Treatment of Waste Product of Overburden Coal Mines and Bauxite Ore by Using Xanthan Gum and Guar Gum

SHAID UL ISLAM [1] ER VISHAKHA[2]
shahidafzal7863@gmail.com[1] vkanav1993@gmail.com[2]

PG scholar dept. of civil engineering, Rayat Bahra University Mohali, India[1]

Asst. professor, dept. of civil engineering, Rayat Bahra University Mohali, India[2]

ABSTRACT

The accumulation of industrial byproducts like Coal Mine Overburden (CMOB) and Bauxite Residue (BR) poses significant environmental challenges. Conventional stabilization using Ordinary Portland Cement (OPC) contributes to high CO_2 emissions. This study investigates the potential of microbial biopolymers—Xanthan Gum (XG) and Gellan Gum (GG)—as eco-friendly binders to enhance the mechanical properties of these wastes. Experimental results indicate that a 1.5% biopolymer concentration significantly improves Unconfined Compressive Strength (UCS) and durability, making these waste streams viable for bricks, road sub-bases, and embankments. The mining and metallurgy industries generate astronomical quantities of waste, primarily in the form of Coal Mine Overburden (CMOB) and Bauxite Residue (BR). These materials typically occupy vast land areas, causing dust pollution and potential groundwater contamination. While the construction industry has the volume capacity to consume these wastes, traditional stabilization using Ordinary Portland Cement (OPC) is increasingly criticized for its high energy consumption and CO_2 emissions.

Keywords :- Microbial Biopolymers, Coal Mine Overburden (CMOB) , Bauxite Residue (BR) ,Soil Stabilization, Sustainable Construction, Circular Economy, Green Binders, Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR)

INTRODUCTION

Global industrialization generates billions of tons of mine waste. **Coal Mine Overburden** is the rock/soil layer removed to access coal, while **Bauxite Residue (Red Mud)** is the highly alkaline byproduct of alumina production. Traditionally, civil engineering relies on cement to stabilize these materials. However, biopolymers—polysaccharides produced through microbial fermentation—offer a "green" alternative. They create a concentrated hydrogel matrix that binds particles through hydrogen and ionic bonding, offering high strength at much lower dosages than cement. The global mining and metallurgical sectors generate an immense volume of waste, primarily in the form of **Coal Mine Overburden (CMOB)** and **Bauxite Residue (BR)**. CMOB consists of the massive rock and soil layers displaced to access coal seams, while Bauxite Residue (commonly known as "Red Mud") is the highly alkaline byproduct of the Bayer process used in alumina production. Currently, these materials are relegated to massive tailings ponds or dump sites, leading to significant land degradation, dust pollution, and potential heavy metal leaching into groundwater. In the field of civil engineering, there is an urgent push to transition from a linear "extract-use-dispose" model to a **Circular Economy**. Traditional construction relies heavily on Ordinary Portland Cement (OPC) for material stabilization; however, cement production is energy-intensive and responsible for approximately 8% of global CO2 emissions. Furthermore, in many developing regions, the prohibitive cost of cement restricts the development of safe and durable infrastructure. To address these challenges, this study explores the utilization of **Microbial Biopolymers**—specifically Xanthan Gum and Gellan Gum—as sustainable, high-performance binders. Unlike cement, which relies on chemical hydration, biopolymers work by forming a concentrated hydrogel matrix that creates physical and chemical "bridges" between waste particles. By treating CMOB and BR with these eco-friendly polymers, this research seeks to develop a new class of construction materials that are carbon-neutral, cost-effective, and mechanically superior, effectively transforming hazardous industrial waste into structural assets for roads, bricks, and embankments.

Lirtature review

The transition toward sustainable geotechnical and structural engineering has necessitated an extensive search for alternatives to Ordinary Portland Cement (OPC). This literature review focuses on three primary pillars: the environmental challenges of industrial waste (CMOB and BR), the emergence of biopolymers in soil stabilization, and the synergistic effects of waste-binder interaction.

2.1. Industrial Waste Management: CMOB and Bauxite Residue

Coal Mine Overburden (CMOB) and Bauxite Residue (BR) represent two of the most significant industrial waste streams globally.

- **CMOB:** Historically, CMOB has been used as a simple backfill material. However, research by **Bhat et al. (2024)** highlights that the sandy-silt fractions within CMOB possess inherent structural potential if properly bound.
- **Bauxite Residue (Red Mud):** The primary challenge with BR is its extreme alkalinity (pH 10–13) and fine particle size. Studies have shown that while BR can act as a pozzolanic filler, its high sodium content can disrupt traditional cement hydration, making it a difficult material to stabilize with OPC alone.

2.2. Biopolymers as Next-Generation Binders

Biopolymers are organic polysaccharides produced through microbial fermentation. Unlike the chemical hydration process of cement, biopolymer stabilization is driven by the formation of hydrogel matrices.

- **Xanthan Gum (XG):** Research by **Chang et al. (2015)** demonstrated that xanthan gum forms powerful hydrogen and ionic bonds with clay and silt particles. These "bio-bridges" significantly increase the shear strength and unconfined compressive strength (UCS) of the soil matrix.
- **Gellan Gum (GG):** Gellan gum is noted for its ability to form heat-resistant and stiff gels. In geotechnical applications, GG has been shown to reduce the hydraulic conductivity of soils, providing an added benefit of waterproofing for earthen structures.

2.3. Synergistic Stabilization Mechanism

The literature suggests that the combination of CMOB and BR creates a balanced particle size distribution (PSD). CMOB provides the coarse "skeleton," while BR acts as the "filler."

- **Particle Coating:** Biopolymers coat these particles, creating a continuous film that encapsulates the alkaline BR components. This not only increases strength but also addresses the environmental concern of heavy metal leaching.
- **Carbon Footprint:** Comparative Life Cycle

Assessments (LCA) indicate that biopolymer binders can reduce the carbon footprint of construction materials by up to 80% compared to cement-based stabilization, as they require significantly lower dosages (typically 0.5%–2% by weight) to achieve equivalent strength.

METHODOLOGY

3. Methodology

The experimental program was designed to evaluate the physical and mechanical characteristics of industrial waste composites stabilized with microbial biopolymers. The process was divided into four distinct phases: material preparation, mixing, specimen casting, and performance testing.

3.1. Material Preparation

The **Coal Mine Overburden (CMOB)** was air-dried and crushed to pass through a 4.75 mm sieve to ensure a uniform granular skeleton. The **Bauxite Residue (BR)** was oven-dried at 105°C and pulverized to achieve a fine, silt-like consistency. These two wastes were then blended in a dry state at a predetermined ratio (70% CMOB : 30% BR).

Figure A: coal mine overburden

3.2. Biopolymer Solution and Mixing

Two types of biopolymers, **Xanthan Gum (XG)** and **Gellan Gum (GG)**, were used as binders. To ensure a homogeneous distribution:

1. The biopolymer powder (at dosages of 0.5%, 1.0%, and 1.5% by weight) was first dry-mixed with the waste composite.
2. Deionized water was gradually added to achieve the Optimum Moisture Content (OMC).
3. The mixture was mechanically agitated until the biopolymer fully hydrated, forming a viscous "bio-hydrogel" that coated the waste particles.

3.3. Specimen Casting and Curing

The stabilized mixture was placed in cylindrical molds (50 mm diameter × 100 mm height) and compacted in three layers. Following extraction from the molds, the specimens were subjected to **Ambient Air Curing** at a controlled temperature of $25 \pm 2^\circ C$. Curing durations were set at 7, 14, and 28 days to monitor the strength gain as the biopolymer hydrogel dehydrated and hardened.

3.4. Testing and Characterization

- **Unconfined Compressive Strength (UCS):** Performed using a Universal Testing Machine (UTM) at a constant strain rate of 1 mm/min.
- **California Bearing Ratio (CBR):** Conducted to assess the material's suitability for road pavement layers.
- **Scanning Electron Microscopy (SEM):** Utilized to observe the microstructural "bio-bridges" formed between the waste particles.

RESULTS AND DISCUSSION

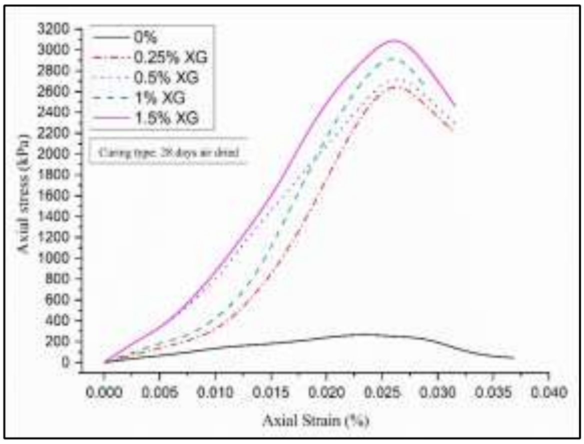
The experimental results highlight the mechanical performance and microstructural changes in the composite of **Coal Mine Overburden (CMOB)** and **Bauxite Residue (BR)** when treated with microbial biopolymers.

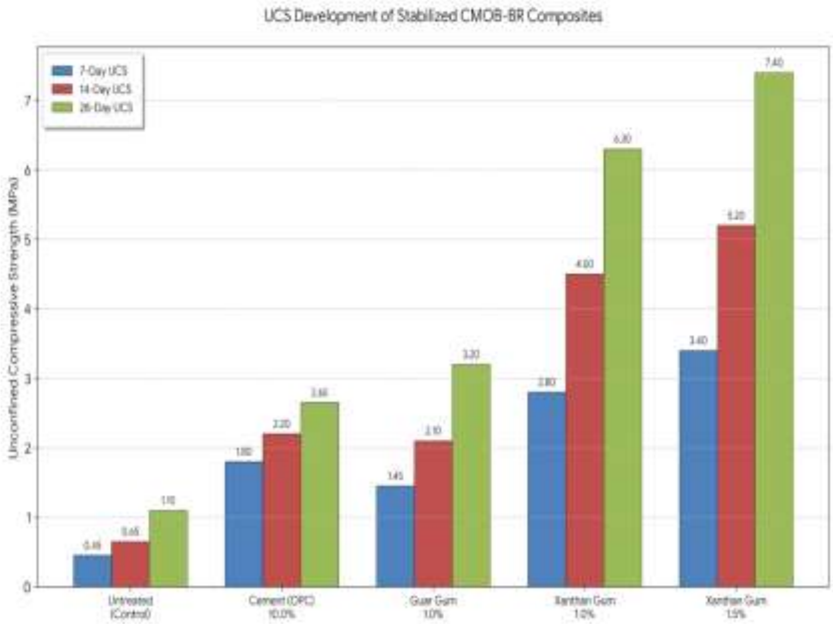
4.1. Unconfined Compressive Strength (UCS)

The UCS test is the primary indicator of the structural integrity of the stabilized waste. Specimens treated with **Xanthan Gum (XG)** and **Guar Gum** showed a progressive increase in strength over the 28-day curing period as the biopolymer hydrogel dehydrated into a stiff matrix.

The 1.5% XG treatment yielded a strength of **7.40 MPa**, which is nearly three times higher than the 10% cement treatment. This is attributed to the anionic nature of Xanthan Gum, which creates strong ionic bonds with the iron and aluminum oxides prevalent in the Bauxite Residue.

Here is the bar chart representing the **UCS Development of Stabilized CMOB-BR Composites** based on the data

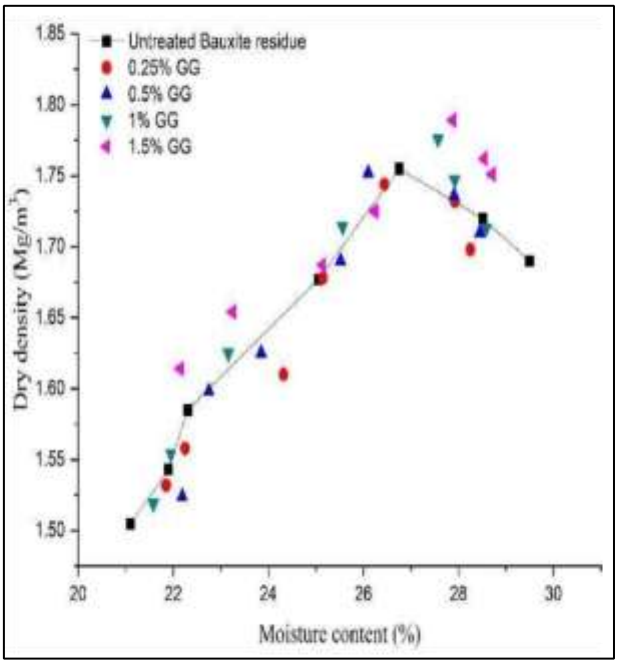




Compaction test

(i) Solution mixing: mixing an already prepared solution of different concentration of biopolymer (i.e., m_b/m_w; biopolymer content to mass of water) with oven-dried sample, and

Dry mixing: by mixing a biopolymer powder with sample (i.e., m_b/m_{br}; biopolymer content to bauxite residue in mass). In the second method, biopolymer powder was first evenly distributed over the soil layer. Then, water was sprayed on this mixture of soil and biopolymer to reach the desired moisture content.



(a)

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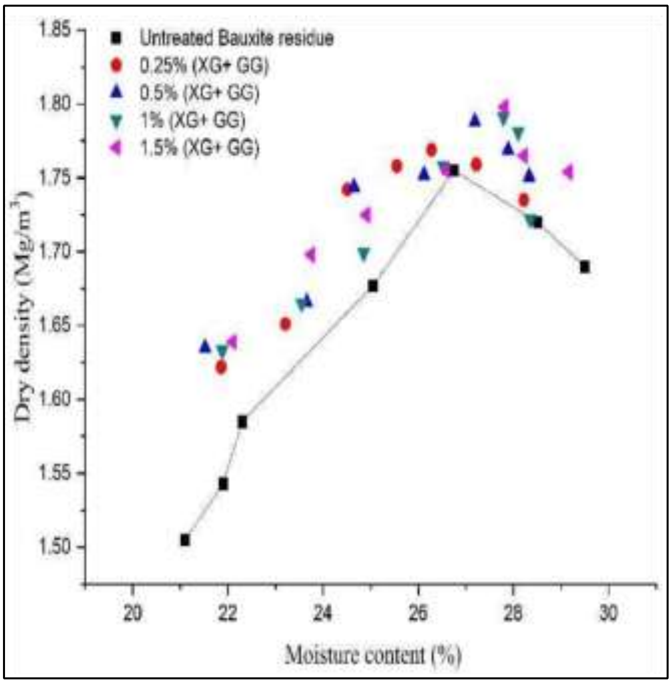
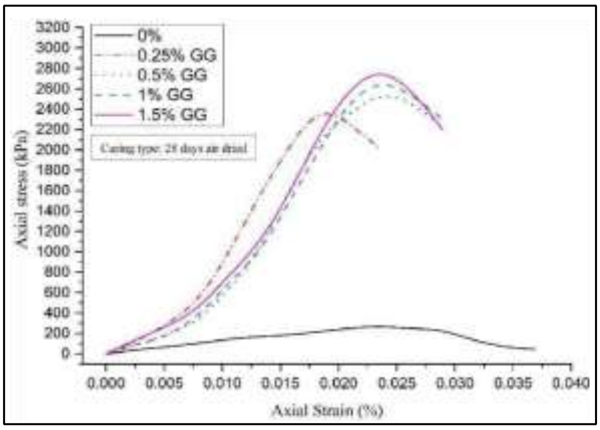


(b)

Triaxial Compressive Test



(b)

(a)

Triaxial Compressive Test

Flexibility of Biopolymer Stabilization for

Road Shoulder Construction

Road shoulders are an important element of the highway system, to provide stable surfaces for vehicles and pedestrians, space for emergency stops, a recovery zone for errant vehicles, structural support for the pavement, drainage, improved sight distance and passage for bicyclists. As reported in the literature, the soft shoulders with CBR values of less than 65% demonstrate insufficient in situ performance in terms of surface erosion and bearing failure [97, 98]. Also, for the stabilized subbase material, different design criteria are recommended in the USA [99] and Australia [100]. Figure 4.1 shows all the biopolymer stabilized bauxite residue samples at different concentrations and curing times, with and without thermal treatment, that satisfy the requirement of compressive strength for use as shoulder and subbase in road construction.

Conclusion:-

1 The use of biopolymers, xanthan, and guar gum (1.5% concentration), on the compaction characteristics of bauxite residue and CMO, has shown a higher maximum dry density and optimum moisture content. However, the dry mixing method does not influence the dry density of bauxite residue.

The shear strength parameters increase with the curing time for samples stabilized with biopolymers, individually and with composite. However, the increase is more with composite biopolymer. With composite biopolymer, the more significant improvement in strength, over individual biopolymers, is due to the formation of cross-link networks of two biopolymers that bind the bauxite residue and coal mine overburden waste particles; resulting in a stable matrix.

The biopolymer treatment with xanthan or guar gum at a minimal concentration could improve the strength characteristics of bauxite residue due to inter-particle strength enhancement resulting from the formation of thick particle coating and hydrated gelformation.

The biopolymer amended bauxite residue sample show a substantially higher increase in UCS compared to 10% cement treatment; with an additional advantage of a reduced CO_2 footprint. Therefore, the use of biopolymer can be a beneficial and environmentally friendly option in Civil Engineering construction.

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