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New Materials For Use In Concrete: A Review Of The Potential Of Mining And Steelmaking Waste As Aggregates

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Abstract:
Background*: The mining and steel industries are sectors that provide great economic boosts to the nations that develop them. However, these sectors generate large quantities of unusable materials that are discarded and generate accumulations, which can be seen as passive problems in contrast to demands for sustainable practices.*
Materials and Methods*: Visualizing this situation, a bibliographical survey was carried out to describe aspects related to the industrial sectors of mining, steel and civil construction, focusing on scientific production for the reuse of materials rejected during reincorporation as aggregates in the production of Portland cement matrix composites.*
Results*: The results demonstrate that, due to the number of articles published and related to the proposed search themes, for the last decade, the need to encourage the development of research in the direction addressed is evident.*
Conclusion: *Furthermore, it is noteworthy that waste as aggregates presents possible viability for gains in the sustainable development of the sectors to which they are related.*
Key Word: *Concrete; Sustainable Development Indicators; Iron and Steel Industry; Mining; Aggregate.*

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I. Introduction

The economic activities of Brazil, according to the CNI[1], include the secondary sector, which encompasses the manufacturing industry, civil construction, and energy production. In 2022, this sector represented 20.30% of the composition of the Gross Domestic Product (GDP).

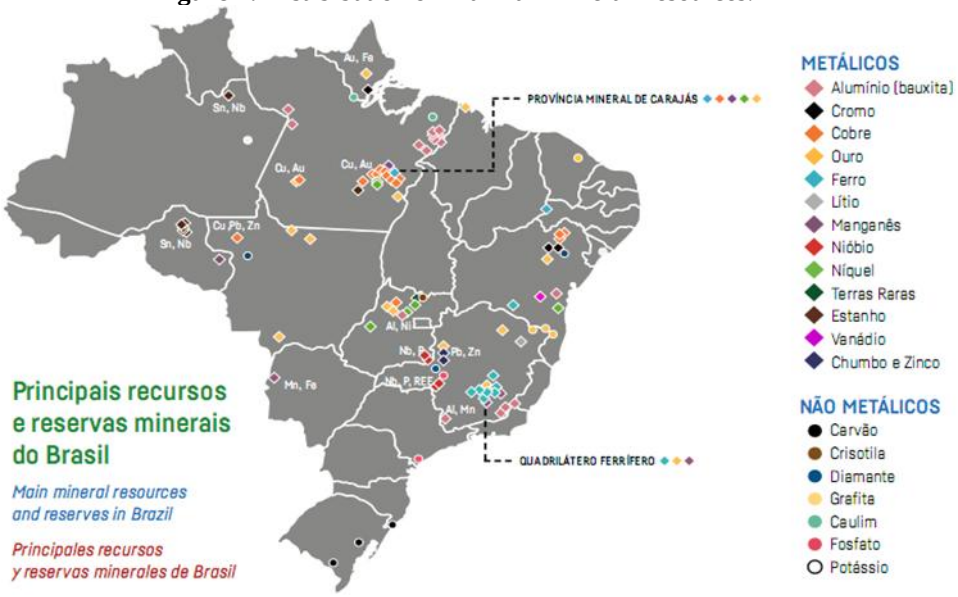
In this context, the sustainability tripod assumes a win-win relationship between the economic, social, and environmental dimensions. However, it is common for companies to suppress trade-offs and prioritize short-term economic gains[2].

In line with this discussion, and according to the United Nations (UN)[3], there are 17 Sustainable Development Goals (SDGs), which consist of action targets to be fulfilled by 2030, focusing on sustainable consumption and production. Therefore, it is necessary to encourage the reuse of materials that are rejected and discarded, which, in some way, are not directly used in their original sectors. This contributes to the reduction of accumulation and potential technical gains when these materials are applied as raw materials in other productive sectors.

The Mining Industry and Its Waste

Brazil has significant mineral potential, which has been explored since the colonial period, as well as to support the growth of the consumption of mining-derived products[4]. According to the Brazilian Mining Institute (IBRAM)[5], the three main substances produced with economic revenue in the national scenario in 2022 were iron ores (61.40%), gold (9.60%), and copper (6.10%). Figure 1 shown below, illustrates the distribution of Brazil's main mineral resources.

Figure 1: Distrbibution of Brazilian Mineral Resources.



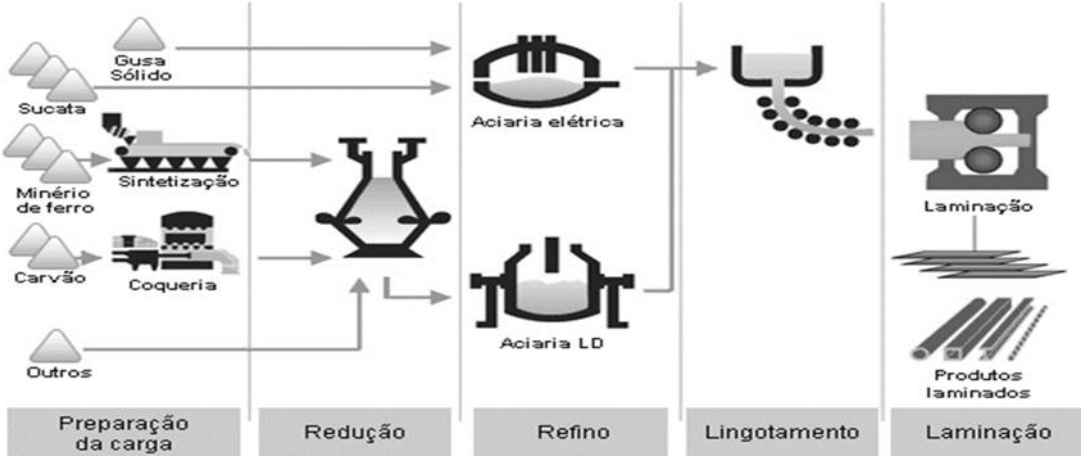
Source: IBRAM[5]

In 2021, the state of Pará stood out as the main producer of minerals in Brazil, accounting for 85% of the national copper production, according to data from the Marabá City Council [6], in the Carajás region, and according to the National Mining Agency (ANM)[7].

The Steel Industry and Its Perspectives in Steel Production

The steel industry, also known as the steel-producing industry, gained momentum in production after the end of World War II[8]. In the Brazilian economy, the steel industry, which is generally vertically integrated, operates the various stages of the process, from the transformation of ore into primary iron (pig iron). Carvalho, Mesquita, and Araújo[9] highlight that steel products, such as rebar, are essential for the construction of housing and infrastructure.

Figure 2: Simplified Steel Production Flow. Institute of Steel Brazil[21].



According to Nogueira and Madureira[10], the stages in steel production involve the reduction of ore, steel refining, casting, and rolling[11]. As Viana[12] states, in the production process of various steel products, it must be noted that sustainable development is one of the main challenges of the steel sector, as this industry is highly intensive in CO2 emissions and energy consumption.

According to the Institute of Steel Brazil[13], the steel industry generates waste that can be classified into steel slag aggregates from pig iron (40%), from steelmaking (27%), dust and fines (7%), sludge (6%), and other unidentified categories.

Civil Construction and Sustainability in the Production of New Products

According to Picanço[14] and Smith and Hashemi[15], a composite material is a multifaceted material formed by the association of two or more distinct phases, chemically and/or physically interacting, forming a new material with distinct or enhanced characteristics from its constituents.

Therefore, as emphasized by Aguiar Neto[16], Leal[17], and Batista[18], it can be concluded that the reuse of materials in civil construction, especially those previously considered useless in their sector of origin, is an effective way to reduce the environmental impact caused by accumulation.

II. Material And Methods

The methodological approach was based on conducting a bibliographic survey, aiming to describe the main aspects related to the manufacturing industry. For this purpose, the theoretical foundation relied on information sources from scientific articles published in national and international journals, accessed through the CAPES Periodicals platform and Google Scholar. Subsequently, a quantitative analysis was performed through the counting of articles using search criteria from the CAPES Periodicals platform.

The search was conducted in January 2024, and scientific articles published between 2011 and 2023 were identified. The searches were conducted using terms indexed in English. Two searches were performed using three groups each, with the boolean operator "and" to add the combinations.

For the first search, the first search term was 'dam tailings', the second was 'construction', and the third term was 'aggregate'. For the second search, the change occurred only in the first search group, where it was replaced with 'steel mill waste', while the other terms remained the same.

The goal of this approach is to establish a parameter regarding the manufacturing industrial sector, particularly for the mining, steel, and construction industries, where interaction will be sought for potential viability in the national context.

III. Result And Discussion

Mining and Steelmaking Waste as Aggregates in Cementitious Matrix Composites

Industrial mining is an activity that generates large amounts of solid waste, known as mineral tailings. According to Baričević[19], due to a lack of knowledge about their properties and impact on structural performance, residual materials are often unjustly overlooked.

The fineness of aggregates is an important property for concrete mix design and specification. Additionally, Fabro[20] highlights that natural aggregates are typically sourced from riverbeds, while artificial aggregates come from crushed rock.

According to Soares[21], there is a natural granulometric segregation when this type of material is deposited along beach lines in tailings dams; therefore, compatibility should be sought. The fineness of aggregates plays a crucial role in the mix design and specification of concrete, as it influences the cohesion and void distribution in cementitious composites. Additionally, Fabro[20] points out that natural aggregates typically come from riverbeds, while artificial aggregates originate from crushed rock.

According to Cia and Cunha[22], most materials from tailings dams consist of a solid mineral bulk with physical characteristics similar to sand but with slightly higher density.

In a study conducted by Campolina[23] on the production of hollow soil-cement blocks, the research indicates that using steel slag percentages above 8% can increase the compressive strength of the blocks by up to 15%. Therefore, the authors conclude that the higher the amount of waste added, the greater the long-term compressive strength of soil-cement blocks. Martins[24] investigated the potential of plaster mortars composed of mining and steelmaking waste to improve the thermal performance of buildings in Brazil.

Thus, as also reviewed by Silva[25], these materials can be used as a binding or recycled material to replace conventional aggregates.

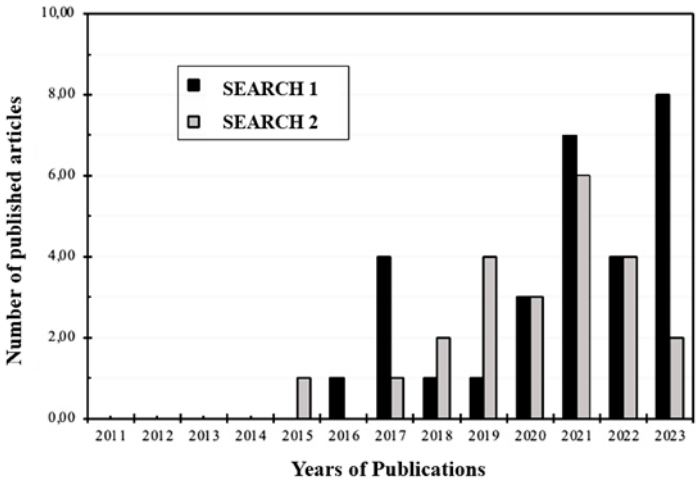
Bibliometric Perspective on the Use of Mining and Steelmaking Waste as Aggregates in Cementitious Matrix Composites

From the survey conducted through the CAPES periodicals platform, results were obtained that provide an overview of the use of mining and steelmaking waste as construction aggregates.

In general, based on the research strategies used, the number of articles found was relatively small. For the use of waste as aggregates in construction, the first search identified twenty-nine articles discussing the use of dam tailings, while the second search found twenty-three articles addressing the use of steelmaking waste.

The results are presented in Figure 3, showing data on mining and steelmaking waste from the literature survey conducted for the period 2011 to 2023.

Figure 3: Results of the second search of the study, use of steelmaking waste between 2011 and 2023.



In general, based on the research strategies used, the number of articles found is relatively small, which highlights the need to encourage the development of new studies in this area. For the use of waste as aggregates in construction, the first search identified twenty-nine articles discussing the use of dam tailings, while the second search found twenty-three articles addressing the use of steelmaking waste.

In both searches, it is observed that only from the middle of the decade did tailings begin to be considered as potential aggregates for construction, with peak results in the years 2023 and 2021 for mining and steelmaking waste, respectively.

Regarding the use of mining dam tailings, most articles focus on the use of iron ore waste, with articles discussing copper mining waste found only in the years 2020 and 2021.

According to Muleya[26], when these tailings are used as aggregates for cementitious matrix composites, such as concrete, the maximum replacement limit is around thirty percent, leading to an increase in uniaxial compressive strength. This finding is also highlighted by Lam Esquenazi[27].

In the replacement of aggregates with steelmaking waste, improvements in mechanical strength are also observed. This can be explained, as noted by Premkumar, Chokkalingam, and Rajesh[28], by the cementitious nature of the fine particles and carbonate components present in steel slag, which enhance the final strength and durability properties of the resulting products. The incorporation of steel waste increases the final amount of sand in the mix, which contributes to greater long-term strength[23].

Jiang[29] supports this idea, concluding that steel slag, besides being a crucial strategy in industrial waste management for a circular economy, possesses characteristics that make it viable for various applications. The authors concluded that the rocky appearance of slag allows it to be used as an aggregate in concrete, as well as a supplementary cementitious material.

Additionally, beyond what has been discussed, the durability of concrete containing steel slag under various exposure conditions is compared to conventional concrete through ultrasonic pulse velocity tests, rapid chloride penetration tests, and acid resistance tests. This type of concrete can be used in highly severe environments, such as tidal zones and underground structures[30].

IV. Conclusion

Tailings can be hazardous if they contain toxic substances used in the ore processing and steelmaking transformation. Therefore, it is essential to understand their properties before any handling. However, it is necessary for the material that is no longer useful to its origin sectors to be reincorporated in some way into secondary production chains, as this may infuse technical, economic, and environmental feasibility into the material that is accumulating and temporarily useless.

For a context of sustainable improvement in the exploration of natural resources, we must ensure that technological and scientific advancements are directly linked to optimizing improvements in the exploration of natural materials and their industrial processing. Thus, specifically for the scope of this work, it is understood that perspectives should be improved for the development of scientific research that encourages the incorporation of dam and steelmaking tailings into new production chains. These can be seen as a pathway to contribute to improving the quality of life for the population and to sustainable development.

In terms of the exploration of natural mineral resources, the tailings deposited in dams are liabilities that can be estimated for use in other sectors, such as civil construction. The reduction of accumulations will help maintain the mining sector itself.

Another factor highlighting the use of mine tailings is that, according to the studies analyzed, a large portion of these tailings are considered chemically inactive materials, with compounds similar to natural materials. For instance, depending on the granulometry, dam tailings can be used to replace aggregates in Portland cement-based composites.

For materials from the steel industry, it is known that the construction sector is a major consumer of products generated by the industry, especially rebars and steel. However, throughout the manufacturing process, a large amount of unusable material is produced, which is poorly disposed of and results in large accumulations. Thus, ensuring the incorporation of these tailings into the construction industry, through reverse logistics processes, can promote technical benefits, such as improved mechanical strength and durability.

It is also highlighted, according to the studies analyzed in the review, the agglomeration characteristics of these steel industry residual materials. This is already well known by cement-producing factories, but it is envisioned that using these materials as aggregates in concrete and Portland cement mortar also shows improvements, thus providing greater possibilities for volume utilization.

Especially in the production of Portland cement-based composites, where better intellectual production incentives are expected, as this could lead to the creation of new products for a future market.

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