iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 Issue: XII Month of publication: December 2024

DOI: https://doi.org/10.22214/ijraset.2024.65834

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 12 Issue XII Dec 2024- Available at www.ijraset.com

Over-Burnt Bricks in Sustainable Construction a Viable Alternative to Natural Aggregates

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Abstract: Brick production plays a vital role in the construction industry, where high temperatures are used to shape and fire clay or shale into durable building materials. However, over-burnt bricks—resulting from excessive or prolonged heating—often become brittle, darkened, and structurally compromised, making them unsuitable for typical construction applications. These over-burnt bricks are commonly discarded as waste, contributing to landfill build up and environmental concerns. In contrast, repurposing over-burnt bricks offers an opportunity for sustainable waste management and resource conservation. When crushed into a material known as brick blast, these over-burnt bricks can serve as a substitute for coarse aggregates in concrete or partially replace coarse aggregate, reducing the dependence on natural resources. An experimental investigation was conducted to assess the potential of using brickblast in concrete production, focusing on its impact on mechanical properties, workability, and durability. Early results indicated that brickblast not only serves as an effective waste disposal method but also enhances concrete strength and durability, offering a more eco-friendly alternative to conventional concrete. By incorporating brickblast, energy consumption and carbon emissions from cement production can be minimized, while contributing to a circular economy. This innovative approach supports sustainability in the construction industry by reducing landfill waste, conserving natural aggregates, and providing a cost-effective solution to enhance concrete performance. Ultimately, utilizing over-burnt bricks in concrete production can lead to more sustainable and environmentally responsible building practices.
Keywords: Bricks, Density, Durability, Strength, Sustainability.

I. INTRODUCTION

Brick production is an essential process in the construction industry, involving the shaping, drying, and firing of clay or shale at high temperatures, typically between 900°C and 1,100°C. In District Budgam, Jammu and Kashmir, the brick manufacturing sector plays a pivotal role in meeting the region's construction material demands, leveraging the abundance of clay and water resources. However, the production process occasionally results in over-burnt bricks, characterized by darkened, brittle, and structurally compromised properties, rendering them unsuitable for conventional construction purposes. These defective bricks are often discarded as waste, leading to significant environmental and economic challenges. Improper disposal of over-burnt bricks in landfills or open spaces contributes to land pollution and ecosystem degradation, while also representing economic losses for kiln owners due to missed opportunities for recycling or repurposing. Such practices undermine the potential for resource optimization and may incur penalties or reputational damage for brick manufacturers. Conversely, reusing over-burnt bricks presents a sustainable alternative for the construction industry, aligning with principles of a circular economy. Crushed over-burnt bricks, known as "brickblast," can be repurposed as aggregates in concrete or as partial cement replacements, providing a dual benefit of waste reduction and resource conservation. Integrating brickblast into concrete production offers an eco-friendly solution to the environmental and economic issues posed by over-burnt bricks. Experimental investigations were undertaken to explore the feasibility of utilizing crushed over-burnt bricks as substitutes for conventional coarse aggregates in concrete production. The study assessed various performance metrics, including mechanical strength, durability, and workability, to determine the suitability of brickblast as an alternative material. Results revealed that concrete incorporating crushed over-burnt bricks as substitute to aggregates exhibited enhanced mechanical properties. Additionally, the concrete demonstrated superior durability, with greater resistance to environmental, suggesting its viability for long-term applications in construction. Beyond performance improvements, the substitution of natural coarse aggregates with overburnt brick blast significantly reduced the demand for virgin materials, contributing to the conservation of natural resources. This approach aligns with sustainable construction practices, offering an eco-friendly solution to waste management challenges associated with brick production. The findings highlight the potential of integrating over-burnt bricks into concrete as a cost-effective, resource-efficient alternative that promotes environmental sustainability and supports the transition toward a circular economy.

II. LITERATURE REVIEW

1) Suehail Aijaz Shah and Dr. Umer Mushtaq, 2024 investigated Brick Kiln Dust (BKD) as a partial cement substitute, finding that 15% replacement improved compressive and tensile strength due to pozzolanic reactions. Beyond this, strength declined due to hydration issues. The study highlights BKD's potential for sustainable construction by reducing cement use, managing waste, and lowering costs.
2) Modi Himabindu et al., 2024 explored the potential of using waste materials in brick production to address the growing demand for building materials while promoting sustainability. They highlighted the importance of converting various waste types, such as bottom ash, clay waste, and red mud, into valuable resources for brick manufacturing. The study emphasizes the need for energy-efficient and environmentally friendly brick production processes that reduce pollutants. Additionally, the paper calls for further research to improve cost-effectiveness and develop low-cost, lightweight, and eco-friendly bricks, aligning with the construction industry's shift towards greener building materials.
3) Deb et al., 2024 explored sustainable solutions for demolition waste management, focusing on the reuse of brick aggregates and brick dust in the construction industry. Their study found that bricks from demolition sites exhibited higher compressive strength than regular bricks, making them suitable for building purposes. Brick dust was also identified as an effective void filler. The research demonstrated that incorporating recycled brick waste into lean concrete not only enhanced strength but also offered significant cost savings, contributing to environmental sustainability. The study emphasized the benefits of recycling brick waste, including reducing carbon emissions, conserving resources, and fostering a circular economy in construction.
4) Lihua Zhu and Zengmei Zhu, 2020 examined the reuse of clay brick waste in mortar and concrete, highlighting its potential for both cement and aggregate replacement. They found that clay brick powder (CBP) exhibits pozzolanic activity, making it suitable as a partial cement substitute, while recycled clay brick aggregate (RBA) can replace natural coarse aggregates. The study demonstrated that recycled clay brick aggregate concrete (RBAC) could achieve medium- to low-strength concrete, suitable for various construction applications. The research emphasizes the importance of understanding the mechanical and durability properties of clay brick waste for its effective use in sustainable construction.
5) Shooshtarian et al. 2011 examined strategies to minimize brick waste in Australia's construction sector using the Brick-LoWMoR (Low of Waste, More of Resource) model. Applying circular economy principles, the study analysed the brick supply chain from production to end-of-life stages. It proposed practical solutions to improve construction and demolition waste management and informed building codes to promote sustainable resource use and reduce environmental impact.

III. MATERIAL

A. Cement

The experimental investigation utilized Khyber Brand Ordinary Portland Cement (OPC) 43 Grade. This cement is commonly used in construction for general-purpose applications due to its reliability and strength. The OPC 43 Grade is known for its high initial strength, making it suitable for a variety of structural works.

In this study, Khyber Brand OPC 43 Grade cement was chosen to ensure consistency and quality, allowing for an accurate assessment of the experiment's parameters and outcomes.

B. Fine Aggregate

The fine aggregate used in the experimental investigation was natural river sand, sourced from the Doodganga River in the Chadoora belt of District Budgam.

The river sand was carefully selected to ensure it was free from any debris, organic material, or vegetative cover, ensuring its purity and suitability for the study. This high-quality sand was chosen to provide a consistent and reliable material for the experiment, helping to maintain the integrity of the results.

C. Coarse Aggregate

The coarse aggregate used in the experimental investigation consisted of 20 mm crushed river bed boulders, collected from the crusher zone in Astanpora, Chattergam. These aggregates were carefully selected to ensure uniform size and quality, making them ideal for the study.

The crushed aggregate from this region is known for its durability and strength, contributing to the overall reliability of the experimental outcomes.

D. Water

The concrete mix for the experimental investigation was prepared using portable water supplied through the drinking water line. This water was free from any impurities or harmful substances, ensuring that it met the required standards for mixing and curing concrete. The use of clean, potable water was essential to achieve the desired strength and quality of the concrete, ensuring reliable and accurate results in the study.

E. Over-Burnt Bricks – Crushed

Overburnt bricks were collected from a nearby brick kiln located in Nowbugh, Chadura, Budgam. This brick kiln is known for producing a variety of bricks, including overburnt ones, which are typically discarded due to their compromised quality. These overburnt bricks were selected for the experimental investigation, as they possess unique properties that can be useful for specific applications in construction materials. The bricks were gathered from the kiln site and processed further to meet the required specifications for the study, ensuring their suitability for use as an alternative material in the concrete mix. Overburnt bricks were initially crushed using a Compression Testing Machine (CTM) to reduce their size. Subsequently, medium-sized pieces were further broken down into smaller fragments by placing them on a solid iron block in the Blacksmith section of the workshop, where they were struck with a club hammer. The broken brick pieces were then collected and passed through an IS 20 mm size sieve, with the fraction that passed retained for use in the experimental investigation. The remaining fraction, which was retained on the sieve, was further broken down to reduce its dimensions to meet the required size specifications.

IV. CONCRETE MIX

For the experimental investigation, M20 grade concrete was considered, typically requiring about 8 bags of cement per cubic meter, with each bag weighing approximately 50 kilograms. This corresponds to a cement content of 400 kg per cubic meter, based on a nominal mix ratio of 1:1.5:3 for cement, sand, and aggregates, respectively. Subsequently, the quantity of coarse aggregate in the mix was replaced with crushed overburnt bricks to examine their impact on the concrete's properties in successive mix ratios. The detailed mix proportions, including the substitution of coarse aggregates with crushed overburnt bricks, are provided in the table below for reference and further analysis.

Table 1: Concrete Mix ratios

MIX	Cement kg/cum	Fine Aggregate kg/cum	Coarse Aggregate kg/cum	Crushed Over Burnt Brick kg/cum	Remarks
REF	400	600	1200	0	Reference Mix
10BC	400	600	1080	120	10% of crushed over burnt bricks
20BC	400	600	960	240	20% of crushed over burnt bricks
30BC	400	600	840	360	30% of crushed over burnt bricks
40BC	400	600	720	480	40% of crushed over burnt bricks
50BC	400	600	600	600	50% of crushed over burnt bricks

A water-cement ratio of 0.45 was maintained for all the concrete mixes throughout the experimental investigation. Initially, the batched quantities of the dry mix were combined in a concrete mixer for 2-3 minutes to ensure uniform distribution of the ingredients. Following this, the calculated amount of water was added to the mix, and the mixer was operated for another of 5-7 minutes to achieve a homogeneous mixture. A fraction of the fresh concrete was then collected in a mix collecting tray and assessed for workability. The remaining concrete was poured into cube and cylindrical moulds for each respective mix. These moulds were subsequently placed in a shaded area overnight. After this initial setting period, the specimens were removed from the moulds and submerged in a curing tank until the specified testing age.

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V. RESULTS & DISCUSSION

A. Workability

The workability of each concrete mix was assessed using the slump test, as outlined in the relevant standards. According to the Indian Standard (IS) 1199:1959, which specifies the procedure for conducting the slump test, the slump value serves as an indicator of the workability of the concrete mix. The slump values obtained for each mix are presented in Figure 1.

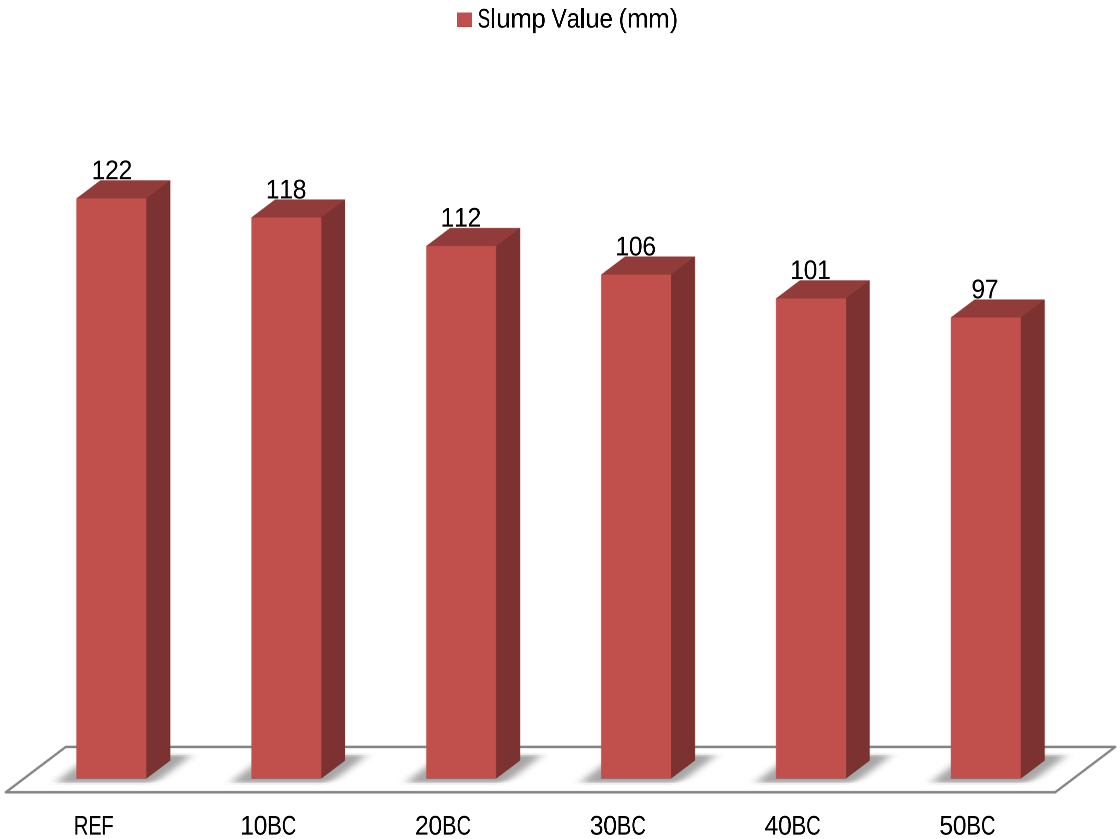

Fig. 1 Slump value for different Concrete Mix

The slump values for each concrete mix show a clear decline in workability as the proportion of crushed brick (BC) increases. The reference mix (REF) with conventional coarse aggregate recorded the highest slump value of 122 mm, indicating good workability. However, as the proportion of crushed brick increased, the slump values decreased progressively: 118 mm for 10% BC, 112 mm for 20% BC, 106 mm for 30% BC, 101 mm for 40% BC, and 97 mm for 50% BC. This reduction in workability is primarily due to the angular shape, rough texture, and higher water absorption of crushed bricks, which increase internal friction and reduce the amount of free water available for the mix (Neville, 2012; Kumar & Gupta, 2015). The porous nature of crushed bricks also results in greater water absorption, reducing the effective water content available for hydration and flow, which contributes to a stiffer, less workable mix (Poon et al., 2004). These factors lead to a noticeable decline in the flowability and ease of placement of the concrete as the proportion of crushed brick increases.

B. Density

To calculate the density of concrete using the weighing cubes method, prepared and cured standard concrete cubes (150 mm each side) for the required period. After curing, surface-dry the cubes and weigh them accurately. Calculate the density by, using the formula:

Density = Weight/Volume

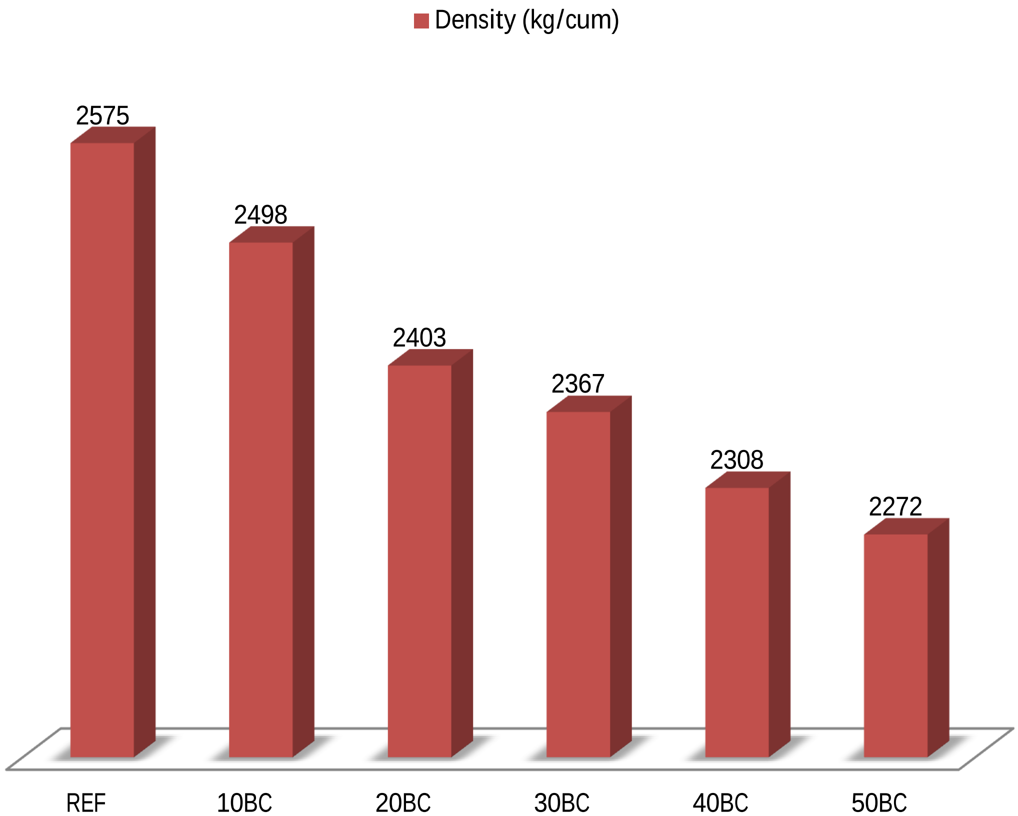

Fig. 2 Density of hardened Concrete from different mix proportions.

The Figure - 2 shows that the density of concrete decreases as the percentage of crushed over-burnt brick (COB) content increases. The reference mix (REF) has the highest density (2575 kg/m³), while the mix with 50% COB content (50BC) exhibits the lowest density (2272 kg/m³).

This trend can be attributed to the intrinsic properties of overburnt bricks, which typically have a lower density compared to natural aggregates. Overburnt bricks are porous due to their irregular microstructure formed during excessive firing, resulting in a reduced overall mass when used as a partial replacement for conventional aggregates. Observation, indicating that incorporating porous materials into concrete increases void spaces within the mix, further reducing density.. The decrease in density aligns with findings by researchers such as Nataraja et al. (2001) and Ahmad et al. (2013), who noted similar reductions in density when using lightweight or recycled aggregates.

C. Compressive strength

Compressive strength, a key property of concrete, reflects its ability to resist axial loads without failure. Typically assessed using standard cubic specimens under controlled conditions, as per ASTM C39 or IS 516, it provides critical insights into structural capacity and material quality.

The compressive strength of concrete with overburnt brick inclusion shows a distinct trend, varying with the percentage of inclusion, as illustrated in Figure 98. Compressive strength, a key property of concrete, reflects its ability to resist axial loads without failure. Typically assessed using standard cubic specimens under controlled conditions, as per ASTM C39 or IS 516, it provides critical insights into structural capacity and material quality. The compressive strength of concrete with overburnt brick inclusion shows a distinct trend, varying with the percentage of inclusion, as illustrated in Figure 3. Compressive strength, a key property of concrete, reflects its ability to resist axial loads without failure. Typically assessed using standard cubic specimens under controlled conditions, as per ASTM C39 or IS 516, it provides critical insights into structural capacity and material quality. The compressive strength of concrete with overburnt brick inclusion shows a distinct trend, varying with the percentage of inclusion, as illustrated in Figure 3.

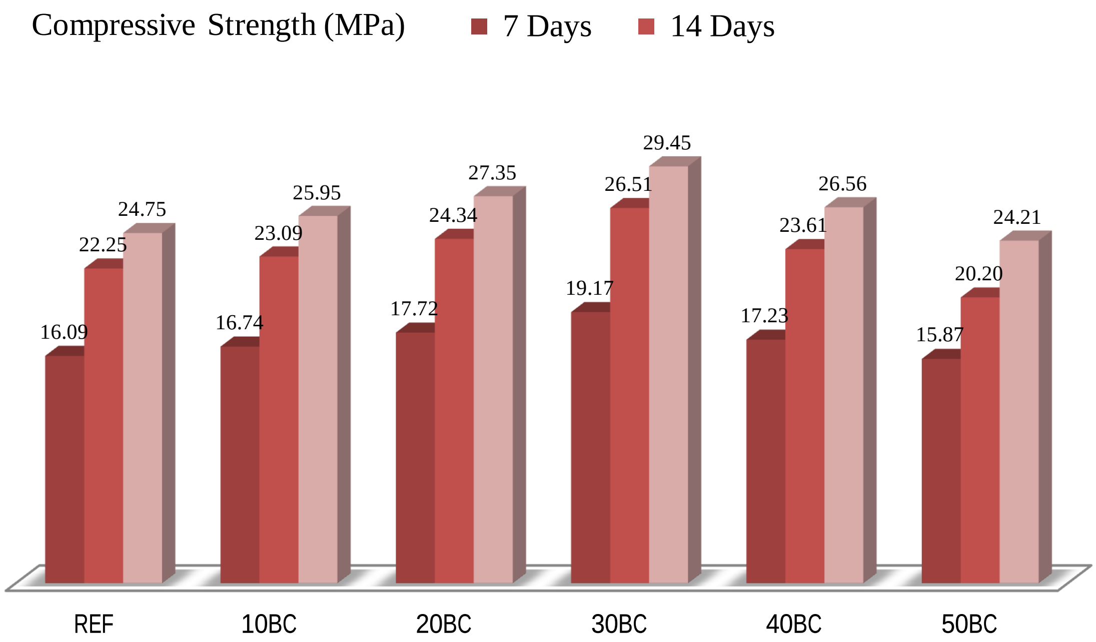

Fig. 3 Compressive Strength for various Mix (MPa)

The reference mix (REF), without the inclusion of overburnt brick, exhibited a compressive strength of 24.75 MPa at 28 days. The addition of 10% overburnt brick (10BC) resulted in a slight increase to 25.95 MPa, indicating a marginal improvement. A further increase to 20% inclusion (20BC) enhanced the strength to 27.35 MPa, reflecting a noticeable improvement. The highest compressive strength, 29.45 MPa, was observed at 30% inclusion (30BC), identifying this as the optimal replacement level. However, beyond 30% inclusion, the strength began to decline, with 40% (40BC) and 50% (50BC) inclusions reducing the strength to 26.56 MPa and 24.21 MPa, respectively, the latter falling below the reference mix. These results indicate that while overburnt brick inclusion improves compressive strength up to an optimal threshold, excessive replacement negatively affects the concrete's performance, likely due to reduced workability and weaker bonding within the matrix. The observed trend can be attributed to the physical and chemical characteristics of overburnt brick and its interaction with the cementitious matrix. Initially, strength enhancement is attributed to the pozzolanic activity and filler effect of overburnt brick particles, which are rich in silica and alumina. These components contribute to secondary hydration reactions, generating additional calcium silicate hydrate (C-S-H) gel that strengthens the concrete (Memon et al., 2019). Additionally, the angular shape and rough texture of the particles enhance interlocking and bonding between the cement paste and aggregates (Safiuddin et al., 2018), contributing to the improved mechanical performance observed up to the 30% inclusion level. Beyond the optimal 30% inclusion, the compressive strength decline can be explained by the excessive replacement of conventional aggregates, disrupting particle packing density and reducing the cohesiveness of the mix. Moreover, the relatively lower density of overburnt brick compared to natural aggregates increases porosity, weakening the hardened concrete (Kumar et al., 2020). Excessive replacement may also dilute the cement paste's ability to effectively bind particles, thereby compromising the overall mechanical properties. These findings align with previous studies that emphasize the significance of maintaining an optimal replacement level for alternative materials in concrete. For example, Safiuddin et al. (2018) and Kumar et al. (2020) have highlighted that while partial substitution with pozzolanic materials improves strength and durability, excessive replacement leads to diminished performance due to increased porosity and weakened bond strength within the matrix.

D. Split Tensile Strength

Split tensile strength is a critical property of concrete, reflecting its resistance to tensile stresses important for structural design. Evaluated using cylindrical specimens under diametral compression per ASTM C496 or IS 5816, this test indirectly measures tensile capacity by inducing failure through tensile stress. It provides valuable insights into the material's performance under tensile and flexural forces, essential for structural integrity.

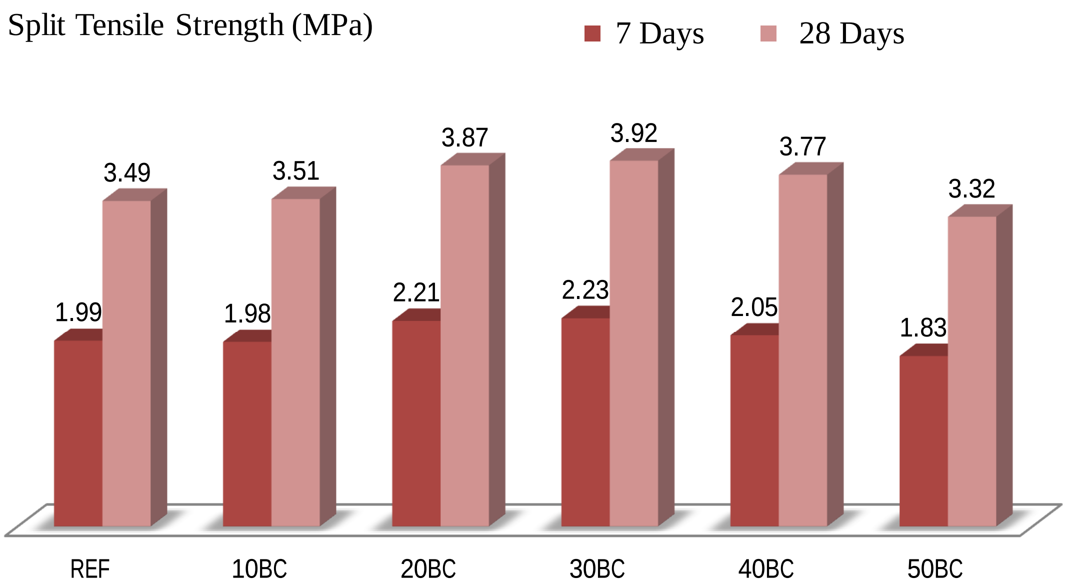

Fig. 4 Split Tensile Strength (MPa)

The split tensile strength of concrete incorporating overburnt brick exhibits a clear variation dependent on the percentage of inclusion. The reference mix (REF), without overburnt brick, demonstrated a split tensile strength of 3.49 MPa at 28 days. A marginal increase to 3.51 MPa was observed with a 10% inclusion of overburnt brick (10BC). At 20% inclusion (20BC), a more pronounced improvement was noted, with the tensile strength rising to 3.87 MPa. The peak tensile strength of 3.92 MPa was recorded at 30% inclusion (30BC), suggesting this as the optimal replacement level for enhancing the tensile properties of the concrete. However, beyond this optimal 30% inclusion, a decline in split tensile strength was observed. The tensile strength decreased to 3.77 MPa at 40% inclusion (40BC), and further reduced to 3.32 MPa at 50% inclusion (50BC), lower than that of the reference mix. The initial enhancement in tensile strength is primarily attributed to the pozzolanic activity of overburnt brick. This activity contributes to the formation of additional calcium silicate hydrate (C-S-H) gel through secondary hydration reactions, which improves the bond strength and cohesion within the concrete matrix. The angular, rough texture of the overburnt brick particles likely improves the interlocking between the particles and enhances stress distribution under tensile loading. The observed decline in strength beyond the 30% inclusion level can be attributed to increased porosity and reduced density associated with higher levels of overburnt brick. Excessive replacement of conventional aggregates can disrupt the particle packing density, thereby weakening the bond between the cement paste and aggregates. This reduction in homogeneity can compromise the concrete's ability to resist tensile stresses effectively. These findings are consistent with similar studies, which emphasize the importance of maintaining an optimal replacement level to balance the benefits of improved strength with the potential drawbacks of excessive inclusion. The variation in split tensile strength observed in this study can be explained by the physical and chemical properties of overburnt brick and its interaction with the cementitious matrix. Up to 30% inclusion, the improvement in tensile strength is primarily attributed to the pozzolanic activity of overburnt brick, which promotes the formation of additional C-S-H gel, thereby enhancing the concrete's tensile capacity (Memon et al., 2019). Moreover, the rough texture and angular shape of the overburnt brick particles contribute to improved interlocking and stress distribution, further enhancing performance (Safiuddin et al., 2018). However, beyond 30% inclusion, the decline in tensile strength can be attributed to the increased porosity and reduced cohesiveness of the mix caused by excessive overburnt brick replacement. The lower density of overburnt brick relative to natural aggregates increases voids within the concrete matrix, weakening its tensile resistance (Kumar et al., 2020). Furthermore, excessive overburnt brick inclusion can dilute the cement paste's capacity to effectively bind the particles, leading to diminished mechanical properties (Zhu et al., 2017). These results are in alignment with existing literature, which underscores the necessity of optimizing the replacement level of alternative materials to balance improvements in strength and durability with potential drawbacks such as increased porosity and weakened bond strength.

VI. COST COMPARISON

A cost comparison was conducted by evaluating the market rates of raw materials used in the manufacturing of 1 cubic meter of concrete, based on a local survey of the Nagam, Chadoora district in Budgam, Jammu and Kashmir. The rates were carefully estimated to reflect current market prices for the material components only, including aggregates, cement, and additives, without considering other factors such as labour, transportation, or overhead costs. The comparison was made between the reference concrete mix and the mix containing 30% over-burnt brick (30BC), which yielded the optimum results in terms of strength and performance. This focused analysis provides an accurate representation of the economic feasibility of incorporating over-burnt bricks as a partial replacement for conventional aggregates in concrete production, highlighting the potential cost implications of using alternative materials in the region's construction industry.

Table 2- 453534 Cost Comparison

S. No	Raw Material	Rate (₹)	Unit	Reference Concrete		Mix 30 BC	
				Quantity (Kg)	Amount (₹)	Quantity (Kg)	Amount (₹)
1	Cement	9.5	Kg	400	3800	400	3800
2	Fine Aggregate	2	Kg	600	1200	600	1200
3	Coarse Aggregate	0.87	Kg	1200	1044	840	730.8
4	Over Burnt Bricks	0.34	Kg	0	0	360	122.4
					6044		5853.2

The cost comparison between the reference concrete mix and the 30% over-burnt brick (30BC) mix revealed a 3.15% variation in cost. This slight difference in cost emphasizes the economic feasibility of incorporating over-burnt bricks as a partial replacement for conventional aggregates, offering a cost-effective alternative without significant financial impact. The relatively small variation underscores the potential for utilizing over-burnt bricks in concrete production, particularly when considering the associated environmental and sustainability benefits.

VII. CONCLUSION

1) Workability decreased with increasing crushed brick (BC) content, from 122 mm slump in the reference mix to 97 mm at 50% BC. The reduction in workability is attributed to the angular shape, rough texture, and higher water absorption of crushed bricks.
2) Density decreased as overburnt brick (COB) content increased, from 2575 kg/m³ in the reference mix to 2272 kg/m³ at 50% COB. The reduction in density supports the development of lightweight concrete.
3) Compressive strength improved up to 30% COB inclusion, reaching 29.45 MPa, but declined at higher replacement levels. Optimal strength is achieved through pozzolanic activity, while excessive replacement increases porosity, weakening the mix.
4) Split tensile strength increased up to 30% COB inclusion, peaking at 3.92 MPa, before decreasing with higher inclusion levels. Strength improvement is due to pozzolanic activity and enhanced interlocking, while excessive inclusion reduces tensile resistance.
5) The reduction in density facilitates the development of lightweight concrete, offering potential cost savings in materials and transportation.
6) The inclusion of overburnt brick may improve thermal conductivity, enhancing the insulation properties and energy efficiency of concrete.
7) The use of recycled overburnt and crushed bricks helps reduce construction waste, conserve natural resources, and lower the carbon footprint of concrete production.
8) The cost comparison between the reference concrete mix and the 30% over-burnt brick (30BC) mix revealed a minimal 3.15% variation, demonstrating that incorporating over-burnt bricks as a partial replacement for conventional aggregates is a cost-effective alternative with negligible financial impact.
9) The study supports a circular economy by incorporating recycled materials, reducing the demand for virgin aggregates, and promoting sustainable construction practices.

The findings of this experimental investigation highlight the potential of over-burnt bricks (COB) as a sustainable alternative to natural aggregates in concrete production. The results demonstrate that incorporating over-burnt bricks can reduce concrete density, facilitating the development of lightweight concrete, which offers significant benefits in terms of material savings and transportation costs. Additionally, the inclusion of over-burnt bricks can improve the thermal conductivity of concrete, contributing to better insulation and energy efficiency in buildings. Most importantly, the use of recycled over-burnt bricks supports environmental sustainability by reducing construction waste, conserving natural resources, and lowering the carbon footprint of concrete production. This aligns with the principles of a circular economy, offering a viable and sustainable solution for the construction industry. Thus, the incorporation of over-burnt bricks not only provides an effective way to manage waste but also serves as a promising and environmentally friendly alternative to traditional natural aggregates.

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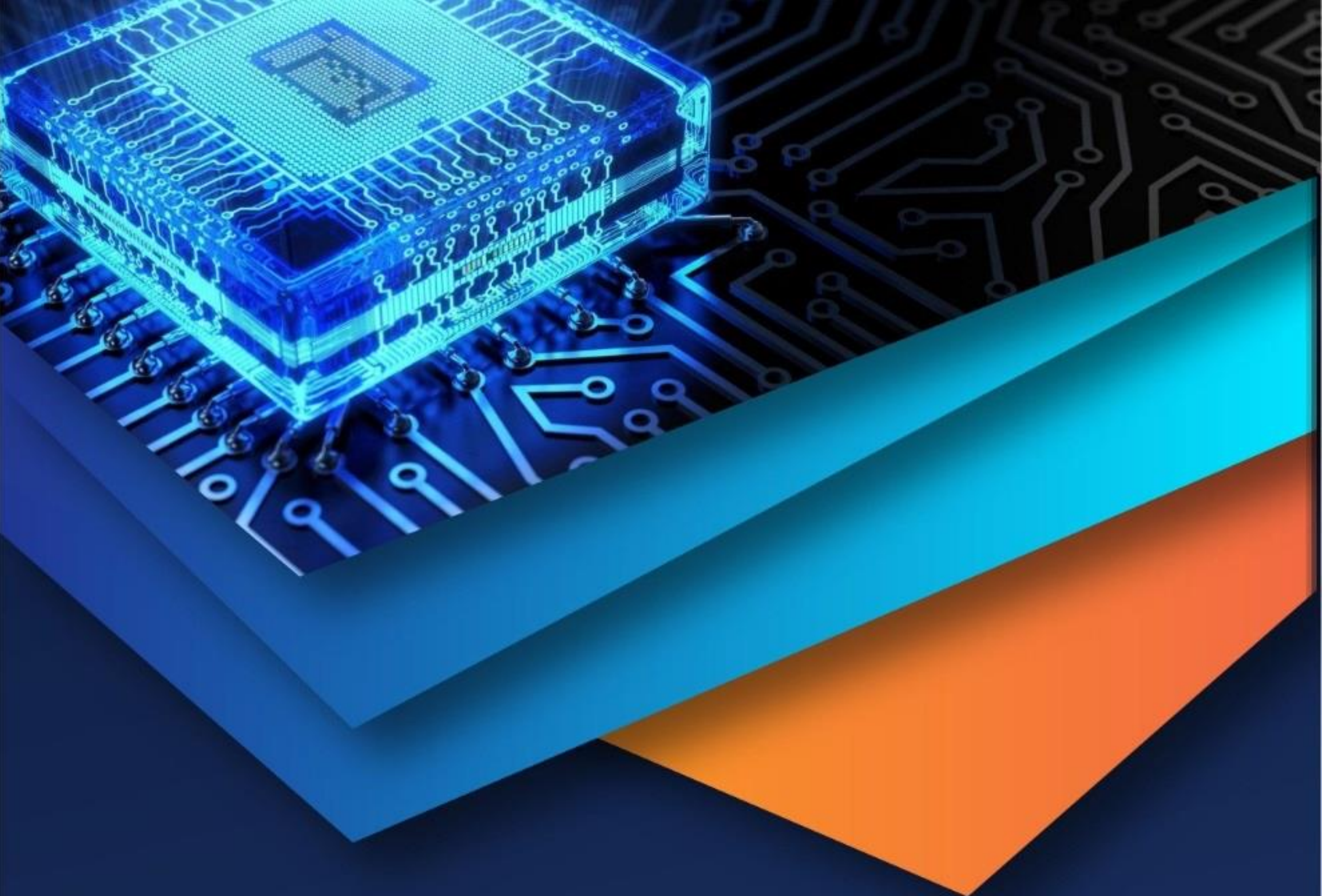

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