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Performance of Concrete with Partial Basalt Aggregate Replacement

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ABSTRACT

This study explores using basalt aggregate as a replacement for traditional aggregates in concrete, aiming to improve its strength, workability, and durability. Basalt, a strong igneous rock with low water absorption and excellent abrasion resistance, presents a promising sustainable alternative in construction.

To assess these benefits, five concrete mixes were prepared: a control mix with no basalt, and four experimental mixes containing 25%, 50%, 75%, and 100% basalt as coarse aggregate. In all mixes, the coarse aggregate consisted of 60% 20 mm size and 40% 10 mm size. A comprehensive testing program will evaluate the workability of fresh concrete and the compressive strength of hardened concrete at various curing ages.

The main goal is to develop optimized concrete mix designs leveraging basalt's superior properties. By systematically analyzing these mixes, the study aims to show that partially or fully replacing aggregates with basalt can significantly enhance concrete's mechanical and durability characteristics, such as increasing toughness and reducing permeability. These findings are vital for advancing sustainable, high-performance concrete solutions, offering a viable option for diverse construction applications like infrastructure, high-rise buildings, and structures in harsh environments. This research contributes to more resilient and environmentally friendly construction practices.

Introduction

Concrete stands as the most extensively utilized construction material globally, forming the structural basis for a vast array of constructions, from residential foundations to high-rise buildings and extensive infrastructure. Its adaptability is unparalleled in civil engineering, allowing it to be cast into virtually any shape and engineered for diverse strength requirements. Concrete remains the material of choice when strength, performance, durability, impermeability, fire resistance, abrasion resistance, and economic considerations are paramount. Within the complex composition of concrete, coarse aggregate plays a profoundly important role, typically occupying over one-third of the material's total volume. Research consistently indicates that even subtle changes in the type, size, and content of coarse aggregate can significantly alter both the strength and fracture properties of the concrete. Therefore, a deep understanding of these aggregaterelated effects is crucial for accurately predicting concrete behavior under various loading conditions. This necessitates ongoing research into optimizing concrete's constituents to further enhance its properties and expand its applications.

This study investigates the potential of basalt aggregate as a partial replacement for traditional aggregates in concrete, aiming to enhance its compressive strength, workability, and durability. Basalt, an igneous rock, is known for its high strength, low water absorption, and excellent abrasion resistance, making it a promising sustainable alternative to conventional aggregates in construction.

Literature Review

Several studies have explored the use of basalt in concrete and asphalt mixes: • **Asi et al. (2009)** investigated basalt in asphalt concrete mixes, focusing on skid resistance and stripping reduction by optimizing limestone aggregate replacement with basalt. They utilized the Marshall Mix design to prepare asphalt mixes and evaluated them for Marshall stability, indirect tensile strength, stripping resistance, resilient modulus, creep, fatigue, and permanent deformation.

• **Masad et al. (2003)** evaluated aggregate characteristics affecting HMA concrete performance, assessing HMA sensitivity to aggregate shape characteristics. Aggregate shape was detailed through measurements of angularity, form, and texture using the Aggregate Imaging System (AIMS), presenting characteristics as property distributions rather than average indices.

• **Sudha et al. (2019)** studied the mechanical properties, including compressive strength and split tensile strength, of basalt-reinforced concrete in beam-column joints. They observed the behavior of beam-column joints with 0.75%, 1%, and 1.25% basalt fiber under cyclic loading. Results showed that basalt fiber addition improved beam-column joint performance, enhancing flexural, compressive, and split tensile strength and toughness, while reducing crack size during failure.

• **Rathod et al. (2013)** studied the flexural and compressive strength behavior of basalt fiber reinforced concrete and normal concrete, casting separate specimens with 1% and 2% basalt fiber. The results indicated higher flexural and compressive strength in basalt fiber specimens compared to normal concrete. Adding 2% fiber increased 14-day flexural strength by 40-50% and 28-day compressive strength by 83-92%.

• **Kishore et al. (2015)** focused on the effect of basalt aggregate content and its combination with limestone aggregate in concrete mix, using different percentage combinations. They performed compressive strength, workability, specific gravity, and Los Angeles abrasion tests to evaluate basalt aggregate performance. The tests concluded that concrete mixes with basalt aggregate are more workable than limestone aggregate and achieve higher strength. • **Lokesh et al. (2015)** evaluated the performance characteristics of steel rebar and basalt rebar in concrete beams, testing flexural and shear capacity. A comparative study found that beams with BFRP bars showed less deflection and higher flexural strength and stiffness than steel rebar beams, with good bond between basalt rebar and concrete, confirming BFRP bars as an excellent alternative to steel bars in concrete beams.

• **Urbanski et al. (2013)** identified differences and limitations of basalt rebar in concrete structures compared to steel reinforcement. They compared deflection and crack patterns of simply supported basalt-reinforced and steelreinforced beams, finding that basalt-reinforced beams failed gradually with significantly higher deflection due to lower BFRP bar modulus. The average crack width was 3 to 4 times higher than steel-reinforced beams, highlighting deflection and crack width as major design factors for basalt-reinforced concrete beams.

Methodology

To evaluate these effects, five distinct concrete mixes were prepared: a control mix (0% basalt aggregate) and four experimental mixes incorporating 25%, 50%, 75%, and 100% basalt as coarse aggregate. In all mixes, the coarse aggregate composition was standardized at 60% of 20 mm size and 40% of 10 mm size. The research will involve a comprehensive testing program to assess the workability of fresh concrete and determine the compressive strength of hardened concrete specimens at various curing ages.

Materials Used

Cement: A fine, powdered binding material made from limestone, clay, and other raw materials. It is used to bind sand and gravel, forming the basis for structures like housing, roads, and bridges. It is also used for mortar, grouting, precast pipes, and decorative architectural detailing.

Basalt Aggregate: Crushed basalt rock used in construction for its hardness, durability, and density. It is used in applications requiring high strength and wear resistance, such as highway and airport runway construction, as well as for railroad ballast, road construction, and rock wool insulation. Coarse Aggregate: Granular materials larger than 5mm, typically gravel or crushed stone. They contribute significantly to the strength, durability, and dimensional stability of concrete structures, occupying 60-80% of its volume. Fine Aggregate: Small-sized particles, generally less than 4.75 mm in diameter, composed of sand, crushed stone, or crushed slag. They fill gaps between coarse aggregates, improving consistency, stability, and overall appearance, and contribute to lower water-cement ratios, leading to higher concrete strength and reduced shrinkage and cracking.

Water: A transparent, odorless, and tasteless liquid essential for biological processes and indispensable in construction. It reacts with cement in hydration, forming a binding paste, and its quality and quantity significantly impact concrete strength and durability. It is also used for curing concrete, pre-wetting bricks, and dust control.

Properties of Materials

Cement

Property	Description	Value
Specific Gravity	Ratio of cement density to water density	3.10-3.25
Fineness	Measure of cement particle size	225-350 m^2/kg
Soundness	Ability to Resist volume change	\le 10mm
Setting Time	Time for Cement to Set	Initial setting time \ge 30 minutes, final setting time \le 600 minutes

Basalt Aggregate

Property	Value
Specific Gravity	2.8-3.0

Water Absorption	0.5-2.0%
Bulk Density	1600-1800 kg/m^2
Crushing Value	10-20%
Impact Value	10-20%
Abrasion Value	15-30%
Compressive Strength	High / Dependent On Rock Source
Tensile Strength	20-20 MPa
Flexural Strength	10-25 MPa
Silica Oxide	45-55%
Aluminium Oxide	15-20%
Iron Oxide	10-15%
Calcium Oxide	5-10%
Color	Dark Gray And Black
Durability	High Resistances To Weathering And Erosion

Coarse Aggregate

Characteristic of Coarse Aggregate	Value
Type	Crushed
Specific Gravity	2.68
Total Water Absorption	0.6%
Fineness Modulus	7.68
Maximum Size	20mm

Fine Aggregate

Property	Description	Value
Specific Gravity	Ratio of sand density to water density	2.5-2.7
Bulk Density	Mass per unit volume of sand	1400-1700 kg/m^3
Fineness Modulus	Measure of sand particle size distribution	2.0-3.5
Water Absorption	Amount of water absorbed	\le 3%

Water

Property	Description	Value
Specific Gravity	Ratio of water density to itself	1 [cite: 97]
Density	Mass per unit volume	[cite_start]1000 kg/m^3
Viscosity	Measurement of water viscosity	0.89 Cp
Boiling Point	Temperature at which water boils	100°C
Freezing Point	Temperature at which water freezes	0-14°C
pH	Measure of water acidity	6.5-8.5
Solubility	Ability to dissolve substances	\le 10-1000ppm

Fresh Concrete Testing

Routine testing of fresh concrete typically includes assessing its workability, air content, and maturity.

Slump Test

The slump test is a widely used method to measure the consistency of fresh concrete before it sets. It primarily gauges the mix's workability, indicating how easily the concrete will flow and be placed. This test is popular due to its simplicity and effectiveness in ensuring uniformity across different batches of concrete under field conditions, and can help identify issues with improperly mixed batches.

Degree of Workability	Slump Value (mm)
Very Low	0-25mm
Low	25-50mm
Medium	50-100mm
High	100-175mm
Very High	Collapsed

Compaction Factor Test

The Compaction Factor Test is a laboratory method for determining the workability of concrete, particularly effective for mixes with low workability. It measures the ratio of the weight of partially compacted concrete to fully compacted concrete, providing more precise results than the slump test for concrete compacted by vibration.

Workability	Compacting Factor	Slump (mm)
Very Low	0.78	0-25
Low	0.85	25-50
Medium	0.92	50-100
High	0.95	100-175

Hardened Concrete Testing

Hardened concrete tests are essential for evaluating the strength, durability, and overall quality of concrete once it has cured, ensuring structures meet critical design specifications and structural requirements. Key tests include compressive strength, split tensile strength, and flexural strength, alongside non-destructive methods.

Compressive Strength

The compressive strength test measures a material's ability to resist forces that push or squeeze it, which is critical for determining concrete's durability and structural integrity. A concrete specimen is subjected to a gradually increasing load until it fractures, with the maximum load it can bear before failure indicating its compressive strength.

Replacement Percentage (Basalt Aggregate)	Compressive Strength (MPa)
0%	30-40
25%	35-45
50%	40-50
75%	45-55
100%	50-60

Split Tensile Strength

The split tensile strength test is an indirect method to determine the tensile strength of concrete, measuring its resistance to pulling apart. A concrete cylinder is laid horizontally and subjected to compressive forces along its diameter, causing it to split along its vertical diameter due to induced tensile stresses, which is crucial for understanding how concrete resists splitting or cracking.

Replacement Percentage (Basalt Aggregate)	Split Tensile Strength (MPa)
0%	35-45
10%	40-50

20%	45-55
30%	50-60
40%	55-65

Mix Design

Volume of concrete = 1 m^3

Volume of cement = Mass of cement / (Specific gravity of cement x 1000) = [383.16 / 3.15] \times [1 / 1000] = 0.122 m^3

Volume of water = Mass of water / (Specific gravity of water x 1000) = [192 / 1] \times [1 / 1000] = 0.192 m^3

Volume of all-in aggregates (Z) = Volume of concrete - (Volume of cement +

Volume of water) = 1 - (0.122 + 0.192) = 0.686 m^3

Mass of coarse aggregates = Z x Volume of CA x Specific gravity of CA x 1000 = 0.686 \times 0.6 \times 2.68 \times 1000 = 1103 kg

Mass of basalt aggregates = Z x Volume of BA x Specific gravity of BA x 1000

= 0.686 \times 0.8 \times 2.8 \times 1000 = 1537 kg (Note: Specific gravity of Basalt Aggregate is 2.8-3.0 as per Table 2, here 2 is used in calculation)

Mass of fine aggregates = Z x Volume of FA x Specific gravity of FA x 1000 =

0.686 \times 0.4 \times 2.65 \times 1000 = 727 kg

Mix Proportions:

Cement = 383 kg/m^3

Water = 191.6 kg/m^3

Fine aggregate = 727 kg/m^3

Coarse aggregate = 1103 kg/m^3

Basalt aggregate = 1547 kg/m^3

Water cement ratio = 0.50

Conclusion

The study's findings strongly support the use of basalt aggregate as a coarse aggregate, offering a viable strategy to produce stronger, more workable, and costeffective concrete, thereby contributing to enhanced structural performance and efficiency in construction.

1. **Superior Material Properties:** Basalt aggregate inherently possesses denser, more durable, and less water-absorbing characteristics compared to conventional limestone, directly contributing to enhanced concrete performance.
2. **Enhanced Strength Development:** Laboratory tests consistently show a direct correlation between increased basalt aggregate percentage and enhanced concrete mix strength (compressive and split tensile).
3. **Significant Strength Increase for M50 Grade Concrete:** For M50 Grade concrete with basalt replacement (25% to 100%), there is a significant 25.21% increase in compressive strength and a 10.5% increase in split tensile strength.
4. **Strength Increase for M60 Grade Concrete:** For M60 Grade concrete with basalt replacement (25% to 100%), increases of 6.46% in compressive strength and 4.62% in split tensile strength are observed.
5. **Substantial Compressive Strength at 100% Replacement:** Specifically, 100% basalt aggregate replacement yields substantial compressive strength increases: 27.12% for M50 and 24.91% for M60 compared to conventional concrete.
6. **Improved Workability:** Higher basalt aggregate content leads to improved concrete workability, which can directly result in reduced labor costs during placement and compaction.
7. **Economical and Accessible:** As a natural aggregate available in abundance at a low cost, basalt aggregate offers an economical solution for achieving relatively high-strength concrete.
8. **Water-Cement Ratio Adjustment:** It is crucial to correct the original watercement ratio of the concrete mix to account for any inherent water present in the basalt aggregate, ensuring optimal mix design.

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