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An Experimental Study on Optimum Usage of Red Mud And GGBS In Concrete: A Review

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ABSTRACT

Concrete is a widely used material in construction, consisting of fine and coarse aggregates bound by cement. However, the production of cement is responsible for approximately 7-8% of global CO2 emissions. This has led researchers to explore alternatives that can partially replace traditional cement in concrete, such as Ground Granulated Blast Furnace Slag (GGBS) and red mud, an industrial by-product from aluminum production. This study examines the use of GGBS and red mud as partial replacements for cement in concrete. GGBS enhances the durability, strength, and environmental sustainability of concrete, reducing CO2 emissions. Red mud, with its pozzolanic properties, also shows promise as a cement substitute, increasing the strength and durability of concrete while contributing to the safe disposal of industrial waste. The research highlights the benefits of using GGBS and red mud, particularly their role in improving the mechanical properties of concrete. However, the study also identifies challenges, such as the slower early strength development of GGBS concrete and the workability issues associated with red mud, which can be mitigated through the use of superplasticizers. The findings suggest that these materials can significantly contribute to sustainable construction practices, reducing the environmental impact of cement production while enhancing the performance of concrete.

Keywords: Concrete, GGBS, Red mud, Sustainability, Cement replacement

1. INTRODUCTION

Concrete is a composite material composed of fine and coarse aggregate bonded together with fluid cement that hardens over time. When aggregate is mixed with dry Portland cement and water, the mixture forms a fluid slurry that is easily poured and molded into shape. The cement reacts with water and other ingredients to form a hard matrix over time. [24] Concrete is a fundamental material in infrastructure development, comprising cement, fine aggregate, coarse aggregate, and water. Its extensive use in buildings, bridges, and highways leads to significant consumption of its components, which are often scarce and costly [13] Cement production is responsible for approximately 7-8% of global CO2 emissions. This is primarily due to the calcination process, where limestone (calcium carbonate) is heated to produce lime (calcium oxide), releasing CO2 as a by-product. Replacing a portion of cement with alternative materials can significantly reduce these emissions. [21-23]The rising costs of conventional materials have prompted researchers to seek economically viable alternatives. This has led to the exploration of new materials that can replace traditional concrete ingredients [13]

Various industrial by-products, such as Fly Ash (FA), Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), Rice Husk Ash (RHA), and metakaolin (MK), are being investigated as potential substitutes for cement. These materials can enhance the workability,

strength, and toughness of concrete while also reducing porosity and maintenance costs [12] The use of GGBS in concrete significantly reduces the environmental impact associated with cement production. The processing of GGBS saves substantial amounts of energy and results in lower CO2 emissions compared to Ordinary Portland Cement (OPC) production. The cement industry is responsible for about 8% of global CO2 emissions, releasing one ton of CO2 for every tons of cement produced. The use of GGBS in concrete offers numerous advantages, such as improved strength, durability, workability, and economic and environmental benefits. However, a notable drawback is that GGBS concrete exhibits slower strength development under standard curing conditions compared to Portland cement concrete, although it ultimately achieves higher strength for the same water-binder ratio [6]

2. RED MUD

Red mud is a strong waste produced in aluminium plants from bauxite using the Bayer process, generated worldwide. Due to its complex physical properties, finding conservative uses and safe disposal methods for red mud is a challenging task for manufacturers. The partial replacement of this by-product with ordinary Portland cement not only meets the strength and durability requirements of concrete but also addresses the safe disposal of red mud. [24] It highlights that approximately 90 million tonnes of red mud are generated globally each year, with limited industrial applications leading to increasing stockpiles. [22] The particles are very fine, usually less than 10 micrometres in size, with a high surface area (13–22 m^2/g). When mixed with water, red mud creates highly alkaline slurries with a pH of 10–12.5[21] The analysis revealed that red mud mortar showed higher levels of certain hydration products, such as larnite and hatrurite, which are associated with early and later strength gains.[9] SEM images indicated that red mud contributes to a denser microstructure in the mortar by filling voids, which helps enhance the material's durability.[9] The chemical composition of red mud includes mineral compounds like gismondine, goosecrekite, and epistilbite, which belong to the zeolite group. These minerals contribute to the pozzolanic activity of red mud, making it a valuable material in the construction industry when appropriately processed and utilized [18]

The incorporation of red mud into concrete not only helps in reducing chloride migration rates and corrosion potential but also increases the overall durability of the concrete structure, making it a promising material for sustainable construction practices [17] Research has shown that red mud can be used as a partial replacement for cement in concrete production. Studies indicate that replacing cement with red mud can enhance the internal microstructure of concrete, leading to improved strength and reduced voids. However, optimal replacement levels are crucial, as excessive substitution can lead to decreased strength and disturbed microstructure [4] It is also utilized in the manufacturing of ceramic tiles and bricks, contributing to sustainable building materials [2].The incorporation of red mud has shown promising results in improving the mechanical properties of concrete, such as compressive and flexural strength, while also enhancing its durability against chloride penetration[3] Hematite and Goethite: These iron-rich minerals are the primary sources of iron oxide. Quartz: A common mineral that contributes to the overall structure. Gibbsite and Boehmite: These are aluminum hydroxides found in red mud. Anatase: A form of titanium dioxide. [1] Utilizing red mud in construction not only reduces waste but also lowers costs associated with cement production. This dual benefit promotes the sustainable application of red mud in the construction industry [10]

Table 1

Properties of Red mud

S. No	Content	Values
1	SiO_2	6-6.5%
2	Al_2O_3	18.1-21%
3	Fe_2O_3	35-37%
4	CaO	1.7-2.2%
5	TiO_2	17-19%
6	Na_2O	5.2-5.5%
7	L.O.I.	11.8-14%
8	Specific gravity	2.71
9	Colour	Red
10	Alkalinity	10-13

[24]

Physical properties of red mud. Colour- Radish brown

Texture - Irregular

Odour - Odourless

Specific gravity - 2.45

Fineness - 2800 cm^2/gm [4]

3. GGBS

GGBS is a by-product from the blast-furnaces of iron and steel industries. It is produced when molten iron slag is rapidly cooled and granulated, resulting in a fine glassy material. [14] According to ASTM C 989, GGBS is classified into three grades based on its relative compressive strength: Grade 80, Grade 100, and Grade 120[25] GGBS is primarily composed of silicates and alumino-silicates of calcium, along with metallic products like iron and manganese. It has two distinct phases: a glassy phase, which contributes to its cementitious properties, and a crystalline phase, which is mainly responsible for hydration. [16]. The addition of GGBS can enhance the durability and performance of concrete, particularly in terms of compressive strength and resistance to environmental factors [7]. GGBS concrete exhibits enhanced durability compared to traditional OPC concrete, especially in aggressive environments. Research indicates that GGBS composites are more resistant to acids and salts, which can be detrimental to concrete structures. [19]. The use of GGBS serves as an eco- friendly alternative to conventional building materials. By utilizing this waste product, it helps reduce landfill waste and promotes a greener environment. This is particularly important as traditional materials become increasingly scarce and expensive. [13] The chemical composition of GGBS plays a crucial role in its performance as a cement substitute, enhancing the properties of concrete when used appropriately. [12]

Table 2 Physical & mechanical properties of cement &GGBS

Test	Cement	GGBS
Color	Gray	Off white
Consistency	25%	33%
Soundness	4 mm	--
Initial setting time	110 minutes	--
Final setting time	290 minutes	--
Specific gravity	3.13	2.95
Fineness (sieving on 90µm)	8.5 %	0%
Fineness (Blain's air permeability)	302 m^2/kg	320 m^2/kg
Bulk density	1.48 gm/cm^3	1.29 gm/cm^3
Compressive strength	N/mm^2	
3days	23.33	--
7days	34.33	--
28 days	46.18	--

[6]

4, TEST RESULT

4.1 Compressive Strength of Red Mud

Red mud as a partial replacement for cement can significantly enhance the compressive strength of concrete, particularly at a 10-15% replacement level, while higher percentages may not provide additional benefits. [24]

4.2 Water absorption of red mud concrete

Red mud when used in mortar has been found to reduce water absorption due to its fine particle size compared to cement. Research indicates that the reduction in water absorption can range from **18%** (in the control mix without red mud, RM0) to **9%** (with 20% red mud replacement, RM20) after **28 days of curing**. The finer particles of red mud fill more pores within the mortar matrix, leading to a denser structure and thereby decreasing the permeability. This reduced water absorption improves the durability of the mortar, making it more resistant to moisture-related damage and increasing its lifespan. [9]

4.3 Chloride Penetrability of red mud concrete

Replacing 12% of cement with red mud in concrete mixes reduces chloride penetrability, as indicated by lower. Rapid Chloride Penetrability Test (RCPT) values. This implies that such a mix can effectively improve the resistance of concrete to chloride-induced corrosion. Consequently, this type of concrete could be particularly advantageous in environments exposed to high chloride levels, such as sewage treatment plants or chemical plants.

Percentage replacement of cement by red mud	Total charge pass (coulombs)	Percentage increase or decrease with reference mix	Permeab ility of chloride (astmc- 1202)
0 (Ref.)	3749.85	–	Moderate
2	3685.50	—1.70	Moderate
4	3646.98	—2.74	Moderate
6	3430.48	—8.51	Moderate
8	3356.88	—10.47	Moderate
10	3245.66	—13.44	Moderate

12	2412.18	—35.67	Moderate
14	3366.88	—10.21	Moderate
16	3888.65	+3.70	Moderate
18	4531.32	+20.84	High
20	5860.93	+56.29	High

4.4 Workability of GGBS

The percentage of GGBS increases, the workability of the concrete also increases, and this relationship appears to be linear up to a certain point. The maximum workability is observed when 50% of the cement is replaced with GGBS.This means that at 50% GGBS replacement, the concrete mix becomes the easiest to work with (i.e., it is more fluid and easier to pour and spread). This observation could be due to GGBS particles being finer than cement particles, which helps to fill voids and improve the consistency and flow of the mix. Additionally, GGBS can improve the workability of concrete because it reduces the water demand of the mix. [13]

4.5 Effect of Acid on Compressive Strength

The compressive strength of concrete decreases when exposed to acidic conditions compared to normal concrete. The adverse effect of acid on concrete reduces as the percentage of GGBS in the mix increases. At 40% GGBS replacement, the concrete exhibits greater resistance to acid attack. **HCl vs. H2SO4 Impact**: The compressive strength of GGBS concrete exposed to hydrochloric acid (HCl) is higher than that of concrete exposed to sulfuric acid (H2SO4). This indicates that HCl has a less detrimental effect on the strength of GGBS concrete compared to H2SO4. [19]

4.6 Split Tensile Strength of GGBS concrete

The split tensile strength of concrete decreases when GGBS is used, particularly after 7 days of curing. This suggests that the early strength development is slower when GGBS is incorporated into the mix. However, after 28 days, the split tensile strength increases with the incorporation of GGBS, indicating a delayed but more substantial strength gain as the curing progress. The split tensile strength of the concrete after 28 days is 22.58% higher than that of conventional cement concrete, demonstrating a significant improvement in long-term tensile strength. [6]

4.7 Alkali silica reaction OF GGBS Concrete

GGBS is highly effective in controlling ASR in concrete through multiple mechanisms, including reducing alkalinity, alkali mobility, and free lime content. Various studies support the efficacy of GGBS in reducing the expansion caused by ASR, with higher replacement levels and finer GGBS being more effective. The effectiveness of GGBS in controlling ASR is most significant at higher replacement levels (e.g., 50% to 65%) and with higher fineness, making it a valuable component in concrete design for durability. [14]

4.8 Sulphuric Acid Resistance of GGBS Concrete

The formation of gypsum and ettringite, which are products of chemical reactions in concrete exposed to acid, causes an increase in volume. This expansion generates tensile stresses within the concrete, leading to cracking and spalling (flaking or breaking off) of the concrete surface. The attack by sulfuric acid primarily occurs in a narrow zone within the interfacial transition zone (the region between the aggregate and the cement paste in concrete). This leads to a reduction in the thickness of this zone, making it a critical area for acid resistance. [7]

5. Conclusion

- Concrete with 20% Red Mud replacement shows increased compressive and tensile strength compared to conventional concrete.
- Higher flexural strength is observed in concrete with 30% Red Mud replacement.
- Beyond 20% replacement, further increases in Red Mud content lead to a decrease in compressive strength
- Red Mud addition reduces water absorption due to the filling of voids, but high Red Mud content increases permeability and water absorption due to microcracks.
- The presence of Red Mud in concrete improves resistance to chloride-ion penetration and rebar corrosion, especially between 20% and 30% replacement.
- Concrete with 20% Red Mud exhibits better strength and durability.
- Microscopic studies reveal that Red Mud enhances the interfacial transition zone (ITZ) characteristics and modifies the cement paste structure.

- Red Mud increases tricalcium silicate content and iron and sodium levels in the cement paste.
- Workability decreases with increasing Red Mud content due to higher water absorption by Red Mud particles.
- Superplasticizers are recommended to improve flow properties, particularly at higher Red Mud levels.
- Red Mud has low pozzolanic activity but can enhance pozzolanic reactivity in cementitious materials due to its high alkalinity.
- The workability of concrete increases with GGBS content, reaching its peak at around 50% replacement. This is due to the smoothness and fineness of GGBS, which also enhances the volume of paste.
- The compressive strength of concrete improves with GGBS up to an optimal content of about 40-60%. Beyond this point, strength decreases, likely due to excess unreacted GGBS acting as filler rather than contributing to the concrete matrix.
- Split tensile and flexural strengths increase with GGBS, peaking around 40-60% replacement. These strengths are also higher than conventional concrete at optimal GGBS levels.
- Early-age strength is lower in GGBS concrete compared to OPC, but GGBS concrete shows greater strength gains over time due to its slower pozzolanic reaction.
- GGBS inclusion improves concrete's resistance to sulfate attack, chloride ion ingress, and alkali-silica reaction, leading to better long-term durability.

6. Research Gap

- The chemical composition of red mud varies significantly depending on its source, affecting the pozzolanic properties and overall performance in concrete. Most studies do not provide detailed chemical compositions of the red mud used, leading to discrepancies in reported results. Conduct a systematic study comparing the effects of different chemical compositions of red mud on the mechanical properties, durability, and microstructure of concrete.
- While some studies have examined the microstructure of red mud concrete, there is a need for more detailed analysis, particularly regarding the interfacial transition zone (ITZ) and the formation of microcracks and voids.
- Red mud tends to decrease the workability of concrete, leading to increased water demand and the need for superplasticizers. The exact relationship between red mud content and the workability of concrete is not fully understood.
- While the studies have addressed short to medium-term durability improvements with GGBS, there is limited information on long- term durability, especially in various aggressive environments (e.g., marine, freeze-thaw cycles, high temperatures).
- The effects of very high GGBS content (above 70%) on mechanical properties and microstructure over an extended period have not been fully explored. Understanding these effects could help in applications where low cement content is necessary.
- The effect of GGBS on other important properties such as shrinkage, creep, and thermal properties (e.g., heat of hydration) is less documented. These factors are crucial for large-scale structural applications and long-term performance.
- Most research suggests optimum GGBS content around 40-60%, but the exact impact of varying cement types, curing methods, and environmental conditions on this optimum range is not well explored. More detailed studies could refine the optimum GGBS content for different scenarios.

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