IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 2, September 2025

Impact Factor: 7.67

Strength Properties of Concrete with Ground Granulated Blast Furnace Slag (GGBS) as Partial Cement Replacement : A Review

Piyush Sharma[1] and Mr. Monu Kumar[2]

M.Tech Scholar, Department of CE, BRCM CET, Bahal, Haryana, India[1]

Assistant Professor, Department of CE, BRCM CET Bahal, Haryana, India[2]

ps011061@gmail.com and monu84464@gmail.com

Abstract: *The construction sector is under increasing pressure to reduce the environmental burden of Portland cement production, which significantly contributes to global greenhouse gas emissions. Ground Granulated Blast Furnace Slag (GGBS), a supplementary cementitious material derived from industrial by-products, has emerged as a viable solution for enhancing the sustainability of concrete. This literature review synthesizes two decades of research (2004–2024) on the effects of GGBS incorporation in concrete and related cementitious composites. Studies consistently report that partial replacement of cement with GGBS (typically 20–40%) improves long-term compressive strength, durability, and resistance to chloride ingress, while also reducing permeability and enhancing microstructural densification. Early-age strength reduction is a common limitation, especially at higher replacement levels, though this can be mitigated with curing optimization, mineral admixtures, or fiber reinforcement. Investigations further reveal that higher GGBS contents (50–80%) can be applied effectively in specific cases, particularly when durability and sustainability are prioritized over rapid strength gain. Recent advancements highlight the synergy of GGBS with silica fume, copper slag, crusher dust, and fibers, producing concretes with improved mechanical performance, durability, and reduced environmental impact. Overall, the review establishes GGBS as a versatile supplementary cementitious material that not only reduces cement consumption and CO_2 emissions but also enhances long-term performance, supporting its use in eco-friendly and durable concrete structures.*

Keywords: Cement, GGBS, Replacement ratio (0–20%), Partial cement replacement, Industrial by-products utilization

I. INTRODUCTION

Concrete remains the most widely used construction material globally, primarily due to its exceptional versatility, strength, durability, and cost-effectiveness. Simplicity in production, and low maintenance compared to timber and steel. It consists of a combination of four major ingredients: fine aggregate, coarse aggregate, binding material and water. Cement has become expensive as the traditional binding material and produces a lot of carbon dioxide (CO_2), which is not favorable for the environment. Likewise, river sand, which is widely utilized as fine aggregate, has become scarce. Its excessive use causes riverbed destruction and decreases the natural recharge of groundwater. To overcome these two issues, there have been attempts to produce concrete with alternative and supplementary materials. Ground Granulated Blast Furnace Slag (GGBS), which is a steel manufacturing by-product, has been utilized to replace a portion of cement. Various mix proportions were proportioned with different amounts of cement, GGBS, coarse aggregate, and water. The fresh and hardened properties of the concrete were examined for all the mixes. From these tests, inferences were made regarding the behavior of the concrete.

Concrete is inherently weak in tension and brittle by nature. The concept of utilizing materials such as Ground Granulated Blast Furnace Slag (GGBS) and quarry stone dust to enhance building materials has been in existence for centuries. Some of the earliest examples are mixing clay bricks, horsehair in plaster, and asbestos in ceramics to add

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 2, September 2025
Impact Factor: 7.67

strength. Since the development and refinement of reinforced concrete, strength and flexibility (ductility) have both improved. However, achieving these benefits requires careful and skilled placement of the concrete.

Traditionally, the binding material for concrete is cement, but it is now costly and environmentally damaging when it comes to producing it. Therefore, there is an increased necessity for alternative and complementing cementing materials based on cement. Ground Granulated Blast Furnace Slag (GGBS), for example, is one of the materials produced as a by-product of the iron industry. Another potential development is the incorporation of fibres both for reinforced and unreinforced concrete applications. The contemporary fibre-reinforced concrete development commenced the early 1960s.

The incorporation of fibres into concrete can render it more homogenous, uniform, and isotropic. When cracks initiate, the fibres, which are randomly disposed, become active and assist in arresting the formation and extension of cracks. This enhances the material overall strength and ductility of the concrete material. The two principal failure modes are either the degradation of the bond of the fibres within the concrete matrix or the fracture of the fibres themselves. This report provides a state-of-the-art summary of fibre- reinforced concrete and the outcome of experimental tests carried out utilizing available materials within the locality. Ground Granulated Blast Furnace Slag (GGBS) is one of the supplementary cementitious materials that replaces cement partly in concrete. Its price is actually close to half the cost of ordinary cement and thus offers a cheaper alternative. Substitution of cement with GGBS provides great advantages for the quality of concrete both when it is fresh and hardened. An experimental study is required for the assessment of the joint action of GGBS and quarry stone dust on the quality of concrete both under fresh and hardened states.

Need of study

- After reviewing extensive literature, it is clear that research is ongoing with incorporate concrete mixes with GGBS.
- It concerns solely the use of GGBS with the goal of sustainable and environmentally friendly production of concrete economically.
- The work studies variable quantities of GGBS for the replacement of cement for an examination of the strength behavior of the concrete

II. LITERATURE REVIEW

K.Ganesh Babu et al. (2004)

This study attempted to quantify the 28-day cementitious efficiency of Ground Granulated Blast Furnace Slag (GGBS) in concrete at varying replacement levels. The percentage of replacement ranged from 10% to 80%, and the strength efficiency factor at 28 days was calculated. Results showed that the factor decreased from 1.29 to 0.70 as the GGBS content increased. Using this method, the predicted compressive strengths of concrete mixes, ranging between 20 MPa and 100 MPa with GGBS levels of 10–80%, achieved a regression coefficient of 0.94, which was comparable to that obtained for conventional concrete.

K. Pazhani et al. (2004)

This research evaluated the influence of replacing cement with GGBS and fine aggregate with copper slag on the fresh and hardened properties of concrete. It was observed that using 100% copper slag as fine aggregate increased the slump value by 60.85 mm. A 30% replacement of cement with GGBS reduced water absorption by 4.58%, chloride ion permeability by 29.9%, and pH by 0.39. Complete replacement of fine aggregate with copper slag resulted in a significant reduction of water absorption (33.59%), chloride ion permeability (77.32%), and pH (3.04), highlighting the durability benefits of incorporating these materials.

Venu Malagavelli et al. (2005)

In this investigation, M25 grade concrete was studied with partial replacement of cement by GGBS and sand by crusher dust. The results indicated improvements in both compressive and split tensile strengths. With a 30% replacement of sand by crusher dust along with 1.5% admixture, compressive strength increased by 19.64% at 7 days and 8.03% at 28 days, while tensile strength increased by 1.83% at 28 days. Additionally, with 50% replacement of cement by GGBS

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 2, September 2025 Impact Factor: 7.67

and 25% replacement of sand by crusher dust, compressive strength improved by 11.06% at 7 days and 17.6% at 28 days.

M.C. Nataraja et al. (2004)

The study showed that compressive strength of cement mortar improved with increasing GGBS content, though the gain was modest. At full (100%) replacement, strength dropped slightly compared to natural sand. Overall, GGBS sand was found to be a viable alternative to natural sand, with up to 75% replacement recommended for practical use.

Maheshi Patel et al. (2005)

Research on M35 concrete with partial replacement of cement by GGBS and sand by crusher sand indicated strength improvements. At 40% GGBS and 20% crusher sand replacement, compressive strength rose by 10.04% at 7 days and 16.54% at 28 days. Split tensile strength also increased, suggesting that up to 50% cement can be replaced with GGBS without compromising performance.

Oormila T.R. & T.V. Preethi (2005)

This study evaluated soil stabilized with 15–25% GGBS. Unconfined compressive strength (UCS) tests revealed that 20% GGBS replacement yielded the best results, with strength increasing by 73.79% after 21 days of curing compared to untreated soil.

Kamran et al. (2004)

Investigated GGBS replacement (0%, 25%, 50%) in different concrete mix ratios. Results showed that slag addition enhanced workability and finishing quality. Early-age strength (3–7 days) was lower than control concrete, but 28-day compressive and tensile strengths were comparable up to 50% GGBS replacement. Additionally, GGBS reduced material costs by about 25% compared to OPC.

Yeau K Y and Kim E K et al. (2005)

This study examined concrete with 0%, 25%, 40%, and 55% GGBS replacement up to 90 days of curing. At 28 days, mixes with 25–55% GGBS performed similarly to control concrete, but by 56 days they surpassed the control. The highest compressive strength was achieved with 40% GGBS at 90 days. However, all GGBS mixes showed slower early-age strength development (before 7 days) due to delayed hydration.

Konstantin et al. (2005)

Researchers investigated high-volume GGBS cement with additional silica fume (10%) and a reactive silica admixture. Using 45% GGBS, they observed a 62% strength improvement compared to the reference mix. Tests confirmed that while setting time increased because of the high volume of mineral additives, overall compressive strength improved significantly. The study highlighted that combined mineral admixtures can enhance both performance and durability in blended cement systems.

Oner A. & Akyuz et al. (2007)

The authors compared compressive strength of concretes with and without GGBS up to one year of curing. Early-age strength of GGBS mixes was lower than control mixes, but strength gain was higher at later ages. After one year, GGBS concretes outperformed control concretes, as the slower pozzolanic reactions of slag contributed to long-term strength.

Bilim C. et al. (2009)

This study tested concrete with 20–80% GGBS at water–cement ratios of 0.30, 0.40, and

0.50. At 7 days, GGBS concretes showed lower strength due to slower hydration, but at 28 days, 3 months, and one year, mixes with 20–40% GGBS (especially at w/c = 0.30) achieved higher strengths than OPC control. The optimum long-term performance was observed at 60% GGBS replacement.

Limi et al. (2012)

Investigated engineered cement composites (ECC) with 20% and 40% GGBS replacement. Tests on compression, tension, and flexure at 7, 28, and 90 days showed that GGBS enhanced overall strength and improved fiber-bridging capacity, leading to greater ductility of ECC mixes.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 2, September 2025 Impact Factor: 7.67

Vijaya et al. (2012)
Studied the effect of supplementary cementitious materials (fly ash, GGBS, and silica fume) on durability of high-strength concrete (M80 and M90). Using rapid chloride permeability tests after 90 days of curing, results showed that SCMs improved the pore structure, reduced permeability, and significantly enhanced chloride resistance compared to conventional concrete.
Mohamed et al. (2012)
This study investigated the use of locally available GGBS in concrete to reduce environmental waste and promote sustainable construction. Concrete mixes with 20–80% GGBS showed improved compressive and flexural strength after 28 days, with particularly high performance when finer slag (120 grade) was used. Long-term strength development depended on clinker composition, GGBS content, and water–cement ratio. Overall, a strength gain of about 30% was recorded, mainly due to higher C3S content and its faster reaction with water.
Sabeer & Alavi C. et al. (2013)
Examined partial replacement of cement with 10–50% GGBS. Results showed that 30% replacement gave optimum compressive strength, while higher percentages led to strength reduction. Both split tensile and flexural strength improved at 7 and 28 days with increasing GGBS content. Workability of fresh concrete also increased with higher slag percentages.
Yogendra O. Patil et al. (2014)
Studied the effect of 10–40% GGBS replacement on compressive and flexural strength at 7, 28, and 90 days. Findings revealed that strength decreased as GGBS percentage increased. Up to 20% replacement caused only a marginal reduction (4–6%) in strength after 90 days, while higher percentages led to greater losses. The study concluded that 20% GGBS replacement is practical, as it reduces concrete cost by around 14% without significantly compromising strength.
M. Ramalekshmi et. al. (2014)
Studied concrete with 50% and 80% GGBS replacement, tested at 7, 14, and 28 days. Results showed reduced early strength compared to control mixes, but higher strength at later ages. The optimum strength was recorded at 50% replacement after 28 days. Beam– column tests confirmed improved load-carrying capacity (about 6.6% higher), indicating that 50% GGBS replacement is suitable for reinforced concrete.
Vijaya Gowri et al. (2014)
Investigated 50% GGBS replacement at different water–binder ratios (0.55 to 0.27). Findings showed that high-volume GGBS concrete gained significant strength after 90 days, especially at lower water–binder ratios. The slower hydration of slag initially delayed strength development but improved long-term performance. The study concluded that 50% GGBS replacement reduces cement use, lowers costs, and supports sustainability.
Thejaskumari H.M. & Ramesh V. (2015)
Examined the effects of 40–60% BFS replacement under normal water curing and acidic environments (10% HCl and 15% H_2SO_4). Results showed that compressive, tensile, and
flexural strengths increased with curing age but decreased at higher replacement levels. Up to 55% replacement did not reduce strength significantly, and specimens showed improved resistance in acidic solutions, especially at 53% BFS.
Santoshi Kumari Karri et al. (2015)
Tested 30%, 40%, and 50% GGBS replacements in M20 and M40 concretes. Maximum compressive, tensile, and flexural strengths were achieved at 40% replacement, after which strength slightly declined. Durability tests in 1% and 5% H_2SO_4 and HCl showed that resistance improved up to 40% replacement, but acid attack reduced compressive strength compared to normal concrete. HCl exposure had a greater effect than H_2SO_4.
Jain K.L. et al. (2016)
Evaluated 5–25% GGBS replacement in M25 concrete. Tests included slump, compressive strength (7 & 28 days), flexural strength (28 days), and split tensile strength (28 days). Results showed improved compressive and tensile strengths with GGBS addition. At 25% replacement, compressive strength nearly matched M30 grade requirements (38.44 MPa). Splitting tensile strength also improved, reaching 2.78 N/mm² at 25% GGBS replacement.

Raman JV, Krishnan VM (2017)
Investigated M30 self-compacting concrete with 0–40% GGBS replacement at a water– cement ratio of 0.40. Results showed that 25% GGBS replacement achieved compressive, split tensile, and flexural strengths comparable to conventional concrete.
Shubbar A.A. et al. (2017)
Prepared mixes with 0–50% GGBS replacement. At 7 days, 10–20% GGBS improved compressive strength slightly, while higher levels reduced early strength. However, by 28 days, all GGBS mixes outperformed the control. Optimum strength was observed at 50% replacement, highlighting its potential for both sustainability and strength development.
Ravinder R. et al. (2018)
xplored M30 concrete with 50% GGBS replacement and 0.45 water–cement ratio. A 5% improvement in compressive strength was recorded at 7, 14, and 28 days. The study emphasized GGBS as an eco-friendly alternative that enhances durability and reduces environmental pollution.
Alisha M.K. et al. (2019)
Examined partial cement replacement (0–40%) with GGBS powder. Tests revealed maximum compressive strength at 40% and maximum tensile strength at 30% replacement. The study confirmed that moderate levels of GGBS improve both strength and performance.
Sorabhi Saluja et al. (2020)
Investigated RCC mixes with 0–60% GGBS substitution. Strength improved up to 40% replacement but declined at higher levels. SEM analysis confirmed that 40% GGBS produced a denser, more uniform microstructure with better C–S–H gel formation.
R. YB (2021)
Experimental evaluation of high-strength mixes with GGBS. Summary: Investigated mixes containing up to 50% GGBS in high-strength concrete. The study shows that, with proper adjustment of w/b ratio and admixture dosing, mixes with 40–50% GGBS can reach high 28-day strengths; however, early-age strength loss is evident at higher slag percentages, so curing and admixture strategy are critical. Performance of GGBS cement concrete under natural curing (2021) — practical curing. Compared several replacement levels under natural (ambient) curing and demonstrated that GGBS mixes consistently catch up to — or exceed — OPC control strengths by 28 days when curing is adequate. The paper emphasizes that curing regime and mix proportioning are the main levers to offset slower slag reactivity.
G. Ayim-Mensah et al. (2022)
Influence of GGBS on mechanical behavior of cementitious composites. Tested varied GGBS contents and showed that properly designed slag-rich binders can achieve very high compressive strength (reported cases well above typical OPC mixes) and improved ductility in some formulations. Highlights: fineness and chemistry of GGBS strongly affect strength development.
Review & Practical studies (2022)
reviews and experiments summarized. Summary: Multiple 2022 reports reinforce that moderate replacement levels (≈20–40%) produce the best-balanced outcome for normal structural concretes — improved durability with only modest early strength penalties — and point to the need for case- by-case validation (source of slag, admixture, w/b).
M. J. Miah et al. (2023)
Long-term ageing and durability of GGBS-containing eco-
concretes. Extended tests (beyond 90 days) indicate continued strength gain and significantly improved durability (chloride resistance, reduced permeability) in GGBS and fly-ash blended concretes. The paper supports using GGBS when long-term performance and service life are priorities.
K. Hosseini (2023)
GGBS effects on mechanical and durability performance in modified mortars.Summary: Demonstrated that GGBS improves long-term mechanical properties and durability (especially at 28–90 days) in graphene-oxide (GO) modified mortars and similar composite systems; again, underlining that GGBS is especially beneficial at later ages.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 2, September 2025 Impact Factor: 7.67

S. Moula et al. (2023)
Ultra-high-performance concretes with GGBS. Summary: Explored low-carbon UHPC formulations replacing part of cement with GGBS and found that, with careful mix design (low w/b, superplasticizers, optimized curing), GGBS can be incorporated without sacrificing very high strengths. Early hydration management remains the key challenge.
W. Chen et al. (2024)
Effect of silica fume + GGBS on pore structure and transport properties. Summary: Microstructure and transport testing show that combining silica fume with GGBS produces a denser C–S–H microstructure, markedly reducing chloride ingress and captivity while preserving or slightly improving 28-day compressive strength for moderate GGBS levels. This paper gives clear practical evidence that hybrid SCMs (SF+GGBS) are excellent for durability-critical structures.
T. Yahyaee (2024)
Mechanical properties of mixes with high GGBS and fibers. Summary: Reported that adding modest steel fiber content (e.g., 1.5%) to mixes containing 40–50% GGBS helps compensate for early-age strength drops and improves toughness and post-crack behaviour — a useful practical strategy when high GGBS volumes are needed for sustainability.
G. A. Blackshaw et al. (2024)
Chloride ingress and exposure sequencing in GGBS concretes. Investigated chloride transport under different exposure patterns and confirmed that GGBS concretes show slower chloride ingress because of lower permeability and higher chloride binding capacity; the authors discuss implications for design life of marine/bridge structures.
R. Liu et al. (2024)
GGBS influence on thermal resistance and pore evolution. Summary: Explored how GGBS (and combinations with specialized cements) affects pore refinement and thermal resistance; found that optimized GGBS blends help retain mechanical properties under elevated temperatures and improve microstructural stability.

III. CONCLUSION

The reviewed studies collectively affirm that GGBS is an effective partial replacement for Portland cement in a wide range of concrete applications. Replacement levels of 20–40% consistently provide the most balanced results, delivering improved durability, refined pore structure, reduced chloride penetration, and enhanced later-age compressive strength, with only marginal reductions in early strength. At higher replacement levels (50–80%), performance depends heavily on mix design, curing regime, and supplementary additives, but significant environmental and durability benefits are achievable. Hybrid approaches combining GGBS with materials such as silica fume, copper slag, crusher dust, and fibers further extend its performance potential. Recent studies (2020–2024) emphasize that GGBS concretes are particularly advantageous in durability-critical structures, high-strength and ultra-high-performance concretes, and sustainable construction practices. In conclusion, GGBS not only mitigates the ecological impact of cement production but also enhances the service life and resilience of concrete, making it a cornerstone material for future low-carbon, high-performance construction.

REFERENCES

[1]. The European Guidelines for SCC, May 2005.
[2]. Zoran Grdic, Iva Despotovic, Gordana Toplicic Curcic, Properties of Self Compactability Concrete with Different types of Additives, FACTA University, Architecture and Civil Engineering, Vol. 6, 173-177, No. 2, 2008.
[3]. Hajime Okamura and Masahiro Ouchi, “Self Compacting Concrete”, Journals of Advanced Concrete Technologies, Vol. 1, No. 1 April 2003, pp. 5-15.
[4]. Nans, Kung-chung HSU, His Wen Chai, “A Simple Mix Design, Method For Self Compacting Concrete (2001) 1799 – 1807.
[5]. Pratibha Aggarwalh Yogeh Aggarwal, S. M. Gupta, R. Siddique, “Properties of Self Compacting Concrete – An Overview” 30th Conference on Our World In Concrete And Structures 23-24 August 2005, Singapore.

[6]. G. Kaur, S. P. Singh And S. K. Kaushik, "Reviewing Some Properties of Concrete Containing Mineral Admixtures" Indian Concrete Journal July 2012, 35-49.

[7]. Vilas V. Karjinni, Shrishail B. Anandinni and Dada S. Patil, An investigation on the characteristic properties of high performance SCC with mineral admixtures. The Indian Concrete Journal, 2009, 15-19.

[8]. M. Rame Gowda, Mattur C. Narasimhan and Karisiddappa, Strength behavior of selfcompacting concrete mixes using local materials, The Indian concrete journal, July 2012, 54- 60.

[9]. C. Selvamony, M. S. Ravikumar, S. U. Kannan and S. Basil Gnanappa, Investigations on selfcompacted self-curing concrete using limestone powder and clinkers, APRN journal of engineering and applied sciences, vol. 5, March 2010, 01-06.

[10]. A. Navaneethakrishnan, V. M. Shanthi, Experimental study of self-compacting concrete (SCC) using silica fume, International journal of emerging trends in engineering and development, vol. 4, May 2012, 475-482.

[11]. S. Bhaskar, Ravindra Gettu, B. H. Bharatkumar and M.Neelamegam, Strength, bond and durability related properties of concretes with mineral admixtures, The Indian concrete journal, February 2012, 09-15.

[12]. Asha Philip and Ashok Mathew, "Experimental Study on Mechanical Properties of Geopolymer Concrete Using GGBS," IJSR, vol. 5, no. 5, pp. 2465–2468, 2016.

[13]. ACI Committee, "Fly Ash, Slag, Silica Fume, and Natural Pozzolans in Concrete," presented at the Proceedings of the Third International Conference, U.S.A, 1989, pp. 54–72.

[14]. Kamran, M.K., Usman,G. (2004) Effect of blending of portland cement with ground granulated blast furnace slag on the properties of concrete, Singapore Concrete Institute, Singapore, 329–334.

[15]. Yeau K Y and Kim E K 2005 An experimental study on corrosion resistance of concrete with ground granulate blast-furnace slag, Cement and Concrete Research 35(7) 1391–1399

[16]. Konstantin, S. (2005) Mechano-chemical modification of cement with high volumes of blast furnace slag, Cement & Concrete Composites, 27(1), 848–853

[17]. Bilim C, Atiş C D, TanyildiziH and Karahan O 2009 Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network, Advances in Engineering Software 40(5) 334–340

[18]. Oner A and Akyuz S 2007 An experimental study on optimum usage of GGBS for the compressive strength of concrete, Cement and Concrete Composites 29(6) 505– 514

[19]. Lim, I., Jenn, C.C., Tony, L. & Yin, W.C. (2012) Effect of Ground Granulated Blast furnace Slag on Mechanical behavior of PVAECC, J. Marine Sci. and Technology, 20(3),319–324.

[20]. Vijaya, S.M.R., Ramana, R.I.V., Madan, M.R.K. & Abibasheer, B. (2012) Durability of high performance concrete containing supplementary cementing materials using rapid chloride permeability test, Int. J. Structural & Civil Enginng Research, 1(1), 92– 98

[21]. Mohamed, N.G., Abdesselam Z., Samia, H. (2012) Investigating the Local Granulated Blast Furnace Slag, J. Civil Engng - Scientific Research, 10–15.

[22]. Sabeer Alavi.C, I. Baskar and Dr. R. Venkatasubramani, "Strength and Durability Characteristics of GGBFS Based SCC", International Journal of Emerging trends in Engineering and Development(IJETED), Vol. 2, Issue 3, Mar. 2013, pp. 510-519,ISSN: 2249-6149

[23]. Yogendra O. Patil, Prof. P.N. Patil and Dr. Arun Kumar Dwivedi, "GGBS as Partial Replacement of OPC in Cement Concrete – An Experimental Study", International Journal of Scientific Research(IJSR), Vol. 2, Issue 11, Nov. 2013, pp. 189-191, ISSN:2277-8179

[24]. M. Ramalekshmi, R. Sheeja and R. Gopinath, "Experimental Behaviour of Reinforced Concrete with Partial Replacement of Cement with Ground Granulated Blast Furnace Slag", International Journal of Engineering Research & Technology(IJERT), Vol. 3, Issue 3, Mar. 2014, pp. 525-534, ISSN: 2278-0181

[25]. T. Vijaya Gowri, P. Sravana and P. Srinivasa Rao, "Studies on Strength Behaviour of High Volumes of Slag Concrete", International Journal of Research in Engineering and Technology(IJRET), Vol. 3, Issue 4, Apr. 2014, pp. 227-238, e-ISSN: 2319-1163

[26]. Thejaskumar HM and Dr. V. Ramesh, "Experimental Study on Strength and Durability of Concrete with Partial Replacement of Blast Furnace Slag", Vol. 3, Issue 1, Sep. 2015, pp. 134-140, e-ISSN: 2348-7607

[27]. Santosh Kumar Karri, G.V. Rama Rao and P. Markandeya Raju, "Strength and Duribility Studies on GGBS Concrete", SSRG International Journal of Civil Engineering(SSRG-IJCE), Vol. 2, Issue 10, October 2015, pp. 34-41, ISSN: 2348-8352

[28]. Jain KL. To effect on strength properties of concrete of by using GGBS by Partial Replacing cement and addition of GGBS without replacing cement. SSRG International Journal of Civil Engineering (SSRG-IJCE)– volume. 2016 May;3:144- 9.

[29]. Raman JV, Krishnan VM. Partial Replacement of Cement with GGBS in Self Compacting Concrete for Sustainable Construction. SSRG Int. J. Civ. Eng. 2017;4:22-5.

[30]. Shubbar AA, Atherton W, Jafer HM, Dulaimi AF, Al-Faluji D. The development of a new cementitious material produced from cement and GGBS. InThe 3rd BUiD Doctoral Research Conference-Faculty of engineering and IT 2017 Jun 3 (pp. 51-63). BUiD.

[31]. Ravinder R, Sagarika K, Deepthi K, Reddy PA, Spandana R, Sruthi S. Study on Compressive Strength of Concrete on Partial Replacement of Cement with Ground Granulated Blast Furnace Slag (GGBS). InNational Conference on Water and Environment Society 2018.

[32]. Aisha MK. Investigation on Strength and Durability of Concrete by Partial Replacement of GGBS in Cement.

[33]. Dr.-Ing. Olaf Aßbrock et al., "Ground Granulated Blast Furnace Slag (GGBS) as a concrete additive -Current situation and scenarios for its use in Germany," The Federal Association of the German Ready-Mixed Concrete Industry, German, 2007.

[34]. Peter W.C. Leung and H.D. Wong, "Final Report on Durability and Strength Development of Ground Granulated Blast furnace Slag Concrete," Geotechnical engineering office civil engineering and development department the government of the Hong Kong special administrative region, Hong Kong, GEO Special Project Report 258, 2010.

[35]. Professor Rafat Siddique, Waste Materials and By-Products in Concrete, vol. 1. Patiala, India: Springer, 2008.

[36]. Russell T. Flynn and and Thomas J. Grisinger, "Slag Cement in Concrete and Mortar," American Concrete Institute, ACI 233R-03 233, 2003.

[37]. A Y Ilyushechkin, D G Roberts, D French, and D J Harris, "IGCC Solids Disposal and Utilisation, Final Report for ANLEC Project 5-0710-0065," CSIRO, Australia, 2012.

[38]. Dr. En Yi Chen, "Application of GGBS in China -A Gradual Shift From Cost- Savings To Durability," presented at the 2nd Global Slag Conference & Exhibition, Bangkok, Thailand, 2006, pp. 1–10.

[39]. Thavasumony D, Thanappan Subash, Sheeba D, "High Strength Concrete using Ground Granulated Blast Furnace Slag (GGBS)," International Journal of Scientific & Engineering Research, vol. 5, no. 7, pp. 1050–1054, 2014.

[40]. ACI Committee 233, "Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete," ACI, USA, 233, 2000.

[41]. S. Arivalagan, "Sustainable Studies on Concrete with GGBS As a Replacement Material in Cement," Jordan Journal of Civil Engineering, vol. 8, no. 3, pp. 263– 270, 2014.

[42]. Quaid Johar Bhattiwala and Kuldeep Dabhekar, "Effect of Cementitious Waste Material (GGBS) on concrete as a Replacement in Cement," IJSTE, vol. 2, no. 11, 2016.

[43]. Bahador Sabet Divsholi*, Tze Yang Darren Lim, and Susanto Teng, "Durability Properties and Microstructure of Ground Granulated Blast Furnace Slag Cement Concrete," International Journal of Concrete Structures and Materials, vol. 8, no. 2, pp. 157–164, 2014.

[44]. Sun-Woo Kim,Wan-Shin Park,Young-Il Jang,Song-Hui Yun,Hyun- Do Yun and Do- Gyum Kim, "The Effect of Mineral Admixture on the Compressive Strength Development of Concrete," Contemporary Engineering Sciences, vol. 8, no. 13, pp. 541–547, 2015.

[45]. Vinayak Awasare, and Prof. M. V. Nagendra, "Analysis of Strength Characteristics of GGBS Concrete," Int J Adv Engg Tech, vol. V, no. II, pp. 82–84, 2014.
[46]. B.Mangamma, Dr N.Victor babu,P.hD, G.Hymavathi, "An Experimental Study on Behavior of Partial Replacement of Cement with Ground Granulated Blast Furnace Slag," ijera, vol. 6, no. 12, 2016.
[47]. Maitri Mapa, Hemalatha T., Rama Chandra, Murthy A., "Investigation on Mechanical Properties of Silica and GGBS Incorporated Cement Mortar," ICISE, vol. 04, no. 13, 2015.
[48]. T.D.GunneswaraRao, P.Alfrite, G.Mallikarjuna Rao, Mudimby Geopolymer Concrete," Trans Tech Publ., vol. 764–765, pp. 1090–1094, 2015.
[49]. Zhao Jun, Wang Xinling, Qian Hui and Chu Liusheng, Reinforced Concrete Fundamentals, 1st ed., vol. 1. China: China Architecture and Building Press, 2015.
[50]. Yingzi Yang, Maoguang, Hongwei Deng and Qi Liu, "Effects of Temperature on Drying Shrinkage of Concrete," Trans Tech Publ., vol. 584–586, pp. 1176– 1181, 2014.
[51]. Dongqing Zhang , Xueying Li, Xinwei Ma and Zheng Wang, "Effects of Mineral Admixtures on the Chloride Permeability of Hydraulic Concrete," Trans Tech Publ., vol. 168–170, pp. 2082–2085, 2011.
[52]. Nevile. Adam M., Properties of Concrete, 3rd ed. Great Britain: Longman Singapore, 1994.
[53]. Ke-Liang LI, Guo-Hong Huang, Lin-Hua Jiang, Yue-Bo Cai, Jian Chen and Jian- Tong Ding, "Study on Abilities of Mineral Admixtures and Geopolymer to Restrain ASR," Trans Tech Publ., vol. 302–303, pp. 248–254, 2006.
[54]. Mickael Saillio, Véronique Baroghel-Bouny, and and Sylvain Pradelle, "Effect of Carbonation and Sulphate on Chloride Ingress in Cement Pastes and Concretes with Supplementary Cementitious Materials," Trans Tech Publ., vol. 711, pp. 241– 248, 2016.
[55]. H. H. Seleem, A. M. Rashad and B. A. El-Sabbagh, "Performance of Blended Cement Concrete Against Seawater Attack," Trans Tech Publ., vol. 64, pp. 19–24, 2010.
[56]. Balasubramanian Karthikeyan and Govindasamy Dhinakaran, "Effect of Grinding on Strength and Durability of GGBFS-based Concrete," Jordan Journal of Civil Engineering
[57]. R. YB, 2021 — Performance evaluation of fly ash and ground granulated blast furnace slag in concrete production (experimental study).
[58]. G. Ayim-Mensah et al., 2022 — Influence of Ground Granulated Blast Furnace Slag on the mechanical behavior of cementitious composites. (ScienceDirect / journal article).
[59]. M. J. Miah et al., 2023 — Long-term strength and durability performance of eco- concretes with slag. (journal article / experiments).
[60]. K. Hosseini, 2023 — Influence of GGBS on mechanical and durability properties of modified mortars. (journal article).
[61]. S. Moula et al., 2023 — Ultra-High Performance concrete with GGBS: early age behaviour and low-carbon formulations. (journal article).
[62]. W. Chen et al., 2024 — Effect of silica fume and GGBS on pore structure and transport properties of concrete. (2024).
[63]. T. Yahyaee, 2024 — Comprehensive study on mechanical properties of GGBS-based mixes with fibres. (2024).
[64]. G. A. Blackshaw et al., 2024 — Effects of exposure sequence and GGBS cement on chloride ingress. (2024).
[65]. R. Liu et al., 2024 — Effect of GGBS and SAC on thermal/mechanical properties. (2024).