

**“PERFORMANCE OF CONCRETE CONTAINING GGBFS AND RCA
AT ELEVATED TEMPERATURE”****Agre S.V.*¹, Ghodake A.R.², Jadhav S.S.³, Undare R.S.⁴, Palaskar S.M.⁵**

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Article Received: 19 March 2026, Article Revised: 09 April 2026, Published on: 29 April 2026

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DOI: <https://doi-doi.org/101555/ijarp.1954>

ABSTRACT

The construction sector consumes vast natural resources and generates significant demolition waste, while cement production contributes heavily to CO₂ emissions. This study explores sustainable concrete by partially replacing coarse aggregate with recycled concrete aggregate (RCA) and cement with Ground Granulated Blast Furnace Slag (GGBFS). Experimental investigation assesses workability, compressive strength, and durability. By conducting the SEM (Scanning Electron Microscopy) tests provide high-resolution images and chemical composition data to characterize a material's surface morphology, topography, and elemental makeup, which is crucial for quality control, failure analysis, and R&D across materials science, nanotechnology, and other fields.

KEYWORDS: Ground Granulated Blast Furnace Slag (GGBFS), Recycled Concrete Aggregate (RCA), SEM (Scanning Electron Microscopy).

1. INTRODUCTION

The rapid growth of the construction industry has led to an increased demand for conventional construction materials such as cement and natural aggregates, resulting in significant environmental concerns. Cement production is one of the major contributors to carbon dioxide emissions, while excessive extraction of natural aggregates leads to depletion of natural resources and ecological imbalance. At the same time, large quantities of

construction and demolition waste are generated worldwide, posing serious disposal and environmental challenges.

In recent years, the use of sustainable materials such as Ground Granulated Blast Furnace Slag (GGBFS) and Recycled Coarse Aggregate (RCA) has gained considerable attention in the development of eco-friendly concrete. GGBFS, an industrial by-product, can partially replace cement and improve durability and long-term strength, while RCA obtained from demolished concrete can serve as an alternative to natural aggregates, reducing waste and conserving natural resources. However, the incorporation of these materials may influence the mechanical and durability properties of concrete due to variations in composition, porosity, and interfacial bonding.

In addition to sustainability concerns, the performance of concrete under elevated temperatures is a critical aspect, especially in structures exposed to fire or high-temperature environments. Exposure to high temperatures can lead to degradation of mechanical properties, development of microcracks, and changes in the internal microstructure of concrete. Therefore, it is essential to evaluate the behaviour of sustainable concrete under such conditions.

This study aims to investigate the mechanical performance and microstructural characteristics of concrete incorporating GGBFS and RCA when subjected to elevated temperatures. The findings of this research contribute to the development of sustainable and fire-resistant construction materials, promoting both environmental conservation and structural safety.

2. LITERATURE REVIEW

1. Lubnar Alkhteb (2025): 'The effect of recycled aggregate on properties of concrete: A review'

Recycled Concrete Aggregate (RCA) exhibits lower density and significantly higher porosity compared to natural aggregates due to the presence of adhered old mortar. This leads to increased water absorption and reduced mechanical properties such as compressive strength and stiffness. The weaker Interfacial Transition Zone (ITZ) further contributes to crack development and reduced durability. However, advanced treatment techniques such as carbonation, acid soaking, and nano-modification help to densify the surface and remove कमजोर mortar. These methods enhance bonding, reduce permeability, and improve overall durability of RCA concrete. Thus, treated RCA can be effectively used in structural applications.

2. Girum Mindaye Mengistu (2025): ‘Predicting the compressive strength of sustainable recycled aggregate concrete using multi-NDT methods’

This study focused on evaluating the reliability of Non-Destructive Testing (NDT) methods for RAC. Techniques such as Ultrasonic Pulse Velocity (UPV) and rebound hammer tests were used to estimate compressive strength. It was observed that moisture content significantly affects test accuracy, as wet surfaces reduce rebound values. Correction factors were proposed to improve prediction accuracy under different conditions. The results showed that with proper calibration, NDT methods can provide reliable strength estimation. This approach is useful for in-situ assessment of RAC structures.

3. Jiehong Li (2025): ‘Synergistic enhancement of sulphate resistance in recycled aggregate concrete through multi-pathway blocking via carbonation treatment and fly ash incorporation’

The study investigated carbonation treatment as a method to improve RCA properties. Carbonation fills pores and microcracks by forming calcium carbonate, resulting in a denser structure. This reduces water absorption and enhances resistance to sulfate attack. The treated RCA concrete showed improved long-term compressive strength and durability. Additionally, mass loss during sulfate exposure was significantly reduced. Overall, carbonation treatment proved to be an effective technique for enhancing RCA performance.

4. Anstey Vathani (2023): ‘A novel approach to utilize recycled concrete aggregates as landfill liner’

This research explored the use of paper pulp as a binding agent with RCA in environmental applications. It was observed that adsorbent materials alone did not effectively bond with RCA. The addition of paper pulp improved adhesion and stability of the composite material. This combination was particularly useful in filtration systems and landfill liner applications. The study also noted improvements in leachate pH control. Hence, paper pulp acts as a sustainable and effective binder in RCA-based systems.

5. Tran Minh Tung (2023): ‘Experimental investigation of the performance of ground granulated blast furnace slag blended recycled aggregate concrete exposed to elevated temperatures’

The study examined the performance of GGBFS-blended RAC under elevated temperatures. It was found that GGBFS improved residual compressive strength and ductility of concrete. The presence of GGBFS refined the pore structure and enhanced the formation of secondary C–S–H gel. This resulted in improved crack resistance and reduced microstructural damage

at high temperatures. Concrete with GGBFS showed better stability up to 600°C compared to conventional mixes. Thus, GGBFS enhances fire resistance and durability of RAC.

6. Bright Asante (2025): ‘Optimized mix design and fire resistance of geopolymer recycled aggregate concrete under elevated temperatures’

This study focused on geopolymer recycled aggregate concrete exposed to high temperatures. It was observed that the material retained a significant portion of its strength at moderate temperatures (up to 600°C). However, at extreme temperatures around 900°C, severe cracking and structural degradation occurred. The loss of water and shrinkage of aggregates caused internal stresses and microcracking. SEM analysis confirmed the presence of voids and weakened bonding. Therefore, geopolymer RAC performs well at moderate heat but deteriorates at very high temperatures.

7. Hilal El-Hassan (2023): ‘Synergic effect of recycled aggregates, waste glass, and slag on the properties of pervious concrete’

The study reported that replacing natural aggregates with RCA reduces compressive strength due to increased porosity. However, tensile and flexural strength showed slight improvement in some mixes. This was attributed to better crack bridging and energy absorption characteristics of RCA. The higher roughness of RCA particles enhances mechanical interlocking. Despite reduced density, the material showed acceptable structural performance. Hence, RCA can be beneficial in applications where tensile behavior is important.

8. Athika Wongkvanklam (2025): ‘Enhanced strength reduced modulus high calcium FA geopolymer concrete containing recycled aggregate concrete and Portland cement’

This research investigated geopolymer concrete containing RCA and GFRP waste. RCA reduced workability due to its irregular shape and high water absorption capacity. Compressive strength decreased by around 11%, while flexural strength showed a significant drop of 44%. The addition of GFRP helped improve certain mechanical properties by enhancing reinforcement behaviour. However, porosity increased due to lower compaction efficiency. The study highlights the need for mix optimization when using RCA in geopolymer systems.

9. Jianhua Li (2025): ‘Fully recycled aggregate concrete composite functional additives: Proportioning tests and verification of engineering adaptability’

The study highlighted the effect of RCA on fresh and hardened concrete properties. Due to high water absorption, RCA caused rapid slump loss and reduced workability. It also led to lower compressive strength and higher porosity. To overcome these issues, superplasticizers and water-retaining agents were used. These admixtures improved flowability and ensured

proper compaction. As a result, fully recycled aggregate concrete achieved performance suitable for pumping and construction applications.

10. Sheelan M. Hama (2017): ‘Improving mechanical properties of lightweight Porcelanite aggregate concrete using different waste material’

This study investigated the use of glass powder and fibers in concrete. Glass powder improved compressive strength and density by enhancing the pozzolanic reaction. It also reduced water absorption by refining the pore structure. The addition of fibers significantly improved flexural strength and crack resistance. Optimal proportions resulted in better overall mechanical performance. Thus, glass powder and fibers contribute to stronger and more durable concrete.

3. METHDOLOGY

1. General

This study investigates the performance of sustainable concrete incorporating Ground Granulated Blast Furnace Slag (GGBFS) and recycled aggregates from demolition waste. Concrete mixes were prepared and tested to evaluate workability, strength, microstructure, and behaviour under elevated temperatures.

2. Materials

Ordinary Portland Cement (OPC), GGBFS, recycled coarse aggregates, natural fine aggregates, and potable water were used. GGBFS was obtained from JSW Cement Ltd., and recycled aggregates were sourced from construction and demolition waste.

3. Batching and Mixing

Concrete of M25 grade was prepared using weight batching with a water-cement ratio of 0.5. Materials were mixed uniformly to achieve consistent color and homogeneity before casting specimens.

4. Tests on Aggregates

4.1. Impact Value Test

This test determines the toughness of aggregates under sudden impact. A standard sample was subjected to 15 blows from a 14 kg hammer, and the percentage of fines passing the 2.36 mm sieve was calculated.

4.2. Crushing Value Test

The crushing value test evaluates the compressive strength of aggregates. A gradually applied load up to 400 kN was used, and the fraction passing the 2.36 mm sieve was measured.

4.3. Abrasion Test

The Los Angeles abrasion test measures aggregate resistance to wear. The sample was rotated with steel balls for 500 revolutions, and the percentage loss due to abrasion was determined.

4.4. Flakiness and Elongation Index

These tests assess the shape characteristics of aggregates. Flakiness index represents thin particles, while elongation index indicates elongated particles, both expressed as percentage by weight.

4.5. Bulking of Sand

Bulking of fine aggregate was determined by measuring the increase in volume due to moisture content. The percentage increase in volume was calculated to assess its effect on mix proportions.

4.6. Specific Gravity

Specific gravity was determined using the water displacement method. It is defined as the ratio of the weight of aggregates to the weight of an equal volume of water.

5. Tests on Concrete

5.1. Initial Setting Time

Initial setting time was determined using Vicat apparatus. It is defined as the time from water addition until the needle penetrates only up to a specified depth in the cement paste.

5.2. Final Setting Time

Final setting time was measured using Vicat apparatus with annular attachment. It is the time when the paste becomes sufficiently rigid and the attachment fails to leave an impression.

5.3. Workability Test

Workability was evaluated using the slump cone test. The slump value indicates the consistency and ease of handling of fresh concrete.

5.4. Compressive Strength

Compressive strength was determined using cube specimens tested at 7 and 28 days. The strength was calculated as the ratio of failure load to the cross-sectional area.

5.5. Scanning Electron Microscopy (SEM)

SEM analysis was performed to examine the microstructure and surface morphology. Samples were coated and scanned under an electron beam to obtain high-resolution images.

5.6. Elevated Temperature Test

Concrete specimens were exposed to temperatures of 200°C, 400°C, and 800°C. After cooling, residual compressive strength was measured to evaluate thermal resistance.

4. PROBLEM STATEMENT

- Concrete production emits 0.9 tons of CO₂ per ton of cement produced.
- Growing construction demand increases pollution and depletes natural resources rapidly.
- Using mineral admixtures reduces cement use, cost, and environmental impact.
- GGBFS replaces 30% cement, improving durability and lowering CO₂ emissions.
- Demolition waste replaces 100% coarse aggregate, reducing landfill and promoting sustainability.

5. OBJECTIVES

- To study the mechanical performance of GGBFS–RCA concrete when exposed to elevated temperatures: -

This objective focuses on evaluating how concrete made with Ground Granulated Blast Furnace Slag (GGBFS) as a partial cement replacement and Recycled Coarse Aggregate (RCA) as a substitute for natural aggregate behaves under high-temperature conditions. The study investigates key mechanical properties such as compressive strength, residual strength, and structural stability after exposure to different temperature levels (e.g., 200°C, 400°C, 800°C). It aims to determine the extent of strength degradation, cracking behavior, and load-carrying capacity of the modified concrete compared to conventional concrete. The results help in assessing the suitability of GGBFS–RCA concrete for structures subjected to fire or high-temperature environments.

- To study microstructural changes in GGBFS–RCA concrete subjected to elevated temperatures: -

This objective deals with understanding the internal structural changes occurring within GGBFS–RCA concrete when exposed to elevated temperatures. Using microstructural analysis techniques such as Scanning Electron Microscopy (SEM), the study examines variations in the Interfacial Transition Zone (ITZ), pore structure, microcracking, and bonding characteristics between aggregate and cement paste. It also evaluates the decomposition of hydration products and the effect of GGBFS on improving thermal resistance and matrix densification. The aim is to correlate these microstructural changes with the observed mechanical performance, providing a deeper insight into the behavior of sustainable concrete under thermal stress.

6. MATERIAL PROPERTIES

1. Cement

Ordinary Portland Cement (OPC) of grade 53 was used as the primary binding material.

Specific Gravity: 3.15

Standard Consistency: 30–35%

Initial Setting Time: 30–45 minutes

Final Setting Time: \leq 600 minutes

2. Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS was used as a partial replacement for cement to enhance sustainability and thermal resistance.

Specific Gravity: 2.8 – 2.9

Fineness: 350–450 m²/kg

Color: Off-white

Property: Improves long-term strength and reduces permeability

3. Fine Aggregate

Natural river sand conforming to Zone I was used.

Specific Gravity: 2.5 – 3.0

Fineness Modulus: 2.6 – 3.0

Water Absorption: 1–2%

Bulk Density: 1600–1800 kg/m³

4. Natural Coarse Aggregate (NA)

Crushed angular aggregate of size 20 mm was used.

Specific Gravity: 2.5 – 3.0

Water Absorption: 0.5 – 1%

Bulk Density: 1500 – 1700 kg/m³

5. Recycled Coarse Aggregate (RCA)

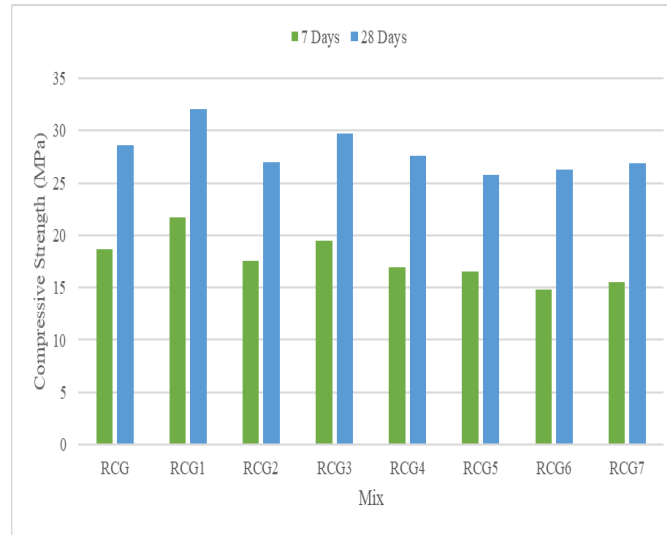
RCA was obtained by crushing waste concrete cubes of size 150 mm. Due to the presence of adhered mortar, it exhibits different properties compared to natural aggregate.

Specific Gravity: 2.4 – 2.6

Water Absorption: 4 – 6%

Bulk Density: 1300 – 1500 kg/m³

Property: Higher porosity and lower strength than natural aggregates.



7. RESULTS AND DISCUSSION

• Compressive Strength

In this study, the compressive strength test was conducted to evaluate the effect of partial replacement of cement with GGBFS and substitution of natural coarse aggregate with RCA. The objective is to understand how these sustainable materials influence the strength characteristics of concrete under normal and elevated temperature conditions.

The compressive strength results indicate that the concrete mix with 10% GGBFS replacement achieved the highest strength at both curing periods, recording 19.50 N/mm² at 7 days and 29.68 N/mm² at 28 days, which is higher than conventional concrete.

The control mix showed moderate strength (18.63 N/mm² at 7 days and 28.63 N/mm² at 28 days), while further increase in GGBFS content beyond 10% resulted in a gradual reduction in strength.

At higher replacement levels (20-30%), the strength decreased but it remains within

Figure 1 Compressive Strength of Various Mixes Containing GGBFS and RCA.

acceptable limits for M25 grade concrete. The reduction may be attributed to slower pozzolanic activity and increased replacement of cement content. Additionally, the use of RCA also influenced the compressive strength, as it generally leads to a slight reduction due to the presence of adhered old mortar, higher porosity and increased water absorption.

In terms of strength and durability, partial replacement with GGBFS enhances compressive strength up to an optimum level due to improved microstructure, after which it gradually declines. With increasing temperature, mass loss increases and indicates progressive thermal damage, while compressive strength remains stable or improves at moderate temperatures due to continued hydration but reduces significantly at very high temperatures due to severe

microstructural degradation. Overall, the combined use of RCA and GGBFS produces sustainable concrete with satisfactory performance when properly optimized.

8. CONCLUSION

The study concludes that the use of RCA and GGBFS can produce sustainable concrete with satisfactory performance. GGBFS improves workability, setting characteristics, and strength up to an optimum level, while also enhancing resistance to moderate temperatures. The compressive strength results indicate that partial replacement of cement with GGBFS (around 10%) provides optimum strength, while higher replacement levels lead to gradual reduction in strength. However, excessive replacement and very high temperatures adversely affect strength and durability, highlighting the need for proper mix optimization.

9. REFERENCE

1. Mr. Vipin Malik et al."cementing growth: opportunities and challenges in india's cement sector 20 november 2024"infomerics valuation and rating pvt. ltd.
2. Mr. Vipin Malik et al."cementing growth: opportunities and challenges in india's cement sector 10 may 2023"infomerics valuation and rating pvt. ltd.
3. L.P.S.S. Panagod et al."cement manufacturing process and its environmental impact"j. res. technol. eng. 4 (3), 2023, 161-168
4. Rahul Mahajan et al."ground granulated blast furnace slag - an overview"ijsrd - international journal for scientific research & development| vol. 4, issue 07, 2016 | issn (online): 2321-0613
5. V. G. RAM et al."challenges and prospects of demolition waste recycling in india"indian concrete journal september 2019
6. Job Thomas et al."construction waste management in india"american journal of engineering research (ajer)
7. IS 10262: 2009 Indian Standard concrete mix proportioning - guidelines (first revision)
8. . IS 516:1959. Method of Tests for Strength of Concrete. Bureau of Indian Standards, New Delhi 110002.
9. .IS 8142:1976. Method of test for determining setting time of concrete by penetratio resistance. Bureau of Indian Standards, New Delhi 110002
10. IRC: 44, 2017. "Guidelines for Cement Concrete Mix Design for Pavements". S.V National Institute of Technology Surat Chchhanath, Gujarat, India.

11. .IS: 10262, 2019. "Concrete Mix Proportioning Guidelines". Bureau of Indian Standards. New Delhi, India.
12. IS: 2386 (Part III), 1963. "Methods of Test for Aggregates for Concrete Part (iii) Specific Gravity, Density, Voids, Absorption, and Bulking". Bureau of Indian Standards. New Delhi, India.
13. . IS: 4031 (Part 4), 1988. "Part 4 Determination of Consistency of Standard Cement Paste". Bureau of Indian Standards. New Delhi, India.
14. IS: 4031 (Part 5) 1988. "Part 5 Determination of Initial and Final Setting Times". Bureau of Indian Standards. New Delhi, India.
15. Lubnar Alkhteerecycled"the effect of recycled aggregate on properties of concrete: a review"hybrid advances 11 (2025) 100535
16. Athika Wongkvanklom et al."enhanced strength reduced modulus high calcium fa geopolymer concrete containing recycled aggregate concrete and portland cement."cleaner waste systems 12 (2025) 100384
17. Jiehong Li et al."synergistic enhancement of sulfate resistance in recycled aggregate concrete through multi-pathway blocking via carbonation treatment and fly ash incorporation"construction and building materials 491 (2025) 142685
18. Jan Pizoń et al."recycled concrete paving block waste as a selected sustainable substitute for natural aggregate in cement composites"construction and building materials 478 (2025) 141356
19. Girum Mindaye Mengistu et al."predicting the compressive strength of sustainable recycled aggregate concrete using multi-ndt methods" results in engineering 26 (2025) 105650
20. Salman Masood et al."performance and sustainability in hybrid concrete: a study of recycled aggregates and activated fly ash"ain shams engineering journal 16 (2025) 103597
21. Raymond Wellington Suomie et al."performance of rice husk ash (rha) and recycled coarse aggregate (rca) for sustainable concrete: a review"next materials 8 (2025) 100778
22. Jianhua Li et al."fully recycled aggregate concrete composite functional additives: proportioning tests and verification of engineering adaptability"results in engineering 27 (2025) 106910
23. M. Rosales et al."sustainable concrete manufactured with mixed recycled aggregate and biomass bottom ash, replacing aggregate and cement to a high percentage"case studies in construction materials 22 (2025) e04785

24. Anand Raj et al."enhancing recycled aggregate concrete with graphene quantum dots (gqds): refining wastes from construction demolitions and out-of-service railway sleepers"developments in the built environment 23 (2025) 100729
25. Eethar Thanon Dawood et al."production of sustainable concrete brick units using nano-silica"case studies in construction materials 14 (2021) e00498
26. Ji-Won Hwang et al."case study on lifecycle co2 assessment of recycled aggregate concrete"case studies in construction materials 23 (2025) e05261
27. Subham Mishra et al."experimentation of concrete properties of crumb rubber with scms: mechanical, stiffness, ndt and micro-structural"cleaner waste systems 12 (2025) 100395
28. Paing Htet et al."influence of micro basalt and recycled macro polypropylene hybrid fibre on physical and mechanical properties of recycled aggregate concrete"journal of building engineering 76 (2023) 107083
29. Shriful Islam et al."partial replacement of sand by fine-grained crushed waste glass along with fly ash stabilization for geotechnical applications in pavement"heliyon 10 (2024) e38754
30. S. Alqarni et al."shear performance of reinforced concrete deep beams using different coarse aggregates under the effect of elevated temperatures"case studies in construction materials 16 (2022) e01087
31. Mateusz Poppek et al."abrasion resistance of concrete containing selected mineral powders"procedia engineering 153 (2016) 617 - 622
32. Ram Prasad Neupane et al."cutting-edge techniques and environmental insights in recycled concrete aggregate production: a comprehensive review" resources,conservation & recycling advances 25 (2025) 200241
33. Abba Fatihaa et al."enhancing performance of recycled aggregate concrete with supplementary cementitious materials"cleaner materials 15 (2025) 100298
34. Hilal El-Hassan et al."synergic effect of recycled aggregates, waste glass, and slag on the properties of pervious concrete"developments in the built environment 15 (2023) 100189
35. Anupama Krishna. D et al."effect of elevated temperatures on the mechanical properties of concrete"procedia structural integrity 14 (2019) 384-394
36. Mervin Ealiyas Mathews et al."effect of elevated temperature on interfacial shear transfer capacity of self-compacting concrete"case studies in construction materials 15 (2021) e00753
37. M. S. Khan et al."effect of elevated temperature on the behavior of high volume fly ash concrete"ksce journal of civil engineering (2015) 19(6):1825-1831

38. Nabil Abdelmelek et al."effect of elevated temperatures on microstructure of high strength concrete based-metakaolin"journal of king saud university - engineering sciences xxx (xxxx) xxx
39. Bright Asante et al."optimized mix design and fire resistance of geopolymer recycled aggregate concrete under elevated temperatures"case studies in construction materials 22 (2025) e04401
40. Fengzhen He et al."effects of elevated temperature and water re-curing on the compression behavior of hybrid fiber reinforced concrete"journal of building engineering 67 (2023) 106034
41. Tran Minh Tunga et al."experimental investigation of the performance of ground granulated blast furnace slag blended recycled aggregate concrete exposed to elevated temperatures"cleaner waste systems 4 (2023) 100069
42. Yiman Jiang et al."a review on mechanical properties and durability of recycled coarse aggregate concrete exposed to elevated temperatures" renewal and sustainable energy reviews 217 (2025) 115730
43. Suha Ismail Ahmed Ali et al."effect of metakaolin and boron-carbide on the properties of magnetite, basalt and quartz concrete at different elevated temperatures"construction and building materials 400 (2023) 132593
44. Bassam A. Tayeh et al."effect of elevated temperatures on mechanical properties of lightweight geopolymer concrete"case studies in construction materials 15 (2021) e00673
45. Ofuyatana et al."dataset on the durability behavior of palm oil fuel ash self compacting concrete"data in brief 19 (2018) 853-858
46. Callum White et al."unified fresh-state concrete field testing via digital rheological measurement"construction and building materials 491 (2025) 142550
47. Roja A. Nambiar et al."mechanical and durability study of high performance concrete with addition of natural fiber (jute)"materials today: proceedings 46 (2021) 4941-4947
48. T. Anstey Vathani et al."a novel approach to utilize recycled concrete aggregates as landfill liner"waste management bulletin 1 (2023) 39-48
49. Melvin Glenn Veigasa et al."cementitious composites made with natural fibers: investigation of uncoated and coated sisal fibers"case studies in construction materials 16 (2022) e00788

50. Rajib K. Majhia et al."performance of structural lightweight concrete produced by utilizing high volume of fly ash cenosphere and sintered fly ash aggregate with silica fume"cleaner engineering and technology 3 (2021) 100121
51. Mahfuzur Rahmana et al."a comprehensive review on fresh and rheological properties of 3d printable cementitious composites"journal of building engineering 91 (2024) 109719
52. Sheelan M. Hama."improving mechanical properties of lightweight porcelanite aggregate concrete using different waste material"international journal of sustainable built environment (2017) 6, 81-90
53. Dipti Ranjan Nayak et al."study on relative shrinkage of cement-based micro-concrete for durable concrete repair"cleaner engineering and technology 8 (2022) 100444
54. Shaik Numan Mahdia et al."mitigation of environmental problems using brick kiln rice husk ash in geopolymer composites for sustainable development" current research in green and sustainable chemistry 4 (2021) 100193