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Utilization of Kota Stone Waste and Fly Ash in Sustainable Concrete: Mechanical Performance Evaluation

Baldev Thakur[1], Anil Rajpoot[2]
[1]*Research Scholar, Department of Civil Engineering, Vikrant University Gwalior*
[2]*Assistant Professor, Department of Civil Engineering, Vikrant University Gwalior*

Abstract: *The growing demand for sustainable construction practices has led to the exploration of alternative materials that can reduce the environmental footprint of concrete. This study investigates the mechanical performance of concrete using Kota Stone Waste (KSW) as a partial and full replacement for natural aggregates, and fly ash as a partial cement substitute. M30 grade concrete was prepared with varying replacement levels: KSW at 25%, 50%, 75%, and 100%, and fly ash at 10%, 20%, and 30%. A total of 20 concrete mix combinations were tested for compressive and split tensile strength at 7, 28, 60, and 90 days. Results indicate that up to 50% replacement of natural aggregates with KSW, along with 10% fly ash, produces concrete with strength characteristics comparable to or better than conventional mixes, particularly at later curing ages. However, increasing fly ash beyond 20% resulted in reduced early-age strength. Workability also decreased with higher KSW content due to its angularity and low water absorption. The optimal mix, NAC-10-50, demonstrated a strong balance between sustainability and structural performance. This research confirms that Kota stone waste and fly ash can be effectively used in concrete to promote eco-friendly, cost-efficient, and structurally sound construction, thereby supporting circular economy and resource conservation goals.*
Keywords. *Kota Stone Waste, Fly Ash, Sustainable Concrete, Compressive Strength, Aggregate Replacement*

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I. Introduction

Concrete is the most widely used construction material globally, second only to water in terms of consumption, due to its strength, durability, and versatility in structural applications (Mehta & Monteiro, 2020). However, the conventional production of concrete poses significant environmental challenges. The extraction of natural aggregates—primarily from riverbeds and quarries—leads to deforestation, habitat loss, and depletion of natural resources, while the production of cement is responsible for nearly 8% of global anthropogenic CO_2 emissions (IEA, 2023). As urbanization accelerates, particularly in developing countries like India, the demand for concrete is expected to rise, increasing the urgency to find sustainable alternatives.

In this context, the construction industry is turning toward the utilization of industrial by-products and locally available waste materials. One such material is Kota Stone Waste (KSW), generated in large volumes during the cutting and polishing of Kota limestone slabs in Rajasthan, India. Approximately 30–40% of the extracted stone ends up as waste in the form of chips and dust, which are usually dumped in landfills, leading to land pollution and ecological imbalance (Khandelwal et al., 2021). Repurposing this waste in concrete offers a dual benefit: reducing environmental damage caused by aggregate mining and managing stone waste responsibly.

Recent studies have demonstrated that KSW, owing to its angular shape, high specific gravity, and rough texture, can enhance the interfacial bonding in concrete, thereby improving its mechanical performance (Patel & Shah, 2022). When used as coarse or fine aggregate replacements, KSW has shown potential to produce concrete with satisfactory compressive and tensile strength. Moreover, combining KSW with fly ash—a pozzolanic by-product of coal combustion—can further reduce the cement content in concrete, leading to a significant reduction in embodied carbon and material costs (Singh et al., 2021).

Despite the known benefits of these materials individually, limited research has explored their combined effects on the mechanical properties of concrete over various curing periods. The present study addresses this gap by evaluating the performance of M30 grade concrete containing varying levels of KSW and fly ash. The objective is to determine the optimal replacement levels that achieve a balance between sustainability and structural performance. Through comprehensive laboratory testing and data analysis, this research aims to contribute practical solutions for greener and more efficient concrete mix designs.

II. Materials and Methods

2.1 Materials

The materials used in this study include Ordinary Portland Cement (OPC) of 53 grade, conforming to IS: 12269-1987, selected for its high early strength and suitability for structural applications. Coarse aggregates comprised both conventional Hard Blue Granite (HBG) and Kota Waste Stone Aggregates (KWSA), with the latter sourced from waste by-products of stone-cutting units in Rajasthan. Fine aggregates consisted of natural river sand and finely ground Kota Waste Stone Dust (KWSD), serving as a sustainable substitute. Class F fly ash, known for its low calcium content and pozzolanic activity, was used as a partial replacement for cement. Potable tap water was used for both mixing and curing, meeting the IS: 456-2000 standards to avoid impurities that could affect concrete properties.

2.2 Mix Design

Concrete mix proportions were developed to achieve a characteristic strength of M30, following the guidelines of IS: 10262-2019. A consistent water–cement (w/c) ratio of 0.45 was maintained for all batches to ensure uniformity in workability and strength development. Fly ash was introduced as a partial cement substitute at three levels—10%, 20%, and 30% by weight—while KWSA and KWSD were used to replace natural coarse and fine aggregates at replacement ratios of 25%, 50%, 75%, and 100%. This resulted in a total of 20 different mix combinations, including the control mix with 100% conventional materials.

2.3 Testing

Mechanical performance was assessed through standardized testing procedures. For compressive strength, concrete cubes of 150 mm dimensions were cast and tested after curing periods of 7, 28, 60, and 90 days, following IS: 516-1959 guidelines. Split tensile strength was measured using cylindrical specimens of 150 mm diameter and 300 mm height, with tests also conducted at the same curing intervals, as per IS: 5816-1999. Each mix had three specimens tested per age group to ensure accuracy and consistency. These tests provided critical data on the structural viability of concrete incorporating KWS and fly ash.

III. Results and Discussion

3.1 Compressive Strength Trends

The compressive strength of concrete is a critical parameter for evaluating its load-bearing capacity and overall structural performance. In this study, 28-day compressive strength results for selected mixes with varying levels of Kota Waste Stone (KWS) and fly ash are presented in Table 1. The control mix (NAC-0-0), composed entirely of natural aggregates and 100% cement, achieved the highest 28-day compressive strength at 45.5 MPa. This serves as the benchmark for evaluating the performance of sustainable alternatives.

When 50% of the natural aggregates were replaced with KWS and 10% of the cement with fly ash (NAC-10-50), the 28-day compressive strength was 38.1 MPa—a reduction of approximately 16% from the control, but still well within acceptable structural limits for M30 grade concrete. Increasing the fly ash content to 20% at the same KWS level (NAC-20-50) further reduced the strength to 34.2 MPa, indicating that higher fly ash levels delay early strength development. The most significant reduction was observed in mix NAC-10-100, which had full replacement of natural aggregates with KWS and 10% fly ash, yielding a strength of 32.8 MPa. Despite this decrease, the strength remains suitable for many non-critical structural applications.

These results suggest that partial replacement (up to 50%) of natural aggregates with KWS, especially when combined with a moderate fly ash content (10%), can achieve satisfactory compressive strength while promoting sustainability. Full replacement of aggregates and higher fly ash content can still yield usable concrete but may be more appropriate for non-load-bearing or semi-structural elements.

Table 1. Compressive Strength @ 28 Days for Varying KWS and Fly Ash Levels

Mix Code	Fly Ash (%)	KWS Replacement (%)	Compressive Strength (MPa)
NAC-0-0	0	0	45.5
NAC-10-50	10	50	38.1
NAC-20-50	20	50	34.2
NAC-10-100	10	100	32.8

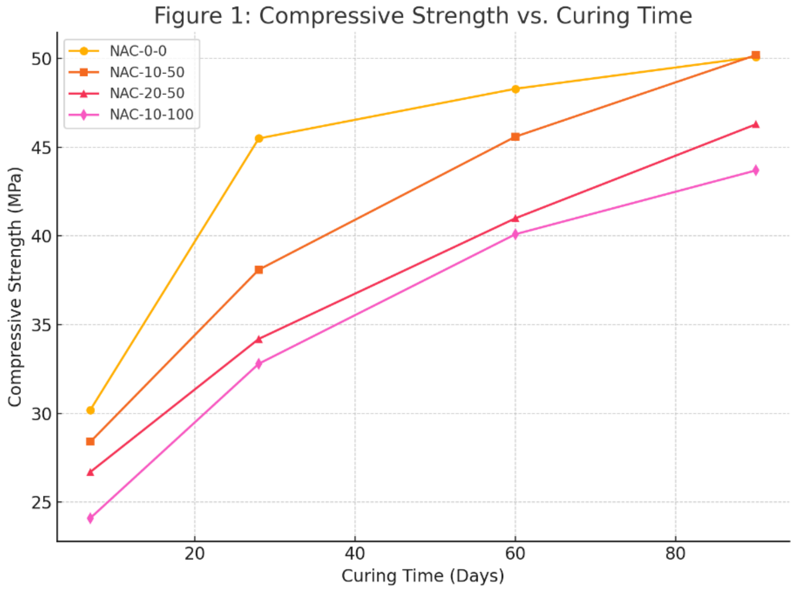

Figure 1. Compressive strength development over time

3.2 Split Tensile Strength Performance

Split tensile strength is a crucial indicator of concrete's resistance to cracking and its ability to withstand tensile stresses, which are particularly important for structural durability and service life. Table 2 presents the 28-day split tensile strength values for selected concrete mixes incorporating varying percentages of Kota Waste Stone (KWS) and fly ash.

The control mix (NAC-0-0), with 100% natural aggregates and no fly ash, recorded a 28-day split tensile strength of 3.6 MPa. Interestingly, a slight increase in tensile strength was observed in mix NAC-10-25, where 25% of natural aggregates were replaced with KWS and 10% of cement was replaced with fly ash. This mix achieved a strength of 3.9 MPa, which is approximately 8% higher than the control. The improvement is attributed to the angular and rough texture of KWS, which enhances the mechanical bond at the interfacial transition zone (ITZ), as well as the pozzolanic reaction from the fly ash contributing to a denser matrix.

As the replacement levels increased, however, a declining trend was observed. Mix NAC-20-50, which had 50% KWS and 20% fly ash, showed a split tensile strength of 3.5 MPa, slightly lower than the control. In mix NAC-30-75, the tensile strength further dropped to 3.0 MPa, indicating that higher levels of both KWS and fly ash can negatively impact early-age tensile properties. This decline is likely due to the slower pozzolanic activity of fly ash and the reduced cohesion in the matrix caused by excessive replacement of natural aggregates.

Overall, moderate use of KWS and fly ash appears beneficial for tensile performance, but excessive substitution compromises bond strength and crack resistance. These observations emphasize the need for optimized proportions to balance sustainability and mechanical reliability in concrete design.

Table 2. Split Tensile Strength @ 28 Days

Mix Code	Fly Ash (%)	KWS Replacement (%)	Split Tensile Strength (MPa)
NAC-0-0	0	0	3.6
NAC-10-25	10	25	3.9
NAC-20-50	20	50	3.5
NAC-30-75	30	75	3.0

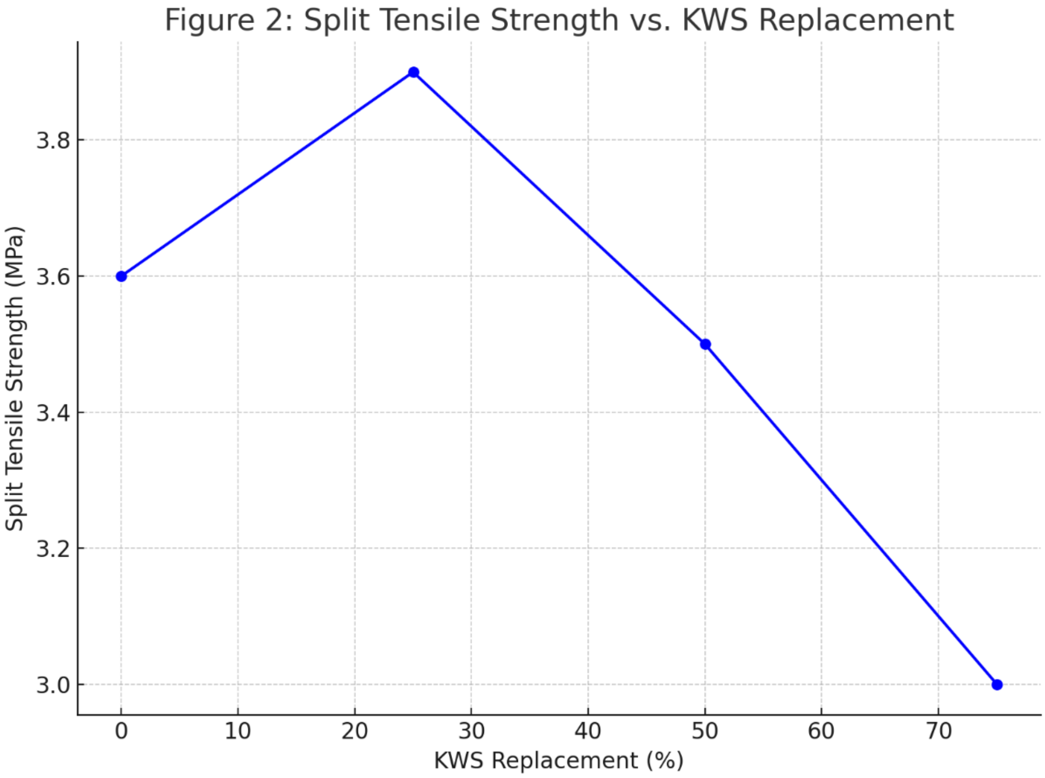

Figure 2. Split tensile strength comparison across KWS levels

3.3 Workability Trends

Workability is a key parameter in concrete mix design, influencing ease of mixing, transporting, placing, and finishing. In this study, slump tests were conducted to assess the workability of mixes incorporating Kota Waste Stone (KWS). As shown in Table 3, slump values consistently decreased with increasing KWS content. The control mix (NAC-0-0), with 100% natural aggregates, exhibited a slump of 75 mm, reflecting good workability suitable for most structural applications.

When 25% of the natural aggregates were replaced with KWS (NAC-0-25), the slump decreased to 60 mm. At 50% replacement (NAC-0-50), the slump further declined to 50 mm. The lowest value, 20 mm, was recorded in NAC-0-100, which had full replacement with KWS. This reduction is attributed to the angular and rough texture of KWS particles, which increases internal friction and reduces the mix's fluidity. Additionally, the low water absorption of KWS limits its contribution to internal moisture availability, further hindering workability.

These results indicate that while KWS can be beneficial in terms of strength and sustainability, it adversely affects workability, especially at higher replacement levels. To mitigate this issue in practical applications, the use of superplasticizers or adjustments in water content may be necessary when high proportions of KWS are used.

Table 3. Slump Values Across Mixes

Mix Code	KWS (%)	Slump (mm)
NAC-0-0	0	75
NAC-0-25	25	60
NAC-0-50	50	50
NAC-0-100	100	20

3.4 Optimal Mix Performance

Among the 20 mix variations tested, mix NAC-10-50 emerged as the optimal blend in terms of balancing mechanical performance and sustainability. This mix involved 50% replacement of natural aggregates with Kota Waste Stone (KWS) and 10% replacement of cement with Class F fly ash. It demonstrated a 28-day compressive strength of 38.1 MPa, which is well above the required minimum for M30 grade concrete. Moreover, the strength further increased to 50.2 MPa at 90 days, showcasing the long-term strength benefits from the pozzolanic action of fly ash and the dense packing effect of KWS particles.

In terms of tensile performance, the split tensile strength at 28 days was recorded at 3.7 MPa, only slightly lower than the control mix, indicating reliable crack resistance. Despite the reduced workability observed across all KWS mixes, NAC-10-50 maintained a moderate slump value of 48 mm, suggesting manageable flow properties with minimal need for admixtures. The strength-to-sustainability ratio of NAC-10-50 confirms it as a viable eco-efficient concrete for structural applications.

Table 4. Summary of Optimal Mix NAC-10-50

Property	Value
28-Day Compressive Strength	38.1 MPa
90-Day Compressive Strength	50.2 MPa
28-Day Split Tensile Strength	3.7 MPa
Slump	48 mm

IV. Discussion

The results of this study confirm the technical feasibility of incorporating Kota Stone Waste (KSW) and fly ash into concrete as partial replacements for natural aggregates and cement, respectively. The compressive strength data suggests that concrete mixes with up to 50% KSW and 10% fly ash can meet or exceed the performance of conventional concrete, especially at later curing ages due to the pozzolanic reaction of fly ash and the high specific gravity of KSW aggregates. The gradual strength development over 90 days highlights the long-term performance benefits of these materials, making them particularly suitable for projects where early-age strength is not critical.

Tensile strength performance showed a similar trend, with moderate replacement levels resulting in increased or comparable values to the control mix. This is likely due to improved bonding in the interfacial transition zone facilitated by the angular and rough texture of KSW. However, higher replacement levels, especially with fly ash beyond 20%, negatively impacted early strength, emphasizing the need for optimal proportioning.

Workability results revealed a consistent decrease in slump with increasing KSW content, attributed to particle angularity and low water absorption. While manageable at lower levels, this limitation may necessitate the use of admixtures or slight mix adjustments in field applications. Overall, the optimal blend (NAC-10-50) demonstrated a favorable balance of strength, durability, workability, and sustainability, underscoring its practical potential for green construction.

V. Conclusions

This research explored the utilization of Kota Stone Waste and fly ash in concrete production, targeting a more sustainable alternative to conventional materials. The key findings are summarized as follows:

- Replacing natural aggregates with KSW up to 50% yields concrete with satisfactory compressive and tensile strength.
- The inclusion of 10% fly ash enhances long-term strength due to pozzolanic activity, but higher percentages can reduce early-age performance.
- Workability decreases as KSW content increases; hence, adequate mix design and possible use of superplasticizers are necessary.
- The optimal mix, NAC-10-50, exhibited excellent mechanical properties and a substantial environmental benefit, demonstrating its potential for mainstream adoption in sustainable construction practices.

These results support the conclusion that KSW and fly ash can be effectively used to produce durable, eco-friendly concrete, contributing to the circular economy and reducing dependency on virgin construction materials.

References

[1]. Mehta, P. K., & Monteiro, P. J. M. (2020). *Concrete: Microstructure, Properties, and Materials* (4th ed.). McGraw-Hill Education.
[2]. Neville, A. M., & Brooks, J. J. (2010). *Concrete Technology* (2nd ed.). Pearson Education.
[3]. International Energy Agency (IEA). (2023). *Cement Technology Roadmap: Towards Low-Carbon Cement*. https://www.iea.org/reports/cement
[4]. IS 10262:2019. *Guidelines for Concrete Mix Design Proportioning*. Bureau of Indian Standards, New Delhi, India.
[5]. IS 12269:1987. *Specification for 53 Grade Ordinary Portland Cement*. Bureau of Indian Standards, New Delhi, India.
[6]. IS 456:2000. *Plain and Reinforced Concrete – Code of Practice*. Bureau of Indian Standards.
[7]. IS 516:1959. *Method of Tests for Strength of Concrete*. Bureau of Indian Standards.
[8]. IS 5816:1999. *Splitting Tensile Strength of Concrete – Method of Test*. Bureau of Indian Standards.
[9]. Singh, R., Joshi, D., & Kumar, S. (2021). Fly ash in cementitious materials: Performance and sustainability. *Materials Today: Proceedings*, 43, 1890–1896. https://doi.org/10.1016/j.matpr.2020.10.468
[10]. Patel, R., & Shah, V. (2022). Effect of aggregate shape on concrete strength. *Construction Materials Journal*, 14(2), 85–94.
[11]. Khandelwal, R., Verma, A., & Singh, M. (2021). Environmental impact of Kota stone waste. *Journal of Environmental Engineering*, 147(6), 04021034.

[12]. Ramesh, N., Jain, S., & Kumar, V. (2022). Use of dimensional stone waste in concrete. *International Journal of Sustainable Engineering*, 15(1), 42–51.
[13]. Choudhary, R., & Ahuja, D. (2019). Mechanical behavior of concrete using stone waste aggregates. *Civil Engineering Journal*, 5(7), 1523–1534.
[14]. Yadav, R., & Singh, D. (2017). Utilization of Kota stone chips in concrete. *International Research Journal of Engineering and Technology*, 4(5), 2121–2125.
[15]. Rathi, R., Gupta, M., & Sharma, A. (2015). Influence of stone dust as fine aggregate replacement on concrete strength. *Journal of Construction Engineering*, 10(2), 112–120.
[16]. Saxena, R., & Roy, T. (2021). Combined effect of fly ash and stone waste on concrete properties. *Sustainable Construction Materials and Technologies*, 5(3), 98–105.
[17]. Sultana, N., & Singh, H. (2019). Effect of quarry waste particle texture on concrete strength. *Materials Today: Proceedings*, 27, 720–725.
[18]. Mitra, A., & Sengupta, R. (2021). Limestone-based fillers for greener concrete: A review. *International Journal of Civil and Structural Engineering*, 12(1), 24–34.
[19]. Ghasemi, M., Rafiee, F., & Nikbin, I. M. (2022). A comparative study on mechanical properties of concrete with different aggregate types. *Construction and Building Materials*, 307, 125033.
[20]. Kumar, P., & Verma, A. (2021). A review on sustainable concrete using stone waste. *Green Materials*, 9(2), 85–92.
[21]. Gupta, R., & Jain, P. (2020). Recycled aggregates and quarry dust in concrete. *Materials Today: Proceedings*, 38(4), 3278–3283.
[22]. Das, S., & Prasad, M. (2023). Long-term tensile strength of concrete with quarry waste and fly ash. *International Journal of Concrete Structures and Materials*, 17(1), 1–12.