Sustainable Utilization of Bauxite Residue in Road Construction

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Abstract

Utilization of bulk waste as a secondary resource is a crucial aspect of environmental stewardship. Rapid urbanization is driving high demand for aluminium and other construction materials. Depending on the quality of ore and the processes involved, each ton of alumina generates 1–2.5 tonnes of bauxite residue. Globally, more than 3 billion tonnes of bauxite residue are stored, and annual generation is approximately 150 million tonnes, with India accounting for around 10 million tonnes per year.

Utkal Alumina International Ltd., a Hindalco unit, is one of the most cost-efficient refineries in the world and also a major generator of bauxite residue, producing approximately 3 million tonnes per annum. Despite efforts to utilize the residue in cement production, dyke strengthening, backfilling, and brick manufacturing, alternative avenues were required to increase its utilization rate, as there is no cement plant in the vicinity. The feasibility of using bauxite residue in road construction was explored in collaboration with the CSIR-Central Road Research Institute (CRRI). CRRI conducted detailed laboratory tests assessing mechanical and leaching properties along with settlement studies under seismic and varying saturation conditions to assess its suitability for embankments. Laboratory results confirmed that heavy metal concentrations were within the limits. The mechanical properties were within the limits of the Indian Road Congress (IRC) and meeting the embankment and subgrade. Settlement results were also below the National limits.

The performance of Bauxite Residue was evaluated through a pilot test section on the National Highway (NH-130) near Koraput, Odisha. Ambient air, groundwater, and soil were monitored at regular intervals and at multiple sampling locations since the construction stage. A metal analysis on the blood sample of the working personnel involved was conducted to examine exposure to heavy metals, particularly aluminium and iron. The environmental and health parameter will be assessed again in 2026 for any residual impacts.

Keywords: Bauxite residue, Embankment, Subgrade, Circularity, Waste material.

1. Introduction

Bauxite residue is a waste generated during the Bayer process in alumina refining. As per the Indian Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016, it is categorized as a high-volume, low-effect waste. Bauxite residue (commonly referred to as red mud) is characterized by its high alkalinity and the presence of heavy metals, posing potential risks to surrounding ecosystems. Improper handling, storage, or disposal can result in

contamination of groundwater, surface water, soil, and air, making its management a critical environmental issue. To address these challenges, industries have adopted sustainable practices for red mud utilization. Examples include its use in cement manufacturing as replacement of laterite, mine backfilling, bricks and aggregate production. Given the rapid pace of infrastructure development in India and the increasing scarcity of natural resources, the National Highways Authority of India (NHAI) has initiated efforts to evaluate the feasibility of using bulk industrial wastes, such as fly ash, jarofix, copper slag, steel slag, zinc slag, red mud, and jarosite,as alternative materials for road construction. Hindalco Industries Ltd. carried out a pilot study to develop a construction methodology with economically viable technology, in collaboration with NHAI, CRRI (Central Road Research Institute) and IMMT (Institute of Minerals & Material Technology). As part of the study, one section of road was constructed using red mud and fly ash (Embankment & Subgrade) while a second section was constructed using a mixture of red mud only (embankment). Based on the study findings, guidelines will be developed by IRC for application of red mud in road construction.

2. Literature Review

Numerous studies have highlighted the potential application of red mud in road infrastructure. For instance, suitability of red mud for use in constructing road bases, embankments, and coastal protection structures like seawall [1]. It has been demonstrated that the stabilization of red mud with up to 4 % with Eko Soil Enzyme (ES) enhances its moisture retention capacity and increases the maximum dry density, thereby improving its engineering properties [2]. Similarly, Panda et al. [3] and He et al. [4] investigated the feasibility of employing red mud in bulk quantities as structural fill and embankment material. Singh et al. [5] explored the feasibility of utilizing bauxite residue to prepare construction materials for highways, showcasing a notable 14.01 % increase in compressive strength, a 6.74 % boost in flexural strength, and a 7.58 % enhancement in split tensile strength following a 28-day curing period in the lab environment.

Further, experiments were conducted using red mud sourced from Muri (Hindalco), India, blended with fly ash in varying ratios (5 to 50 %) [6]. Their findings indicated that the blended material meets the Ministry of Road Transport and Highways (MoRTH) specifications for embankment construction, specifically in accordance with IRC: SP: 84-2014. However, there is a lack of studies that establishes the viability of the red mud usage in actual field conditions. Hindalco Industries Limited, in collaboration with CRRI, New Delhi, undertook an initiative to assess the feasibility of applying red mud in road construction applications. A series of laboratory tests were performed on red mud, both in its natural state with fly ash stabilization, to evaluate its geotechnical characteristics and settlement behaviour, followed by the field trials.

3. Methodology: Lab Trial

3.1 Red Mud Fly Ash Mix

Red mud is a silty and non-plastic fine-grained material. To investigate the improvement in its engineering properties and its workability, it was blended or mechanically stabilized with fly ash (another waste material) in different proportions. Red mud was mixed with fly ash in the ratio of 75:25. Dry density/California Bearing Ratio (CBR) decreases with addition of fly ash in the red mud while the Optimum Moisture Content (OMC) increases. The angle of internal friction of red mud-fly ash mixes varied in the range of 30° to 32° while cohesion value is between 6 to 7 kPa (Table 1).

aluminium and iron concentrations. This analysis aimed to assess the possible bioaccumulation of metals and any related health effects associated with prolonged exposure to red mud.

7. Conclusion & Way Forward

Lab test results have shown suitability of red mud as embankment and subgrade material. TCLP test results confirmed that heavy metal concentrations in the bauxite residue were within the limits specified by USEPA. It had a higher specific gravity (3.2) and CBR (25 %) than soil, with a similar density. The maximum dry density (MDD) and optimum moisture content (OMC) were 21.28 kN/m³ and 18 %, respectively. Settlement (31–51 mm) was well below the Indian Road Congress (IRC) 75 (2015) limit. The factor of safety was found to be greater than 1. It meets the embankment and subgrade specifications as per MORTH (2015) and IRC SP:132 (2022).

For the field trial, performance evaluation by CRRI has shown that all the structural-stability parameters are within norms as per IRC 75 (2013 & 2015). 32 000 t Red Mud has been used in this pilot and Environmental monitoring is ongoing, ending in Dec 2025, and comparative analysis with the baseline parameters after 2 years of monitoring will establish long term sustainability of the bauxite residue use-case in road construction. For this pilot project, red mud and fly ash mix was being used as embankment and subgrade material; however, it can also be used for sub-base construction by mixing it with cement. Suitability of usage of red mud as sub-base construction has been proved through laboratory tests by CRRI. A request letter is submitted to Chairman, NHAI, Delhi for allotment of additional sections of road for utilization of further red mud. Also, in order to streamline the cross-sectoral collaboration and synergy between all the stakeholders, project protocol and SOP will be formulated to be adopted across all sites for consistency and compliance.

8. References

1. Peerapong Jitsangiam, Performance, evaluation, and enhancement of red sand for road bases, embankments, and seawall fills, PhD Thesis, Curtin University, Australia, 2007.
2. S.S. Kushwaha, D. Kishan, M.S. Chauhan and S. Khetawath, Stabilization of red mud using eko soil enzyme for highway embankment, *Materials Today: Proceedings*, 5(9), 2018, 20500–20512. https://doi.org/10.1016/j.matpr.2018.06.427
3. Yufeng He et al., Flash flood vulnerability assessment of roads in China based on support vector machine, Geocarto International, 37(21), 2021, 1–28. https://doi.org/10.1080/10106049.2021.1926560
4. Ipsita Panda, Surabhi Jain, Sarat Kumar Das and R. Jayabalan, Characterization of red mud as a structural fill and embankment material using bioremediation, *International Biodeterioration & Biodegradation*, 119, 2017, 368–376. https://doi.org/10.1016/j.ibiod.2016.11.026
5. Vikash Singh et al., Red mud as a sustainable road construction material: an experimental investigation, *Construction and Building Materials*, Vol. 411, 2024, 134549. https://doi.org/10.1016/j.conbuildmat.2023.134549
6. G.S. Parvathi, A.K. Sinha and V.G. Havanagi, Red mud - fly ash mix as an embankment fill material, *Journal of Indian Road Congress*, 47(3), 2019, 20–25.
7. IRC 75 (2015): Guidelines for the design of high embankments first revision, *Indian Road Congress*, New Delhi, India, 2015.
8. IRC 75 (2013): Specifications for road & bridge works, fifth revision, *Indian Road Congress*, New Delhi, India, 2013.
9. IRC 37 (2014): Guidelines for the Design of Flexible Pavements, *Indian Road Congress*, New Delhi, India, 2014.
10. IRC: SP: 84, 2014: Manual of specifications and standards for four laning of highways through public private partnership, *Indian Road Congress*, New Delhi, India, 2014.

11. IRC: SP:132-2022: Guidelines on use of Industrial Wastes for Road Embankment and Subgrade Construction, *Indian Road Congress*, New Delhi, India, 2022.
12. Bureau of Indian Standards, IS 10500:2012: Drinking water – Specification, IS 10500, New Delhi, India, 2012.
13. United States Environmental Protection Agency, Method 1311: Toxicity characteristic leaching procedure (TCLP), USEPA, Washington, D.C., USA, 1992.
14. MoRTH (2013): Specifications for road and bridge works. Ministry of Road and Highway Transport, New Delhi, India, 2013.
15. MoEFCC (2016): Ministry of Environment, Forest and Climate Change, New Delhi, India, 2016.
16. NAAQ Standard (2009): National ambient air quality standards. Central pollution control board, New Delhi, India, 2019.