundant sources of natural materials in Herat City, which is widely used in the construction industry. The waste coarse marble aggregate can be used in a concrete mix since it can enhance the concrete compressive strength remarkably. In contrast, the fine marble aggregate decreases the concrete performance due to the high water absorption and contains CaCO3, which reduces the cement viscosity. Marble has a lighter weight than normal concrete aggregate, which can control structural weight. The result of applied tests on the marble and normal aggregates shows the physical performance of each, and their advantages and disadvantages. Overall, marble coarse aggregate can be an acceptable component in concrete mix design.

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