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Utilization of Manganese Ore Waste in Concrete: A Review of Experimental and Sustainability Studies

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ABSTRACT

Mining produces a large amount of waste like tailings, slags, and waste rocks, which create serious environmental problems. To solve this, researchers around the world have tried using these wastes in construction materials such as concrete, bricks, ceramics, and asphalt. This helps reduce the use of natural sand and stones and supports sustainability. Studies on iron, manganese, and other mining wastes show that they can partly replace sand, clay, and aggregates in building materials. These wastes are easily available and show good strength when used in small amounts usually up to 40 50%. With proper methods like mechanical processing and geopolymerization, these materials can achieve good strength and meet environmental standards. However, there are still some challenges. Large-scale use, long-term durability, and complete life-cycle studies have not been fully done yet. Use of mining waste in construction helps to protect the environment, saves natural materials, and promotes a sustainable future. However, more studies are needed to make this method safe and effective for regular use.

1. INTRODUCTION

The exponential growth of the construction sector has placed immense pressure on the resources, particularly fine aggregates like river sand, leading to escalating environmental degradation and resource depletion. As Sustainability becomes a central goal within the construction industry, the quest for suitable alternatives to natural aggregates is crucial for realizing Environmentally responsible development. Industrial byproducts, such as Manganese ore wastage (MOW) and low-grade unused manganese rocks, offer a Promising Avenue to reduce environmental footprints while Simultaneously addressing the challenge of industrial waste management.

Manganese, a versatile and indispensable element in metallurgy, is chiefly utilized in the formation of iron and steel alloys, imparting benefits such as enhanced strength, toughness, and deoxidation properties. Globally, approximately 90 95% of manganese ore is consumed by the steel industry. In India, substantial reserves and production capacity place the country as the

world's fifth-largest producer, following China, Gabon, South Africa, and Australia. India holds the second-largest manganese reserves globally, estimated at around 430 million tonnes, and produced a record 3.4 million metric tons of manganese ore in the 202324 fiscal year, Manganese, a versatile and indispensable element in metallurgy, is chiefly utilized in the formation of iron and steel alloys, imparting benefits such as enhanced strength, toughness, and deoxidation properties. Globally, approximately 90 95% of manganese ore is consumed by the steel industry. In India, substantial reserves and production capacity place the country as the world's fifth largest producer, following China, Gabon, South Africa, and Australia. India holds the second-largest manganese reserves globally, estimated at around 430 million tones, and produced a record 3.4 million metric tons of manganese ore in the 202324 fiscal year, representing about five percent of worldwide output. Major mining states such as Madhya Pradesh, Maharashtra, and Odisha collectively account for the majority of the country's output, with significant reserves also distributed across Andhra Pradesh, Karnataka, Gujarat. Production strength, much of the manganese resouemains Underutilized, particularly low-grade ores and by-products left over from mining and metallurgical activities. These wastes, often relegated to landfills or Stockpiles, pose long- term environmental hazards but harbour potential as viable Construction materials. Harnessing these materials as partial replacements for fine Aggregates aligns with circular economy principles and sustainable development Goals, converting waste into a functional.

2. LITERATURE REVIEW

Several researchers have investigated the feasibility of utilizing manganese ore waste and other mining residues as substitutes for construction materials. The following section summarizes key studies relevant to this research. 2.1 2.2 2.3 Gonçalves reviewed several studies showing the potential reuse of mining waste in construction materials. Researchers like 5656, Freitas, De Andrade, and Bolzan used mining residues such as iron and limeston tailings for producing blocks and pavement materials, proving their availability and effectiveness. Pablos et al. emphasized strength and absorption standards. However, most studies lacked large-scale testing and optimization of material mixtures. Gonçalves focused on evaluating flotation mud (LFS) and sandy waste (RAS) for Méndez et al. (2022) investigated the feasibility of using gravimetric mining tailings as a partial or complete substitute for natural sand in concrete block production. Their study emphasized the abundance and easy availability of mining tailings, reducing environmental impact and promoting sustainable construction. The researchers evaluated mechanical strength and durability, achieving comparable performance to conventional blocks. However, they did not explore long-term environmental effects, large-scale implementation, or optimization for diverse mining waste Previous studies by Thomas et al., Gupta et al., Topçu et al., and Ostrowski et al. demonstrated that industrial by- products like copper tailings, granite waste, and recycled aggregates can partially replace natural sand in concrete with acceptable strength resource for infrastructure. and durability. However, limited research has focused on the utilization of manganese tailing stone, despite its abundant availability as a mining waste. Most works emphasized mechanical behaviour, neglecting its microstructural effects and environmental safety, creating a clear research gap 2.4 2.5 2.6 Mohan Yellishetty et al. (2008) show that various researchers such as Fine & Heising (1968), Dean et al. (1986), and Juwarkar et al. (2003) explored the reuse of mine waste for bricks, ceramics, and concrete. Materials like iron ore tailings, fly ash, and siliceous gangue were found locally abundant and suitable for construction. However, earlier works lacked detailed mechanical testing, environmental leaching studies, and region specific evaluations, which this study effectively Previous researchers, including Manchini et al. (2024), González-Corrochano et al. (2016), and Suárez-Macías et al. (2020), explored the reuse of mining, sludge, and industrial wastes in ceramics to reduce environmental impact. Materials such as sewage sludge, biomass ash, and mining tailings were found readily available but often caused inconsistent strength or contamination. However, none achieved full waste substitution. Terrones Saeta et al. (2024) uniquely utilized 100% aggregate washing sludge and manganese waste, creating stable, eco-friendly ceramics meeting Alaa Abbadi and Gábor Mucsi (2024) reviewed studies on mine tailings (MTs) utilization, highlighting previous work on rare earth element (REE) recovery through hydrometallurgical and bioleaching methods. Researchers found MTs rich in valuable minerals like REEs, silica, and alumina readily available for reuse in geopolymer materials. However, most studies focused only on extraction methods, not on integrating mechanical activation and geopolymerization for complete residue utilization. Thus, full- scale recycling 2.7 Araujo et al. (2022) reviewed studies on recycling and reusing mine tailings, highlighting techniques such as flotation, bioleaching, geopolymerization, and reuse in construction and agriculture. Researchers found materials like copper, iron, slag, and

phosphogypsum suitable for building and soil applications. However, large-scale use remains under 1% due to high costs, limited technology, and inadequate regulation. Previous studies focused on laboratory research but lacked industrial-scale implementation and economic feasibility assessments for sustainable mine waste utilization 2.8 Adeel Iqbal, Nuha S. Mashaan, and Themelina Paraskeva (2025) reviewed 41 studies on using mining wastes mainly iron and copper tailings in asphalt pavements. Researchers found these wastes improve rutting resistance, stiffness, and sustainability while ensuring environmental safety through bitumen encapsulation. Materials like iron tailings, copper tailings, and overburden are abundantly available near mining sites. However, previous studies lacked detailed long-term durability tests, comprehensive life-cycle assessments, and standardized evaluation methods 2.9 Ally et al. (2021) reviewed various studies on utilizing mining wastes such as tailings, slags, and waste rocks in concrete, fired bricks, and road embankments. Researchers like El Machi, Ince, and Ettoumi demonstrated good mechanical strength and environmental safety when substituting natural materials. These wastes are abundantly available and can reduce raw material dependency. However, studies on coltan, cobalt, and cassiterite wastes remain limited, indicating the need for further research on their use and environmental effects 2.10 The literature review by Lamani, Aruna, and Vardhan (2016) summarizes the work of various researchers who utilized mine and industrial wastes such as iron ore tailings, fly ash, copper, gold, manganese, and tungsten residues to produce eco friendly bricks, blocks, and tiles. These studies proved the availability and suitability of waste materials as construction aggregates, enhancing strength and reducing costs. However, limited large-scale implementation and insufficient standardization remain challenges. Further research is needed for commercial adoption and 2.11 Mancini et al. (2024) presented a detailed review on the sustainable management and utilization of extractive waste (EW) and tailings to ensure a continuous raw material supply. The authors emphasized the need for comprehensive chemical and mineralogical characterization of waste before reuse. They proposed integrated decision-making frameworks for assessing environmental risks and identifying suitable reuse pathways such as construction material production and recovery of critical raw materials. While the paper offers a strategic foundation for sustainable mining and waste management, it remains conceptual, lacking experimental validation or detailed studies on manganese tailing applications and their mechanical behavior in construction materials

2.12 Jaganmohan (2024) reported on the annual production volumes of manganese ore in India between fiscal years 2012 and 2024. The statistical data indicated fluctuating but generally stable contribution to the global manganese market. This dataset is valuable for understanding the scale of manganese mining and the corresponding potential for waste generation. However, it provides no technical insights into the reuse or management of manganese ore waste, serving primarily as a background reference for assessing material availa 2.13 The Lotus Arise (2024) publication outlined the geographical distribution of manganese ore deposits across India, including key mining states such as Madhya Pradesh, Maharashtra, Odisha, and Karnataka. The study identified the major geological belts where manganese ore is extracted, helping locate potential sources of manganese waste for reuse in construction. While informative for understanding resource distribution, the article lacks peer-reviewed analysis or technical evaluation of waste characteristics and its applicability in civil 2.14 This report from the Investing News Network provided global data on the leading manganese producing countries, including South Africa, Australia, China, and India. The analysis emphasized global production volumes, export trends, and industrial demand for manganese in steelmaking and battery manufacturing. It provided the manganese supply chain and the potential scale of mining waste generation worldwide. However, the report focuses on economic and industrial aspects without addressing waste recovery, reuse, 2.15 The Indian Bureau of Mines (2022) published a comprehensive statistical report summarizing estimation, and regional mining activities. The report highlighted that manganese ore production during FY 2021 22 reached approximately 2.7 million tonnes, maintaining a consistent output level. This document provides reliable government-verified data useful for assessing the magnitude of waste generation potential. However, it does not include any experimental or engineering studies on manganese waste utilization, focusing instead on mining performance and resource 2.16 India achieved record mineral production in FY 202425, including manganese ore output of approximately 3.8 million metric tonnes an increase of nearly 12% compared to the previous fiscal year. The report reflects the rapid growth of rise in the generation of manganese tailings and waste materials. This supports the need for sustainable reuse strategies in construction applications. However, the publication is limited to policy and production highlights and does not provide technical or scientific data related to waste 2.17 The United States Geological Survey (2022) compiled global

data on manganese ore production, trade, and usage. The report noted that global manganese ore output in 2022 reached around 56 million metric tonnes, with South Africa, Gabon, and Australia being the leading producers. The document also identified the steel industry as the primary consumer of manganese, accounting for over 90% of total usage. This international perspective establishes the global importance of manganese and highlights the associated waste volumes generated from large-scale mining operations. However, it lacks technical details on the reuse of manganese waste in construction and does not address its mechanical or environmental Conclusions The study collectively emphasizes the large scale production and availability of manganese ore, particularly in India and globally. However, these studies primarily focus on statistical, economic, or policy aspects, with limited discussion on the engineering reuse or valorization of manganese waste. Further the necessitating comprehensive experimental, microstructural, and environmental studies on the reuse of manganese ore waste in construction materials is to be done. Acknowledgment I would like to express my gratitude to all researchers and authors whose valuable studies on partial replacement of fine aggregate with manganese ore waste in concrete have greatly contributed to this review and enhanced my understanding of sustainable construction materials.

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