

THE IMPORTANCE OF IDENTIFICATION OF ZINC-BEARING SECONDARY RESOURCES AND THEIR INVOLVEMENT IN INDUSTRIAL UTILIZATION PROCESSES

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Abstract. The depletion of primary zinc resources and the increasing generation of industrial waste make zinc-containing secondary materials an important alternative resource. This study emphasizes the identification and industrial utilization of zinc-bearing wastes such as dross, dust, and scrap materials. Their processing enables zinc recovery, reduces environmental impact, and improves resource efficiency in metallurgical production. The results highlight the importance of integrating secondary zinc resources into a closed-loop production system.

Keywords: zinc recycling; secondary resources; industrial waste; zinc recovery; dross; resource efficiency; circular economy

Introduction. The recycling of zinc-containing industrial waste remains one of the most pressing issues in global metallurgy today, both from the perspective of environmental safety and economic efficiency [1]. Zinc is not only a valuable non-ferrous metal, but its technogenic wastes (such as electric arc furnace dust, galvanic slags, residues from zinc production, clinker, dross residues, and beneficiation tailings) pose a serious environmental threat as sources of heavy metals. In modern research, there is a shift toward considering these wastes as secondary raw materials based on the principles of the “circular economy,” since the metal content in zinc-bearing wastes is often higher than in natural ore deposits [2]. Currently, researchers are working on reducing the high energy consumption of pyrometallurgical processes and improving the selectivity and efficiency of leaching in hydrometallurgical processes. Therefore, the improvement of integrated technologies for processing zinc-containing wastes contributes both to the conservation of natural resources and to the reduction of anthropogenic load on the biosphere [3].

Zinc ash. Zinc ash, or oxidized zinc (scale), is one of the important technogenic wastes formed in zinc metallurgy and hot-dip galvanizing processes (Figure 1). This waste is mainly generated on the surface of molten zinc baths during hot-dip galvanizing of steel products, zinc melting, and zinc coating processes as a result of the oxidation of liquid zinc by atmospheric oxygen [4]. Under high-temperature conditions, the intensive reaction of zinc with oxygen leads to the formation of zinc oxide and other complex compounds, which accumulate on the surface of the molten metal and form an ash layer [5]. During the process, the transfer of iron, aluminum, lead, and other elements into the melt further complicates the composition of the waste [6]. Zinc ash typically contains 60–90% metallic zinc and zinc oxide, while the remaining portion consists of Fe_2O_3 , PbO , Al_2O_3 , CdO , CuO , SiO_2 , as well as chloride and sulfate compounds [7].





Fig. 1. Zinc dust waste generated at the Rezinal company

The main reasons for the formation of zinc dust include high technological temperatures, direct contact of the molten metal surface with the atmosphere, the high volatility of zinc, and the tendency of the metal surface to oxidation. In hot-dip galvanizing baths, the temperature is typically maintained in the range of 440–470 °C, under which conditions zinc undergoes intensive oxidation. In addition, the presence of iron oxides on the melt surface accelerates the formation of ferritic compounds. According to practical data, the amount of zinc dust (dross) generated during the galvanizing process constitutes on average 0.5–2.0% of the total zinc mass used, and in some technological regimes this value may be even higher. In metallurgical furnaces and zinc melting units, additional losses occur due to the transition of zinc into the dust and gas phases. Therefore, the high content of valuable components in zinc dust makes it a valuable secondary raw material that requires recycling. Modern studies show that zinc ash can be processed using pyrometallurgical and hydrometallurgical methods, enabling zinc recovery, reduction of waste volume, and development of resource-efficient technologies [8].

Secondary zinc metals. Zinc sheets are among the important metallic materials widely used in modern construction due to their high corrosion resistance. They are mainly used for roofing, water drainage systems, drainage pipes, façade cladding, and various architectural structures. After long-term operation, used zinc sheets and scraps that have lost their functional properties are generated as technogenic waste. However, since these wastes still contain a high amount of metallic zinc, they represent an important secondary raw material source for the zinc metallurgy industry. Typically, zinc sheets contain up to 95–99% Zn, while the remaining portion consists of Pb, Fe, Al, Cu, as well as oxide and carbonate compounds. Under prolonged exposure to the atmosphere, protective surface layers based on ZnO, ZnCO₃, and Zn(OH)₂ are formed on the sheets, which increases their corrosion resistance (Figure 2).

From a technological perspective, the generation of zinc sheet waste is caused by several factors. The main sources include the aging of construction structures, mechanical deformation, corrosion processes, reconstruction activities, and technological cutting during production. In addition, small fragments and residues generated during installation and cutting processes also contribute significantly to technogenic waste formation. According to practical observations, during the production and installation of zinc sheets, on average 3–8% of the total raw material



may be lost as waste. Failure to recycle these wastes leads to economic losses and inefficient use of valuable metal resources.



Fig. 2. Fragments of aged zinc sheet waste

Recycling of zinc sheet waste is of great ecological and economic importance. Secondary zinc production technologies require significantly less energy compared to primary zinc production and reduce the need for ore extraction. As a result, atmospheric emissions, greenhouse gas emissions, and industrial waste generation are reduced. At the same time, by remelting and refining zinc sheets, high-purity metallic zinc can be obtained, which can be used in the production of construction materials, protective coatings, and other metallurgical products. In modern metallurgy, such an approach is considered an important component of resource-efficient and closed-loop technologies [9].

Zinc-rich sludge accumulated at the bottom of galvanizing baths (bottom dross). Bottom dross accumulated at the bottom of the galvanizing bath is one of the important technogenic wastes formed during the hot-dip galvanizing process, resulting from the interaction between molten zinc and steel. During contact between steel products and molten zinc in hot-dip galvanizing baths, iron and zinc atoms diffuse and form Fe–Zn intermetallic compounds (FeZn_{13}). These phases, particularly FeZn_{13} , are denser than molten zinc and therefore sink to the bottom of the bath, forming a solid sludge-like “bottom dross”.

This waste typically consists of an iron–zinc alloy containing up to 92–97% metallic zinc and about 3–8% iron. In addition, it may also contain Pb, Al, Cu, Cd, and oxide compounds. From a phase perspective, the bottom dross contains γ (gamma), δ (delta), and ζ (zeta) Fe–Zn intermetallic phases. The formation of these phases is directly influenced by galvanizing temperature, steel composition, aluminum content in the bath, and processing time.



Fig. 3. Residues of zinc dross accumulated at the bottom of the galvanizing bath

The formation mechanism of zinc bath bottom dross is mainly explained by diffusion processes between molten zinc and the steel surface. In hot-dip galvanizing baths, the temperature is typically maintained in the range of 440–460 °C, under which iron atoms begin to diffuse from the steel surface into molten zinc. As a result, complex intermetallic layers form between iron and zinc. Since the density of these phases is higher than that of molten zinc, they settle at the bottom of the bath. As the process continues, the amount of dross increases. According to practical observations, the amount of bottom dross generated in hot-dip galvanizing plants constitutes on average 0.5–2.5% of the total zinc mass used (Figure 3). In particular, an increase in iron concentration in the bath and deviations from technological regimes intensify dross formation and lead to technological losses of zinc.

Bottom dross (i.e., the lower-layer sludge) accumulated in the molten zinc bath has significant industrial importance as a valuable secondary raw material due to its high metallic zinc content. Through its processing, zinc can be recovered, thereby reducing the demand for primary zinc production. In modern recycling technologies, bottom dross is processed through mechanical crushing, melting and separation, pyrometallurgical treatment, or refining processes. As a result, high-purity zinc is obtained and returned to the production cycle. This contributes to efficient utilization of metal resources, reduction of waste volume, and improvement of environmental safety. Therefore, the recycling of zinc bottom dross is considered one of the key directions in modern metallurgy for the development of resource-efficient and closed-loop technologies.

During the melting of zinc cathodes, technogenic secondary by-products in the form of zinc dross are also generated. This type of dross differs to some extent from those formed during galvanizing or ore smelting processes, as it is mainly produced during the melting of high-purity electrolytic zinc cathodes in induction or flame furnaces. During melting, the interaction of molten zinc with atmospheric oxygen leads to the formation of an oxidized layer on the metal surface, which is subsequently separated as dross. This dross typically contains metallic zinc, zinc oxide (ZnO), as well as certain alloying elements and intermetallic compounds involved in the technological process.

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