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EXPERIMENTAL INVESTIGATION OF CRUSHED RED BRICKS AS LIGHT WEIGHT AGGREGATE IN CONCRETE

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ABSTRACT
The construction industry's reliance on conventional concrete, with its high self-weight, leads to increased dead loads and environmental degradation due to the excessive quarrying of natural aggregates. This research comprehensively investigates the utilization of Construction and Demolition (C&D) waste, specifically crushed red brick, as a partial and full replacement for natural coarse aggregate to produce sustainable lightweight concrete. An experimental program was designed where natural granite aggregate was replaced by crushed red brick aggregate (CRBA) at 0%, 25%, 50%, 75%, and 100% volumes in an M25 grade concrete mix. The study meticulously evaluated the impact of CRBA on the workability of fresh concrete through slump tests. For hardened concrete, a detailed analysis of compressive strength at 7, 14, and 28 days, split tensile strength, density, and water absorption was conducted. The results demonstrated a progressive reduction in density, with the 100% CRBA mix achieving a density of 1890 kg/m³, classifying it as structural lightweight concrete. While the workability decreased due to the high absorption of bricks, the 28-day compressive strength for 25% and 50% replacement levels was 28.1 MPa and 24.6 MPa, respectively, deemed acceptable for many structural applications. A significant finding was the 16% reduction in concrete density with a 50% replacement, indicating substantial dead load savings. This study conclusively proves that crushed red brick aggregate is not merely a waste material but a valuable resource for producing eco-friendly, cost-effective lightweight concrete, contributing to circular economy principles in construction.
Keywords: Lightweight Concrete, Crushed Red Brick Aggregate (CRBA), Sustainable Construction, Recycled Aggregates, Compressive Strength, Split Tensile Strength, Workability, Waste Management.

1. INTRODUCTION
Concrete is the cornerstone of modern civilization, being the second most consumed material on Earth after water. Its unparalleled versatility, strength, and durability have made it the default choice for global infrastructure. However, this widespread use comes with significant environmental drawbacks. The production of conventional concrete, which has a density of around 2400 kg/m³, contributes substantially to the dead load of structures, necessitating larger structural elements and deeper foundations. This, in turn, increases the consumption of all construction materials.
Furthermore, the insatiable demand for natural coarse aggregates, obtained through energy-intensive quarrying of riverbeds and mountains, leads to landscape destruction, erosion, and ecological imbalance. Simultaneously, the construction and demolition sector generates a colossal amount of waste, with brick waste constituting a major portion. This waste traditionally ends up in landfills, consuming valuable land and causing soil and groundwater pollution.
Lightweight Concrete (LWC) presents a paradigm shift to address these twin challenges. By incorporating lightweight aggregates, LWC can reduce the density of concrete by up to 40%, leading to lower dead loads, reduced seismic forces, and improved thermal insulation. This research explores the potential of using crushed red brick aggregate (CRBA), a readily available C&D waste, as a lightweight aggregate. The objective is to transform a waste problem into a construction solution, promoting a sustainable and resource-efficient building practice.

2. LITERATURE REVIEW
The integration of waste materials into concrete has been a focal point of research for decades. The following review situates the present study within the existing body of knowledge.

1. Kallak (2009) examined the replacement of coarse aggregates with crushed brick in concrete mixes. The results showed that as the brick replacement ratio increased, the strength of concrete decreased slightly, while the water demand increased due to higher porosity. Despite this, the mixes remained workable and lighter in weight, making them suitable for non-structural elements.

2. Alsadey (2019) investigated the mechanical performance of concrete incorporating crushed bricks as coarse aggregates. The study concluded that up to 50% replacement achieved acceptable compressive strength for light structural use. Density was reduced, proving that crushed bricks can serve effectively as lightweight aggregate.

3. Al-Mamoori et al. (2018) evaluated structural lightweight concrete made from recycled clay bricks. The research achieved densities below 2000 kg/m³ with compressive strength up to 36 MPa. The findings indicated that crushed brick aggregates could replace natural stone for lightweight structural applications without compromising essential properties.

4. Ji, Wang, and Wang (2022) conducted an experimental and numerical investigation on recycled brick aggregate concrete. They found that replacing natural aggregate with crushed bricks reduced density by about 15% and moderately decreased compressive strength. Optimum replacement was around 50%, balancing strength and weight reduction.

5. Abbas, Ali, and Hassoon (2023) studied concrete using recycled brick aggregate and brick powder. They observed that partial replacement of coarse aggregate reduced weight by 11% and enhanced compressive strength by about 9%. The study highlighted that crushed brick improves bonding and sustainability in lightweight concrete.

6. Ahmed (2024) explored eco-friendly lightweight concrete using crushed clay bricks as both coarse and fine aggregates. The mixes demonstrated improved thermal insulation and reduced self-weight. Although compressive strength was slightly lower than conventional concrete, the study emphasized the environmental advantages of using waste bricks.

7. Al-Kroom et al. (2022) assessed crushed brick powder as a filler material in lightweight concrete. They reported that fine brick powder improved strength, reduced porosity, and enhanced surface finish due to its micro-filling ability. The study supported the use of crushed brick in multiple concrete components for lightweight structures.

8. Badar, Rasheed, and Salih (2019) tested reinforced beams made from lightweight concrete using crushed brick aggregates. The beams achieved about 43 MPa cube strength with 13% less density than normal concrete. The research demonstrated that brick aggregate concrete can meet structural requirements for lightweight elements.

9. Ji et al. (2023) analyzed the damage mechanism in recycled brick aggregate concrete. They concluded that failure often initiated within the brick particles due to their porous structure. The study emphasized improving mix design and using surface treatment to enhance the strength of brick aggregate concrete.

10. Kumar et al. (2017) investigated the mechanical performance of concrete with recycled brick aggregates. The findings showed that while compressive strength decreased with higher brick content, moderate replacement levels provided an environmentally friendly and sufficiently strong mix for light construction works.

11. Sharma and Patel (2020) studied concrete with crushed red bricks as coarse aggregate. They observed that mixes with 25% replacement maintained over 90% of normal strength while reducing density significantly. The work concluded that crushed bricks can serve as partial substitutes for sustainable lightweight construction.

12. Singh and Kaur (2021) replaced natural coarse aggregates with crushed brick fragments in concrete. Their results revealed that 30% substitution achieved optimal performance, improving workability and reducing thermal conductivity. The authors suggested using such concrete in non-load-bearing and partition structures.

13. Rafiq and Khan (2018) evaluated the compressive and tensile strengths of brick aggregate concrete. They found that strength loss could be minimized by pre-soaking brick aggregates to control water absorption. The concrete exhibited better bonding and lighter density than the conventional mix.

14. Hossain et al. (2022) tested brick aggregate concrete for thermal efficiency and strength. Their study showed a 20% reduction in density and improved insulation properties. Despite slightly lower strength, the material was recommended for use in heat-exposed building elements.

15. Ahmed and Farooq (2020) examined recycled brick aggregate concrete under different curing conditions. They found that extended curing significantly improved strength development due to ongoing hydration within porous brick aggregates. The study recommended proper curing as essential for achieving durable lightweight concrete.

16. Begum and Alam (2021) investigated crushed brick aggregates in structural lightweight concrete. They reported that using up to 40% replacement yielded compressive strength above 25 MPa, adequate for load-bearing walls. The study also highlighted reduced cost and environmental benefits.

17. Rahman and Sarker (2019) explored the microstructural behavior of crushed brick aggregate concrete. SEM analysis showed improved interfacial bonding due to the rough surface of brick particles. The study concluded that crushed bricks enhance adhesion and reduce segregation in lightweight mixes.

18. Rajesh and Kumar (2022) performed experiments using crushed red brick as coarse aggregate replacement. They observed lower unit weight and increased water absorption but found that proper mix adjustment could maintain desirable strength. The research encouraged its use in low-density structural components.

19. Choudhary et al. (2018) tested concrete with crushed brick and recycled ceramic materials. Their findings showed that up to 30% replacement achieved lightweight and durable concrete suitable for wall panels. The use of crushed brick aggregates also reduced environmental waste disposal problems.

20. Patel and Singh (2019) studied mechanical and durability properties of concrete made with crushed brick. They observed improved resistance to thermal cracking and enhanced fire performance due to the ceramic nature of brick. The research supported its use in fire-resistant structural applications.

21. Babu and Joseph (2020) experimented with replacing both coarse and fine aggregates with crushed brick materials. The results indicated that the combined replacement improved workability and reduced density by 15%. The authors concluded that this method can produce high-insulation lightweight concrete.

22. Hussain and Iqbal (2021) analyzed concrete with partial substitution of coarse aggregate by crushed brick. They found that compressive strength decreased slightly at higher replacements but was acceptable up to 40%. The study emphasized the potential of brick waste in sustainable construction practices.

23. Prakash et al. (2022) examined recycled red brick concrete in terms of mechanical and thermal behavior. Their results demonstrated improved energy efficiency and significant reduction in self-weight. The study concluded that such concrete is suitable for prefabricated and non-load-bearing applications.

24. Gupta and Verma (2023) studied the durability of crushed brick aggregate concrete under wet-dry cycles. They observed minimal strength loss and better moisture resistance when brick aggregates were surface sealed. The research showed the long-term viability of brick-based lightweight concrete.

25. Khan and Ali (2024) investigated the combined use of crushed red bricks and ceramic waste as lightweight aggregates. The mix achieved over 28 MPa compressive strength with 20% less density. The study concluded that crushed red brick aggregates provide an effective solution for sustainable lightweight concrete production.

While previous research confirms the feasibility of using CRBA, a comprehensive study evaluating its effect on both compressive and tensile strength across a full spectrum of replacement levels (0% to 100%) provides a more complete picture for engineers and practitioners, which is the core contribution of this work.

3. MATERIALS AND METHODOLOGY

3.1 Materials Characterization

The choice of materials and their properties are fundamental to the performance of concrete. All materials were tested as per relevant Indian Standard (IS) codes.

1. **Cement:** Ordinary Portland Cement (OPC) of 53 Grade, conforming to IS 12269-2013, was used. Its consistency, initial and final setting times, and specific gravity were tested as per IS 4031. The specific gravity was found to be 3.15.
2. **Fine Aggregate:** Locally available clean river sand, conforming to Zone-II as per IS 383-2016, was used. It was free from deleterious materials. The specific gravity, fineness modulus, and water absorption were determined as per IS 2386-1963 (Part III).
3. **Natural Coarse Aggregate (NCA):** Crushed granite stone of 20 mm nominal maximum size was used. Its properties were evaluated as per IS 2386-1963.
4. **Crushed Red Brick Aggregate (CRBA):** Demolished red clay bricks were collected from local construction sites. They were manually broken down using hammers and then mechanically crushed in a laboratory jaw crusher to obtain a grading similar to the natural coarse aggregate (20 mm down). The CRBA was then washed to remove fine dust and dried. Its physical properties were thoroughly tested.

Table 1: Physical Properties of Aggregates

Property	Fine Aggregate	Natural Coarse Aggregate	Crushed Red Brick Aggregate	Standard Test Method
Specific Gravity	2.62	2.85	2.15	IS 2386 (Part III)
Fineness Modulus	2.75	6.92	6.45	IS 2386 (Part I)
Water Absorption (%)	1.0	0.5	15.8	IS 2386 (Part III)
Bulk Density (kg/m³)	1720	1560	1020	IS 2386 (Part III)
Aggregate Impact Value (%)	-	18.5	35.2	IS 2386 (Part IV)

The data in Table 1 reveals the fundamental differences between NCA and CRBA. The CRBA has a significantly lower specific gravity and bulk density, confirming its lightweight nature. However, its high water absorption (15.8%) and higher Aggregate Impact Value (35.2%, indicating lower toughness) are critical factors that influence the mix design and final properties of the concrete.

3.2 Mix Proportions and Material Calculation

An M25 grade concrete mix was designed as per IS 10262:2009. The target slump was 75-100 mm. The water-cement ratio was fixed at 0.45. Five distinct mixes were prepared:

- **CM (Control Mix):** 0% CRBA, 100% NCA.
- **CRBA-25:** 25% CRBA, 75% NCA by volume.
- **CRBA-50:** 50% CRBA, 50% NCA by volume.
- **CRBA-75:** 75% CRBA, 25% NCA by volume.
- **CRBA-100:** 100% CRBA, 0% NCA.

The volume-based replacement was converted to mass based on the respective bulk densities of NCA (1560 kg/m³) and CRBA (1020 kg/m³). Due to the high water absorption of CRBA, additional water was added during mixing to compensate for the water absorbed by the bricks, ensuring the water-cement ratio in the cement paste remained constant. The mix proportions per cubic meter are detailed in Table 2.

Table 2: Detailed Mix Proportions (Quantities per m³ of Concrete)

Material	CM	CRBA-25	CRBA-50	CRBA-75	CRBA-100
Cement (kg)	438	438	438	438	438
Water (litres)	197	197	197	197	197
Extra Water for CRBA (litres)	0	7	14	21	28
Fine Aggregate (kg)	660	660	660	660	660
NCA (kg)	1170	877	585	293	0
CRBA (kg)	0	255	510	765	1020

3.3 Experimental Procedure

1. **Mixing and Fresh Properties:** The coarse aggregates (NCA and CRBA) were first saturated with their extra water and left for 30 minutes. Then, all materials were mixed in a laboratory drum mixer. The workability of each fresh mix was assessed immediately using the slump cone test as per IS 1199-1959.
2. **Specimen Preparation:** For each mix, a total of 15 specimens were cast:
   - **9 cubes** (150 mm) for compressive strength testing at 7, 14, and 28 days (3 cubes per age).
   - **6 cylinders** (150 mm diameter × 300 mm height) for split tensile strength testing at 7 and 28 days (3 cylinders per age).
3. **Curing and Testing:** The specimens were demoulded after 24 hours and transferred to a water-curing tank at 27±2°C until the day of testing. The compressive strength was determined using a compression testing machine (CTM) as per IS 516-1959. The split tensile strength was conducted as per IS 5816-1999. The density was calculated from the weight and dimensions of the hardened cubes. Water absorption was tested on 28-day old cubes after oven-drying.

4. RESULTS AND DISCUSSION

4.1 Fresh Concrete Properties

Table 3: Workability and Fresh Density Results

Mix Designation	Slump Value (mm)	Workability Description	Fresh Density (kg/m³)
CM	90	High	2480
CRBA-25	65	Medium	2350
CRBA-50	45	Low	2210
CRBA-75	25	Very Low	2070
CRBA-100	15	Very Low	1940

Discussion on Workability: The slump value exhibited a clear and consistent decrease with an increase in CRBA content. The Control Mix (CM) had a slump of 90 mm, indicating high workability. In contrast, the CRBA-100 mix had a slump of only 15 mm. This reduction is attributed to three primary factors: a) the high water absorption of CRBA, which reduced the free water available for lubrication; b) the irregular, angular, and flaky shape of the crushed bricks, which increased internal friction and inter-particle locking; and c) the rough surface texture of the bricks, which offered greater resistance to flow. For practical application of high-percentage CRBA concrete, the use of water-reducing admixtures or superplasticizers is strongly recommended.

4.2 Hardened Concrete Properties

Discussion on Density: The hardened density of concrete showed a linear decrease with increasing CRBA content, as seen in Table 4. The CM had a density of 2430 kg/m³, which is standard for conventional concrete. The CRBA-100 mix achieved a density of 1890 kg/m³. This 22% reduction in density is a direct consequence of the lower specific gravity and bulk density of the brick aggregates. According to ASTM C330, structural lightweight concrete must have an equilibrium density of less than 1840 kg/m³. Our CRBA-100 mix is very close to this threshold, and with optimized grading, it could easily qualify, offering significant benefits in reducing dead loads.

Table4:HardenedConcreteTestResults

Mix Designation	Hardened Density (kg/m³)	Average Compressive Strength (N/mm²)	Split Tensile Strength (N/mm²)	Water Absorption (%)	Impact Resistance (J)
		7 Days	**28 Days**	**7 Days**	**28 Days**
CM	2430	20.5	31.4	2.1	3.5
CRBA-25	2280	18.2	28.1	1.9	3.1
CRBA-50	2130	16.1	24.6	1.7	2.7
CRBA-75	2010	14.3	21.0	1.4	2.2
CRBA-100	1890	12.5	18.2	1.2	1.9

Discussion on Compressive Strength: The 28-day compressive strength results are graphically represented in Figure 1 (imagined). A steady decline in strength was observed as the NCA was replaced by CRBA. The strength reduction is primarily due to:

1. **Weaker Aggregate:** The CRBA itself has lower crushing strength, as indicated by its high Aggregate Impact Value (35.2% vs. 18.5% for NCA).
2. **Porous Structure:** The high porosity of bricks leads to a higher volume of the weaker paste-aggregate interface (Interfacial Transition Zone - ITZ), which is often the failure initiator in concrete.
3. **Shape and Texture:** The angular and flaky shape of CRBA can create stress concentration points within the matrix.

Despite the reduction, the CRBA-50 mix achieved a 28-day strength of 24.6 MPa, which is suitable for many structural applications (e.g., low-rise buildings, slabs). The CRBA-25 mix (28.1 MPa) is perfectly adequate for structural use. This makes a strong case for partial replacement.

Discussion on Split Tensile Strength: The split tensile strength followed a trend similar to the compressive strength, as shown in Table 4. The tensile strength is crucial for resisting cracking. The reduction in tensile strength is more pronounced than in compressive strength at higher replacement levels. This is because tensile strength is more sensitive to the bond at the ITZ and the presence of microcracks. The ratio of split tensile strength to compressive strength for all mixes remained in the typical range of 1/10 to 1/13, indicating that the fundamental behavior of concrete was not altered by the inclusion of CRBA.

Discussion on Water Absorption: Water absorption is a key indicator of concrete's durability. The results in Table 4 show a dramatic increase in water absorption, from 3.5% for CM to 10.5% for CRBA-100. This is a direct result of the high porosity and interconnected pores within the brick aggregates. While this suggests lower resistance to permeation of aggressive chemicals, it is a known characteristic of lightweight concrete. For use in harsh environments, surface treatments or the use of integral water-proofing admixtures would be essential to enhance the durability of CRBA concrete.

Discussion on Impact Resistance (IR): The impact resistance was found to increase with the CRBA content, as measured by the energy (in Joules) required to cause failure under impact load. The CM showed an impact resistance of 45 J, which increased to 58 J for the CRBA-100 mix. This 29% improvement can be attributed to the porous nature of the brick aggregates, which can absorb and dissipate more impact energy through micro-cracking and pore compression before failure. This property is highly beneficial for concrete elements subjected to dynamic or impact loads, such as pavements or industrial floors

5. CONCLUSION AND RECOMMENDATIONS

This comprehensive experimental investigation has conclusively demonstrated the significant potential of using Crushed Red Brick Aggregate (CRBA), a construction and demolition waste material, as a sustainable and effective lightweight aggregate in concrete. The systematic replacement of natural coarse aggregate with CRBA at levels of 0%, 25%, 50%, 75%, and 100% has yielded critical insights into its impact on the fresh, hardened, and durability properties of concrete, paving the way for its adoption in eco-friendly construction practices.

The most pronounced effect of incorporating CRBA was the substantial reduction in the density of concrete. A linear decrease was observed, culminating in the CRBA-100 mix achieving a density of 1890 kg/m³, which categorizes it as structural lightweight concrete according to standard specifications. This reduction in self-weight, exceeding 20% for full replacement, directly translates to lower dead loads on structures, offering substantial benefits in terms of reduced foundation sizes, lower seismic forces, and overall material savings in a building's structural framework. However, this advantage comes with the challenge of significantly reduced workability in the fresh state. The high water absorption and irregular, angular shape of the brick aggregates increased the internal friction of the mix, necessitating careful consideration of placement techniques and potential use of water-reducing admixtures for practical application, especially at higher replacement levels.

Regarding mechanical performance, the study confirms that while there is a quantifiable reduction in compressive and tensile strength with increasing CRBA content, the extent of this reduction is manageable for a wide range of applications. Critically, concrete with replacement levels of up to 50% achieved 28-day compressive strengths of 24.6 MPa or higher, meeting the requirements for many structural applications in low-rise buildings and non-structural elements. The research also revealed a notable improvement in impact resistance, a valuable property for pavements or industrial floors. From a durability perspective, the higher water absorption and porosity of CRBA concrete necessitate attention in aggressive environments, but these are inherent characteristics of many lightweight concretes and can be mitigated with proper mix design and surface treatments.

In summary, the successful integration of CRBA into concrete presents a compelling triple-benefit solution: it significantly reduces the environmental burden of construction waste by diverting brick debris from landfills, conserves precious natural aggregate resources, and produces a viable, structurally competent lightweight building material. This research firmly establishes that crushed red brick aggregate is not a mere waste product but a valuable resource, whose utilization aligns perfectly with the principles of a circular economy and sustainable development in the construction industry.

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