"A Review on Fly Ash and Coconut Shell Based Steel Fiber Reinforced Concrete for Sustainable Construction"

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Abstract - The construction industry is under increasing pressure to reduce its environmental footprint while maintaining structural performance and durability. One promising approach is the development of sustainable concrete through the partial replacement of cement and natural aggregates with industrial and agricultural by-products, coupled with fiber reinforcement. This review paper critically examines existing research on the use of fly ash as a partial replacement of cement and coconut shell as a partial replacement of coarse aggregate in Steel Fiber Reinforced Concrete (SFRC). The paper synthesizes findings related to fresh properties, mechanical performance, durability characteristics, and sustainability benefits of fly ash–coconut shell–SFRC systems. Particular attention is given to the role of steel fibers in mitigating strength loss, enhancing ductility, and improving crack resistance. The review identifies optimal replacement ranges, discusses key challenges such as workability and water absorption, and highlights research gaps for future investigation. The study concludes that fly ash–coconut shell–SFRC represents a viable and eco-friendly alternative to conventional concrete, with strong potential for structural and non-structural applications.

Key Words: optics, photonics, light, lasers, templates, journals

1.INTRODUCTION

Concrete is the most widely used construction material worldwide due to its versatility, availability, and relatively low cost. However, conventional concrete production is associated with significant environmental impacts, primarily due to high carbon dioxide emissions from cement manufacturing and excessive consumption of natural aggregates. Cement production alone contributes a substantial share of global CO_2 emissions, while aggregate mining leads to ecological imbalance and depletion of natural resources.

In response to these challenges, researchers have increasingly focused on sustainable alternatives that reduce cement content and replace natural aggregates with waste or renewable materials. Fly ash, a by-product of coal-based thermal power plants, has been extensively studied as a supplementary cementitious material due to its pozzolanic properties and ability to enhance durability. Similarly, coconut shell, an agricultural waste material, has emerged as a potential lightweight coarse aggregate owing to its availability, renewability, and low density.

While the individual use of fly ash and coconut shell in concrete has shown promising results, their combined incorporation may lead to reductions in mechanical strength, particularly tensile and flexural performance. The addition of steel fibers offers an effective solution by improving crack control, energy absorption, and post-cracking behavior. This review paper consolidates and analyzes previous research on fly ash and coconut shell based SFRC to assess its feasibility, performance trends, and sustainability potential.

2. Problem statement

- Need for eco-friendly alternatives to cement and aggregates.
- The production of conventional concrete relies heavily on cement and natural aggregates, both of which have significant environmental drawbacks. Cement manufacturing is energy-intensive and a major source of carbon dioxide emissions, contributing substantially to global greenhouse gas levels. Meanwhile, the extraction of natural coarse aggregates leads to habitat destruction, soil erosion, and depletion of finite natural resources.
- There is an urgent need to identify and develop eco-friendly alternatives that can partially replace cement and aggregates without compromising the structural integrity and durability of concrete. Utilizing industrial by-products like fly ash and renewable agricultural

wastes such as coconut shell in concrete mix design offers a sustainable solution. These materials help reduce environmental pollution, conserve natural resources, and promote waste valorization. However, concerns about the potential weakening of concrete properties necessitate further experimental research to optimize mix proportions and enhance performance, such as through the addition of steel fibers.

- This study addresses the problem of sustainability in concrete production by investigating the combined effects of fly ash and coconut shell as partial replacements along with steel fiber reinforcement to achieve an eco-friendly, durable, and structurally reliable concrete composite.

3. Literature Review

Extensive research has been carried out on the utilization of supplementary cementitious materials, agricultural waste aggregates, and fiber reinforcement to improve the sustainability and performance of concrete. The following section reviews key studies relevant to the use of fly ash, coconut shell aggregate, and steel fibers in concrete.

Kalyana Chakravarthy P. R. et al. (2023) investigated the mechanical performance of steel fiber reinforced conventional concrete and coconut shell concrete of M25 grade. Steel fibers were incorporated in the range of 0.5–2.0% by volume. A total of 12 beam specimens and 36 cylindrical specimens were tested for flexural strength, split tensile strength, impact resistance, and modulus of elasticity. The study concluded that steel fibers significantly improved all mechanical properties of both conventional and coconut shell concrete. An increase in flexural strength of 6.67% was observed at 1.0% steel fiber content in conventional concrete, while a 5.87% increase was reported at 1.5% fiber content in coconut shell concrete, confirming the effectiveness of fibers in crack control and strength enhancement.

Avinash Kumar Padhy and N. Manoj Kumar (2022) examined the effect of a triple blend system comprising fly ash, silica fume, and steel fibers on the strength properties of concrete. Fly ash replacement levels of 0%, 20%, and 40% and silica fume contents of 0–15% were combined with steel fiber dosages of 0%, 0.5%, and 1%. Test results indicated that an optimum mix consisting of 20% fly ash, 10% silica fume, and 1% steel fiber achieved the maximum compressive strength of 81.20 MPa and flexural strength of 8.40 MPa at 28 days, highlighting the synergistic effect of mineral admixtures and fiber reinforcement.

Manvendra Verma et al. (2022) studied the influence of steel fibers on geopolymer concrete cured at ambient temperature using fly ash and GGBS as binders. Steel fibers with an aspect ratio of 60 were added in proportions ranging from 0–2%. The results showed significant improvements in compressive, split tensile, and flexural strength, with an optimum fiber dosage of 1%. Beyond this level, strength reduction was observed due to poor workability and fiber clustering.

Henok Abera and Stephen Jebamalai Raj (2021) reported that partial replacement of cement with fly ash combined with steel fiber reinforcement enhanced the fracture resistance, tensile strength, and ductility of concrete. Their study emphasized that SFRC exhibits superior performance compared to conventional concrete, with properties strongly influenced by fiber geometry, content, and mix proportions.

Sebastin (2021) investigated the use of pulverized coconut shell as a partial replacement for coarse aggregate in M25 grade concrete at replacement levels of 0%, 25%, and 50%. Results indicated a reduction in compressive, split tensile, and flexural strengths with increasing coconut shell content. However, the inclusion of 1% steel fiber and 0.25% glass fiber improved tensile and flexural strength by approximately 10–20%, demonstrating that fiber reinforcement can compensate for strength loss due to coconut shell replacement.

Ichhpal Singh et al. (2020) explored the application of coconut shell aggregate in road construction and pavement layers. Their experimental investigation showed that coconut shell replacement up to 15% satisfied Los Angeles abrasion limits for bituminous roads, while replacement up to 25% was suitable for base and sub-base layers, indicating the material's potential beyond conventional concrete applications.

Babar Ali et al. (2021) studied high-strength concrete incorporating waste steel fibers and fly ash. Fly ash replacement levels of 10–35% and steel fiber dosages of 0.5–1% were examined. Results showed improved tensile properties and durability performance, particularly resistance to chloride penetration and acid attack. The optimum performance was achieved at 1% steel fiber with 10–15% fly ash.

Sai Kumar and M. Jugal Kishore (2021) evaluated self-compacting concrete modified with fly ash and steel fibers. The study revealed that fiber addition adversely affected flow properties beyond 1% fiber content; however, strength characteristics improved, with mixes containing 2% fibers achieving higher compressive and flexural strength.

Ramaiah Prakash et al. (2019) conducted an experimental investigation on eco-concrete incorporating fly ash (10% cement replacement) and coconut shell as coarse aggregate, reinforced with steel fibers (0.25–1.0%). Significant improvements were observed in compressive strength (up to 39%), split tensile strength, flexural strength, and modulus of elasticity. Steel fibers also reduced brittleness and improved post-cracking behavior of coconut shell concrete.

Sanjay Kumar Verma and Sagar Shrivastava (2019) studied coconut shell concrete of M20 grade with replacement levels up to 30%. Results showed a reduction in compressive strength with increased coconut shell content, but confirmed its suitability as lightweight concrete and its potential for sustainable construction.

Earlier studies by Kanojia and Jain (2016), Naresh Kumar and Ganga Raju (2017), and Khadake and Konapure (2012) consistently reported that coconut shell replacement leads to reduced compressive strength; however, acceptable performance can be achieved at moderate replacement levels, particularly when combined with steel fiber reinforcement or increased cement content.

3. Materials Used

Cement (OPC 43 Grade)

Ordinary Portland Cement (OPC) of 43 grade was used as the primary binding material in this study. The cement was fresh, free from lumps, and stored in a dry environment. OPC 43 grade was selected due to its adequate early strength development and suitability for structural concrete applications. The cement properties such as specific gravity, standard consistency, setting time, and compressive strength conform to IS 8112:2013.

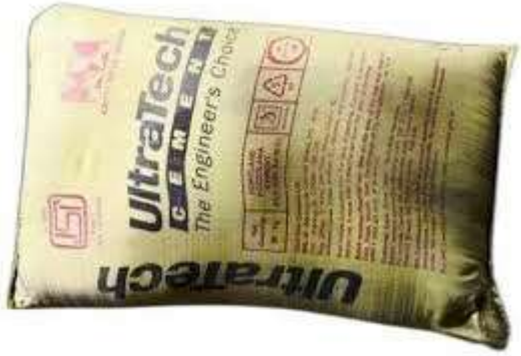

Fig -1: Ordinary Portland Cement (OPC) of 43 grade

Fly Ash

Fly ash used in this investigation was obtained from a thermal power plant and classified as Class F fly ash. It is a fine, powdery material with pozzolanic properties, rich in silica and alumina. Fly ash was used as a partial replacement of cement to enhance sustainability, reduce heat of hydration, and improve long-term strength and durability. The physical and chemical properties of fly ash complied with IS 3812 (Part 1):2013.

Fig -2: Fly Ash

Fine Aggregate (Sand)

Natural river sand conforming to Zone II grading was used as fine aggregate. The sand was clean, well-graded, and free from organic impurities, silt, and clay. Fine aggregate plays a crucial role in workability and strength development of concrete. The properties of sand satisfied the requirements of IS 383:2016.

Fig -3: **Fine Aggregate (Sand)**

Natural Coarse Aggregate

Crushed stone aggregate of nominal maximum size 20 mm was used as natural coarse aggregate. The aggregates were angular in shape, clean, and free from dust and deleterious materials. Natural coarse aggregate provides strength and stiffness to concrete and acts as the primary load-carrying component. The aggregate properties conformed to IS 383:2016.

Fig -4: Crushed stone aggregate

Coconut Shell Aggregate

Coconut shell aggregate was used as a partial replacement for natural coarse aggregate. Coconut shells were collected locally, cleaned to remove fibers and impurities, crushed into angular particles, and sieved to obtain sizes comparable to conventional coarse aggregates. Coconut shell is lightweight, renewable, and eco-friendly, but has higher water absorption compared to natural aggregates. Its use contributes to waste utilization and reduction in concrete density.

Fig -5; Coconut Shell Aggregate

Steel Fibers

Hooked-end steel fibers were used as reinforcement to improve the tensile, flexural, and post-cracking behavior of concrete. The fibers had a high tensile strength and an aspect ratio suitable for concrete applications. Steel fibers were added in varying volume fractions to enhance crack resistance, ductility, and energy absorption capacity of concrete.

Fig -6: **Steel Fibers**

Water

Clean potable water, free from acids, alkalis, oils, and organic matter, was used for both mixing and curing of concrete specimens. The quality of water satisfied the requirements specified in IS 456:2000. Proper water quality is essential for cement hydration and strength development.

Chemical Admixtures

A high-range water-reducing admixture (superplasticizer) based on polycarboxylate ether was used to improve workability and maintain desired slump, especially in mixes containing fly ash, coconut shell aggregate, and steel fibers. The admixture conformed to IS 9103:1999 and helped counteract workability loss due to fiber addition and high water absorption of coconut shell aggregates.

5. CONCLUSIONS

1. This review highlights that the combined use of fly ash, coconut shell, and steel fibers offers a practical and sustainable approach to green concrete development.
2. Moderate replacement levels, supplemented with appropriate fiber reinforcement, can produce concrete with acceptable workability, enhanced mechanical performance, and improved sustainability.
3. Fly ash–coconut shell–SFRC shows strong potential for structural and non-structural applications, particularly in regions with abundant agricultural waste availability.
4. Future research should focus on durability performance, structural-scale testing, and comprehensive life cycle assessment to facilitate widespread adoption.

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