International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 30489458

ANALYSIS OF MECHANICAL PROPERTIES OF CONCRETE PARTIALLY REPLACED BY QUARRY DUST AND GROUND GRANULATED BLAST FURNACE SLAG

DEEPAK
RESEARCH SCHOLAR, DEPARTMENT OF CIVIL ENGINEERING, BABA MASTNATH UNIVERSITY, ASTHAL BOHAR 124021, ROHTAK

Dr. R.S. KESHARWANI
PROFESSOR, DEPARTMENT OF CIVIL ENGINEERING, BABA MASTNATH UNIVERSITY, ASTHAL BOHAR124021, ROHTAK

Abstract

Industrial by-products were used in concrete production because natural river sand resources were depleted and traditional concrete manufacturing methods created environmental problems. The research examined how M30 grade concrete performed through its mechanical strength testing and durability assessment and microstructural analysis when it used sandstone quarry dust to partially replace natural sand. The researchers created concrete mixes with different replacement levels of quarry dust which included 10% 20% 30% 40% and 50% to test workability and density and compressive strength and split tensile strength and water absorption and captivity and chloride ion permeability across various replacement percentages. The research findings showed that workability declined as quarry dust content increased because the dust particles possessed angular shapes and contained more fine material. The 40% replacement level showed a density and mechanical strength improvement because of better particle packing and lower porosity. The control mix reached 28-day compressive strength of 36.13 MPa which increased to 41.83 MPa at 40% replacement for the test. The split tensile strength showed the same improvement as the other strength test results.

The study showed that building materials achieved better durability through the addition of quarry dust because their water absorption and sorptivity values decreased with higher replacement amounts, which resulted in better water resistance. The test results for rapid chloride permeability demonstrated that the material at its optimal replacement rate showed enhanced protection against chloride ion penetration. The microstructural examination through SEM found that the material developed fewer pores while attaining better bonding strength between its components, and the XRD analysis showed that quarry dust functioned mainly as an inert filler which did not change the cement hydration process. The study results proved that the ideal quarry dust replacement amount for construction materials should be set at 40% because this proportion delivers optimal strength, durability, and workability properties. The research established that quarry dust serves as a sustainable substitute for natural sand which enables the production of concrete that exhibits long-lasting strength while maintaining environmental sustainability.

Keyword: Quarry dust, sustainable concrete, compressive strength, durability, sorptivity, chloride permeability.

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 30489458

Introduction

Concrete remains the most common construction material used throughout the globe because it possesses high compressive strength together with durability and ability to work in various building designs and its affordable price. The material serves as an essential component for developing essential infrastructure which includes buildings, bridges, roads, and dams. The environmental impact of concrete production arises from the extensive natural resource requirements needed for its large-scale production. The excessive extraction of river sand causes ecological disruption together with groundwater loss and riverbank destruction while cement production generates high levels of carbon dioxide emissions and energy usage. Researchers and engineers face environmental and economic challenges which drive them to investigate sustainable materials that can replace traditional concrete components without affecting their performance.

Quarry dust, which is generated as a by-product during the rock crushing process in quarries, has emerged as a potential alternative to natural fine aggregate. The material's ability to compact tightly between its tiny particles establishes concrete design requirements that use its angular particle shape. Concrete mixtures achieve increased density and improved mechanical strength when this filler material is used according to correct mixing ratios. Ground Granulated Blast Furnace Slag (GGBS) functions as a supplementary cementitious material because it contains latent hydraulic properties which result from rapidly cooling and grinding molten iron slag from blast furnaces into fine powder. GGBS in concrete creates secondary hydration reactions which result in better strength development and lower heat of hydration and greater durability properties.

Research has shown through various tests that using both quarry dust and GGBS together will enhance concrete strength and durability. The microstructure of concrete improves when quarry dust fills empty spaces, and GGBS provides strength development combined with protection against chemical damage. The use of these industrial by-products decreases material permeability, which improves protection against water infiltration and extreme environmental conditions. The use of quarry dust and GGBS as partial replacements for cement and natural sand leads to sustainable construction processes through two main advantages because it decreases waste and training expenses while cutting carbon emissions. The use of these materials enables the creation of environmentally friendly concrete which retains its structural integrity and cost-effective performance capabilities.

Review of literature

1. GGBS as Partial Replacement of Cement

Researchers have studied Ground Granulated Blast Furnace Slag (GGBS) which serves as a supplementary cementitious material because of its ability to create cement and its positive environmental effects. S. Prakash Chandar et al. (2020) reported that GGBS possesses chemical characteristics similar to cement and can significantly reduce cement consumption and production cost. Their investigation on M20 grade concrete which used quarry dust and different GGBS replacement levels (20-60%) showed that compressive strength improved with higher GGBS content and reached its maximum strength at 60% cement replacement.

Mulayam Singh Yadav and his colleagues conducted their research to assess how GGBS replacement levels between 0 and 40% would affect compressive strength and flexural strength and split tensile strength of concrete until they discovered that 30% GGBS replacement would not disrupt concrete performance. The research conducted by Usha Lodhi and Kamlesh Kumar Choudhary and Kamal Kishor Gupta and Choudhary confirmed that 30% GGBS functions as the ideal replacement level which enhances workability and setting time and concrete compressive strength.

2. Quarry Dust as Replacement of Fine Aggregate

Quarry dust has been extensively studied as an environmentally friendly alternative to natural sand because of its widespread availability and its ability to function as a filler material. The research conducted by Indrapal Singh Dhurvey and Vipin Kumar Tiwari in 2020 showed that using quarry dust powder with metakaolin results in better compressive strength while serving as a cost-effective and environmentally friendly solution. The study confirmed that quarry dust contributes to densification of concrete which results in improved strength performance.

K. Harish Kumar and his team conducted research in 2020 by using partial sand replacement with quarry dust and sawdust for M25 concrete testing and they found that this method improved both compressive strength and tensile strength. The study demonstrated that quarry dust improves particle density while decreasing empty spaces when it is combined with glass fiber strengthening materials. The results demonstrate that quarry dust functions as an effective fine aggregate substitute which enhances the mechanical performance of concrete.

3. Durability and Performance of Blended Concrete

Researchers have studied how GGBS affects material longevity and performance over time. The study conducted by J.E. Oti and his colleagues in 2020 discovered that concrete performance improved when Portland cement was replaced with GGBS and Pulverized Fuel Ash. The study proved that moderate GGBS replacement led to better environmental protection while maintaining strength even though extreme GGBS replacement caused minor strength loss during the initial phase.

The researchers found that GGBS improves concrete mechanical strength and durability but excessive use reduces its flowability. The researchers found that workability and strength properties required an optimum replacement level which needed to be determined through testing. The studies demonstrate that GGBS provides essential benefits for concrete durability and microstructural development.

4. Combined Use of Industrial Waste and Advanced Concrete Applications

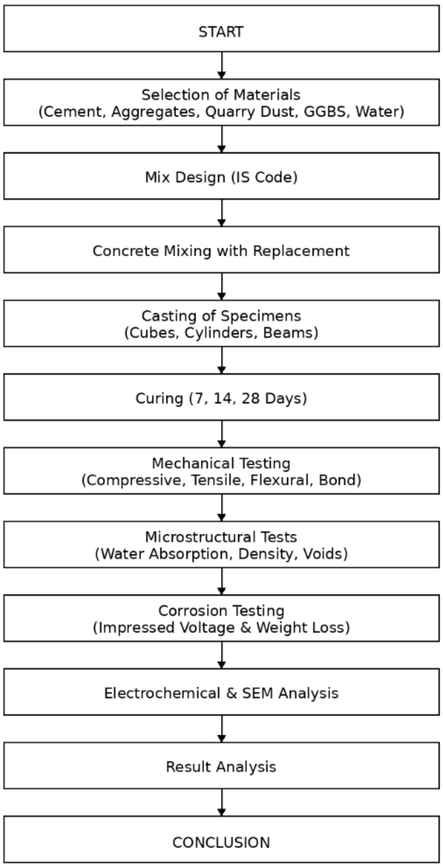
Recent research has focused on combining GGBS with other industrial waste materials and applying them in advanced concrete technologies. The research conducted by Sushil Kumar Giri and Vikas Kumar (2022) used coconut shell concrete which blended GGBS to show better strength and durability results through its 20% steel slag and 5% coconut shell combination. The study demonstrated GGBS potential to improve all alternative lightweight concrete systems.

The researchers investigated the properties of fiber-reinforced self-compacting concrete that contains GGBS. The study found that optimal performance occurs when 25% of GGBS material is used. The researchers demonstrated that their construction method could be applied to current building techniques. Ashish Dhaka and Abhishek Arya (2023) also proposed the use of high volumes of GGBS in self-compacting concrete, emphasizing its role in improving plastic viscosity and sustainability. The studies demonstrate that both quarry dust and GGBS materials can be used to develop new concrete mixtures which provide better strength and durability and reduced environmental impact.

Methodology

1. Research Approach

The present study adopted an experimental methodology to evaluate the mechanical, durability, and corrosion resistance properties of concrete partially replaced with quarry dust and Ground Granulated Blast Furnace Slag (GGBS). The researchers created concrete specimens by using specific replacement amounts which they subsequently tested in controlled laboratory settings. The researchers used strength measurement and microstructural analysis to assess the complete performance of the modified concrete.



2. Materials and Mix Preparation

The concrete mixes were prepared using Ordinary Portland Cement together with natural fine aggregate and coarse aggregate and quarry dust and GGBS and potable water. The construction used quarry dust as a partial substitute for fine aggregate while GGBS served as a cement replacement material at different ratios. The mix design used existing IS code regulations to

International Journal of Advanced Research and Multidisciplinary Trends (IJARMT)
An International Open Access, Peer-Reviewed Refereed Journal
Impact Factor: 6.4 Website: https://ijarmt.com ISSN No.: 30489458

determine the target strength which needed to be attained. The team mixed concrete according to standard procedures which they then cast into moulds of required dimensions before they properly compacted the material and cured it in water for specific periods before testing.

3. Evaluation of Mechanical Properties

The researchers conducted mechanical tests which included compressive strength testing and split tensile strength testing and flexural strength testing and bond strength testing to evaluate the concrete's strength performance. The researchers used cube specimens for compressive strength testing to determine load-bearing capacity while using cylindrical specimens for split tensile strength testing to measure cracking resistance. The researchers used beam specimens to conduct flexural strength tests which assessed bending resistance. The researchers conducted bond strength tests to measure the concrete-to-reinforcing-steel bond strength as a method to assess how reinforcement interacts with modified concrete mixes.

4. Assessment of Microstructural Properties

Researchers used water absorption tests together with bulk density measurements and permeable voids tests to study microstructural characteristics of the material. The water absorption tests provided results that showed how much water could penetrate the material while bulk density tests showed the concrete's compactness. The test examined permeable voids to determine how internal pore structure affected the material's durability. The parameters showed how quarry dust created densification effects and how GGBS performed its pozzolanic function.

5. Corrosion Resistance Evaluation

Accelerated corrosion testing methods were used to evaluate the corrosion resistance of reinforced concrete specimens. Scientists assessed chloride ion penetration through the impressed voltage method which they used in a saline medium that simulated aggressive environmental conditions. The weight loss method assessed corrosion by measuring mass reduction of embedded steel reinforcement after exposure. The tests determined how well modified concrete protected against corrosion of reinforced steel.

6. Electrochemical and Surface Analysis

The researchers conducted AC impedance spectroscopy tests to determine the corrosion performance of embedded steel reinforcement. The method measured charge transfer resistance together with concrete resistivity. The researchers used Scanning Electron Microscope (SEM) analysis to examine the surface characteristics of corroded reinforcement. The SEM examination showed both microstructural changes and corrosion products together with the condition of the interfacial transition zone between steel and concrete.

Objective of study

1. To study the significance of partial replacement of cement by Ground Granulated Blast Furnace Slag (GGBS) on the strength and corrosion resistive properties of quarry dust concrete
2. To find out the inhibitive effect of various organic and inorganic inhibitors on the strength and corrosion resistive properties of concrete having quarry dust as fine aggregate.

Research Gap

The research evaluated how quarry dust and GGBS functioned as complete replacements of natural sand and cement in concrete through assessments of both fresh concrete and strength properties. The research examined how mineral admixtures and corrosion inhibitors could improve protection against corrosion in standard concrete. The technical literature contains limited information about research studies that evaluate how quarry dust-based concrete with mineral admixtures and GGBS and corrosion-inhibiting substances achieve corrosion resistance performance.

Data Table

Mix ID	Quarry Dust Replacement (%)	Slump (mm)	Density (kg/m³)	Compressive Strength 7d (MPa)	Compressive Strength 28d (MPa)	Compressive Strength 90d (MPa)	Split Tensile 28d (MPa)	Water Absorption 7d (%)	Sorptivity 7d	RCPT Resistance
CM	0	90	2411	29.77	36.13	38.49	2.78	3.01	0.1777	High permeability
QD10	10	85	2445	31.24	37.67	39.85	2.82	2.74	0.1441	Improved
QD20	20	78	2472	32.78	39.73	41.62	2.96	2.24	0.1037	Moderate
QD30	30	70	2491	34.22	40.80	42.78	3.25	1.91	0.0840	Low
QD40	40	62	2508	35.44	41.83	44.12	3.39	1.73	0.0721	Very low (Best)
QD50	50	50	2486	33.91	40.55	42.96	3.22	1.44	0.0619	Slight increase

Analysis and Results

1. Introduction

This section presents the experimental results obtained from the investigation on M30 grade concrete incorporating sandstone quarry dust as a partial replacement for natural sand at levels of 10%, 20%, 30%, 40%, and 50%. The performance evaluation of modified concrete mixes included testing their fresh properties and assessing their mechanical strength and durability characteristics and microstructural behavior. The results were compared with the control mix to determine the optimum replacement level and to understand the influence of quarry dust on overall concrete performance.

2. Fresh Concrete Properties

2.1 Workability

The slump test served as the method to evaluate fresh concrete's workability. The study results demonstrated that increasing quarry dust replacement led to decreasing slump measurements. The control mix exhibited a slump value of 90 mm, whereas the mix containing 50% quarry dust showed a slump of 50 mm. The angular particle shape together with the rough surface texture and higher fines content of quarry dust caused this reduction because it increased internal friction and water demand. The reduction in slump values remained within the medium workability range, which permits structural applications for all mixes.

3. Hardened Concrete Properties

3.1 Density

Concrete density increased with increasing quarry dust replacement because fine particles filled the gaps between particles and quarry dust had higher specific gravity than other materials. The control mix exhibited a density of 2411 kg/m³ while the mix containing 40% quarry dust showed the highest density of 2508 kg/m³ which represented an increase of approximately 4%. The 50% replacement showed a minor density decrease because of excessive fines which caused potential compaction issues.

3.2 Compressive Strength

The compressive strength of concrete improved with increasing quarry dust replacement up to 40%. At 7 days, strength increased from 29.77 MPa (control) to 35.44 MPa (QD40), while at 28 days it increased from 36.13 MPa to 41.83 MPa. The improvement occurred because better particle packing together with reduced voids and improved cement paste to aggregate bonding brought about better results. Beyond 40% replacement, a slight reduction in strength was observed due to excessive fines affecting workability and compaction.

3.3 Split Tensile Strength

The splitting tensile strength followed a trend similar to compressive strength. The control mix achieved 2.78 MPa at 28 days while the mixture containing 40% quarry dust reached 3.39 MPa showing better crack resistance and bond strength. The tensile characteristics showed a slight decrease at 50% replacement which demonstrated that excessive quarry dust would have adverse effects on tensile performance.

4. Durability Properties

4.1 Water Absorption

The study found that increasing quarry dust replacement led to a major reduction in water absorption. The control mix exhibited 3.01% absorption, whereas the mix containing 50% quarry dust showed 1.44%, indicating improved compactness and reduced porosity. The reduction was primarily due to the void-filling effect of quarry dust particles.

4.2 Sorptivity

The incorporation of quarry dust into the test samples led to a decrease in sorptivity values, which resulted in better protection against capillary water absorption. The control mix recorded 0.1777, while the mix with higher quarry dust replacement exhibited values as low as 0.0619, demonstrating reduced pore connectivity and improved durability.

4.3 Chloride Ion Permeability

The tests for rapid chloride permeability showed that the material became more resistant to chloride penetration when quarry dust was used as a replacement. The mix that contained 40% quarry dust showed the highest resistance which matched its maximum density and compressive strength. The 50% replacement mix demonstrated higher permeability than QD40 but it still outperformed the control concrete.

5. Microstructural Analysis

5.1 XRD Analysis

The primary cement hydration phases remained unchanged when quarry dust was tested through X-ray diffraction analysis. The detected phases included calcium silicate hydrate and portlandite and calcite which showed that quarry dust functioned as an inert material that enhanced physical densification.

5.2 SEM Analysis

SEM observations showed that quarry dust concrete produced a denser microstructure which reduced pore formation when compared to the control mix. The control concrete showed larger voids than the quarry dust mixes which displayed better particle packing and a better interfacial transition zone. The 40% quarry dust mix showed the most compact microstructure which confirmed the mechanical and durability results.

6. Summary of Findings

The study found that quarry dust improved both mechanical strength and durability of concrete when it was used to partially substitute natural sand. The highest performance occurred when 40% of the material was replaced since this level produced maximum density and compressive strength and tensile strength and chloride resistance. The performance dropped when the replacement exceeded that point because workability decreased and excessive fines became present.

Advantages

- Decreasing cement usage results in decreased carbon emissions and decreased environmental effects
- Industrial by-products including quarry dust and GGBS are used effectively which decreases disposal problems
- The use of quarry dust as a filler material improves particle packing which produces denser concrete
- The system shows better durability because it has decreased permeability and improved resistance against chloride and sulfate damage
- The long-term strength development of the material increases because GGBS produces pozzolanic activity
- The material offers a cost-effective solution to traditional concrete because it decreases the need for natural sand and cement
- The project advances sustainable construction methods which have minimal negative impacts on the environment.

Conclusion

The present study confirmed that quarry dust can be successfully used as a partial replacement for natural sand in concrete without compromising mechanical performance when used within moderate replacement levels. The use of quarry dust in the material composition led to enhanced density and compressive strength and tensile strength because it improved the ability of particles to compact while decreasing the spaces between them. The workability declined at higher replacement levels because the angular shape of quarry dust particles and their increased fines content required accurate mix design and water content measurements.

The incorporation of GGBS as a partial replacement for cement produced better long-term strength and durability through its pozzolanic reaction and microstructural improvement. The combined use of quarry dust and GGBS produced sustainable concrete with improved mechanical and durability performance compared to conventional concrete. The results showed that the optimal replacement level should be determined through a balance between strength and durability and workability parameters which will lead to maximum performance and sustainability advantages.

Future scope

- Investigation of durability performance under aggressive environmental conditions such as marine and sulphate exposure
- Detailed microstructural studies using SEM, XRD, and advanced characterization techniques
- Application in high-performance concrete, self-compacting concrete, and fiber-reinforced concrete systems
- Study of shrinkage, creep, and long-term deformation behavior of quarry dust–GGBS concrete
- Optimization of mix design using chemical admixtures to improve workability at higher replacement levels
- Development of machine learning models for predicting strength and durability of sustainable concrete mixes

References

1. Abed M, Nemes R, Tayeh BA (2020) Properties of self-compact-ing high-strength concrete containing multiple use of recycled aggregate. J King Saud Univ Eng Sci 32:108–114. https://doi.org/10.1016/j.jksues.2018.12.002 Temperature Curing. Cem. Concr. Res. 2006, 36, 1134–1147.
2. Agwa IS, Omar OM, Tayeh BA, Abdelsalam BA (2020) Efects of using rice straw and cotton stalk ashes on the properties of lightweight self-compacting concrete. Constr Build Mater 235:117541.
3. Ahmad, J.; Zaid, O.; Shahzaib, M.; Abdullah, M.U.; Ullah, A.; Ullah, R. Mechanical Properties of Sustainable Concrete Modified by Adding Marble Slurry as Cement Substitution. AIMS Mater. Sci. 2021, 8, 343–358.
4. Alaloul WS, Musarat MA, Tayeh BA et al (2020) Mechanical and deformation properties of rubberized engineered cementitious composite (ECC).
5. Almeshal I, Tayeh BA, Alyousef R et al (2020) Eco-friendly concrete containing recycled plastic as partial replacement for sand.

6. Amin M, Tayeh BA, Agwa IS (2020) Effect of using mineral admixtures and ceramic wastes as coarse aggregates on properties of ultrahigh-performance concrete. J Clean Prod 273:123073.
7. D. Suresh and K. Nagaraju(2021) Properties of Fresh and Hardened Concrete Containing Supplementary Cementitious Materials: State-of-the-Art Report of the RILEM Technical Committee 238-SCM, Working Group 4.
8. Kalaivani M, Shyamala G, Ramesh S et al (2020) Performance evaluation of fy ash/slag based geopolymer concrete beams with addition of lime. Mater Today Proc 27:652–656.
9. Liu, Y.; Shi, C.; Zhang, Z.; Li, N.; Shi, D. Mechanical and Fracture Properties of Ultra-High Performance Geopolymer Concrete: Effects of Steel Fiber and Silica Fume. Cem. Concr. Compos. 2020, 112, 103665.
10. Maruthachalam D, Shyamala G, Sugunadevi M et al (2020) Experimental investigation of different color pigments on concrete.
11. Muthuraman M, Anuradha R, Awoyera PO, Gobinath R (2020) Numerical simulation and speci f cation provisions for buckling characteristics of a built-up steel column section subjected to axial loading. Eng Struct 207:110256.
12. Nazarpour, H.; Jamali, M. Mechanical and Freezing Cycles Properties of Geopolymer Concrete with Recycled Aggregate. Struct. Concr. 2020, 21, 1004–1012.
13. Narasimhan, C., Patil, B.T. and Sankar Sanni, H. “Performance of Concrete with Quarry Dust as Fine Aggregate-An Experimental Study”, CE and CR Journal. pp. 19- 24, 1999.
14. Nataraja, M.C., Nagaraj, T.S. and Reddy, A. Proportioning Concrete Mix with Quarry Wastes Cement. Concrete and Aggregate Journal, ASTM, Vol. 23, No. 2, pp. 81-87, 2001.
15. Nikhil Saboo, Shekhar Shivhare, Krishna Kumar Kori. “Effect of fly ash and metakaolin on pervious concrete properties” Construction and Building Materials 223 (2019) 322–328.
16. Poongodi K, Murthi P, Gobinath R et al (2019) Mechani-cal properties of pavement quality concrete using recycled aggregate. Int J Innov Technol Explor Eng 9:33–38.
17. Palanisamy M, Poongodi K, Awoyera PO, Ravindran G (2020) Permeability properties of lightweight self-consolidating con-crete made with coconut shell aggregate.
18. P.K. Prasanna (2019) “Compressive Strength Assessment using GGBS and Randomly Distributed Fibers in Concrete” International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9 Issue-2, December 2019
19. Rajesh Kumar K, Gobinath R, Shyamala G et al (2020) Free thaw resistance of stabilized and fber-reinforced soil vulner-able to landslides.
20. Rama Krishna, B., Harish Kumar, K., Mani Kumar, T., & Likitha, I., Properties of GGBS concrete under various curing conditions. International Journal of Emerging Trends in Engineering Research, Vol. 8 No. 2, pp. 1384-1387, 2020.
21. Smirnova, O. Compatibility of Shungisite Microfillers with Polycarboxylate Admixtures in Cement Compositions. ARPN J. Eng. Appl. Sci. 2019, 14, 600–610.
22. S.k.Sirajuddin (2019) “Experimental Investigation on Properties of Concrete by Partial Replacement of Cement with GGBS and Fine Aggregate with Quarry Dust” International Conference on Advances in Civil Engineering (ICACE-2019) | 21-23 March 2019

23. Salman, Kumar C (2019) Use of waste material in concrete. Int J Trend Sci Res Dev 3:626–637 Temperature Curing. Cem.
24. Zeyad AM, Tayeh BA, Yusuf MO (2019) Strength and transport characteristics of volcanic pumice powder based high strength concrete.
25. Zhang, P.; Wang, K.; Wang, J.; Guo, J.; Ling, Y. Macroscopic and Microscopic Analyses on Mechanical Performance of Metakaolin/Fly Ash Based Geopolymer Mortar. J. Clean. Prod. 2021, 294, 126193.
26. Harish Kumar, K., et al. (2020). Replacement of sand with quarry dust in concrete. *Materials Today Proceedings*, 27, 1247–1252.
27. Oti, J. E., Kinuthia, J. M., & Bai, J. (2010). Engineering properties of GGBS concrete. *Construction and Building Materials*, 24(10), 1891–1899.
28. Lodhi, U., & Choudhary, K. (2020). Effect of GGBFS on strength and workability. *International Journal of Civil Engineering*.
29. Gupta, K. K., & Choudhary, K. (2022). Strength properties of GGBS and silica fume concrete. *Materials Today Proceedings*.