



Original Research Paper

A COMPREHENSIVE INVESTIGATION OF USING RED MUD FOR ENVIRONMENTALLY FRIENDLY BUILDING

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Abstract

Because of its distinct molecular and mineral makeup, red mud—a residue of the production of construction components and soil stabilization. Because of its high acidity and massive production amount, red mud dumping is a significant environmental concern on a global scale. This substance can be used to clean wastewater and reduce waste, even though it has previously been used as building materials (such as bricks, cement, and building materials). Red mud's alkaline composition, pozzolanic qualities, and fine particle size enhance soil strength and structure while providing an affordable option for soil stabilization. RM may be used as fillers for low-lying regions to help with construction projects and solve the disposal issue. . By using bauxite waste and red mud valorization as an initial source for alkali-activated binding agent, this study emphasizes the mechanical qualities and durability of building materials. This document includes current research findings and real-world applications related to this waste's utilization. It also talks about the advantages and difficulties of using red mud extensively. It provides insight into how to enhance the strength and endurance of building materials while taking the environment into account. To give a thorough grasp of red mud's ability to promote sustainable development, future viewpoints on policy, technological advances, and environmental effect are also covered.

Keywords- Red Mud, Building Material, Construction

Introduction

The idea of sustainability in commercial manufacturing has gained popularity in recent decades as a way to lessen the negative effects of producing and disposing of waste on the surroundings. In the civil construction sector, reusing waste materials is seen to have the most promise. Using industrial waste to make bricks, mortars, concrete, tiles, cement, and other civil building materials has been the subject of several research. A waste product known as red mud is produced when alumina (aluminum oxide) is extracted from the bauxite minerals . Gibbsite that is $(\text{Al}(\text{OH})_3)$, boehmite that is $(\gamma\text{-AlO}(\text{OH}))$, and diaspor () are among the aluminum hydroxide minerals that make up the majority of bauxite, a type of sedimentary rock. It constitutes the primary source of aluminum in the world. It frequently contains different proportions of silica , titanium dioxide , and iron oxides. RM output is increasing along with the world's need for aluminum. This implies that more RM is released as trash as well. For every ton of aluminum produced, an estimated 1 to 1.5 tons of RM are created . Just two to three percent of the 142 million tons of bauxite waste generated each year over the past century has been put to good use of the global output. The annual

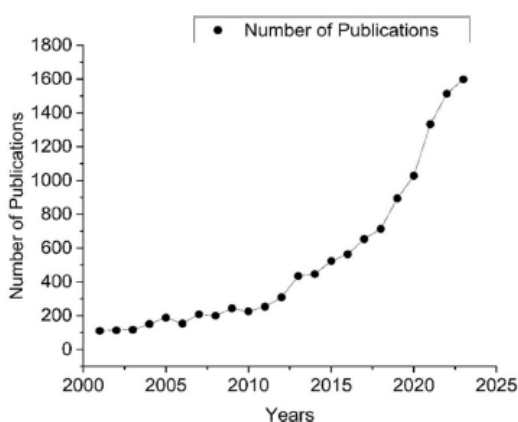
publication data from Web of Science Direct toward using the term "RM as a building material" is shown in Figure 1. According to the observed exponentially development, by 2024, there may be about 2000 publications overall. Due to its extremely high alkalinity, trace levels of hazardous metals, and massive production, red mud presents a number of problems, including disposal. It may be disposed of in a number of ways, including piling it dry, preserving it in lagoons, discharging it into the sea, and employing other dryness methods of elimination . Red sludge dumped into the ocean by the aluminum industry can damage marine life. If not adequately handled, its high hardness ($\text{pH} > 11$) can contaminate soil and water. Red mud is traditionally disposed of by lagooning, which involves pumping the mixture into ponds. These artificial lakes are constructed with dams coated with clay, allowing the slurry to naturally dry. Although this approach is inexpensive and reduces dust, it requires a lot of area and may have negative environmental effects. Animals and humans run the risk of coming into touch with the dangerous chemicals, which might contaminate aquifers. In the dry arranging things the slurry is thinly distributed and hardened to 48–55 percent solids. Before adding a fresh layer, every layer

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is allowed to dry. When the mixture is around 65 percent solid, it may be layered safely. Although this approach requires less space, it may produce more dust and cost more to maintain over time. The residue is processed into a dry cake that contains at least 65 percent solids for dry disposal. To recover soda and lessen its alkalinity, the item is cleaned using steam or water. Without any additional processing, the dry residue is delivered to the disposal location via truck or conveyors. Although this approach reduces the amount of warehouse space needed, a filter plant must be set up and maintained. Large storage spaces are needed to accommodate the massive amounts of red mud, and maintaining these facilities is expensive.



Graph-1 According to the website Science Direct, there has been an increase in the number of publications about "the use of red mud for building materials"

Table-1 Red mud's chemical makeup according to several manufacturing techniques

Production methods	Chemical constituents (%)									
	CaO	Al ₂ O ₃	Fe ₂ SiO ₃	SiO ₂	TiO ₂	Na ₂ O	K ₂ O	MgO	Nb ₂ O ₅	Loss
Bayer process	20.80	17.65	28.33	8.30	7.34	2.30	0.06	0.65	-	13.80
Sintering process	38.07	9.15	6.65	18.0	6.72	4.00	-	-	0.0193	16.96
Combined process	40.78	7.68	10.97	22.66	3.26	2.93	0.38	1.77	-	11.77

Table-2 Red Mud's Mineral Structure In Percentages According To Weight

Mineral constituents	Chemical formula	Production methods		
		Bayer process	Sintering process	Combined process
		(in weight percentages)		
Calcite	CaCO ₃	19	14	10
Boehmite	Al ₂ O ₃ ·H ₂ O	21	–	143
Belite	2CaO·SiO ₂	–	46	43
Anorthite	CaAl ₂ Si ₂ O ₈	20	50	2
Sodium aluminosilicate	Na ₂ O·Al ₂ O ₃ ·2SiO ₂	–	7	8
Sodium aluminate	NaAlO ₂	20	4	4
Tetracalcium aluminoferrite	4CaO·Al ₂ O ₃ ·Fe ₂ O ₃	–	6	12
Calcium titanate	CaO·TiO ₂	15	4	12
Iron sulphide	FeS	–	1	–
Others		1	1	–
Total		100	95	96

2. Red Mud's Properties

The place of extraction of the bauxite ore and the processes employed in its production have an impact on the properties and makeup of RM. A thorough examination of the mineral and chemical constituents of RM from different production techniques is given in Tables 1 and 2, which show that the main ingredients are CaO, Al₂O₃, Fe₂O₃, SiO₂, TiO₂, and Na₂O.

When contrasted with red mud created through other methods, RM produced using the Bayer process has the highest concentration of Fe₂O₃ and Al₂O₃. The red mud produced by the sintering process and the combination approach are comparable. Compared to the red mud through the Bayer process, both methods include significantly more CaO and SiO₂. The primary mineral section, 2CaO·SiO₂, which makes up around 50 percentage of the bulk, is characterized by high quantities of calcium and silicon in the natural RM produced by the mixed and sintering procedures. However, the main minerals found in red mud generated by the Bayer method are sodium aluminosilicate, boehmite, and anorthite.

3. Red Mud's Physical Attributes

Depending on where it comes from and how it is processed, red mud has different physical properties. Red mud's strong iron oxide component gives it a reddish-brown color. Although there may be larger particles present, it possesses a fine, powdery texture. The bulk consistency of red mud fluctuates between 2.5 to 3.4 g/cc, demonstrating its substantial heaviness. Red mud's pH ranges from 10 to 13, indicating that it is alkaline while sodium hydroxide is utilized for alumina extraction. The drainage and storing procedures have an impact on the moisture content, which varies greatly but typically ranges between 20 and 30 percentage. Due to its fine particle size, RM also has a high specific surface area, typically 20–30 m²/g, which influences its reactivity and capacity to absorb contaminants. Its high porosity enables it to hold considerable quantities of water, posing handling and implementation opportunities as well as challenges.

4. Utilization OF RM

RM has a complicated mixture of elements, including a significant quantity of metallic oxides, especially iron, and is quite alkaline. It has a wide surface area, steady behavior in liquids, excellent particle dispersion, and characteristics akin to those of porous materials. These qualities have considerably improved metallurgy, protecting the environment, and building materials. RM has useful uses in many different fields and is significant for protecting the environment and economic benefits. To use red mud efficiently, its many varieties must be coupled with the right basic resources. RM created by the sintering or combined process often has a high concentration of 2CaO·SiO₂.

and other beneficial minerals, which makes it perfect for usage in ceramics, construction materials, and related sectors. However, there are fewer active components in red mud made by the Bayer method, which dissolves bauxite with high concentrations of iron, boehmite, gibbsite, and aluminum. Because of its high iron concentration and low resistivity to corrosion, this Bayer RM is challenging to use primarily in construction. RM may be managed in three primary methods. It must first be utilized to recover precious metals. Second, RM is an unprocessed substance that may be utilized to produce pottery, bricks, and cement. Third, RM may be used for ecological purposes, including restoring soil of dangerous material-contaminated regions, cleaning up wastewater, exhaust gas management, and other ecologically friendly applications.

5. Beneficial Extraction Of Minerals Via Red Mud

RM may be turned from trash into a resource since it includes a variety of precious minerals. The RM may be characterized using methods such as X-ray diffraction and microscopy with scanning electrons to find out the concentration and kinds of precious minerals. These minerals include iron, aluminum, titanium, and elements from rare earths. Iron, which is mostly found in a variety of iron oxides like hematite (Fe_2O_3) and goethite ($\text{FeO}(\text{OH})$), is one of among the most valuable and prevalent elements in red mud. Iron recovery may transform a disposal issue into a resource by making the trash cost-effective and controllable. Smelting, hydrometallurgical procedures, and separation by magnetic forces are some of the methods used to recover iron from RM.

5.1 Technique Of Separation By Magnets

Iron particles are extracted from RM using this technique. Red mud contains magnetized iron oxides, which allow iron to be drawn out and gathered when the mud passes through magnetic fields. It is a straightforward and economical technique, but it only functions if the iron is readily magnetizable. Iron was extracted from RM by Hammond et al. using the balance of the non-magnetic element was used in the construction, together with a high-intensity magnet. In order to improve iron recovery from RM, Yuan et al. developed a unique suspension magnetization roasting method that uses less energy and reacts quicker. This procedure significantly raises iron's magnetic susceptibility, which enhances magnetic separation effectiveness and magnetic iron recovery.

5.2 The Process Of Smelting

In order to recover iron from red mud, the combination must first be dried and mixed with a substance that reduces it. The iron oxides are then reduced to molten iron by heating the combination in a smelting furnace. After being extracted from the slag, the heated iron is collected, cooled, and solidified for further use.

Although this process may yield enormous-purity iron, it is expensive and less ecologically friendly because to its high energy and infrastructural requirements.

Guo et al. investigated using an immediate reduction smelting technique to produce iron nuggets from high-iron RM. Using a certain molar ratio, anthracite coal, calcium carbonate, and raw high-iron RM with a complete iron grade of 45.14 percentage were combined to produce the required basicity. Pellets containing carbon were subsequently formed from this combination. In the muffle furnace, the resulting pellets were immediately reduced for thirty minutes at 1400 °C. The findings demonstrated that it was possible to effectively produce iron chunks with a silicon (Si) concentration of 0.050 percentage and an average iron grade of 95.52 percentage.

6. Creation Of Building Materials Using Red Mud

RM is regarded as significant for the production and use of building materials since its mineralogical, physical, and chemical characteristics are comparable to those of the primary components of binding materials. Numerous investigations have been carried out to find applications for RM. On the other hand, red dirt usage is significantly lower based on output. Generally speaking, only 2 to 3.5 million tons are utilized across many industries.

• Cement

RM may be used as an additive for the making of cement, which improves the cement's durability and hardness while also lowering the amount of clinker and lowering CO_2 emissions related to cement manufacturing. Fine particle size, significant alkalinity, and a variety of oxides, such as titanium, silica, alumina, and iron oxide, are characteristics of red mud. Because of these characteristics, it is perfect for use as an initial component to create cement clinkers or as an additional material in the manufacturing of cement. This substance is widely used as a gelling agent in the construction industry. Additionally, bauxite waste may be used to make specific cement, such as calcium sulfo-aluminate, which produces cement with significantly reduced carbon dioxide emissions. Because of its high iron concentration, red mud may be used as a cheap pigment for colored concrete, which further lessens the requirement for landfilling. Calcium aluminate cement was made with Bayer red mud, and adding 8 percent red mud produced the best results, particularly the notable rise in compressive strength, which reached 44.8 MPa after fourteen days. To lessen the impact on the ecosystem, RM was used in place of cement while making concrete. RM is a primary cement ingredient used to increase cement manufacturing.

• Making Of Bricks

RM recovery for building materials like blocks and ceramics has been the subject of several investigations.

When making bricks, red mud can either completely or partially substitute clay. Its composition can improve the bricks' lifetime and mechanical qualities. RM bricks have been demonstrated to have high mechanical qualities, including compressive strength, which may be improved by adjusting the firing conditions and RM proportion. The ecological effect of RM disposal is lessened when RM is used in the brick-making process. It reduces the amount of natural clay components used.

- **Building Of Roads**

High alkalinity, fine particle size, and the presence of several oxides, such as silica, alumina, and iron oxide, are characteristics of RM. When building roads, these qualities might be advantageous since they increase the strength and longevity of the materials used. When building roads, red mud can be utilized to stabilize the soil. Because of its composition, it can support greater weight, requires less traditional ingredients like cement and lime, and is better suited for base or sub-base ingredients.

- **Uses In The Treatment Of Wastewater**

With its capacity to eliminate harmful metals such as inorganic anions, metallic compounds ions (including fluoride, nitrate, and phosphate), and organic pollutants like phenolic chemicals, dyes, and microorganisms, RM is showing great promise as a material for water treatment. For the removal of ionized metals, RM has been widely used as an adsorbent. The majority of studies have concentrated on cleaning stormwater with fine red mud particles. Because of its vast surface area for adsorbing pollutants, this powder works well. One significant problem, though, is that RM might be challenging to recycle and repurpose after usage.

- **Red Mud's Application As A Catalyst**

Because RM is rich in ferrous oxides, titanium oxides, and additional precious minerals, it may be utilized as a catalyst. RM provides an affordable substitute for conventional catalysts and aids in addressing environmental concerns associated with their disposal. RM has catalytic qualities appropriate for redox reactions, acid-base relationships reactions, and as supporting material supporting active catalytic species because it includes iron oxides, aluminum oxides, silicon dioxide, titanium dioxide, and several other minor elements. RM can use sophisticated oxidation mechanisms in ecological catalysis to break down organic contaminants in wastewater.

7. Conclusion And Discussion

The composition, reuse and possible uses of RM are investigated in this study. This by-product poses difficulties for management that is both economical and ecologically sound. The recovery of precious minerals from RM using different methods has been the subject of several investigations. However, little

thought is devoted to scaling up these procedures for industrial use; instead, they mostly deal with recovering metal at a lab scale. This disparity arises because testing processes frequently need significant energy consumption, expensive cleanup, and regulated surroundings because of the unique nature of the activities required. More study is especially needed on the traditional roasting techniques for recovering iron from RM. Adding more stages to these techniques might improve iron recovery rates and expedite the procedure as a whole. However, large volumes of acid are needed for direct acid leaching, which increases flux and utilization of energy while metal recovery. Furthermore, problems with slag leaching include the development of silica gel during silica breakdown, which makes filtering difficult.

RM provides a sustainable answer to building requirements as well as environmental issues. It is a useful precursor for alkali-activated binder systems, offering a long-lasting, low-carbon substitute for regular Portland cement due to its high silica and alumina content. Powerful aluminosilicate gels are created when red mud is activated with alkaline solutions, improving the performance of building materials, especially under abrasive conditions. The pozzolanic qualities of red mud also enhance soil stabilization, providing an affordable and environmentally responsible substitute for conventional techniques. In general, the valorization of RM lowers waste and encourages the construction of sustainable infrastructure.

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