BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 71 (75), Numărul 2, 2025
Secţia
CHIMIE şi INGINERIE CHIMICĂ
DOI: 10.5281/zenodo.15617748

# SUSTAINABLE UTILIZATION OF STEEL SLAG: GLOBAL PRODUCTION, APPLICATIONS, AND ECONOMIC BENEFITS

BY

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Received: January 15, 2025
Accepted for publication: May 16, 2025

**Abstract.** In recent years, we hear more and more talk about pollution, but especially about what it produces on the environment and implicitly on people's health. All the states of the world, especially the developed ones, are taking increasingly drastic measures to protect the environment. The world's population has grown, its needs have grown, industry has tried to keep up and has also developed to produce much more than 100 years ago, but what do we do with the waste that results from the production process?

Industry is the biggest polluter today, waste from the metallurgical industry has multiplied at an accelerated rate lately and has come to represent a real problem. What would it be like if this problem disappeared and also generated a significant economy of other materials?

The article shows how an industrial waste, steel slag, can be used in several fields, especially in the construction of roads which is a big consumer of resources, both reducing costs for them and solving the problem of occupying ever larger spaces for slag storage. The study shows the amount of steel slag produced by several countries in the world, how much of it is recycled by each mentioned country and for what purpose, also giving some examples of roads where this waste was used.

**Keywords:** recycling, secondary product, steel, crushed steel slag, road construction.

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## 1. Introduction

In the present economic situation, the main objective of all developed nations and of emergent ones is economic growth. This objective can't be accomplished without taking account of the eventually side effects, as environmental pollution. A prosperous society needs solutions that can reach both objectives namely, having a continues economic growth and keeping a clean environment, that is to say, a sustainable development of the society. One of the solutions already exists in our society for several decades, continuing to grow, trying to access more and more different environments, this solution is recycling.

Industry is the main socio-economic segment that certainly has the largest share of environmental pollution. Metallurgy is an industry that deals with the processes of obtaining metals from ores processing ores, extracting metals from ores, refining metals, producing metal alloys, working metals under pressure etc.

Industrial waste is one of the biggest sources of pollution. The massive increase in the amount of waste of all kinds endangers the quality of environmental factors (Iriciuc *et al.*, 2023). This problem is relatively recent, only a few decades old, exploding with industrial development. Any type of material that is no longer useful during or after the processes that take place in factories, mines or units for processing different raw materials to obtain finished products is considered industrial waste. Even though industrial waste is a reality both today, but especially in the future, there are solutions that can help reduce the impact they have on the environment. One of the solutions is efficient waste management. This involves minimizing the production of waste, recovering, recycling, reusing and valorising it. Although the general opinion about waste is that it is a source of pollution, good management of it can generate benefits such as: reducing the demand for natural resources, saving energy and financial resources. Another solution for reducing the impact of waste on the environment is the transformation of waste into reusable resources. This is the main objective of a circular and ecological economy, based on bringing them back into the technological flow. The road industry can contribute significantly to the accomplishment of these global environmental goals (Lizasoain-Arteaga *et al*., 2020).

Steel has been produced by the metallurgical industry for more than a hundred years, using several processes. In the steel production process, results a residue called slag. Slag is defined as a by-product resulting from the process of extracting metals from ores or from the smelting of various materials.

The birth of metallurgical slag is similar to the formation of natural rocks such as basalt or granite. Blast furnace slag arises from the production of pig iron in the blast furnace. Steel slag is an industrial waste produced as a

byproduct during steel manufacturing process (Kumar and Varma, 2021). The iron in the furnace can't be prepared without producing blast-furnace slag as a by-product. Similarly, the steel can't be prepared in a basic oxygen furnace (BOF) or an electric arc furnace (EAF) without producing the steel slag (Lixandru *et al*., 2015).

So, slags are classified into:

1. blast furnace slag, obtained during the manufacture of pig iron, which depending on the cooling methods can be:
   - air-cooled blast furnace slag (raw), slowly solidified under atmospheric conditions;
   - granulated slag, quickly solidified under the action of water;
   - expanded slag, obtained by successive controlled treatment: air/water.
2. steel mill slag, obtained during the manufacture of steel, which, depending on the furnace in which they were produced, can be:
   - converter slag, LD or BOF;
   - electric arc furnace slag, EAF;
   - Siemens - Martin slag (Iriciuc, 2011).

To be able to be used later, steel slag is processed as lumps or fine-grained material. In order to be granulated, they undergo the same procedures as any other natural stone. Both for roads and for airport runways, cycle tracks, etc. crushed steel mill slag is used.

Both in Romania and in other countries steel slag is used and has been used in recent years. But how much and for what? Is steel slag really treated as a by-product or more like a waste? All these questions will find their answers in the following lines.

## 2. Internationally use of slag

Steel production has exploded in the last century thanks to all the discoveries made in this field. In 2020 alone, 1580 million tons of steel were produced. According to the World Steel Association for producing one ton of steel results also 0.180 t of blast furnace slag, 0.126 t of steel slag in conventional furnaces and 0.169 t of steel slag in electric furnaces. Also taking into account the fact that only 35% of the resulting slag comes from electric furnaces, we can state that in 2020 in addition to 1580 tons of steel 284.4 million tons of blast furnace slag and 237 million tons of steel slag were also produced (https://worldsteel.org/wider-sustainability/steel-industry-co-products/).

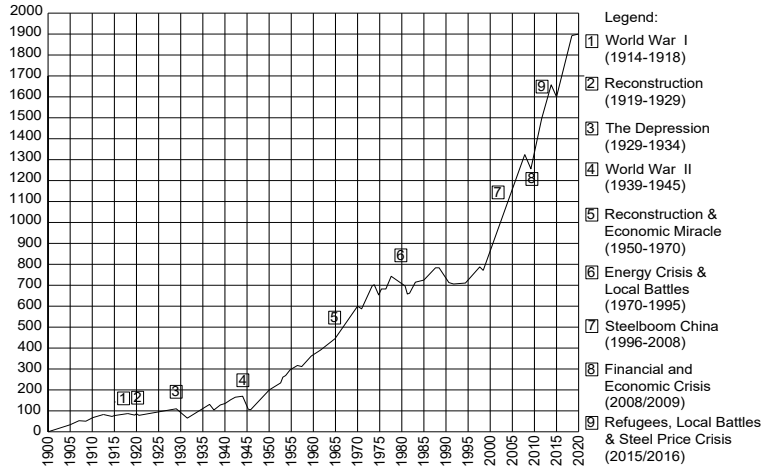


Fig. 1 − Evolution of steel production between 1900 and 2020 (Buchmayr *et al*., 2018; https://worldsteel.org/data/world-steel-in-figures-2023/).

**China**

The largest steel producer by far is China, producing around 60% of the world's steel. In 2020 China produced 1053 million tons of steel out of the total 1580 million tons of steel produced worldwide.

**Table 1**

*Top 10 steel producing countries - Crude steel production in millions of tons*

| Nr. crt. | 1967 | Mt | 2000 | Mt | 2020 | Mt |
|---|---|---|---|---|---|---|
| 1 | S.U.A. | 115.40 | China | 128.50 | China | 1053.00 |
| 2 | U.S.S.R. | 102.20 | Japan | 106.40 | India | 99.60 |
| 3 | Japan | 62.20 | S.U.A. | 101.40 | Japan | 83.20 |
| 4 | F.R. of Germany | 36.70 | Russia | 59.10 | Russia | 73.40 |
| 5 | U.K. | 24.30 | Germany | 46.60 | U.S.A. | 72.70 |
| 6 | France | 19.70 | South Korea | 43.10 | South Korea | 67.10 |
| 7 | Italy | 15.90 | Ukraine | 31.80 | Turkey | 35.80 |
| 8 | Poland | 10.50 | Brazil | 27.90 | Germany | 35.70 |
| 9 | China | 10.30 | India | 26.90 | Brazil | 31.00 |
| 10 | Czechoslovakia | 10.00 | Italy | 26.80 | Iran | 29.00 |
| | **Total** | **407.20** | | **598.50** | | **1580.50** |

Statistical data according to World Steel Association (https://www.h-metal.ro/blog/otelul-este-material-esential/)

Unfortunately, China is doing extremely poorly when it comes to the use of slag. These are only used in a proportion of about 30%, the rest being

stored in landfills which, due to the huge steel production in China, occupy ever larger areas. There are extremely many studies in China that consider the use of steel slag both in the field of road construction, civil construction and agriculture.

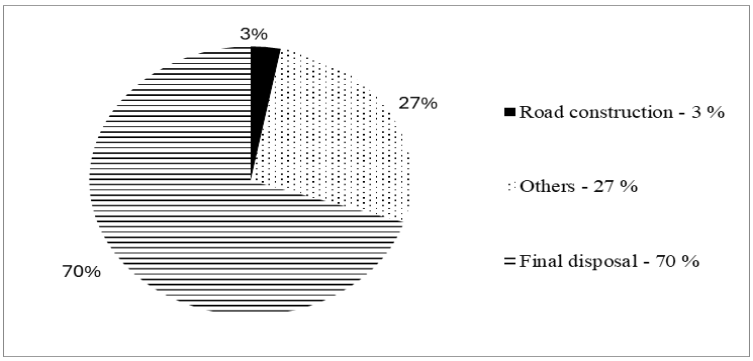


Fig. 2 – The use of steel slag in China (Guo *et al.*, 2018 and Matsuura *et al*., 2022).

**Japan**

At the opposite end is Japan, with a production in 2020 of approximately 83 million tons of steel, ranked 3rd in the world, Japan is the country that uses almost all slag, the largest amount being used in the construction of paths. Some examples of roads where the Japanese have used steel slag for their construction are: Highway 170, Osaka Loop Line, a shoulder of the Himeji Higashi Expressway as well as an important part of the streets of Kobe city.

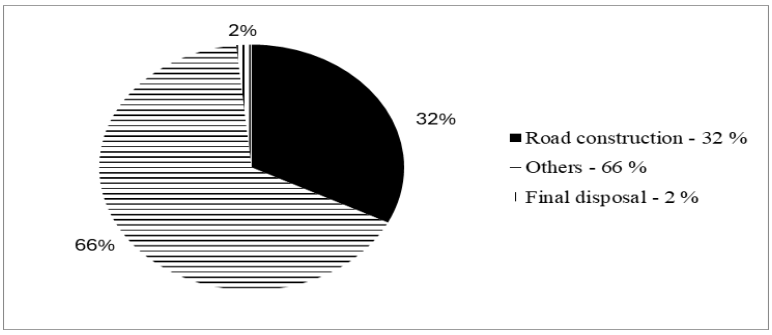


Fig. 3 – The use of steel slag in Japan (Guo *et al.*, 2018; Lin *et al.*, 2022).

**USA**

The United States of America, another major global steel producer, managed to produce 72.7 million tons of steel in 2020, being the 5th largest steel producer in the world after China, India, Japan and Russia.

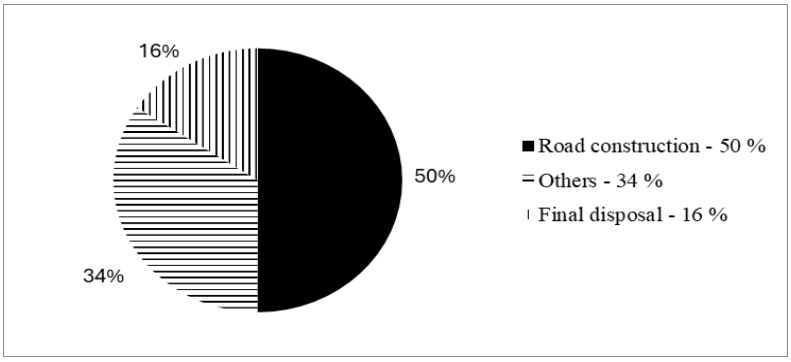


Fig. 4 – The use of steel slag in USA (Guo *et al*., 2018; Lin *et al.*, 2022).

Regarding the use of steel slag, the United States uses about 85% of it, with half of the total amount of steel slag produced being used for road construction, from improving subgrade, using it in the base layer or replacing aggregates from asphalt mixtures.

Compared to steel slag, the United States has an even higher performance of blast furnace slag using 100% of it in the production of cement and concrete.

**Germany**

Germany is the largest steel producer in Europe, if we exclude the partially European countries: Russia and Turkey, with a production of 35.7 million tons in 2020.

Germany is a model country in terms of slag recycling. Of the 35.7 million tons of steel produced, Germany also produced about 4.7 million tons of steel slag, which was fully used, with 70% of the slag used for road construction here.

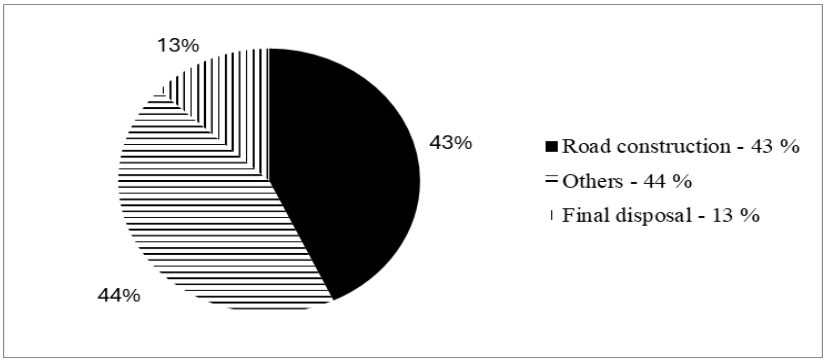


Fig. 5 – The use of steel slag in Europe (Guo *et al*., 2018; Lin *et al.*, 2022).

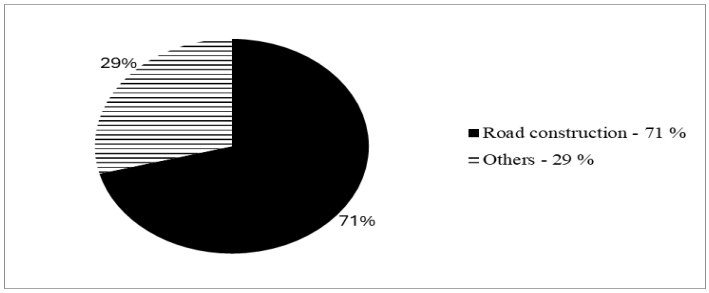


Fig. 6 – The use of steel slag in Germany (adapted from Pasetto *et al*., 2023).

**South Africa**

South Africa is the largest producer of steel on the African continent, with a steel production of 400,000 tonnes in the year 2020. Unfortunately, in South Africa, recycling of steel slag has not been a common practice, because of this the country currently has 20 million tons of steel slag in landfills, 450,000 tons in just one dump, Witbank, and the amount is continually increasing. In recent years, Africans have begun to care more about this subject and have begun to stop treating slag as a waste, but to use it as a co-product, thus having a double benefit. An example of this is the use of steel slag in the construction of the busiest road in South Africa, the N3 highway between Johannesburg and Durban. The road supports a traffic of 800,000 tons per year, that is between 1400 and 3000 heavy vehicles that transit the highway or only parts of it per day (https://www.asa-inc.org.au/uploads/default/files/asa_connections_dec_2007.pdf).

According to the International Energy Agency, the global steel industry is responsible for 20% of industrial energy consumption and 25% of industrial $CO_2$ emissions. Although a reduction in $CO_2$ emissions is desired, global steel production is expected to increase by 30% by 2050.

The increase in steel production also generates an increase in the production of slag that needs to be recycled in order to be able to maintain the standards imposed by the institutions for environmental protection. So, it is absolutely necessary to use slag as close to 100% as possible, in all areas where developed countries already use it, but also to research further to discover new ways of use.

## 3. Steel slag in Romania

Romania was a highly industrialized country until 1989, with many steel mills operating at high capacity. During that period, Romania produced an average of 17 million tons of steel annually, the steel slag being mostly stored in landfills. The amount of slag that can be used at the moment in Romania is

composed of the amount that is in the dumps plus the amount that results from the daily steel production. In order to have a better view of the amount of slag that is produced in Romania, it is necessary to analyze the evolution or involution of steel production at the national level.

Unfortunately, in the last 30 years, Romania's steel production capacity has decreased by 80%, that is, in Romania at the moment only 3.5 million tons of steel are produced.

Of all the steel plants in Romania, Liberty Galați is by far the largest, currently producing more than half of Romania's steel production. It was built starting in 1961, with integrated production starting in 1968. Until 1991, the combine was a state-owned company, later transforming into a joint-stock company, in 2001 the shares were bought by what would become ArcelorMittal. In 2019, the Liberty Steel House group buys the Galați plant from ArcelorMittal, renaming it Liberty Galați.

In 2020, Liberty Galați recorded a production of two million tons of steel out of the 3.5 million tons of steel produced nationally. Liberty Steel Group aims to be the first carbon neutral steel company in the world by 2030 (https://libertysteelgroup.com/ro/greensteel/?lang=en).

In Romania, steel slag is used in: road construction, railway construction, hydrotechnical constructions, civil constructions, agriculture, the cement industry, the glass industry and the refractory materials industry.

In road construction, slag can be used starting with wear, binder and base layers, replacing classic aggregates in mixes, continuing with foundation layers or non-bituminous base layers and ending with embankments. Steel slag can also be used in road repair and maintenance work.

Examples of roads in the construction of which steel mill slag was used:

- A2 highway, the Drajna – Fetești section and the Cernavodă – Medgidia section (in the base layer or foundation);
- DJ101 Jilavele – Dridu (Ialomița county) (in the base layer or foundation);
- DJ213 DN2A – Viziru (Brăila county) (road modernization and rehabilitation works);
- DJ201 Cosereni – Axitele (fillings and surface layer).

In railways, steel mill slag can be used in the execution of foundations, ballasting of railway lines and in maintenance and repair work. Some examples of railway sections where the use of steel slag was preferred are:

- Line 706F Galați Travelers – Pod Prut Frontier (embankment consolidation);
- Industrial railway lines (maintenance and repair work).

Steel slag has also been used in Romania for hydrotechnical constructions: bank protection, restoration of navigable riverbeds, embankments, dams and as aggregates in hydrotechnical concrete.

An example in this regard is the restoration of the dike near the commune of Salcia Liești in Galați county, a dike built to avoid flooding of the commune (Cristea, 2012).

Waste from steel production can also be used in civil construction as aggregates in concrete.

In agriculture, slag helps improve soil acidity and remineralize them.

## 4. Conclusion

After studying the fields of use of slag internationally, we notice that developed countries do not consider steel slag a waste but a co-product in the manufacture of steel that can be used in a proportion of even 100% thus bringing a double benefit. In addition to this double benefit that is given by its physical, chemical and mechanical properties, the use of slag as much as possible leads to extremely many environmental benefits, reducing quarrying and returning to the natural cycle the spaces of former slag storage dumps. It is necessary that we also set such an objective on a national level, namely a use of steel mill slag in an ever-increasing percentage, which is getting closer and closer to 100%, both for the economic benefit and for an environment cleaner.

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## UTILIZAREA DURABILĂ A ZGURILOR DE OȚELĂRIE: PRODUCȚIE LA NIVEL GLOBAL, APLICAȚII ȘI BENEFICII ECONOMICE

(Rezumat)

În ultimii ani auzim vorbindu-se tot mai des despre poluare, dar mai ales despre ceea ce produce ea asupra mediului și implicit asupra sănătății oamenilor. Toate statele lumii, în special cele dezvoltate, iau măsuri tot mai drastice pentru a proteja mediul. Populația lumii a crescut, nevoile acesteia au crescut, industria a încercat să țină pasul și s-a dezvoltat și ea putând să producă mult mai mult decât acum 100 de ani, însă ce facem cu deșeurile care rezultă în urma procesului de producție?

Industria este cel mai mare poluator din prezent, deșeurile din industria metalurgică s-au înmulțit într-un ritm accelerat în ultimul timp și au ajuns să reprezinte o adevărată problemă. Cum ar fi dacă această problemă ar dispărea și ar mai genera și o economie important de alte materiale?

Articolul arată cum un deșeu industrial, zgura de oțelărie, poate fi folosit în mai multe domenii, mai ales în construcția de drumuri care este o mare consumatoare de resurse, reducând atât costurile pentru acestea și rezolvând problema ocupării de spații tot mai mari pentru depozitarea zgurii. Studiul arată cantitatea de zgură de oțelărie produsă de câteva țări din lume, cât din aceasta reciclează fiecare tară menționată și pentru ce anume, dând totodată și câteva exemple de drumuri în care s-a folosit acest deșeu.