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CONSTRUCTION OF ROADS USING STEEL SLAG-A REVIEW IN INDIAN SCENARIO

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Abstract: Accumulation of various waste materials and its effective disposal is now becoming a major concern for Industries and the Environmentalist around the globe. The steel slag which is a by-product of steel processing plant after recycling becomes a promising resource as an aggregate for construction of roads and soil stabilization due to its exceptional strength, toughness, hardness, soundness and other inherent desirable properties. Many of the developed countries have declared this waste as a useful resource rather than waste and have incorporated a significant portion of this waste materials into road construction as aggregate in surfacing and base of flexible pavements. India being second largest producer of Steel in the world, generates million tons of waste every year including steel slag, blast furnace slag and fly ash. Therefore, a series of experimental tasks have been carried out by the agencies related to roads in India for widespread use of these waste from steel plant. In recent years roads have been constructed in India at few places namely-Visakhapatnam, Bokaro, Rourkela, Delhi, Surat and a part of National Highway-713 in Arunachal Pradesh using steel slag. This study presents a summary of recent developments in utilization of steel slag as a road aggregate and its suitability in Indian road infrastructure projects.

Keywords: Aggregate, Steel Slag, by- product, Road, Asphalt, Pavement, Sustainability, Innovative, Infrastructure, Potential, Pollution.

1. INTRODUCTION

The by-products generated from industries not only occupy the available land space but also pollute the environment and create significant difficulties in terms of proper disposal. Steel slag is a residual material that generates during the production of stainless steel by different resources either from the melting of scrape to produce steel in electric arc furnace (EAF), or by converting iron to steel in basic oxygen furnace (BOF). During the production of three tons stainless steel around one ton of steel slag is generated. It has been noticed that per year fifty million tons of steel slag is generated from different steel industries throughout the world. Only in Europe, around 12 millions of steel slag is generated every year [14]. Every year, India's total waste production accounts for 62 million tonnes, out of which 43 million tonnes (70 %) are collected and around 12 million tonnes are treated, and the remaining 31 million tons are dumped into landfills [8]. India's burgeoning steel industry has inadvertently created a significant environmental challenge: the accumulation of millions of tonnes of steel waste each year [8]. India produces about 19 million tonnes of steel slag annually, and this is expected to increase to 60 million tonnes by the year 2030[27]. Traditionally destined for landfills, this by-product is now finding a valuable new purpose. A ground breaking initiative, spearheaded by the Ministry of Steel, Govt. of India under the guidance of National Institution for Transforming India (NITI) Aayog, is transforming steel waste into durable, cost-effective road materials. Through rigorous research at ArcelorMittal Nippon Steel (AMNS) Plant, scientists have successfully processed steel slag into a robust ballast suitable for road construction. This innovative solution prioritizes environmental stewardship, leading to long term economic benefits and a healthier planet.

2. OBJECTIVES

Ineffcient disposal methods of waste from steel processing plant have led to large piles of steel slag around the plants, which have become a major source of water, air and land pollution causing threat to the living beings. Steel slag, a by-product of the steelmaking process, is generated in large quantities as a molten flux material during the high-temperature refining of steel. After cooling and processing, it becomes a stable aggregate with superior properties compared to traditional natural materials used in road construction. As a substitute for traditional aggregates, steel slag can be used in road construction, resulting in roads that are not only stronger but also require less material, leading to a substantial reduction in construction costs. According to Indian

Road Congress guidelines, heavy-duty roads capable of handling thousands of trucks daily require substantial road layers. However, roads constructed with steel slag can be 30% thinner due to the material's superior properties. This not only saves on construction costs but also reduces the environmental footprint of road infrastructure. By repurposing steel waste, India is paving the way for a more sustainable future. This innovative solution helps to mitigate environmental pollution while contributing to the development of durable and cost-effective infrastructure.

The authors of this paper have tried to provide a systematic study on the papers published (delimited to reference paper) about the uses of steel slag, its adaptability and suitability as a road aggregate. This review highlights the technical feasibility, environmental benefits, and economic advantages of using steel slag as an alternative to traditional aggregates. It also covers the history of development of steel road and related Research and Development (R&D) works in respect of India's road sector.

3. METHODOLOGY

A three-stage procedure is followed to obtain the accurate conclusion for the literature review process. In the first stage, the authors have searched the related papers, articles and newsletters etc., in the internet and downloaded the soft copies.

In the second stage, a systematic review was carried out for all the downloaded papers and materials. From the downloaded material most, relevant materials are considered based on review topic. Then they were grouped together as per the nature of similar content.

In third stage, grouped papers are thoroughly reviewed and finally summarized. Lastly, authors conclusions are drawn based on the reviewed literatures.

4. SUMMARY OF THE LITERATURE REVIEW AND DISCUSSION

History of steel slag and it uses in various construction works is quite old in human civilisation. According to Geissler (1996), in 350 BC Aristotle has indicated that during the purification of iron, a by-product is generated like a stone called iron slag. According to Godfrey and Nie, enormous quantity of steel slag was used for wall making and road construction during the period of Roman Empire. According to National Slag Association (NSA), iron and steel slags have been used in engineering constructions for more than 150 years. Up to 97% of the total steel slag produced in 1998 was utilized by Germany in various ways for the construction of heavily travelled roadways [2].

Historical Developments in India:

There have been several significant advancements in the utilization of steel slag for road construction in various parts of India. Central Road Research Institute (CRRI) started a few projects sponsored by Steel Authority of India Limited (SAIL) and all these materials were tested on a big scale in CRRI laboratory. Based on the success of laboratory results. various combinations were tried in the field and finally a road was constructed. This road has been monitored regularly for surface unevenness and pavement structural strength [5].

Following are the different development activities of India in the recent decade in this direction:

1. In 2022, Surat became the pioneer in constructing a road entirely made from processed steel slag. The six-lane public road is a kilometre long stretch in Hazira industries, which also houses the ArcelorMittal-Nippon Steel (AM/NS) plant. This innovative project, a joint venture between Council of Scientific and Industrial Research (CSIR), Central Road Research Institute (CRRI), the Union Ministry of Steel, National Institution for Transforming India (NITI) Aayog, and ArcelorMittal-Nippon Steel (AM/NS), showcased the potential of steel slag as a sustainable road material. The Surat Road has garnered national and international attention, receiving recognition from the India Book of Records and the Asia Book of Records. It has also served as a catalyst for promoting the use of steel slag in other regions [23].

2. The Border Roads Task Force (BRTF) of Border Roads Organization (BRO)'s Project Arunank used steel slag to construct the one-kilometre stretch of National Highway 713 in Arunachal Pradesh. This is an initiative of BRO Director General Lt. Gen Rajeev Chaudhry to introduce environment-friendly new technologies with the help of (Central Road Research Institute-Council for Scientific & Industrial Research (CRRI-CSIR) and Tata Steel Limited. The steel slag material was given by Tata Steel Limited free of cost and transported from far away Jamshedpur to Arunachal Pradesh by Indian Railways free of cost. This road to Chino-India border in Kurung Kumey district connects Joram and district headquarters Koloriang via Palin in sensitive Arunachal Pradesh [24]. This one kilometre stretch of road will certainly boost the security agencies to keep vigilances in the border.

3. India's first National Highway steel slag road section, inaugurated in January 2024 on the Indapur-Panvel Section of NH-66 Mumbai-Goa, marks a significant breakthrough in sustainable infrastructure development. This innovative project demonstrates the potential of steel slag technology to contribute to a more resilient and environmentally friendly road network. Jindal South West (JSW) Steel, in collaboration with CSIR-CRRI, constructed a 1km steel slag road section using 80,000 tons of processed steel slag aggregates. Steel slag roads offer superior mechanical properties, lower costs, and increased durability compared to traditional roads, aligning with Prime Minister Modi's 'Waste to Wealth' mission and addressing environmental challenges associated with steel slag disposal [26].

4. The success of the Surat project has also encouraged other states and cities to explore the use of steel slag in road construction. Initiatives are underway in various parts of India to incorporate steel slag into road infrastructure, including:

- **Maharashtra:** Several projects are being planned or implemented in Maharashtra, leveraging the state's abundant steel slag production.

- **West Bengal**: The state government is actively promoting the use of steel slag in road construction to reduce waste and improve infrastructure.
- **Other States:** Similar efforts are being made in other regions, such as Karnataka, Tamil Nadu, Jharkhand and Odisha.

Materials & Methods of construction of steel road: Various researchers and organization from India and other countries of world have studied about the properties of steel slag and its uses as a partial replacement of natural coarse aggregates in road and construction works. Findings of their research are summarised here chronologically according to the year of publication, giving proper weightage to Indian scenario.

Shaopeng Wu et al. (2007): This study investigates the potential of incorporating steel slag, a byproduct of steel manufacturing, as aggregate material in stone mastic asphalt (SMA) mixtures. Steel slag is often stockpiled in slag storage yards, leading to environmental concerns. The research aims to compare the properties of asphalt mixtures containing steel slag aggregates to those made with traditional basalt aggregates.

The paper acknowledges the limited use of steel slag in China's construction industry and the growing demand for construction aggregates. It also reviews previous research on recycling and utilizing steel slag in various applications. The study underscores the need for further exploration of steel slag as an aggregate in asphalt mixtures, as existing research in this area is relatively scarce.

The findings of the research indicate that steel slag can serve as a viable alternative to basalt aggregates in SMA mixtures. The use of steel slag aggregates enhances the high-temperature performance and resistance to low-temperature cracking of the asphalt mixtures. In-service SMA pavements incorporating steel slag demonstrated excellent performance in terms of surface roughness and British Pendulum Number (BPN) coefficient [17].

A K Sinha et al. (2013): This research investigates the potential of steel slag, a byproduct of steel manufacturing, as a sustainable alternative material for road construction. Steel slag, often disposed of in landfills, poses environmental concerns. The study aims to evaluate the feasibility of using steel slag in various layers of road pavement, including embankment, subgrade, subbase, and base layers.

The study evaluated the geotechnical properties of steel slag, mechanically stabilizing it with locally available soil in varying proportions. Laboratory tests were conducted to determine its strength, compaction characteristics, and permeability. The findings indicate that steel slag, when appropriately stabilized, can be effectively used in different layers of road pavement, offering a sustainable alternative to traditional materials.

The study demonstrates the potential of steel slag as a valuable alternative to traditional construction materials. It can enhance the strength and stability of road pavements, reduce the need for natural aggregates, and contribute to environmental sustainability by diverting waste from landfills. Additionally, steel slag offers a more cost-effective option compared to traditional materials. These findings, along with the developed technical specifications and guidelines for its use in road construction, suggest that steel slag can be effectively utilized, providing environmental benefits, improving mechanical properties, and reducing costs.

The study, while highlighting the potential benefits of steel slag as a construction material, also identifies potential challenges such as moisture absorption, compatibility with other materials, and the need for proper stabilization to ensure adequate strength and durability. Long-term performance evaluation is also crucial. Despite these challenges, the research findings suggest that steel slag can be a valuable resource for road construction, offering a sustainable and cost-effective alternative to traditional materials. Further research and implementation are necessary to fully realize the potential benefits of steel slag in road infrastructure [15].

Mohd. Rosli Hainin et al. (2015): This study delves into the historical context of steel slag, tracing its origins to the Roman Empire era when it was incorporated into road construction. The research highlights the significant volume of steel slag generated globally, exceeding 50 million tons annually. The paper explores the diverse applications of steel slag in road construction worldwide over time.

Furthermore, the study provides a comprehensive overview of the physical, mechanical, and mineralogical properties of steel slag. Through a series of tests, the researchers determined that steel slag possesses favourable engineering characteristics, making it a promising material for future road construction projects. The primary objective of this paper is to evaluate the engineering properties of steel slag and its potential applications in various road construction methods [15].

Sandip S. Patil et al. (2016): This research explores the potential of utilizing steel slag waste as a viable construction material in road pavements. Steel slag, a byproduct of steel manufacturing, poses environmental and health risks when improperly disposed of. The study obtained a representative steel slag sample from M/s Jindal Steel Industry Pt. Ltd., Sinnar MIDC, India, and mechanically stabilized it with local soil in varying proportions (5-25%) to enhance its geotechnical engineering properties.

To assess the suitability of steel slag in different road pavement layers, geotechnical characteristics of the steel slag, local soil, and their mixtures were analysed. The results indicated that steel slag could be effectively employed in the construction of embankment, subgrade, and subbase layers of flexible pavements. Technical guidelines were formulated for incorporating steel slag into road construction.

The study recommends the use of steel slag as a construction material to address the challenges of waste disposal and the depletion of natural resources, such as soil and aggregates [8].

Dhavashankaran et al. (2018): This study investigates the performance of flexible pavements incorporating steel slag as a material component. Road pavements are integral to transportation networks, and their construction typically requires substantial quantities of bitumen and natural aggregates. The paper presents experimental results obtained from testing materials containing steel slag, demonstrating that these materials adhere to the standards established by the Indian Roads Congress (IRC).

The research findings indicate that partially replacing the filler material with steel slag enhances both the strength and load-bearing capacity of the pavement. Marshall stability tests revealed that substituting a portion of the coarse aggregate with steel slag results in a simultaneous increase in Marshall stability and flow, leading to improved pavement performance.

The study utilized basic oxygen furnace (BOF) steel slag, known for its beneficial property of increasing volume stability due to its unique composition [7].

M. A. Aziz et al. (2020): This study investigates the potential of steel slag, a sustainable alternative material derived from electric arc furnace (EAF) and basic oxygen furnace (BOF) processes, for use in highway construction. Steel slag has demonstrated its effectiveness in enhancing the mechanical properties of asphalt and concrete mixtures. To assess its suitability for asphalt mixture production, the research evaluates the chemical, physical, radiochemical, mineralogical, morphological, and textural characteristics of steel slag.

The study explores various applications of steel slag, including its use as a replacement for aggregate, filler material, and subgrade soil stabilizer. The findings indicate that incorporating steel slag in these applications can improve the mechanical properties and durability of pavements, reduce production costs, and offer environmental benefits.

The research also discusses factors influencing steel slag's performance in highway construction. Steel slag emerges as a promising substitute for artificial aggregates, contributing to environmental conservation and providing a material with enhanced resistance. The study concludes that steel slag is a viable and sustainable material for highway construction, with steel slag mixture wearing courses outperforming conventional wearing courses in terms of rutting fatigue, skid resistance, creep, and resilient modulus [6].

Bishow KC et al. (2020): This research investigates the potential of steel slag to enhance the properties of asphalt concrete mixtures. Previous studies have demonstrated the effectiveness of steel slag in improving stability, durability, and rutting resistance in asphalt concrete. The primary objective of this research is to examine the impact of steel slag on Marshall properties in asphalt mixtures.

The study explores various factors that can influence the performance of asphalt concrete mixtures containing steel slag, including particle size and gradation, filler material content, binder type, and environmental conditions. This research focuses on VG-30 grade bitumen. Through Marshall stability tests, the study determines that the optimal steel slag content varies depending on specific application and mixture design.

The findings suggest that incorporating steel slag as a filler material in asphalt concrete mixtures can reduce production costs and provide environmental advantages by minimizing waste generated from steel production and conserving natural resources. However, the study also highlights potential challenges, such as moisture absorption and potential reactions between steel slag and the binder, which may affect pavement performance and long-term durability.

Overall, the research concludes that steel slag offers the potential to improve asphalt concrete mixture properties, reduce production costs, and contribute to environmental benefits [14].

Giulio Dondi et al. (2021): This study explores the potential of Construction and Demolition Materials (CDMs), specifically steel slag, as a viable alternative for use in road pavement construction and rehabilitation. The researchers investigated the feasibility of substituting 30% of the coarse aggregate in road construction with steel slag and included experimental plans for both cement-bound and asphalt-based layers incorporating steel slag.

A series of tests were conducted on both layers to assess their performance. The results consistently demonstrated a correlation between stability and bitumen content, with increasing stability accompanied by decreasing bitumen content and vice versa. However, the cement-bound mixtures exhibited less favorable performance compared to the asphalt-based mixtures in terms of static mechanical characteristics.

The study highlights the potential of utilizing these materials in road infrastructure as a means of advancing sustainable development goals and promoting a circular economy [15].

Marina Díaz-Piloneta et al. (2021): The study delved into the feasibility of utilizing basic oxygen furnace (BOF) steel slag as a component in pavement design. While acknowledging the potential issue of volume instability in water, the researchers conducted a comprehensive evaluation of untreated BOF slag from both technical and environmental perspectives. The study proposed using BOF slag as a viable alternative to natural aggregates in road surface layers and asphalt pavements.

To assess the suitability of BOF slag, a thorough analysis of the requirements for asphalt mix raw materials was conducted. Subsequently, a pilot test was carried out using two different mixtures: one with limestone as the coarse aggregate and another incorporating 15% BOF slag. The findings revealed that substituting limestone with BOF slag in the asphalt mix resulted in a carbon emission reduction of over 14%.

Laboratory analyses further demonstrated that the inclusion of BOF slag in asphalt mixes could enhance skid resistance, mechanical properties, and rutting resistance. Additionally, another study highlighted the potential benefits of combining limestone with steel slag as a coarse aggregate, leading to asphalt mixtures with superior resistance to plastic deformation and fatigue failure.

To ensure a favorable life cycle assessment of the pavement, the researchers recommended replacing only 15% of the coarse aggregate with steel slag [5].

Vedansh et al. (2024): This study investigates the potential of steel slag, a byproduct of steel manufacturing, as a sustainable material for modern road construction. Steel slag is often disposed of in landfills, causing environmental concerns. The research aims to evaluate the feasibility of using steel slag as a component in asphalt mixtures and its impact on pavement performance.

Various laboratory tests were conducted on asphalt mixtures containing different proportions of steel slag. The study analysed the impact of steel slag on Marshall stability, flow, void content, moisture susceptibility and other relevant properties. The results were compared to control mixtures using traditional aggregates.

The study demonstrated the potential of steel slag as a valuable aggregate in asphalt mixtures. It found that steel slag could be effectively incorporated without compromising pavement performance and could even enhance certain properties like Marshall stability and rutting resistance. Additionally, the study highlighted the environmental benefits of using steel slag, including reduced waste disposal, conservation of natural resources, and potential cost savings. These findings suggest that steel slag can be a sustainable and beneficial material for road construction.

Overall, the research indicates that steel slag offers a promising sustainable alternative for road construction, providing both environmental and engineering advantages [2].

5. Conclusions:

Key findings from this review: Steel slag offers a promising alternative to traditional road construction materials, demonstrating several key advantages, including the followings:

1. Enhances mechanical properties.
2. Exhibits superior pavement surface characteristics.
3. Can be used in various layers of road construction.
4. Offers cost savings.
5. Supports circular economy principles.
6. Reduces the need for virgin aggregates and natural resources.
7. Reduces environmental impacts.
8. Aligns with India's sustainable development goals and waste management policies.
9. Meets Indian standards for road construction materials (IRC, MoRTH).

Challenges as an Engineering Material: Despite these benefits, the widespread adoption of steel slag in road construction faces several challenges, such as follows:

1. Standardization and quality control.
2. Regulatory framework and policy support.
3. Insufficient data on long-term performance and maintenance requirements.
4. Limited availability and accessibility.
5. Scarcity of skilled labour and specialized equipment.
6. Potential impact on nearby water sources and ecosystems.

Future research scopes: To fully realize the potential of steel slag in road construction, future research efforts should prioritize the following:

1. Developing standardized guidelines and specifications.
2. Investigating long-term performance and maintenance requirements.
3. Investigating steel slag's potential in other infrastructure sectors (runways and railways).
4. Studying the effects of steel slag on pavement-vehicle interaction.
5. Conducting comprehensive life cycle assessment (LCA) studies.
6. Analyzing economic benefits and cost savings in Indian context.

Recommendations: Based on the findings of this review, the recommendations are as follows:

1. Investing in research and development for quality control and standardization.
2. Opportunities exist for future studies to address knowledge gaps and scale up steel slag applications.
3. Encourage public-private partnerships to promote steel slag-based road construction.
4. Potential solutions include incentivizing steel slag-based road construction through tax benefits or subsidies.
5. International collaborative efforts can facilitate the development of Indian standards for steel slag.

The steel slag-based road construction has immense potential in India, offering a win-win solution for environmental sustainability, economic growth, and infrastructure development. The successful implementation of steel slag roads in India has opened promising avenues for future development and expansion. The utilization of steel slag in road construction offers a promising solution for sustainable infrastructure development in India. The Indian scenario presents unique opportunities for steel slag utilization, given the country's vast steel production and growing infrastructure demands. As a sustainable and cost-effective

alternative to traditional road materials, steel slag has the potential to significantly impact the nation's infrastructure landscape. Collaborative efforts from policymakers, industry stakeholders, and researchers are essential to overcome existing challenges and harness the benefits of this innovative technology.

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