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To Study the Effect of Brick Kiln Ash as a Partial Replacement for Fine Aggregate in Cement Concrete

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Abstract: Concrete is a fundamental construction material composed of cement, sand, and coarse aggregates, with sand and aggregates primarily sourced from natural resources. However, the rapid pace of urbanization and infrastructure development has led to the depletion of these essential materials, necessitating sustainable alternatives. This research investigates the feasibility of using Brick Kiln Ash (BKA), a waste by-product generated from the combustion of agricultural residues such as mustard husks in brick kilns, as a partial replacement for fine aggregates in concrete. The study aims to address environmental concerns associated with the disposal of BKA, while exploring its potential to enhance the mechanical properties of concrete. Concrete mixes of M25 grade were prepared with varying percentages of BKA (0%, 10%, 20%, 30%, 40%, and 50%) replacing natural fine aggregate. Comprehensive tests were conducted to evaluate the workability, compressive strength, split tensile strength, and flexural strength of both fresh and hardened concrete at different curing ages. Preliminary results suggest that BKA, when used within optimal replacement levels, can improve concrete performance while reducing environmental impact and material costs. This research not only contributes to sustainable construction practices but also promotes effective waste management by reusing industrial and agro-waste by-products in concrete production.
Keywords: Brick Kiln Ash (BKA), Sustainable M25 Grade Concrete, Compressive Strength, Split Tensile Strength, Flexural Strength.

I. INTRODUCTION

Researchers have increasingly focused on utilizing industrial and agricultural by-products as partial replacements for conventional concrete constituents. Waste materials such as fly ash, bottom ash, silica fume, and waste glass have demonstrated potential as supplementary cementitious or aggregate materials. Bottom ash, produced by coal combustion in thermal power plants, and brick kiln ash (BKA), generated from brick production using agro-waste fuels, are among the more abundant by-products. In regions like Rajasthan, mustard husk is commonly used as a fuel in brick kilns due to its high calorific value and low ash content, resulting in a substantial volume of BKA. Despite being a waste product, BKA possesses properties such as fine particle size and high silica content, which make it a candidate for partial replacement of fine aggregates in concrete. However, BKA also presents challenges, such as inconsistent composition, high water absorption, and non-cementitious behavior, which can affect concrete performance. Improper disposal of BKA has led to environmental issues, including land degradation, air pollution, and water contamination, highlighting the urgent need for its sustainable utilization. While studies have investigated the use of ash from coal and rice husk-fired kilns, limited research exists on the potential application of brick kiln ash derived from mustard husk—particularly in the Rajasthan region. This study aims to fill that gap by evaluating the feasibility of using BKA as a partial replacement for fine aggregates in concrete. The research focuses on analyzing the impact of BKA on concrete's workability, compressive strength, tensile strength, flexural strength, and cost-effectiveness. By exploring these parameters, the study seeks to promote sustainable construction practices and provide a productive solution to the environmental challenges posed by industrial and agro-waste disposal.

II. LITERATURE REVIEW

1) Dongsheng Zhang et al. (2024) explored the use of fly ash (FA) as a substitute for sand in concrete, replacing cement with 0–100% FA. Results showed enhanced mechanical properties with increases in compressive (40%), split tensile (30%), flexural (30%) strength, and elasticity modulus (40%). High FA content improved matrix density but reduced porosity at 80–100% due to limited interaction. Concrete with 100% FA had the lowest dry unit weight, suggesting reduced seismic risk. Overall, FA improved strength and sustainability in concrete applications.

2) P. Aggarwal et al. (2007) studied bottom ash as a fine aggregate replacement in concrete (0–50%). Although early-age strength was lower than normal concrete, long-term results showed bottom ash mixtures (20% and 50%) exceeded control strength at 90 days. Workability and density decreased with higher ash content, but strength gain over time proved its viability for structural use.
3) Parvati V. K et al. (2013) examined fly ash as a sand replacement (0–80%) under elevated temperatures (200–800°C). Optimal strength performance occurred at 40% replacement, especially at 200°C. Beyond 40%, strength declined. Fly ash increased strength and reduced workability, requiring superplasticizers. The study confirms FA as a viable substitute even under thermal stress.
4) Kiran Kumar M S et al. (2018) analyzed bottom ash as a partial fine aggregate replacement (up to 50%). Optimal performance was at 10% replacement, improving compressive (15.05%), split tensile (10.5%), and flexural strength (8.2%). The study concluded that low-percentage bottom ash enhances mechanical properties and supports sustainable waste reuse.
5) Amith S D et al. (2015) investigated Brick-Kiln-Ash (BKA) as a sand replacement in M30 concrete (15–30%). At 25% replacement, compressive and tensile strengths increased by 21.78% and 13.53%, respectively. However, 30% replacement showed a decline. Reinforced beams with 25% BKA performed well, suggesting its effective use in sustainable concrete design.
6) Dilip Kumar et al. (2014) evaluated bottom ash as a fine aggregate replacement (10–50%) in M30 concrete. Maximum compressive (39.16 N/mm²) and flexural strength (9.24 N/mm²) were achieved at 40% replacement after 56 days. Beyond 40%, strengths declined. The study demonstrated that bottom ash is effective up to 40% replacement, promoting environmental sustainability and economic benefits.
7) B. Archana et al. (2014) studied the mechanical properties of concrete with 0–50% bottom ash as a sand substitute. Initial strength was lower, but long-term performance improved. At 30%–40% replacement, compressive strength reached 108%–105% and flexural strength 113%–118% of the control mix at 90 days, validating bottom ash's potential for sustainable concrete use despite slower strength gain.
8) Dr. R. G. D'Souza (2017) investigated full replacement of sand with bottom ash in M20–M30 concretes. Compressive strength improved, and environmental benefits included reduced illegal sand mining and material cost. The study concluded that bottom ash is a viable full replacement, promoting green construction.
9) Abhyuday Titiksh et al. (2022) analyzed the combined use of fly ash (FA) and bottom ash (BA) in M35 concrete using multiple linear regression (MLR). FA improved strength and durability; however, BA alone underperformed. The FA-BA mix had dense microstructures and lower embodied carbon, confirming the feasibility of using industrial by-products to replace natural sand sustainably.
10) Radhika P. Bhandary et al. (2023) explored coffee husk ash (CHA) as a partial sand substitute (0–8%). At 4% CHA, compressive strength increased by 28.4%, and improved durability against acid and chloride attack was observed. While workability declined at higher CHA levels, the 4% mix optimized strength, workability, and thermal properties, highlighting CHA's potential as a green construction material.

III. OBJECTIVES OF STUDY

The main objectives of this study are:
1) To design M25 grade of reference concrete.
2) To partially replace fine aggregate by brick kiln ash in variable percentages.
3) To determine optimal dose that can replace fine aggregate in design.
4) To study the fresh and hardened properties of modified concrete at different ages.
5) To do cost analysis for determining the viability of replacement.

IV. MATERIALS USED

A. *Cement*

Ordinary Portland Cement (OPC) 43 Grade (Ambuja brand), conforming to IS: 8112–2013, was used. It exhibited a 28-day compressive strength of 52.4 MPa. Key properties: 29.7% consistency, 3.15 specific gravity , initial and final setting times of 135 and 220 minutes, and 375 m²/kg fineness. Test followed IS: 4031 procedures. These characteristics confirm its suitability for general concrete applications.

Table I. Properties of Cement (OPC-43)

S.No.	Particular	Test Results
1.	Consistency of cement	29.7
2.	Specific Gravity	3.15
3.	Initial Setting Time	135 Minute
4.	Final Setting Time	220 Minute
5.	Fineness of cement	375 (m^2/kg)
6	Compressive Strength	
	3 days	32.3 Mpa
	7 days	42.4 Mpa
	28 days	52.4 Mpa

B. *Coarse Aggregate*

Locally sourced crushed stone aggregates (20 mm nominal size) conforming to IS: 383–2016 were used. Physical properties included 2.63 specific gravity and 0.6% water absorption. Sieve analysis showed compliance with grading requirements, indicating good packing potential and suitability for structural concrete.

Table II. Physical properties of coarse aggregate

S.No.	Particulars	Test Results
1.	Water Absorption	0.6%
2.	Specific gravity	2.63
3.	Gradation	20 mm nominal size graded aggregate
4.	Shape	Crushed Angular

C. *Fine Aggregate*

Natural river sand (Zone I, IS: 383–2016) with 2.58 specific gravity and 2.98 fineness modulus was used.

Table III. Physical Property of Brick kiln Ash

S.No.	Characteristics	Test Results
1.	Colour	Yellowish
2.	Specific gravity	2.58
3.	Bulk density	1650 kg/m^3
4.	Fineness modulus	2.98

Additionally, Brick Kiln Ash (Zone II) sourced from multiple brick industries was tested as partial fine aggregate replacement. It showed comparable fineness modulus (2.24), specific gravity (2.52), moderate bulk density (1650 kg/m^3), and acceptable gradation, making it a potential sustainable alternative to sand.

D. *Water*

Clean potable water conforming to IS 456:2000 and IS 3025 standards was used for mixing and curing. Test results: pH 7.4, TDS 1270 mg/l, chloride 260 mg/l, all within permissible limits. The water was found suitable for concrete production.

V. METHODOLOGY

1) M25 grade concrete mix was designed as per IS 10262 with a 0.45 water-cement ratio.
2) Fine aggregate was partially replaced with Brick Kiln Ash (BKA) at 0%, 10%, 20%, 30%, 40%, and 50%.
3) Workability was assessed using the slump test.
4) For strength tests, the following specimens were cast for each mix:
   a. Compressive strength: Cubes (150×150×150 mm)

b. Split tensile strength: Cylinders (150×300 mm)
c. Flexural strength: Beams (150×150×700 mm)

5) All specimens were cured in water for 7 and 28 days.
6) Strength results were recorded and analyzed to evaluate BKA performance.

VI. MIX DESIGN OF CONCRETE

The M25 grade concrete mix was designed according to IS 10262 with varying Brick Kiln Ash (BKA) replacements for fine aggregate from 0% to 50%.

Table IV. Mix proportions after adjustment for dry aggregates

Particulars /Mixture No.	M1 (0%BKA)	M2 (10%BKA)	M3 (20%BKA)	M4 (30%BKA)	M5 (40%BKA)	M6 (50%BKA)
Cement (kg/m^3)	400	400	400	400	400	400
BKA (%)	0	10	20	30	40	50
BKA (kg/m^3)	0	68	136	204	272	340
Fine Aggregate(kg/m^3)	680	612	544	476	408	340
Coarse aggregate(kg/m^3)	1089	1089	1089	1089	1089	1089
Water (Kg)	193	193	193	193	193	193
Air Temperature(^{0}C)	31	30	31	32	32	30
Concrete Density(kg/m^3)	2397	2376	2362	2351	2340	2326

VII. RESULTS AND DISCUSSIONS

A. *Workability*

The slump flow test was conducted to evaluate the workability of self-compacting concrete (SCC) with varying proportions of Brick-Kiln Ash (BKA) as a partial replacement for fine aggregates. All tests were performed in accordance with standard procedures using an Abrams slump cone and a pre-moistened base plate. The results indicated a clear trend: as the proportion of BKA increased, the slump flow diameter decreased, signaling a reduction in the concrete's workability. This decline is primarily attributed to the higher fine content and porous nature of BKA, which increases the overall water demand of the mix. Despite maintaining a constant water-cement ratio across all batches, the reduced flowability suggests that the BKA particles absorb more water and offer higher surface area, thus hindering the free movement of the mix. The observed slump values fell within acceptable limits for measurement validity, and no test had to be repeated due to excessive variation in spread diameter. The results are graphically presented in the accompanying chart, which illustrates the inverse relationship between BKA content and slump flow diameter.

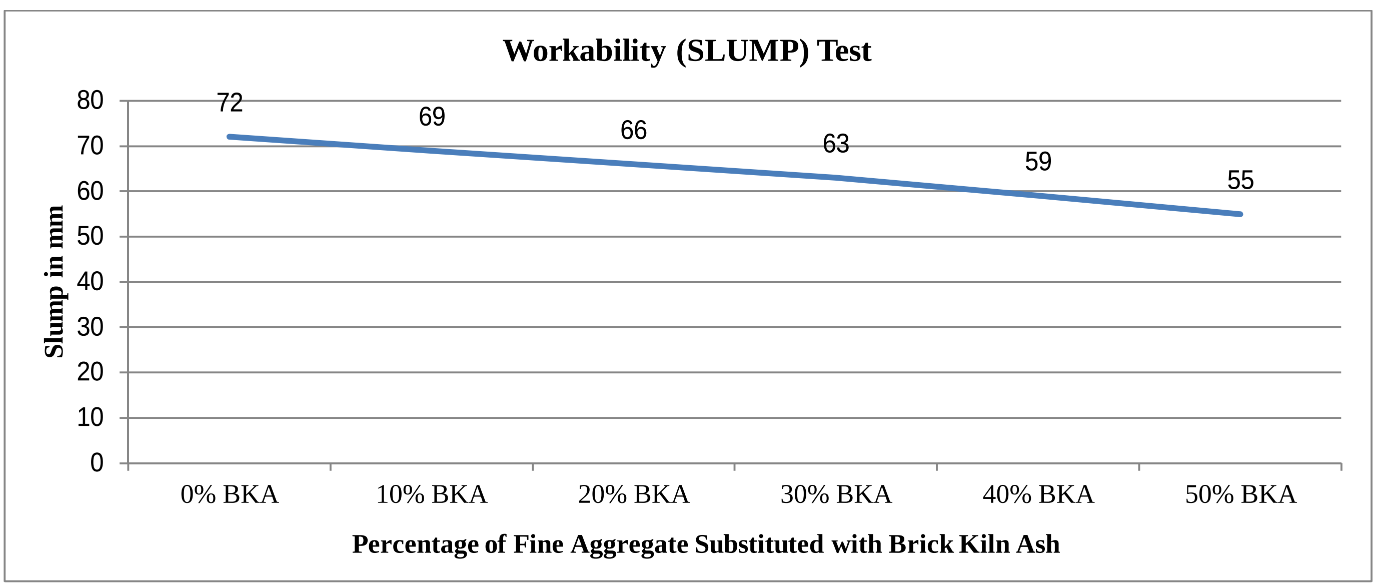

Figure 1: Variation of Slump values at different proportions of Brick Kiln Ash

B. Compressive Strength

The compressive strength test showed that strength generally increased with Brick Kiln Ash (BKA) replacement up to 20–30%. At 0% BKA, the strength was 22.25 N/mm² at 7 days and 31.85 N/mm² at 28 days. The highest values were observed at 20% BKA: 24.10 N/mm² (7 days) and 32.97 N/mm² (28 days). Strength remained stable at 30% but declined beyond this point. At 50% BKA, strength dropped to 20.57 N/mm² and 26.54 N/mm², the lowest among all mixes. Results indicate that up to 30% BKA replacement is viable, with 20% being optimal. The trend highlights BKA's potential as a sustainable partial fine aggregate substitute.

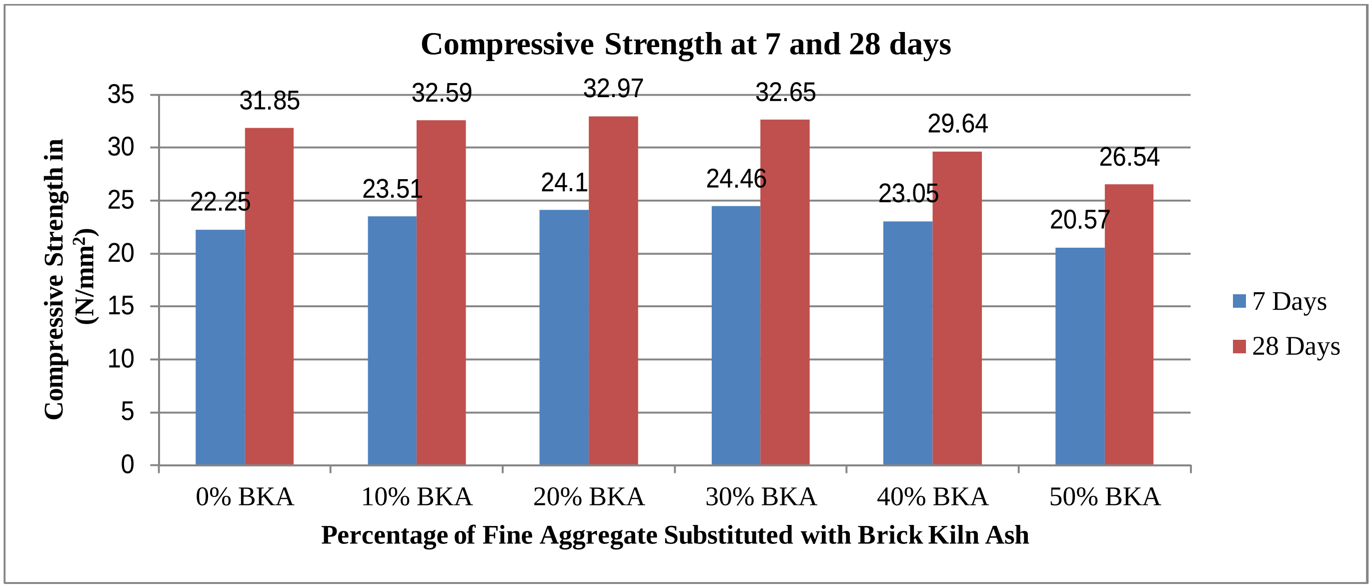

Figure 2: Compressive Strength at 7 & 28 days.

C. Split Tensile Strength

The split tensile strength results of concrete mixes with varying percentages of Brick Kiln Ash (BKA) as partial fine aggregate replacement show a clear pattern over the 7- and 28-day curing periods. The control mix (0% BKA) recorded an average tensile strength of 2.55 N/mm² at 7 days and 3.26 N/mm² at 28 days. A 10% replacement increased the strength slightly to 2.71 N/mm² and 3.36 N/mm², respectively. The highest values were observed at 20% BKA, with 2.73 N/mm² at 7 days and 3.42 N/mm² at 28 days. However, with 30% BKA, the tensile strength began to decrease, measuring 2.45 N/mm² at 7 days and 3.06 N/mm² at 28 days. The strength reduction continued at 40% BKA, showing values of 2.16 N/mm² and 2.69 N/mm², and dropped further at 50% BKA to 2.03 N/mm² at 7 days and 2.48 N/mm² at 28 days. These results suggest that the inclusion of BKA enhances split tensile strength up to 20% replacement, beyond which the performance gradually declines. Thus, 20% BKA appears to be the most effective replacement level for improving tensile strength in concrete

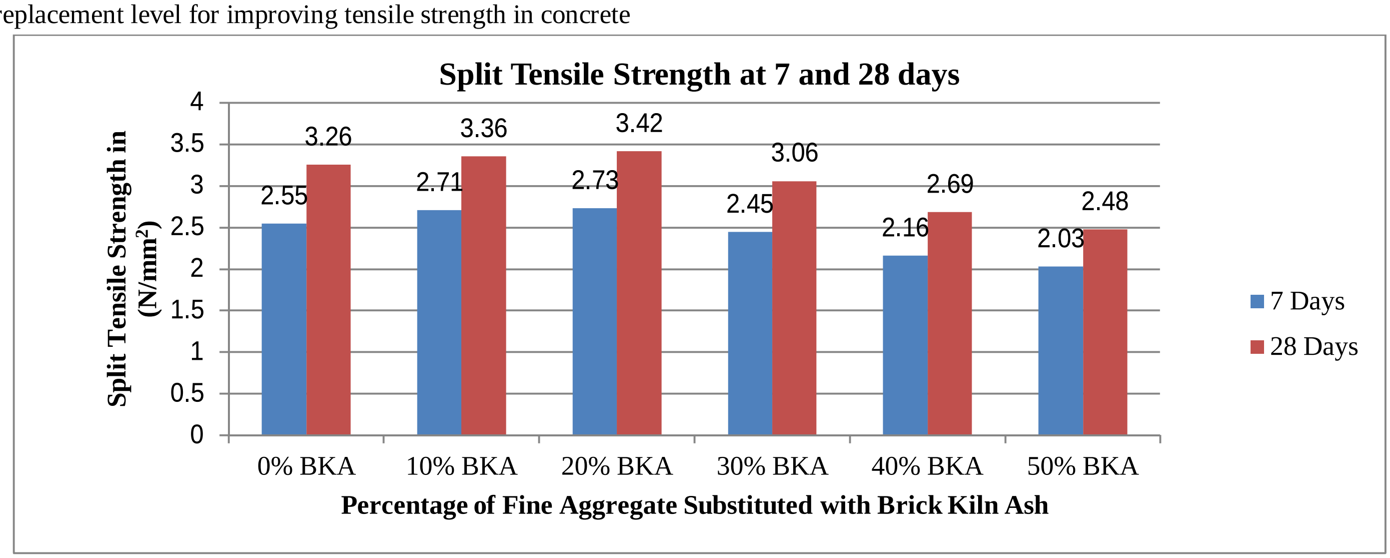

Figure 3: Split tensile strength at 7 and 28 days.

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D. Flexural Strength

The flexural strength (F.S.) results for concrete mixes with varying percentages of Brick Kiln Ash (BKA) at 7 and 28 days show a clear trend. The mix without BKA achieved a flexural strength of 2.95 N/mm² at 7 days and 3.86 N/mm² at 28 days. As BKA was incorporated at increasing levels up to 20%, the flexural strength improved, reaching a peak of 3.19 N/mm² at 7 days and 4.19 N/mm² at 28 days with a 20% replacement. This indicates that replacing fine aggregate with 20% BKA yields the highest flexural strength.

Concrete containing 10% and 30% BKA also showed improved performance compared to the mix without BKA, suggesting that low to moderate amounts of BKA can enhance strength due to its pozzolanic activity. However, when the BKA content exceeded 30%, a decline in strength was observed. At 40% BKA, the strength dropped to 2.91 N/mm² at 7 days and 3.77 N/mm² at 28 days, while at 50% BKA, it further decreased to 2.73 N/mm² and 3.41 N/mm², respectively. This decline is likely due to the reduced cementitious material, which affects strength development. Overall, the results suggest that the optimal BKA replacement level for improved flexural strength is around 20%, beyond which the benefits diminish.

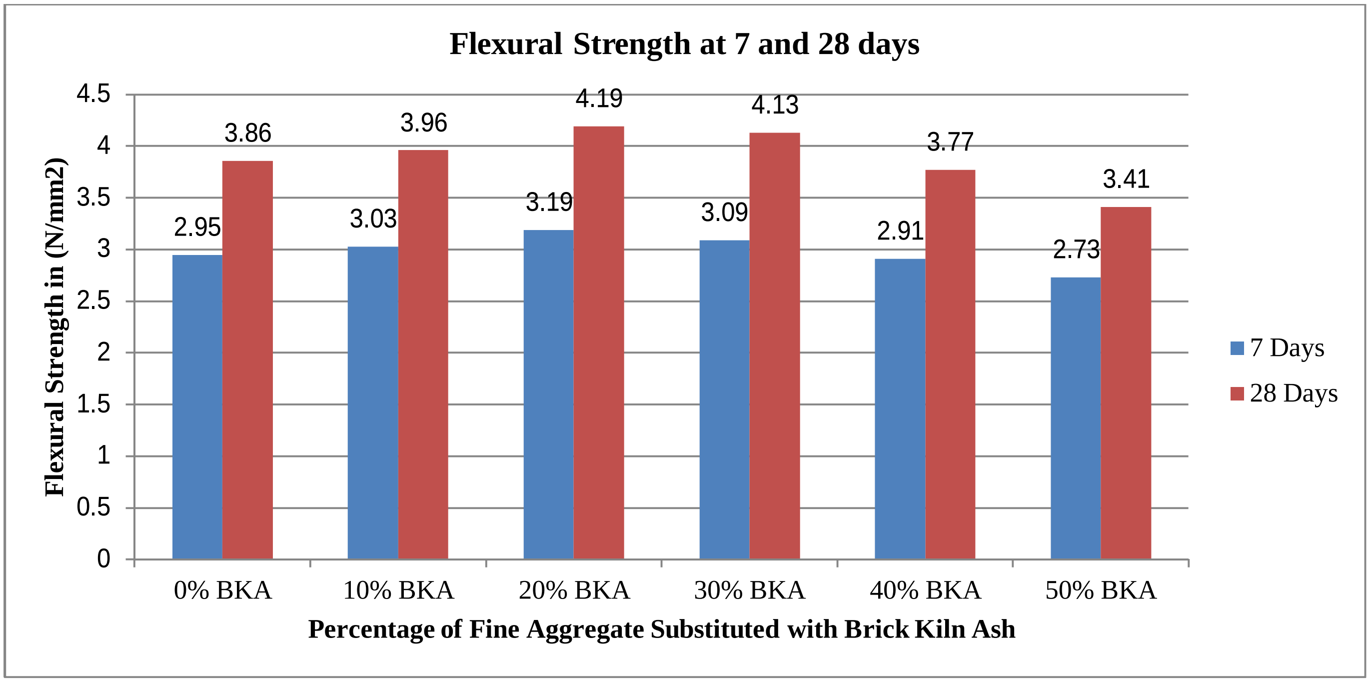

Figure 4: Flexural Strength at 7 & 28 days

E. Material Cost Comparison

The material cost analysis reveals a consistent decrease in concrete cost with increasing Brick Kiln Ash (BKA) content. At 0% BKA, the cost was INR 4650 per m³, which gradually reduced to INR 4378 at 50% BKA. This represents a maximum cost reduction of 5.80%. Each incremental replacement resulted in further savings, with 30% BKA yielding a 3.48% reduction. The trend demonstrates that BKA is a cost-effective alternative to natural fine aggregate. While economic efficiency improves with higher BKA, performance factors must also be considered. Overall, BKA enhances the affordability of concrete without major cost trade-offs.

Table III: Material Cost Comparison (per m³ of concrete)

Concrete Mix	BKA %	Cost (INR)	Cost Reduction (%)
M1	0	4650	-
M2	10	4596	1.16
M3	20	4541	2.32

M4	30	4487	3.48
M5	40	4432	4.64
M6	50	4378	5.80

VIII. CONCLUSIONS

1) Workability decreased as BKA content increased, with slump values dropping from 72 mm (0%) to 55 mm (50%).This is due to BKA's finer particles and high water absorption, which reduce available mixing water. Even with a constant water-cement ratio, BKA lowers slump values significantly.
2) Compressive strength increased up to 20% BKA, peaking at 32.97 N/mm² (28 days), then declined at higher levels. The gain is due to BKA's pozzolanic and filler effects improving matrix bonding. Concrete specimens incorporating 20% brick kiln ash as a fine aggregate substitution showed improved compressive strength compared to the nominal mix. After 7 and 28 days of curing, the strength increased by approximately 8.31% and 3.51%, respectively, indicating better performance under compression at this substitution level.. At 50% BKA, strength dropped to 26.54 N/mm², likely from excess fines and weak bonding.
3) Split tensile strength improved with up to 20% BKA, reaching 3.42 N/mm² at 28 days. Replacing fine aggregate with 20% brick kiln ash in concrete resulted in improved split tensile strength by 7.06% after 7 days and 4.90% after 28 days of curing compared to the nominal mix concrete.. Beyond 20%, strength declined, with the lowest value of 2.48 N/mm² at 50% BKA. This is due to poor aggregate interlock and reduced cohesion from excess fines.
4) Flexural strength peaked at 20% BKA with 4.19 N/mm² at 28 days. Replacing fine aggregate with 20% brick kiln ash in concrete led to increased flexural strength by 8.13% after 7 days and 8.54% after 28 days of curing compared to the nominal mix concrete.Strength decreased after 30% BKA, with 3.41 N/mm² at 50%. Strength reduces at higher fine aggregate replacement because bottom ash particles increase porosity and weaken bonding. Their irregular shape and higher water absorption lower cement hydration and concrete cohesion.
5) Concrete cost dropped steadily from ₹4650 (0% BKA) to ₹4378 (50% BKA), a 5.80% savings. The reduction is due to BKA being cheaper than natural sand. Using BKA lowers cost and supports sustainable concrete production.

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