Review On Comparative Study of Flexural Performance of Lightweight Reinforced Concrete Beams Using Cinder Aggregate with and without J-Hook Anchorage

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***Abstract*— This study investigates the flexural performance of lightweight reinforced concrete beams wherein natural coarse aggregate is partially replaced by cinder aggregate, an industrial byproduct. While previous research has documented strength losses at high replacement levels, no study has proposed or validated a reinforcement strategy to restore beam-scale capacity. The objective of this work is to evaluate whether J-hook anchorage can compensate for the structural deficit caused by high-volume cinder replacement. M30 grade beams were cast with 75% cinder replacement and tested under four-point bending. Three beam configurations were compared: control beams with natural aggregate, cinder beams without J-hooks, and cinder beams with J-hook anchorage. The J-hooks were fabricated from Fe 550 steel and placed at regular spacing within the flexure zone. Results indicate that beams with 75% cinder replacement without J-hooks exhibited significant reduction in ultimate load capacity and failed in a brittle shear mode. In contrast, beams supplemented with J-hook anchorage achieved load capacity comparable to or exceeding the control beams, with failure mode transforming to ductile flexure. This study demonstrates that J-hook anchorage effectively restores structural performance in high-volume cinder concrete, enabling sustainable lightweight construction without compromising safety.**

***Index Terms*— Cinder aggregate, J-hook anchorage, flexural performance, lightweight concrete, shear reinforcement, sustainable construction.**

I. INTRODUCTION

Concrete remains the most widely used construction material globally, but the depletion of natural aggregate sources and the environmental impact of quarrying have driven the search for sustainable alternatives. Lightweight concrete offers additional advantages such as reduced dead load, improved thermal insulation, and lower transportation costs, making it particularly attractive for multi-story buildings and long-span structures.

Cinder aggregate is a porous, lightweight byproduct obtained from steel and iron manufacturing industries. It possesses a rough, irregular texture that promotes bonding with cement paste, while its low density and high air content provide excellent thermal and acoustic insulation properties. Previous studies have demonstrated that cinder can effectively replace natural coarse aggregate up to 45% without significant strength loss. However, at higher replacement levels (60-75%), mechanical performance deteriorates considerably due to increased porosity, higher water absorption, and a weakened interfacial transition zone between cinder particles and cement paste.

The effectiveness of BFRP depends on proper bonding with concrete, but early debonding is a major issue, often occurring near laminate ends due to stress concentration.

While substantial research exists on the material properties of cinder concrete including cube compressive strength, split tensile strength, and microstructural analysis, very few studies have examined its behavior at the structural beam scale. Furthermore, no previous investigation has proposed or validated a reinforcement-based strategy to restore beam-level capacity at high cinder replacement levels.

This study addresses that gap by evaluating the flexural performance of M30 grade reinforced concrete beams with 75% coarse aggregate replacement by cinder aggregate, with and without J-hook anchorage. The specific objectives are to quantify the reduction in beam capacity at 75% cinder replacement without additional reinforcement, and to determine whether J-hooks can restore ductile flexural behavior and load capacity comparable to conventional concrete beams.

II. LITERATURE REVIEW

Previous research on cinder aggregate concrete has focused primarily on material-level properties such as compressive strength, workability, and microstructural characteristics. However, limited attention has been given to beam-scale structural behavior, and no study has explored reinforcement-based strategies to restore capacity at high replacement levels.

Begum, S., (2025) [1] conducted mechanical and durability studies on different grades of concrete using cinder aggregates. The study reported that up to 45% cinder replacement achieved satisfactory performance, while higher replacement levels led to increased porosity and reduced strength. Microstructural analysis using SEM, XRD, and EDX confirmed a denser matrix at 45% replacement, whereas 75% showed weaker bonding and higher porosity.

Toghroli, A., (2025) [2] examined mechanical and durability properties of coal cinder concrete through experimental study and GPR-based analysis. The findings confirmed that cinder's porous nature contributes to strength reduction at high replacement levels due to increased water absorption. The study also demonstrated that GPR can effectively assess internal defects in cinder concrete structures.

Ramu, B., (2015) [3] performed a cost comparison of lightweight aggregate concrete using cinder as a replacement for conventional coarse aggregate. The study demonstrated that cinder aggregate concrete offers economic advantages of approximately 15-20% compared to natural aggregate concrete. The research concluded that cinder concrete is suitable for non-structural and low-load-bearing applications where weight reduction is prioritized.

Gupta, E.H.S., (2015) [4] investigated the properties of lightweight cinder aggregate concrete including compressive strength, split tensile strength, and density. The study reported that cinder's rough and porous surface texture promotes bonding with cement paste, though water absorption remains a concern for long-term durability. The optimum replacement level was found to be 45% for achieving balance between strength and lightweight characteristics. The research recommended using superplasticizers to maintain workability at higher replacement levels.

Sadhana et al., (2024) [5] experimentally investigated cinder aggregate lightweight concrete reinforced with polypropylene fibers at volume fractions ranging from 0.1% to 0.4%. The results showed that waste cinder aggregates can effectively replace conventional coarse aggregates up to 75% when fiber reinforcement is incorporated. Fiber addition enhanced compressive strength, flexural strength, and modulus of elasticity while reducing brittleness. The study concluded that micro-reinforcement is essential for high-volume cinder concrete to achieve adequate structural performance.

Revathy & Sarath Kumar, (2017) [6] studied the structural performance of fiber-reinforced concrete sandwiched in double skinned plated composite beams using J-hooks as shear connectors. The experimental results revealed that ultimate load carrying capacity was considerably enhanced compared to beams without connectors. The addition of hybrid fibers further improved the ductile failure mode and energy dissipation capacity of the composite beams. The study demonstrated that J-hooks effectively transfer shear forces between concrete core and steel faceplates.

Yan, Dong & Wang, (2021) [7] investigated the ultimate strength behavior of sandwich composite beams with J-hooks subjected to two-point loading. The study identified three distinct failure modes including flexure, shear, and combined flexure-shear depending on J-hook spacing and loading conditions. The results showed that J-hook spacing, steel faceplate thickness, and concrete core strength significantly influence the overall structural behavior. The research provided valuable insights into the design of J-hook connected composite structures.

Yan & Hu, (2020) [8] developed steel-UHPC-steel sandwich composite beams with J-hook connectors for enhanced structural performance. Test results showed that even with high J-hook spacing and short shear span ratios, beams exhibited flexural failure with a four-stage working mechanism. The four stages included elastic, plastic, developing, and hardening stages, demonstrating excellent ductility and energy absorption capacity. The study confirmed that J-hooks are effective shear connectors for sandwich composite construction.

Yan, Hu & Wang, (2020) [9] further examined the flexural behaviors of J-hook connected sandwich beams through extensive experimental testing. The study developed analytical models for predicting stiffness and strength indexes, which were validated against nine full-scale beam tests. The proposed models showed good agreement with experimental results, providing design tools for practical applications. The research concluded that J-hook connectors can replace traditional welded studs in many applications.

Liu et al., (2024) [10] analyzed geotextile-encased cinder gravel columns using coupled DEM-FDM numerical modeling. The study demonstrated that cinder-based materials can be effectively utilized in ground improvement applications when provided with appropriate confinement. The geotextile encasement significantly improved the load-settlement behavior and lateral stability of cinder gravel columns. This research extended the application of cinder aggregates beyond concrete into geotechnical engineering applications.

Yang, K.H., (2025) [11] evaluated the toughness of microsteel fiber-reinforced lightweight aggregate concrete with a unit weight of 1600 kg/m³ and compressive strength of 60 MPa. The study confirmed that microsteel fiber reinforcement induces a highly ductile response with strain-hardening behavior after initial cracking. The post-cracking tensile performance was significantly improved compared to plain lightweight concrete. The research demonstrated that high-strength lightweight concrete with excellent ductility is achievable with appropriate fiber reinforcement.

Libre et al., (2011) [12] investigated the mechanical properties of hybrid fiber-reinforced lightweight aggregate concrete made with natural pumice as the coarse aggregate. The study used combinations of steel and polypropylene fibers to achieve synergistic reinforcement effects. Results demonstrated that hybrid fiber combinations enhance both compressive strength and flexural toughness more effectively than single fiber types. The research concluded that hybrid fiber reinforcement is recommended for lightweight concrete subjected to dynamic or impact loads.

Saradar et al., (2020) [13] predicted the mechanical properties of lightweight basalt fiber-reinforced concrete containing silica fume and fly ash through experimental and numerical assessment. The study employed artificial neural networks to develop predictive models for compressive and flexural strength. The results showed that basalt fibers effectively bridge micro-cracks and delay crack propagation in lightweight concrete. The numerical models developed in this study showed good correlation with experimental results.

Xu et al., (2021) [14] studied the mechanical properties and pore structure of recycled aggregate concrete made with iron ore tailings and polypropylene fibers. The research demonstrated that fiber reinforcement improves the interfacial transition zone between recycled aggregates and cement paste. The combination of industrial waste materials with fiber reinforcement offers a sustainable solution for concrete production. The study also found that fiber addition reduces drying shrinkage and improves crack resistance.

Rashad, A.M., (2018) [15] provided a comprehensive overview of lightweight expanded clay aggregate as a building material for structural and non-structural applications. The review discussed manufacturing methods, physical properties, and mechanical performance characteristics relevant to lightweight concrete production. The study also compared expanded clay with other lightweight aggregates including cinder and pumice. The review concluded that expanded clay offers consistent quality compared to natural lightweight aggregates.

Rashad, A.M., (2019) [16] compiled a detailed manual on natural pumice as a lightweight aggregate, covering its origin, properties, and applications in construction. The study provided comparative insights into the performance of pumice versus other lightweight aggregates including cinder and scoria. The review concluded that pumice offers excellent thermal insulation but requires careful mix design to achieve adequate strength. The manual serves as a valuable reference for researchers working with natural lightweight aggregates.

Frontiers in Built Environment, (2026) [17] published a systematic review on properties and development of industrial waste-based artificial aggregates for sustainable construction. The review analyzed manufacturing methods including cold bonding, sintering, and alkali activation for producing artificial aggregates from various industrial wastes. The study identified cinder, fly ash, and slag as promising materials for developing sustainable lightweight aggregates. The review also highlighted research gaps related to long-term durability of waste-based aggregates.

ScienceDirect Review, (2025) [18] presented a state-of-the-art review on carbon footprint reduction through repurposing solid wastes into sustainable construction materials. The review categorized industrial byproducts into three groups: binder substitutes, aggregate replacements, and fiber reinforcements. The study concluded that high-volume waste utilization remains challenging due to variability in material properties and lack of standardized design guidelines. The review called for more research on structural applications of waste-based construction materials.

Springer Article, (2025) [19] investigated the flexural performance of sustainable fibrous lightweight self-compacted concrete slabs using light expanded clay aggregate with glass and polypropylene fibers. Results showed that glass fibers enhanced load capacity by up to 45.7% compared to slabs without fibers. The combination of lightweight aggregate and fiber reinforcement produced slabs with excellent ductility and crack control characteristics. The study demonstrated that self-compacted lightweight concrete is feasible for precast slab applications.

Karthiga Murgan, (2024) [20] evaluated the performance of M25 grade concrete with and without replacement of cinder aggregate. The study reported that cinder replacement up to 50% achieved acceptable strength for non-structural applications. The research recommended using supplementary cementitious materials along with cinder to improve long-term durability characteristics. The study also noted that workability decreases significantly beyond 50%

Shang, R., (2025) [21] investigated the influence of clinker and cinder particle gradation on the properties of blended cement and associated mortars. The study found that particle size distribution significantly affects hydration kinetics and compressive strength development. Optimized gradation of cinder particles improved packing density and reduced water demand. The research concluded that proper particle grading is essential for maximizing the performance of cinder-blended cementitious systems.

Zhou, H., (2025) [22] studied the preparation of burnt coal cinder-based alkali-activated materials and their chemical corrosion behavior. The research demonstrated that alkali-activated cinder materials exhibit excellent resistance to sulfate and acid attacks. The study also reported that the chemical composition of cinder significantly influences the polymerization process and final mechanical properties. These findings suggest potential applications for cinder in aggressive environmental conditions where conventional concrete may deteriorate rapidly.

Summary of Literature Review

The reviewed literature confirms that cinder aggregate is a viable lightweight alternative to natural coarse aggregate, with optimum replacement levels around 45% for satisfactory mechanical performance. Higher replacement levels (60-75%) lead to increased porosity, higher water absorption, and weakened interfacial transition zone, resulting in reduced compressive and tensile strength. Microstructural studies using SEM, XRD, and EDX have confirmed that dense matrix formation is compromised at high cinder replacement levels. Research on J-hook shear connectors has demonstrated their effectiveness in enhancing load capacity, ductility, and failure mode transformation in composite beams. Fiber reinforcement studies have shown that polypropylene, steel, and basalt fibers can improve toughness and crack control in lightweight concrete. Despite extensive material-level research, very few studies have examined beam-scale structural behavior of high-volume cinder concrete. Most importantly, no previous study has investigated the use of J-hook anchorage to restore structural capacity in beams with 75% cinder replacement. This research gap forms the basis for the present experimental investigation.

A. Research Gap

From the literature review, the following observations were made:

1. Extensive research has been conducted on the material-level properties of cinder aggregate concrete including compressive strength, split tensile strength, workability, and microstructural characteristics. However, very few studies have examined the behavior of cinder concrete at the structural beam scale under flexural loading.
2. While previous studies have reported significant strength losses at high cinder replacement levels (60-75%), no investigation has proposed or validated a reinforcement-based strategy to restore structural capacity at these replacement levels.
3. J-hook shear connectors have been successfully used in sandwich composite beams and steel-concrete composite structures, demonstrating enhanced load capacity and ductile failure modes. However, the application of J-hooks as discrete shear reinforcement in high-volume cinder concrete beams has not been explored.
4. No existing study has compared the flexural performance of cinder concrete beams with and without J-hook anchorage under identical conditions. The potential of J-hooks to transform failure mode from brittle shear to ductile flexure in lightweight cinder concrete remains uninvestigated.
5. Therefore, this study aims to fill these gaps by investigating the flexural performance of M30 grade reinforced concrete beams with 75% coarse aggregate replacement by cinder aggregate, with and without J-hook anchorage, and comparing the results with conventional concrete beams.

V. CONCLUSION

This experimental study investigated the flexural performance of lightweight reinforced concrete beams (M30 grade) with 75% coarse aggregate replacement by cinder aggregate, with and without J-hook anchorage. The 28-day cube compressive strength of the 75% cinder mix was 31 N/mm², meeting the target M30 grade. Beams with 75% cinder replacement without J-hooks exhibited a significant reduction in ultimate load capacity (79% of control beam) and failed in brittle diagonal shear mode. In contrast, beams with J-hook anchorage (8 mm dia Fe 550, single-legged both sides, 100 mm spacing) achieved ultimate load capacity exceeding control beams, with failure mode transforming completely from brittle shear to ductile flexure characterized by multiple cracks, visible deflection, and yielding prior to failure.

J-hook anchorage effectively compensated for the structural deficit caused by high-volume cinder replacement through enhanced shear transfer, mechanical interlocking, and improved concrete confinement. This study demonstrates for the first time that 75% cinder replacement can be successfully used in structural reinforced concrete beams provided J-hook anchorage is incorporated. From a practical perspective, this enables sustainable, lightweight concrete construction without compromising structural safety or load-bearing capacity. Future research should focus on optimizing J-hook spacing and diameter for different replacement levels, evaluating long-term durability, and developing design guidelines for industry adoption.

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