ISSN No.: 2455-6130
Special Issue – RAISE2024, 2025, pp. 11-20

website: www.ijoetr.com

International Journal of Emerging Trends in Research

Innovative Concrete Materials: Utilizing Crushed Bricks for Aggregate Replacement

Kaushal Kumar[1*], Rishi Rana[2]

[1]*Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan-173234, H.P.*
[2]*Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat, Solan-173234, H.P.*

* Corresponding author. E-mail: kaushal.kumar@juitsolan.in

Abstract

This study evaluates the viability of using crushed brick aggregates as a partial substitute for natural coarse aggregates in concrete, driven by the escalating demand and diminishing availability of natural aggregates within the construction industry. This trend not only raises economic concerns but also underscores significant environmental impacts. To mitigate these issues, crushed bricks—sourced from demolition waste—present a sustainable alternative aggregate option.

In this research, M20-grade concrete was designed with graded replacements of natural coarse aggregates by crushed brick aggregates at 10%, 20%, 30%, 40%, and 50% (by volume). Key performance metrics, including compressive strength, split tensile strength, and workability (as measured by slump values), were rigorously assessed, alongside bulk density and stress-strain characteristics. Samples were evaluated at both 7 and 28 days of curing to capture the development of concrete properties over time.

The results demonstrate that concrete incorporating up to 30% crushed brick as coarse aggregate maintains compressive and tensile strength levels comparable to conventional concrete, with minimal compromises in workability. However, replacement levels exceeding 30% exhibited marked declines in compressive and tensile performance, suggesting that crushed brick aggregate is best suited for applications up to this threshold. Consequently, crushed brick aggregate can be effectively utilized in concrete production, particularly in non-structural applications, as a means to reduce construction waste and preserve natural aggregate resources. This research advances sustainable construction practices by integrating recycled demolition materials, thereby supporting circular economy principles in the concrete industry.

Keywords:crushed bricks; coarse aggregate; concrete properties; compressive strength; tensile strength; sustainability

1. Introduction

Concrete, known for its strength and durability, is a cornerstone of construction. Traditionally composed of cement, water, sand, and natural aggregates, concrete production has escalated with urbanization, consuming over 26 billion tons of aggregates each year. This rising demand leads to environmental concerns, including habitat loss and depletion of natural resources.

To improve sustainability, researchers are investigating recycled materials, such as crushed brick, to replace natural aggregates. Sourced from construction waste, crushed brick reduces dependence on virgin materials and lowers landfill waste and emissions. This study explores using crushed brick as a partial replacement for natural aggregates in M20-grade concrete, testing levels of 10% to 50% to observe effects on compressive and tensile strength, density, and workability. The results suggest crushed brick can effectively maintain concrete performance, providing a sustainable alternative that supports waste reduction and fosters a circular economy in the construction industry.

2. Literature Review

In recent years, research has increasingly focused on utilizing waste materials as alternatives to natural aggregates in concrete, aiming to address environmental concerns and resource scarcity while maintaining or enhancing concrete’s mechanical properties. Crushed brick, a by-product of construction and demolition waste, has been extensively studied in this context.

Rashid et al. (2009) examined the use of crushed bricks as coarse aggregate in high-strength concrete, reporting compressive strengths between 31 and 45 MPa with brick aggregates, comparable to conventional concrete. Brick aggregate concrete also exhibited about 13% lower density, suggesting potential for lightweight applications. However, the study noted a significant strength reduction as the water-cement ratio increased, which is crucial when using brick aggregates.

Cachim (2009) investigated concrete with 15% and 30% brick aggregate replacements. No significant strength reduction occurred with 15% replacement, but at 30%, both compressive and tensile strengths declined, indicating brick aggregates are more suitable for partial replacement.

Sable and Walke (2015) found that replacing up to 30% of natural coarse aggregate with brick aggregate did not significantly affect compressive strength. They emphasized the economic and environmental benefits, especially in regions with scarce or costly natural aggregates.

Aguwa (2014) explored lightweight concrete with crushed fired clay bricks, finding that although it had lower density and compressive strength compared to conventional concrete, the reduced weight made it ideal for non-structural applications, such as pavements and partition walls.

Challenges with brick aggregates include high porosity and water absorption. Fadia (2009) reported a compressive strength reduction of 11% to 87% at 28 days, depending on the replacement level, due to the high porosity of brick aggregates affecting cement hydration.

Dey and Pal (2013) examined crushed bricks in M25 and M30 concrete, noting high water absorption rates (12% to 20%) that require pre-saturation to maintain workability and prevent excessive strength loss.

Overall, the literature suggests that while crushed brick aggregates can partially replace natural aggregates, effectiveness depends on factors such as replacement level, water-cement ratio, and aggregate properties. Most studies recommend limiting replacement to 30% to maintain mechanical performance, as higher levels tend to reduce compressive and tensile strengths. Additionally, the high porosity and water absorption of brick aggregates necessitate specific mix design adjustments. This study builds on prior findings by investigating various brick aggregate replacement levels in M20 concrete to find an optimal balance between sustainability and performance.

3. Materials and Methods

3.1 Materials

The materials used in this study include Portland Pozzolana Cement (PPC), fine aggregate (river sand), coarse aggregate, crushed brick aggregates, and water.

Cement: Portland Pozzolana Cement (PPC) was selected for its high durability and resistance to harsh environments, as per IS-1489:1991 (Part 1) standards. This cement was obtained from a local supplier.

Fine Aggregate: The study used river sand as the fine aggregate, adhering to IS: 383–1970 specifications. The sand was free of organic impurities and had a fineness modulus appropriate for concrete production. Sieve analysis confirmed that the sand met Zone II specifications according to IS standards.

Coarse Aggregate: The natural coarse aggregate used was locally sourced crushed stone, also conforming to IS: 383–1970. The nominal maximum size of the coarse aggregate was 12.5 mm, aligning with recommended specifications for concrete production.

Crushed Brick Aggregate: Crushed brick aggregates were prepared by manually breaking fired clay bricks with a hammer. These brick pieces were then sieved to create a particle size distribution similar to that of the natural coarse aggregate, ensuring they passed through a 16 mm sieve and were retained on a 4.75 mm sieve. The brick aggregates underwent further testing to determine physical properties, such as specific gravity and water absorption, as part of the material characterization process.

(a). Fine aggregate(sand) *(b). Natural Coarse aggregate* *(c). Crushed Brick aggregate*

Figure 1: Aggregates used for making concrete

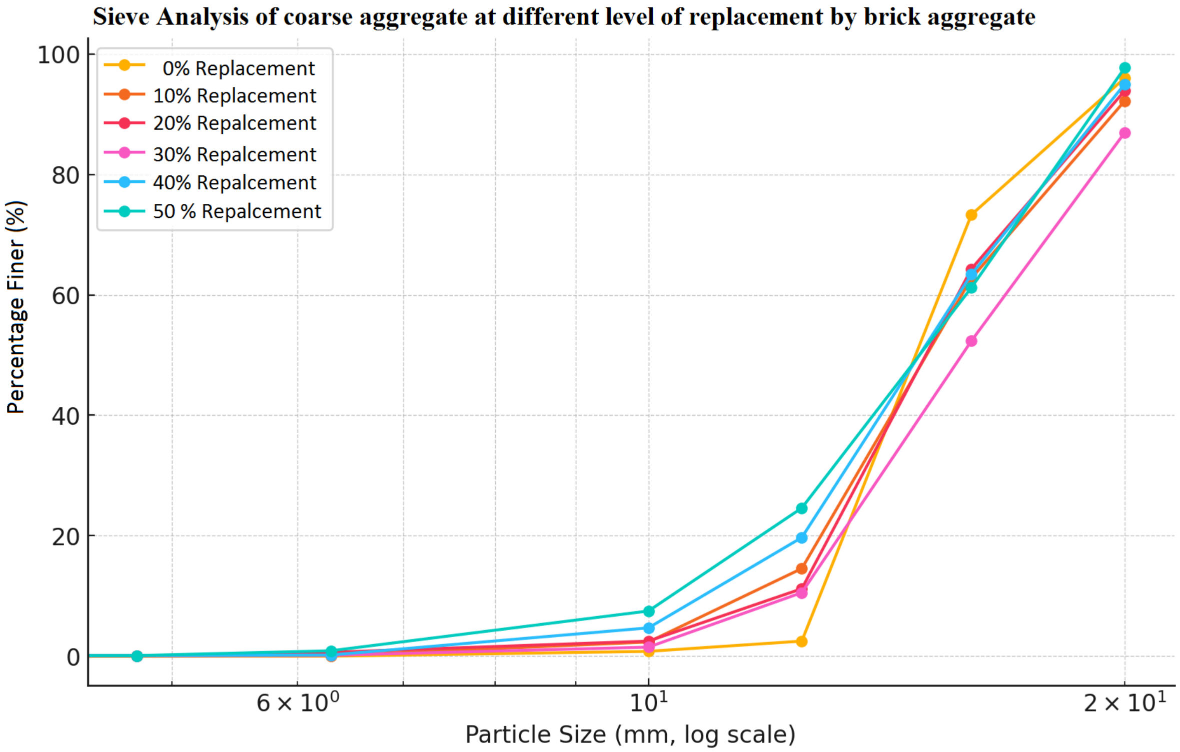

Figure 2: Sieve analysis of course aggregate at different replacement level of Natural Aggregate

The graph shows that as brick aggregate replacement increases (from 0% to 50%), the coarse aggregate mix becomes progressively coarser. Lower replacement levels (e.g., 0% and 10%) have more fines, while higher replacements yield larger particles. All replacement levels converge at larger particle sizes, showing similar proportions of larger particles. This trend toward coarser aggregate with more brick replacement could affect workability, density and strength.

Water: Potable tap water was used for both mixing and curing purposes, meeting the quality requirements outlined in IS: 456–2000. The pH of the water was around 7, and it was free from dissolved salts and other impurities that might interfere with the hydration process of cement.

3.2 Concrete Mix Design

Concrete mix design was carried out in accordance with IS: 10262–2009 for M20 grade concrete. The design mix was calculated based on a target mean strength of 26.6 MPa, with a water-cement ratio of 0.50. The mix proportions for the control concrete and the mixes with 10%, 20%, 30%, 40%, and 50% replacement of natural coarse aggregate with crushed bricks are presented in Table 3.1. The volumetric method was used to calculate the required quantities of cement, water, fine aggregate, coarse aggregate and crushed brick aggregate for each mix. The mix proportions were adjusted to account for the higher water absorption of the brick aggregates.

Table 1: Mix Design Proportions for Concrete with Varying Percentages of Brick Aggregates

Coarse Aggregate	***Cement (kg/m³)***	***Water (kg/m³)***	***W/C Ratio***	***Coarse Aggregate***	***Fine Aggregate***	***Crushed Brick***

Replacement				***(kg/m^3)***	***(kg/m^3)***	***(kg/m^3)***
0%	372	186	0.5	1197.62	588.75	0
10%	372	186	0.5	1077.72	588.75	91.45
20%	372	186	0.5	958.10	588.75	182.91
30%	372	186	0.5	838.2	588.75	274.36
40%	372	186	0.5	718.57	588.75	365.82
50%	372	186	0.5	598.81	588.75	457.27

3.3 Mixing, Casting, and Curing

Concrete mixing was performed using a tilting drum mixer. For each batch, the dry materials (cement, fine aggregate, coarse aggregate and crushed brick aggregate) were mixed for two minutes to ensure uniform distribution of the materials. Water was then added, and mixing continued for an additional three minutes. A total mixing time of five minutes was maintained for each batch.

After mixing, the concrete was cast into steel molds of size 150 mm × 150 mm × 150 mm for compressive strength tests and into cylindrical molds (100 mm diameter × 200 mm height) for tensile strength tests. Each mold was filled in three layers, and each layer was compacted using a vibrating table to eliminate air voids. After 24 hours, the specimens were demolded and transferred to a curing tank, where they were submerged in water for 7 and 28 days.

3.4 Testing Methods

To evaluate the performance of the concrete, several tests were conducted in accordance with Indian standards:

Bulk Density of Concrete: Bulk density is the mass of concrete per unit volume, including voids. It affects the concrete's strength and durability. Measured by filling a container of known volume with concrete and weighing it, higher bulk density usually indicates better compaction and strength.

Slump Test: The workability of the fresh concrete was measured using the slump test, as per IS: 1199–1959. A standard slump cone was filled with fresh concrete, and the cone was lifted vertically. The resulting slump was measured in millimeters, providing an indication of the concrete's consistency and workability.

Compressive Strength Test: Compressive strength was measured on concrete cubes (150 mm × 150 mm × 150 mm) after 7 and 28 days of curing. The test was conducted using a compression testing machine, following the procedure outlined in IS: 516–1959. The average compressive strength of three cubes was recorded for each replacement level.

Split Tensile Strength Test: Cylindrical specimens were used to determine the tensile strength of the concrete. The specimens were tested using the split tensile method, as per IS: 5816–1999. The tensile strength was calculated using the formula:
Tensile Strength;

$$f_c = \frac{2P}{\pi DL} \qquad (1)$$

Where,

P = extreme load applied to specimen, in N;
L = length of cylinder, in mm; and
D = diameter of cylindrical specimen, in mm

Stress-Strain Test: Stress-strain behavior was studied by testing cylindrical specimens in a universal testing machine (UTM) after 28 days of curing. The load and corresponding deformation were recorded, and the stress-strain curve was plotted for each mix.

4. Results and Discussion

4.1 Bulk Density of Concrete:

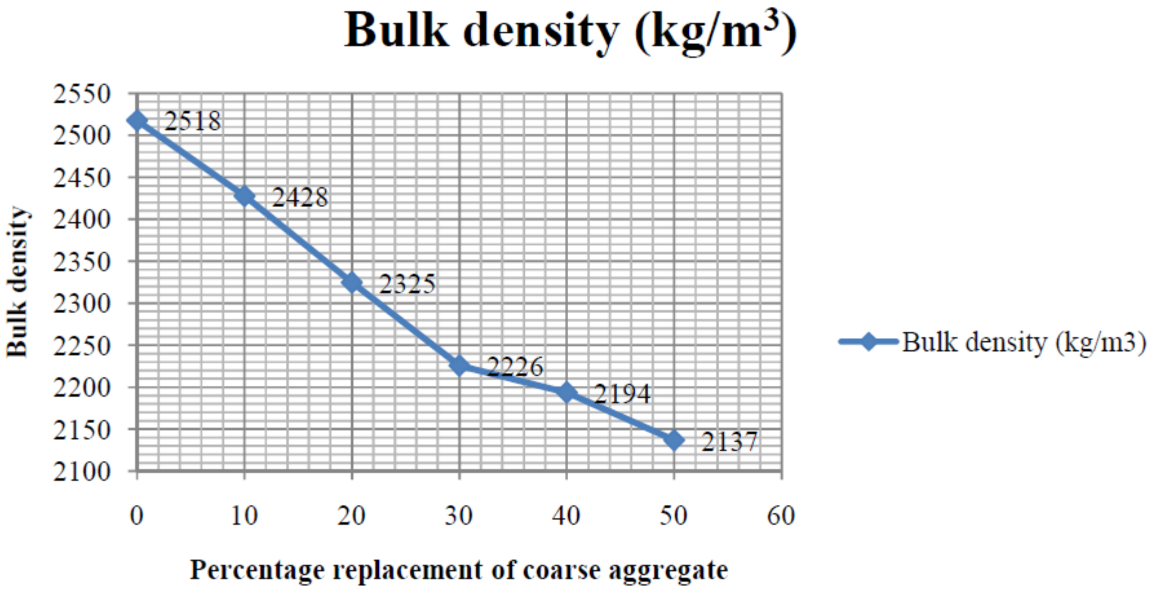

Figure 3: Bulk Density of fresh concrete for different replacement levels.

As the percentage of brick aggregate replacement increased, the bulk density of the concrete correspondingly decreased. Table 5.1 illustrates that the control mix (0% replacement) had a bulk density of 2518.52 kg/m³, whereas a mix with 50% brick aggregate replacement reduced this density to 2137.25 kg/m³. This decrease is due to the lower specific gravity of brick aggregates compared to natural coarse aggregates. While the reduction in density can be advantageous for applications needing lighter materials, such as non-structural components or lightweight partitions, it could reduce the concrete's strength in structural applications.

4.2 Workability (Slump Test)

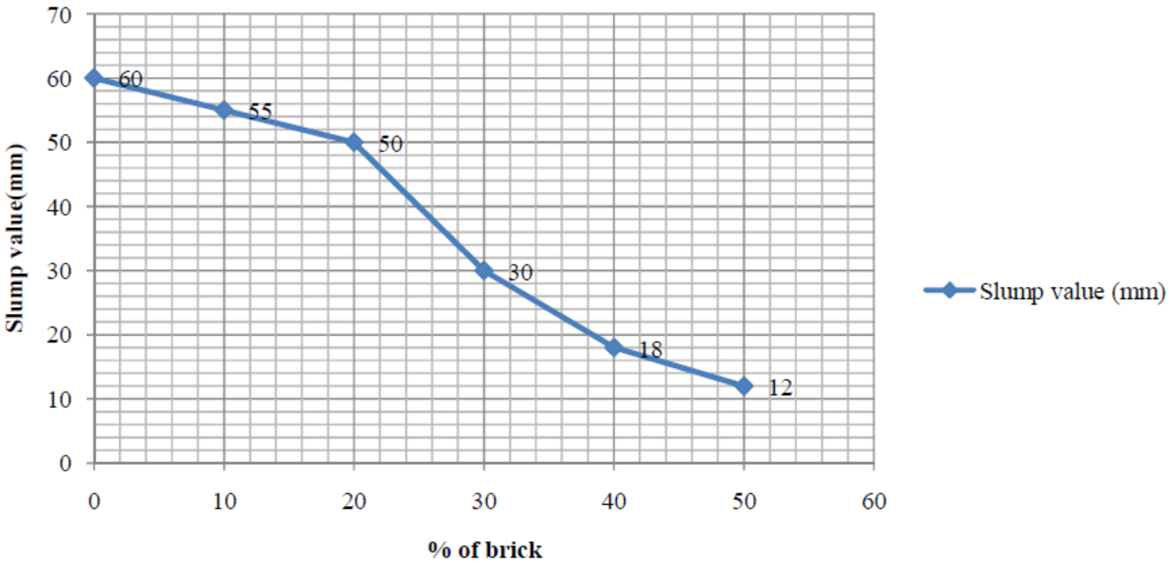

Figure 4: Slump value of fresh concrete for different replacement levels.

Table 5.2 presents slump test results, showing a notable reduction in concrete workability as brick aggregate content increased. The control mix exhibited a slump value of 60 mm, which dropped to 12 mm at 50% brick aggregate replacement. This decline in workability is attributed to the high water absorption of brick aggregates, which reduces the available free water in the mix for lubrication. To achieve comparable workability with higher brick aggregate contents, additional water or admixtures may be necessary.

4.3 Compressive Strength

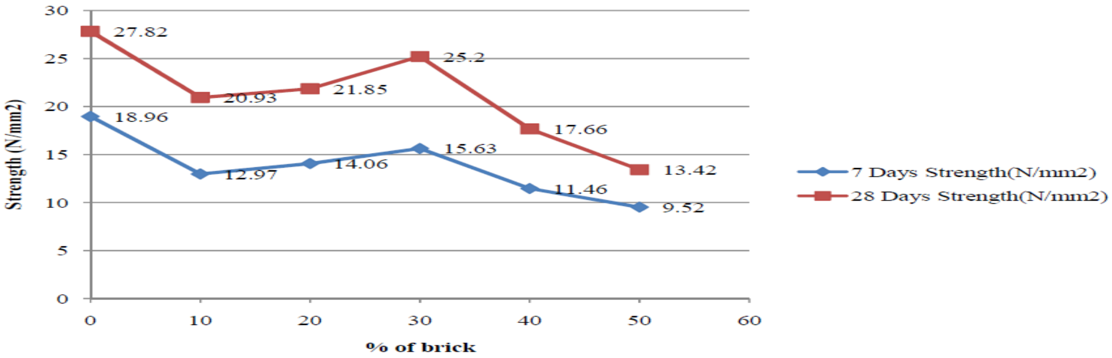

Figure 5: Compressive Strength of concrete for different replacement levels at 7 and 28 days.

The compressive strength results for various concrete mixes at 7 and 28 days are displayed in Tables 5.3 and 5.4. At 28 days, the control mix reached a compressive strength of 27.82 MPa. With a 10% replacement, the strength slightly reduced to 20.93 MPa, and a 30% replacement achieved 25.2 MPa. However, beyond 30% replacement, strength decreased sharply; the 50% replacement mix only reached 13.42 MPa. This indicates that brick aggregates can replace natural aggregates up to 30%

without significantly compromising strength. At higher replacement levels, the reduced density and increased porosity of brick aggregates impair the concrete's load-bearing capacity.

4.4 Tensile Strength

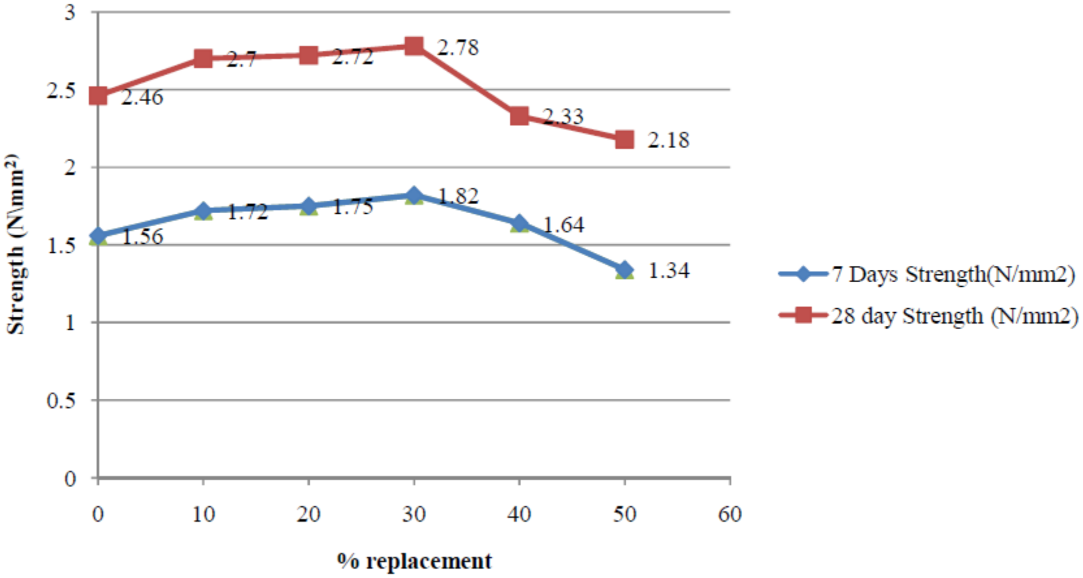

Figure 6: Tensile Strength of concrete for different replacement levels at 7 and 28 days.

The tensile strength results, shown in Tables 5.5 and 5.6, follow a similar pattern to compressive strength. At 28 days, the control mix had a tensile strength of 2.46 MPa, whereas a 30% brick aggregate replacement achieved 2.78 MPa. This increase is due to the angular shape of brick aggregates, which enhances interlocking and improves tensile properties. Nevertheless, at higher replacement levels, tensile strength declined; the 50% replacement mix reached only 2.18 MPa, suggesting that 30% is the optimal level for achieving balanced compressive and tensile strengths.

4.5 Stress-Strain Behavior

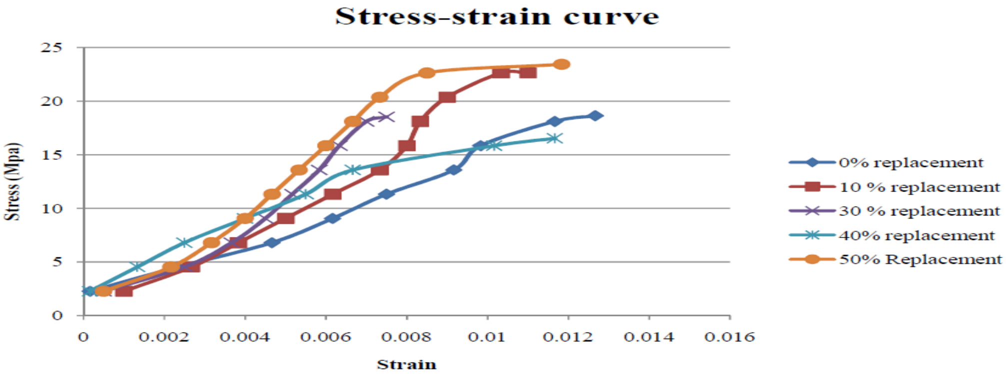

Figure 7: Stress-strain comparison curve for concrete at different replacement levels

Figures 5.7 to 5.12 depict the stress-strain behavior for each concrete mix. The control mix demonstrated a standard stress-strain curve with a peak stress of 27.82 MPa. The 30% brick aggregate mix showed a comparable peak stress of 25.2 MPa, while the 50% replacement mix had a much lower peak stress of 13.42 MPa. Mixes with higher brick aggregate content also exhibited more pronounced strain-softening, indicating reduced stiffness with increased brick aggregate proportion. This trend aligns with the lower modulus of elasticity of brick aggregates compared to natural aggregates.

5. Conclusion, Applications, and Future Scope

5.1 Conclusions:

- Crushed brick aggregates are a promising partial replacement for natural coarse aggregates, making concrete production more sustainable.
- Using up to 30% crushed brick retains the necessary strength for non-structural applications, ensuring satisfactory compressive and tensile performance.
- Replacements above 30% lead to significant reductions in strength, due to higher porosity and lower density, making them less suitable for structural purposes.
- Concrete with crushed brick requires adjustments in water or admixture levels to maintain workability, as crushed brick absorbs more water.
- Incorporating crushed brick helps reduce reliance on natural resources, supports circular economy goals by recycling waste, and lowers the environmental footprint of construction.
- Optimal replacement levels allow for sustainable concrete use without sacrificing performance, showing crushed brick's potential for diverse concrete applications.

5.2 Applications:

- Ideal for non-structural elements like pavements, partition walls, and sidewalks.
- Beneficial for lightweight construction applications because of its reduced density.
- Valuable in areas with limited access to natural aggregates, encouraging the use of local resources.
- Suitable for eco-friendly projects focused on minimizing construction waste and reducing carbon emissions.

5.3 Future Scope:

Future research should enhance the workability of high crushed-brick concrete through improved admixtures and treatments to control water absorption. Evaluating durability across climates (e.g., freeze-thaw, humidity) and conducting long-term studies on strength and deformation will clarify its potential for structural use. Developing specific design guidelines will enable sustainable application while maintaining performance. Expanding studies to other recycled materials, like crushed glass or ceramic, may also reveal additional eco-friendly aggregate options for concrete production.

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