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Effect of Mechanical Properties by Replacing Coarse Aggregate with Pebble Aggregates on M30 Grade of Concrete

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Abstract: This experimental study explores the feasibility of partially replacing conventional coarse aggregate with naturally available pebble stone in M30 grade concrete. The replacement was carried out at varying proportions of 0%, 10%, 20%, 30%, 40%, and 50% by weight. The objective was to evaluate the effect of this replacement on the mechanical properties of concrete, specifically key strength parameters such as compressive strength, split tensile strength, and flexural strength were evaluated to determine the performance of the modified concrete mix. Standard mix design procedures were followed for M30 grade concrete, and specimens were tested under controlled laboratory conditions. The results indicated that partial replacement with pebble stone up to certain levels does not significantly compromise the concrete's strength. At lower replacement levels, some strength parameters, including flexural strength, showed slight improvements, while higher replacement levels led to a gradual reduction in performance, helping to identify an optimal range for replacement. In addition to mechanical performance, the study emphasizes the environmental benefits of using pebble stone. As a naturally occurring and locally available material, it requires minimal processing compared to traditional crushed stone, resulting in reduced energy consumption and lower carbon emissions. This supports the development of more sustainable and eco-friendly construction practices. In conclusion, the study confirms that pebble stone can serve as a viable, environmentally friendly alternative for partial coarse aggregate replacement in concrete, aligning durability and strength with sustainability objectives.

Keywords: M30 Grade, Pebble stone, Compressive strength, Split tensile strength, Flexural strength, Eco-friendly concrete.

I. INTRODUCTION

As global infrastructure continues to expand, concrete is one of the most essential materials in modern construction, Concrete is the most widely used construction material globally, prized for its versatility, strength, and durability. As a composite material, it consists primarily of cement, water, fine aggregate, and coarse aggregate. Among these, coarse aggregate constitutes 60–75% of the concrete volume, making its selection and quality crucial to the performance of the final product. Traditionally, crushed granite has served as the conventional coarse aggregate in concrete, especially in countries like India where it is readily available. However, the surge in construction activities worldwide has led to the rapid depletion of this resource, increased transportation costs, and environmental issues related to quarrying and crushing operations. This situation has intensified the search for sustainable alternatives that are both locally available and environmentally benign. One such promising alternative is natural pebble stone. Pebbles are rock fragments typically ranging in size from 10 mm to 150 mm, characterized by their smooth, rounded, or elliptical shapes. These stones are naturally formed through the continuous action of flowing water, which transports and erodes larger rocks from mountainous regions into smaller, rounded fragments over time. Found along riverbanks and lake shores, pebbles exhibit various colors and textures, often with mineral veins such as quartz running through them. Their smooth surfaces and natural formation process make them an underutilized yet abundant resource in many regions. Despite their availability, pebble stones have rarely been used in concrete production—primarily due to the lack of performance data, standardization, and concerns about their bonding efficiency compared to angular crushed aggregates. Pebbles differ from crushed stone in terms of shape, surface texture, and mineral composition. These differences can influence key concrete characteristics such as workability, compaction, interfacial transition zone (ITZ) behavior, and ultimately the mechanical properties of the hardened concrete. The rounded nature of pebbles, for instance, may affect the aggregate–paste bond, potentially reducing compressive and tensile strength. On the other hand, their uniform shape and low water absorption may enhance workability and compaction. In light of these considerations, this experimental study investigates the feasibility of using naturally available pebble stones as a partial replacement for conventional coarse aggregates in M30 grade concrete. The replacement was carried out at incremental proportions of 0%, 10%, 20%, 30%, 40%, and 50% by weight. The aim is to assess the influence of pebble aggregates on critical mechanical properties of concrete, including compressive strength, split tensile strength, and flexural strength, using standard mix design and laboratory testing procedures. Preliminary observations indicate that replacing coarse aggregate with pebble stone up to a certain threshold does not significantly

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compromise concrete strength. In fact, minor improvements in flexural strength were observed at lower replacement levels, suggesting that pebble stone could contribute positively under the right mix conditions. Beyond strength performance, the study also highlights the environmental benefits of using pebble stone, as it requires minimal processing, thus reducing energy consumption and carbon emissions associated with conventional aggregate production. This investigation supports the potential of pebble stone as a viable, sustainable alternative in concrete production—contributing to more environmentally responsible construction without significantly sacrificing mechanical performance.

1.1 Importance of the study

In the production of conventional crushed aggregates, significant amounts of dust are generated during the mechanical crushing process. If not properly managed, this fugitive dust can contribute to air pollution and pose environmental and health concerns. In contrast, the use of naturally available uncrushed aggregates such as river pebbles eliminates this issue, as they do not require energy-intensive crushing and produce minimal dust during handling. Additionally, pebbles undergo a natural weathering and size reduction process as they travel along riverbeds. This natural erosion smooths the aggregates without introducing micro-cracks or weak fragments, thereby preserving their structural integrity. In comparison, crushed aggregates often contain micro-cracks or loosely attached fragments caused by the mechanical crushing process, which can compromise the overall strength and durability of the concrete. Furthermore, the angular shape of crushed aggregates increases internal friction within the mix, leading to higher water demand to achieve desired workability. As a result, more cement is needed to maintain the water–cement ratio, which can reduce the long-term durability of the concrete due to an increase in paste content and potential for shrinkage and cracking. River pebbles, on the other hand, possess naturally rounded surfaces that enhance workability, reducing the need for excess water and cement. This leads to denser, less permeable, and more durable concrete, making pebble aggregates a promising sustainable alternative in modern construction practices.

1.2 Objectives

1. To determine fresh and hardened properties of concrete made with pebbles and to compare with those using crushed stone aggregate (traditional).
2. To ascertain whether pebbles can be a good aggregate for concrete.

II. MATERIAL AND THEIR PHYSICAL PROPERTIES

The properties of materials used in concrete play a critical role in determining its strength and overall performance. Therefore, fundamental tests were conducted to evaluate the characteristics of each material prior to mix preparation. The primary materials used in this study include:

- ❖ Ordinary Portland Cement (OPC) – 43 Grade
- ❖ Water
- ❖ Aggregate
  - ➢ Fine Aggregate
  - ➢ Coarse Aggregate
  - ➢ Pebbles

Each of these components was tested to ensure suitability and consistency for use in the concrete mix.

Table:-1 Physical properties of OPC 53 grade cement.

Properties	***Results***
28 days Compressive strength	53 N/mm^2
Initial setting time	40 Min
Final setting time	240 Min
Fineness	2890 m^3/Kg
Soundness	2.7

2.1 Cement

Cement is a crucial component of concrete, playing a vital role in setting, hardening, and binding other materials together in construction. The most commonly used type of cement is Portland cement. In this study, 53-grade Ordinary Portland Cement is used as the binder, and it has been tested in accordance with IS 4031-1988 [24], meeting the various standards outlined in IS 12269-1987.

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2.2 Water

Water is essential for the hydration of the cement paste, which contributes to the majority of the concrete's strength. Only water free from salts, acids, alkalis, and other harmful substances is used. When the precise amount of water is added to the mix, it helps achieve higher strength in the concrete.

2.3 Aggregate

Aggregates are serving as reinforcement that provides strength to the overall composite material. They include various types such as gravel, crushed stone, sand, slag, recycled aggregates, and synthetic aggregates. For a concrete mix to be effective, it is essential that the aggregates are free of dust, clay coatings, chemicals, and other impurities that can negatively impact the concrete's performance. The quality of aggregates directly influences the workability, strength, durability, and cost-effectiveness of the concrete. Well-selected, clean aggregates help ensure that the final concrete mix maintains its structural integrity and performs efficiently over time.

Table: - 3 Properties of sand of zone –II.

Properties	Results
Specific gravity (G)	2.67
Bulking	34.30%
Water absorption (WA)	1.20%
Density (q)	1610 Kg/m^3

2.3.1 Fine Aggregate (FA)

Fine aggregate is defined as material that passes through a sieve with a particle size of 150 µm and a thickness of 2.36 mm. It serves as a filler material to occupy voids between coarser particles, contributing to the workability of the concrete. According to IS 383-1970 (29), the sand used is classified under Zone II. Additionally, experiments were conducted in accordance with IS 2386-1963 (28).

Table: - 4 Properties of coarse aggregate.

Properties	Results
Specific gravity (G)	2.74
Aggregate crushing value	29.32%
Water absorption (WA)	0.8%
Density (q)	1780 Kg/m^3

2.3.2 Coarse Aggregate (CA)

The coarse aggregate component of concrete is the most durable and least permeable. It is enhancing the durability and strength of concrete. The use of angular, machine-crushed aggregates with a 10 mm size helps in preventing issues like drying shrinkage and dimensional changes. These aggregates impact the workability, strength, and water requirements of the mix. Tests, as per IS 2386–1963 Part 3, were conducted to assess their properties, confirming their suitability for the intended concrete applications.

Table: - 5 Properties of River Pebble Aggregate

Properties	Results
Specific gravity (G)	2.32
Fineness modulus	4.92
Water absorption (WA)	0.90%
Density (q)	1430 Kg/m^3
Crushing Value	23%

2.3.3 Pebble Stone

Pebble stones are small, naturally rounded rocks commonly found near rivers, lakes, and coastal areas. Their size, shape, and color vary based on the geological characteristics of the region in which they are formed. Due to their smooth texture and aesthetic appeal, pebble stones are widely used for decorative purposes in landscaping, garden pathways, and driveways. They are also popular in arts and crafts, as well as in aquariums and terrariums. Their natural look and pleasant feel make them a favored choice for enhancing both indoor and outdoor environments.

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III. RESULT ANALYSIS

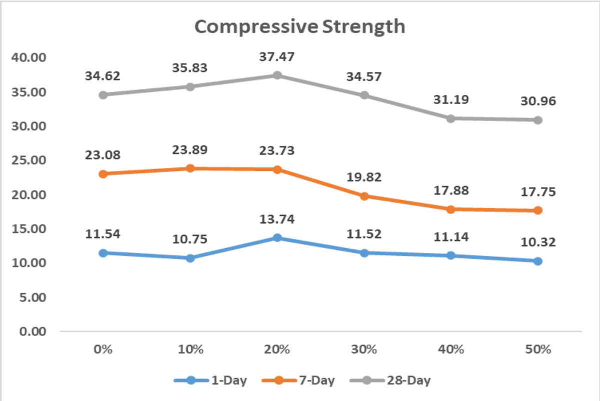

Fig - 1 Compressive strength of M30 grade of concrete

The compressive strength development of concrete with varying percentages of additive replacement was assessed at 1, 7, and 28 days to understand its influence on early and long-term performance. Based on the updated compressive strength data for various concrete mix proportions tested at 1, 7, and 28 days, the influence of additive replacement on strength development can be clearly observed. The control mix (0% replacement) achieved compressive strengths of 11.54 N/mm² at 1 day, 23.08 N/mm² at 7 days, and 34.62 N/mm² at 28 days, providing a reference point for performance evaluation. With a 10% replacement, the concrete exhibited a slightly lower 1-day strength of 11.23 N/mm², but surpassed the control at later ages, reaching 23.89 N/mm² at 7 days and 35.83 N/mm² at 28 days. This suggests improved long-term performance with minimal compromise in early strength. The 20% replacement mix delivered the highest 1-day strength of 13.74 N/mm², indicating accelerated early-age hydration. Although its 7-day strength (23.73 N/mm²) was slightly below the 10% mix, it recorded the highest 28-day strength at 37.47 N/mm², confirming 20% as the optimum replacement level for maximizing compressive strength. However, increasing the replacement level beyond 20% led to a decline in strength. The 30% mix had slightly lower values across all stages, with 11.52 N/mm² at 1 day, 19.82 N/mm² at 7 days, and 34.57 N/mm² at 28 days—comparable to the control, but underperforming relative to the 20% mix. Further increasing the replacement to 40% and 50% resulted in significant reductions. At 28 days, strengths dropped to 31.19 N/mm² and 30.96 N/mm², respectively, alongside weaker early-age strength.

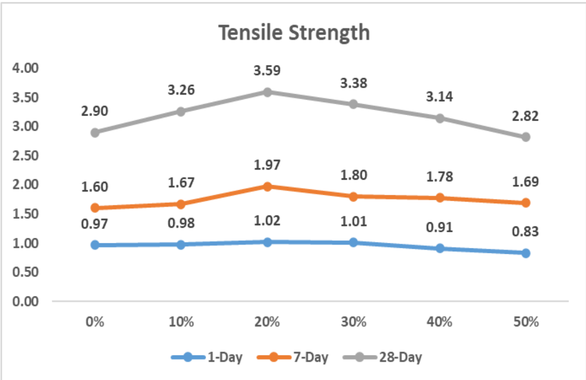

Fig - 2 Tensile strength of M30 grade of concrete

The split tensile strength results at 1, 7, and 28 days reveal how different percentages of additive replacement influence the tensile properties of concrete over time. The control mix (0% replacement) recorded a 1-day split tensile strength of 0.97 N/mm², increasing to 1.60 N/mm² at 7 days, and reaching 2.90 N/mm² at 28 days. This performance serves as a reference to assess the effects of partial replacement in the modified mixes. The 10% replacement mix showed a slight improvement in early-age strength with a 1-day value of 0.98 N/mm², and more significantly at later ages with 1.67 N/mm² at 7 days and 3.26 N/mm² at 28 days, indicating enhanced tensile performance. The 20% mix displayed the highest strength across all curing periods, achieving 1.02 N/mm² at 1 day, 1.97 N/mm² at 7 days, and a peak value of 3.59 N/mm² at 28 days. This clearly demonstrates that 20% replacement is the optimal level for improving split tensile strength without compromising early performance. The 30% mix also performed well, showing 1.01 N/mm², 1.80 N/mm², and 3.38 N/mm² at 1, 7, and 28 days, respectively—still above the control but slightly lower than the 20%

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mix. However, as the replacement level increased to 40% and 50%, a downward trend became evident. The 40% mix reached only 3.14 N/mm² at 28 days, and the 50% mix dropped further to 2.82 N/mm², which is lower than the control.

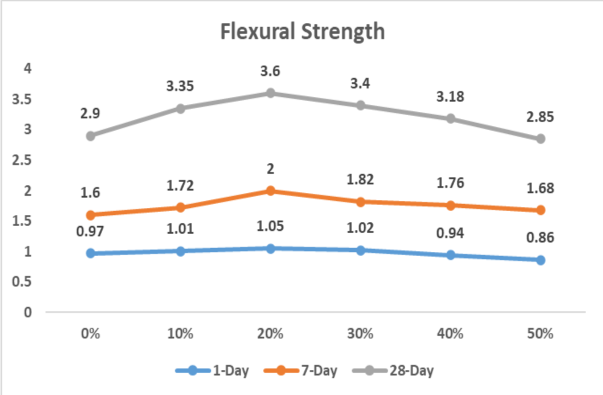

Fig - 3 Flexural strength of M30 grade of concrete

The flexural strength performance of concrete mixes with varying percentages of additive replacement was evaluated at 1, 7, and 28 days to assess their structural behavior over time. The control mix (0% replacement) exhibited flexural strengths of 0.97 N/mm² at 1 day, 1.60 N/mm² at 7 days, and 2.90 N/mm² at 28 days. This mix serves as the baseline for comparing the impact of partial replacement. A 5% replacement showed slight improvements across all ages, reaching 0.98 N/mm² at 1 day, 1.65 N/mm² at 7 days, and 3.10 N/mm² at 28 days. These results indicate that even a small amount of additive can positively influence flexural strength. The 10% replacement mix demonstrated further enhancement, recording 1.01 N/mm² at 1 day, 1.72 N/mm² at 7 days, and a notable 3.35 N/mm² at 28 days, clearly outperforming both the control and 5% mixes. The best results, however, were observed in the 20% replacement mix, which achieved the highest flexural strength across all ages: 1.05 N/mm² at 1 day, 2.00 N/mm² at 7 days, and 3.60 N/mm² at 28 days. This indicates that 20% replacement is the optimal level for maximizing flexural performance. Beyond this point, the strength began to decline. The 30% mix recorded 3.40 N/mm² at 28 days, still higher than the control but lower than the 20% mix. At 40% and 50%, the strength reduced further to 3.18 N/mm² and 2.85 N/mm², respectively, also showing lower early-age performance.

IV. CONCLUSION

In conclusion, the data clearly shows that up to 20% replacement enhances both early and long-term compressive strength, whereas higher replacement levels negatively impact strength development. Therefore, a 20% replacement is considered optimal for structural performance and material efficiency.
In conclusion, the results confirm that up to 20% additive replacement enhances split tensile strength at all ages. Beyond this level, strength begins to decline, making 20% the most effective and reliable mix for tensile performance improvement. In conclusion, flexural strength improves with increasing replacement up to 20%, after which it declines. Therefore, a 20% replacement offers the most effective balance between early strength gain and long-term structural performance in concrete flexural applications.

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