Experimental Study on Asphalt by the Partial Replacement of Filler with Red Mud

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Abstract -
Transportation is the main means of communication for trade, commerce, and many other purposes. In transportation, the roadway plays a crucial role as it is having more advantages compared to other forms of transportation. In India, the maximum length of the highway network is of bituminous pavements.

Bituminous pavement is a general type of bitumen mixture with recommended changes if any. Generally, the bituminous pavement has some failures such as potholes, rutting, cracking, shoving, etc, the major cause of the cracking, shoving, rutting is the lack of adhesion in the bitumen and heavy load vehicles. To solve this issue, we are going to replace the filler material with Bauxite residue in the incremental method from 0% to 25%. This study investigated the strength of the marshall stability specimen.

At present NHAI is taking an initiative to construct rigid pavements for highways. Most of the rigid pavements are constructed with cement concrete. It is not always possible to supply cement because of its limited production there is a necessity to go for alternatives.

Bauxite residue, also known as red mud, is a byproduct of aluminum production during bauxite processing. In India, this waste is often improperly managed, with large quantities being stored in deforested areas. Each year, around 22 million tons of red mud are produced in India alone, contributing to a global total of approximately 119 million tons annually [1]. By using this red mud in bitumen pavement, we are expecting to improve the marshal stability of the pavement and reduce the cost of the construction. By using this material in rigid pavements, we are expecting to improve the strength, durability of pavement and reduce the cost of construction and environmental pollution.

Keywords: Bauxite residue powder (red mud), bitumen pavements, marshal stability, rigid pavements, compressive strength, flexural strength.

1.INTRODUCTION

Contemporary civil engineering practices focus on optimizing design parameters while ensuring cost-effectiveness, particularly in cement production and utilization, a cornerstone of economic development. The construction sector faces mounting challenges in balancing growing infrastructure demands with sustainable resource management. In India, the world's second-largest road network, spanning approximately 5.47 million kilometers, highlights the nation's immense infrastructural needs. However, the disparity between cement production and consumption continues to grow. To address this, global trends in construction increasingly emphasize using industrial by-products in concrete manufacturing, promoting resource efficiency and environmental sustainability.

One such by-product is bauxite residue, or red mud, a waste generated during the Bayer Process of aluminium production. India produces about 10 million tons of red mud annually, posing significant disposal challenges. Improper disposal pollutes groundwater, increases soil alkalinity, disrupts plant transpiration, and harms aquatic ecosystems. By incorporating red mud into concrete production, these environmental hazards can be mitigated, addressing cement shortages and reducing waste simultaneously. This innovative approach aligns with sustainable construction principles, offering a solution that supports the construction industry's demands while prioritizing ecological conservation. Utilizing red mud not only reduces environmental pollution but also enhances resource utilization, paving the way for sustainable civil engineering practices.

1.2 OBJECTIVES OF THE STUDY

1. Increase the Strength of Bitumen:

   Enhance bitumen strength for robust and durable road pavements capable of withstanding heavy traffic loads.

2. Decrease the Percolation Index:

   Reduce water infiltration in construction materials to improve resistance to deterioration, cracking, and reduced service life.

3. Enhance Cost-Effectiveness and Strength of Concrete:

   Utilize red mud as a partial replacement for raw materials in concrete to lower production costs and increase strength.

4. Improve the Durability of Concrete:

   Enhance concrete's longevity by reducing permeability, improving resistance to chemical attacks, and minimizing cracking.

5. Reduce Environmental Pollution:

   Incorporate red mud in construction to minimize waste disposal problems, reduce pollution, and promote sustainable practices.

1.3 MATERIALS USED FOR BC AND CONCRETE

Materials Used in BC and Concrete

The materials used in bituminous concrete (BC) and cement concrete include **coarse aggregate, fine aggregate, filler, and binder cement.**

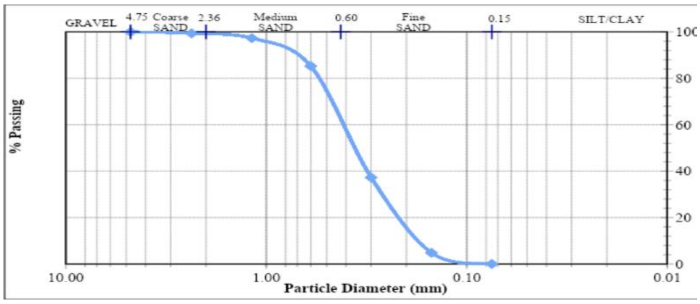
Coarse Aggregate:

Coarse aggregates are hard, durable materials such as crushed rock or gravel, retained on a 4.75 mm sieve. They must be clean, cubical, and meet MORTH specifications, as shown in Table 3.1. Key properties include aggregate impact value (9.5%), specific gravity (2.65), flakiness index (14%), and water absorption (0.15%).

Fine Aggregate:

Fine aggregates pass through a 4.75 mm sieve and are retained on a 75 µm sieve. Sourced from the Krishna riverbed, the sample belongs to Zone III. Granulometric analysis per IS: 383-1970 classifies it in Zone II, with a fineness modulus ensuring compliance with IS: 2386 standards.

Figure 1.1: Sieve analysis of Fine Aggregate



Red mud, a byproduct of aluminium production, is a highly alkaline industrial waste with significant potential for construction applications. Its fine particle size, high specific surface area, and chemical composition, including oxides of iron, aluminium, and silica, enable its use in cement production, concrete, bricks, and road construction. Stabilization with materials like lime and fly ash enhances its properties for subgrade and embankments. Employing red mud in construction reduces environmental impact, supports sustainable development, and addresses waste management challenges. Its versatility and economic benefits make it a promising alternative material for eco-friendly construction practices globally.

2. METHODOLOGY

This is an exhaustive description of experiments and analyses related to concrete and bituminous samples, with particular attention to the integration of red mud as a sustainable filler in asphalt mixtures. Below is a summarized version of the key points structured for clarity: Concrete Samples: Procedures and Testing

Preparation and Curing:

Materials procured, properties tested, and mix design calculated. Concrete cubes (10×10×10 cm), cylinders, and prisms (10×10×50 cm) are cast for M35 grade concrete. Specimens cured in tanks for 28 days before testing. Materials procured and mix design calculated. Cylindrical specimens (101.6×63.5 mm) compacted after heating materials to specified temperatures.

Marshall Stability Test:

Specimens compacted with a rammer (457 mm drop height, 75 blows/side) after heating. Stability and deformation measured using a stability testing machine at 51 mm/min displacement. Asphalt Mixture with Red Mud as Filler

Volumetric Properties:

Voids in Mineral Aggregate (VMA): Enhanced by red mud's fine distribution. Voids Filled with Asphalt (VFA): Improved due to better binder adhesion. Air Voids: Balanced levels ensure durability and stiffness.

Mechanical Properties:

Indirect Tensile Strength (ITS): Increased tensile strength with optimal red mud content. Resilient Modulus: Enhanced load recovery and stiffness. Fatigue Performance: Improved crack resistance under cyclic loading.

Durability Tests:

Freeze-thaw resistance, aging simulations, and moisture susceptibility improved due to red mud's alkaline and fine particle properties. Red Mud Pre-Treatment for Sustainable Use

Neutralization Techniques:

Acid, seawater, carbonation, and thermal treatment methods reduce alkalinity and enhance compatibility.

Activation Methods:

Chemical and mechanochemical activation improve reactivity for asphalt and concrete use. Environmental and Performance Impacts

Physicochemical Properties:

Higher specific surface area and pore volume in red mud contribute to improved binder-filler interactions. Red mud's chemical composition (higher Fe_2O_3 and Na_2O content) enhances high-temperature performance.

Environmental Safety: Leaching toxicity and radioactivity evaluations indicate safe levels for use in construction. Incorporation in asphalt mastic shows significant improvements in strength, durability, and sustainability.

Comparative Data

Property	Mineral Filler	Sintering Mud	Red Mud
Pore Volume (cc/g)	0.017	0.097	0.099
Specific Surface Area (m²/g)	9.988	35.419	30.996
Fe_2O_3 (%)	1.13	25.11	36.43
Na_2O (%)	0.08	3.21	12.27

Findings: Red mud, especially sintering and Bayer types, demonstrates potential as a sustainable filler alternative, reducing environmental impact while maintaining or enhancing asphalt and concrete performance.

3. RESULTS AND DISCUSSION

The study explored the effects of incorporating varying percentages of Bauxite residue into concrete. The compressive strength results, revealed an initial increase in strength with the addition of Bauxite residue, peaking at 45.89 N/mm² at 10%. Beyond this optimal percentage, the compressive strength decreased significantly, with the lowest value observed at 35% (25.51 N/mm²). This trend suggests that while low percentages of Bauxite residue improve compressive strength, excessive content may reduce bonding, increase porosity, or lead to adverse chemical reactions.

The flexural strength data, showed a distinct trend. Up to 15% Bauxite residue, flexural strength decreased steadily from 7.71 N/mm² to 5.55 N/mm². However, a notable improvement occurred at 20%, where the strength increased to 10 N/mm². Higher percentages-maintained stability with minor fluctuations, indicating that Bauxite residue has a complex influence on flexural performance, depending on content levels. These results emphasize the need to optimize Bauxite residue content for achieving desired mechanical properties in concrete.

Bitumen Samples:

The performance of bitumen mixtures with varying percentages of Red Mud as filler was assessed using Marshall stability, flow, and void analyses The highest Marshall stability (18.22 kN) was achieved at 15% Red Mud, demonstrating enhanced strength at moderate percentages. Flow values increased slightly with higher Red Mud content, suggesting a reduction in material stiffness.

Void-related parameters revealed intricate relationships. Volume of air voids (Va) and voids in mineral aggregates (VMA) decreased with increasing Red Mud content, improving compactness. However, voids filled with bitumen (VFB) increased, indicating improved bitumen absorption. The data highlights that up to 15% Red Mud can optimize the balance between stability and flexibility, while excessive content may reduce compactness.

Graphical Analysis:

Graphs depicting the variation of compressive and flexural strength, along with Marshall stability and void parameters, illustrated the trends. Optimal performance was observed at specific content thresholds: 10% for compressive strength, 20% for flexural strength, and 15% for bitumen stability.

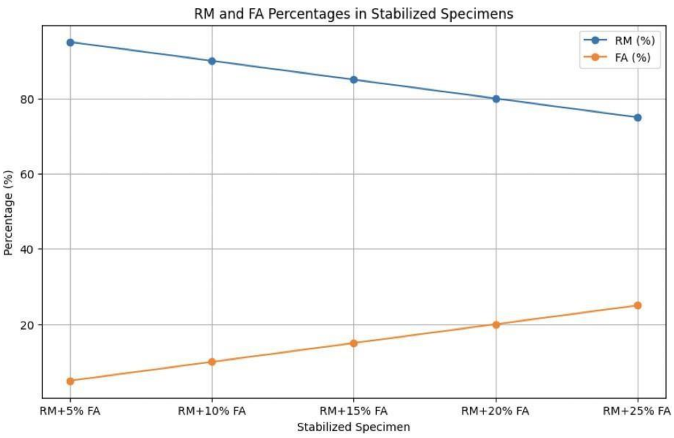


Figure 1.2 RM FA percentages

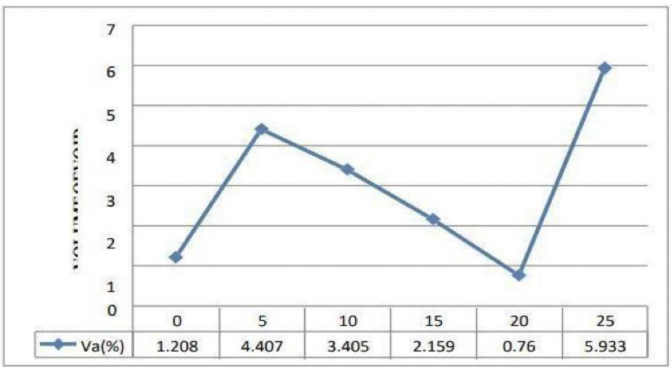


Figure 1.3 Volume of voids Vs % of red mud

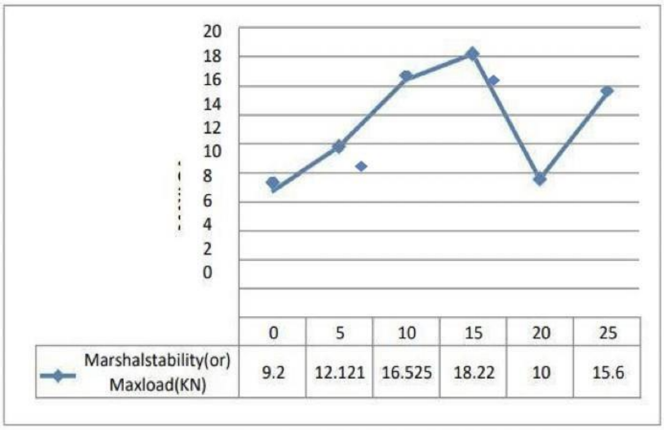


Figure 1.4 Marshall stability Vs % of red mud

4.Conclusion

The optimum percentage of the Bauxite residue for compression strength is10%: The compressive strength of the bitumen mixtures shows an improvement with the addition of Bauxite residue up to 10%. Beyond this percentage, the compressive strength starts to decline. Therefore, 10% Bauxite residue can be considered as the optimal dosage for maximizing the compressive strength of the bitumen mixtures. This finding highlights the importance of carefully selecting and controlling the percentage of Bauxite residue to achieve the desired performance characteristics in bitumen-based applications. Further research and experimentation are warranted to validate and optimize the optimal dosage for Bauxite residue in various bitumen mixtures.

The optimum percentage of the Bauxite residue for flexural strength is 30%: The experimental results suggest that incorporating 30% Bauxite residue in the bitumen mixture leads to the highest flexural strength. This finding indicates that the addition of Bauxite residue at this specific percentage can enhance the ability of the bitumen mixture to resist bending and withstand external loads. It is important to note that the flexural strength may not continue to increase beyond this optimum percentage, and further research is necessary to evaluate the other performance characteristics and long-term durability of the bitumen mixture at this composition. Nevertheless, the identified optimum percentage of Bauxite residue for flexural strength provides valuable insights for the formulation and optimization of bitumen mixtures in road construction applications.

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