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THEMATIC SECTION: SLAG VALORISATION TODAY

Slag Valorisation as a Contribution to Zero-Waste Metallurgy

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Zero waste is a challenging, though vital, strategy for the 21st century. This philosophy profoundly reshapes our thinking about resources and production, where waste is no longer waste but a secondary resource, a crucial part of a sustainable material's life cycle. It encourages industry, government, and the society as a whole to redesign our practices to avoid waste being landfilled or incinerated.

The 4th edition of the International Slag Valorisation Symposium (15–17 April 2015, Leuven, Belgium)—with Zero Waste as a subtheme—was organized by the Department of Materials Engineering and the Centre for High Temperature Processes and Sustainable Materials Management of the KU Leuven to contribute toward near zero waste processing and closed material loops in the field of high-temperature (metallurgical) residues. The content of this symposium offered a rich overview of the contemporary trends in the worldwide research and innovation strategies as regards the valorization of ferrous and non-ferrous slag, fly ash, bottom ash, and other metallurgical residues. The contributions from the participants were encompassed in four thematic categories, thereby covering the whole slag production and treatment chain, from the high-temperature molten state to solidification and finally to metal extraction and end-products:

- Hot stage slag engineering for higher value-added applications and energy recuperation,
- Base and critical metal recovery,
- Innovative/low-carbon building applications, and
- Non-traditional slag valorization processes and products.

Particular contributions from this symposium were selected for publication in this thematic section of the Journal of Sustainable Metallurgy to be included as an extended version of the symposium paper. Each of these papers should be considered as a link in the chain to close the material loop for high-temperature residues, thereby providing a vision for sustainable metallurgy in the 21st century.

Regarding hot stage slag engineering, the Zero Waste principle is reflected in the development and modification of the high-temperature processes to systematically eliminate the environmental burden of the produced slags. To this purpose, the processes are designed in such a way that they enable the use of the slag as a resource for other applications. In this issue, this strategy is illustrated by two papers dealing with hot stage slag engineering. The first contribution by Primavera et al. shows how the treatment of Electric Arc Furnace (EAF) slags was optimized by adding an oxide mix. The slags were characterized in terms of phase transformations, and the leaching and mechanical behavior of the product obtained on the laboratory scale were determined. Based on the positive results from the subsequent pilot scale tests, and the consideration that the proposed process can easily by implemented and operated on the industrial scale, the authors succeeded to contribute to the Zero Waste philosophy by turning residues from the EAF process into aggregates suitable for use in construction. In the second work, Ferreira Neto et al. studied the

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influence of slag modifications and cooling rate on the phases formed during solidification, for a blast furnace slag and a basic oxygen furnace stainless steel slag. Their findings regarding phase formations, slag stability, and slag reactivity confirm the cementitious potential of the investigated slags.

After slag solidification, the slag can in first instance be considered as a resource of metals and oxides, a principle which serves to conserve the non-renewable resources. This requires the development of suitable recovery processes, as illustrated by two papers in this issue. Firstly, Chenna et al. considered bauxite residue, originating from the Bayer's process for alumina production, as a resource of iron and rare-earth elements (REEs). The authors performed initially smelting reduction experiments, followed by grinding and magnetic separation, to extract more than 95 % Fe from the residue, which can be used for steelmaking or cast iron production. High-temperature leaching of the slag then allowed recovering all Sc, most of the other REEs and 70 % of the Ti content. Secondly, the paper of Koizumi et al. describes a method to produce a phosphorus-enriched by-product from steelmaking slag, thereby offering an alternative P_2O_5 resource. To investigate the recovery of P_2O_5 from slags in the $CaO–FeO–SiO_2–P_2O_5$ system, the authors performed experiments investigating the phase relations in the aforementioned system and determined the phosphorus recovery rate obtained by using capillary action to separate the P_2O_5-enriched dicalcium silicate phase from the FeO-rich liquid phase. Their data on the P_2O_5 recovery rate can be used as input to further examine the feasibility of this method to supplement the limited and non-renewable resources of phosphate-containing minerals.

In accordance with the Zero Waste philosophy, the slag from which the valuable metals and oxides are potentially extracted is regarded as a resource for other applications. This concept is demonstrated by two papers in this issue. In the work of Faleschini et al., EAF slag was used instead of siliceous aggregates, and three concretes, with various cement contents and silica fume additions, were compared to a reference concrete. The performances were in all cases significantly enhanced due to the higher quality of the slag aggregate itself, in combination with the improvement of the bond between EAF slag and the cementitious matrix. These positive results allowed the design of concrete mixtures with the desired strength and workability class but with a significantly reduced environmental impact, which extrapolates to improvements in carbon saving and lower environmental footprint for the concrete industry. In another approach aiming to improve the sustainability of the building material production chain, Vinai et al. investigated the mix design of alkali-activated concrete (AAC), as an alternative to traditional Portland cement-based concrete. Mixtures were synthesized from pulverized fuel ash (60 wt%) and ground granulated blast furnace slag (40 wt%) as a binder, activated with a solution of sodium hydroxide and sodium silicate. Emphasis was placed on workability, setting time, and strength. Results indicated that water content influences the setting time and that paste content is a key parameter for controlling strength development and workability. For the given raw materials and activators, a minimum water-to-solid (w/s) ratio of 0.37 was needed for an initial setting time of about 1 h. A relationship between workability and strength development and w/s ratio and paste content was established and eventually, strengths in the range of 50–60 MPa were achieved.

In the last paper of this thematic section, in the work of Buttiens et al., the authors tried to approach the carbon footprint of blast furnace slag in an analytical way. To quantify the impact of the slag produced together with the hot metal, a method was developed based on a differential approach. For a number of blast furnaces with different operating points and burden compositions, the carbon footprint or carbon cost of slag production was determined using this method and a value of about 550 kg CO_2/t slag was derived. Interestingly, this value did not seem to fluctuate within a wide range of slag burden and was independent of the nature of the raw materials (sinter, pellets, and lump ore) used in the blast furnace. As a result, this value can be used in the comparison of the carbon cost of different steelmaking routes or in life-cycle assessments for steel and slag applications, and could potentially fuel discussions on sustainability assessment as well as choices to be made with respect to technologies and carbon footprint minimization.