Recycling and environmental issues of metallurgical slags and salt fluxes

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The target of the current metallurgical industry is to recycle and utilize all their by-products, so as to close the sustainable production loop. Slags are the important wastes and by-products of metallurgical industry, which have been treated, recycled and used worldwide. The present paper summarizes the current status of utilization of the various slags from ferrous and non-ferrous metal production, as well as waste incineration, and recycling of salt fluxes in secondary metal production. In addition, the environmental issues of the metallurgical slags are addressed. The metallurgical oxide slags have stone-like properties and, thus, their major applications are in civil engineering field. The slags should be recycled, modified and processed in a proper way, by taking the environmental impact into consideration. With the treatment of salt slags for melting aluminium scraps, as an example, the recycling and elution properties of the salt slags are discussed. Our research indicates that the viscosity of the salt flux is increased with addition of non-metallic components, that a certain percentage of fines remain in suspension, which determines the viscosity, affecting the settling of heavier materials. High slag viscosity will lead to more fine aluminium metal entrapped in the salt slag (may also be seen as a high temperature slurry), and thus increase the load of salt slag recycling.

Keywords: recycling, environment, metallurgy, slags, fluxes, salts.

Introduction

Slags are produced in a very large amount in pyrometallurgical processes, and are huge sources of waste if not properly recycled and utilized. With rapid growth of industrialization, the available land for land-filling of large quantity of metallurgical slags is reducing all over the world and, correspondingly, the disposal cost becomes increasingly higher. The global warming effect and natural resource saving are the general environmental topics nowadays. In addition, the land filled with the waste materials has become a significant source of pollution of air, water and soil, and further adversely affects the human health, and the growth of plant and vegetation etc.[1]. From the viewpoint of preservation and protection of the global environment, slag recycling has attracted the attention of many scientists in recent years. Boom *et al*.[2] reviewed the recent research trend on slags and found that there is significant increase in studies on recycling of slags and their environmental problems. The ideal target is to develop a sustainable system loop that can convert all the valuable resources which are landfilled as waste materials into useful products, and reach an absolute recycling.

The metallurgical industry is directing their efforts into minimizing and processing the slags in order to meet their environmental responsibility. Various metallurgical slags are generated in metal extraction, refining and alloying processes. Due to the large slag quantities and the stricter environmental regulations, recycling and utilization of these slags are an attractive alternative in order to reduce and eventually to eliminate the disposal cost, to minimize the related environmental pollution, and to save the resource conservation. The compositions of the slag, their mineral constitutes and the cooling rate, play an important role in their utilization. Metallurgical slags from different metallurgical processes are treated and utilized in different ways based on the different slag characteristics.

The most economic and efficient option for reducing the metallurgical waste generation is through recycling. Slag recycling has been successful in a variety of industries, for example, ironmaking and steelmaking. However, some industries are still challenged with efficient utilization of large quantities of generated slags. This paper summarizes the characteristics of different slags and their utilizations based on the information in literature, and presents the research work carried out by the authors on salt slag treatment and their environmental impact.

Recycling of different metallurgical slags

Slags from ferrous metallurgical industry

In general, steel production has the following two routes: using iron ore as raw material in Blast Furnace(BF) for ironmaking, basic oxygen steelmaking (BOF) for steel converting, and secondary metallurgical process (SMP) for steel refining; using scrap based material in electric arc furnace (EAF) for steel making and secondary metallurgical process (SMP) for refining. Correspondingly, slags can be classified as three major types: BF slag, BOF slag and SMP slag. The BF slag accounts for about twice the amount of BOF slag, and the SMP slag is relatively less significant in terms of utilization due to the lower generated amount. Roughly BOF slag, EAF slag and SMP slag can be defined as steel slags.

Reviewing the past, utilization of ironmaking slag has a long history. The broken slag from ironmaking was already

used in road construction in Roman times. Steel industry has been a pioneer for the recycling, due to the high recycling rate of scrap, and the early use of slag products. Nowadays, owing to the intensive research work during the last a few decades, 100% of iron making slags are being re-used in most countries, and utilization rate of steel slags accounts for about 65% in Europe with nearly 12 million tons production. But the remaining 35% of these slags are still dumped[3]. The slag properties are very important for the utilization. In general, the slag product can be produced with different properties by modifying the slag through the use of additives and controlling cooling rate, either during their separation from the iron or steel, or later by re-melting in a separate furnace.

Blast Furnace (BF) slags

BF slag is formed in the reduction process from iron ore, coke, limestone etc. at temperature range from 1450 to 1550°C, thus contains lower iron oxides and is tapped off from time to time. The chemical compositions of the slag depend on the feeding raw materials and, smelting operation. The slag amount depends very much on the charging material, for example, the grade of iron ore. It varies from about 200 to 600 kg for producing one ton of hot metal. On average, it contains about 0.5–0.8 % FeO, 35–42% CaO, 35–40% SiO_2, 8–9% MgO, 8–15% Al_2O_3, 0.3–1.0% MnO and 0.7–1.5%S in weight. The slag basicity CaO/SiO_2 is in the range of 0.95–1.25.

The slag processing techniques have made remarkable progress since 1970s in order to meet the different specifications and applications. At the first processing step, the slag is either quenched or slowly cooled. The BF slags are usually solidified in four different ways: solidification in slag pots or pouring pads in air forms air-cooled slag; water quenching forms granulated slag; foaming with water structures pumice slag with high porosity; blowing with air or steam forms slag wool for thermal insulation.

Due to the similar chemical compositions of the slag to that of the cement, the fast-cooled BF slag can be used as a high-value alternative to conventional Portland cement in a wide range of applications. The vitreous solidification of the BF slags in silicate glass forms is the essential condition for their hydraulic properties, which is affected by all the elements in the slag and cooling rate.

In slow cooling, BF slags precipitate crystallized silicate phases, for example, melilite and merwinite. Melilite is a solid solution of gehlenite $2CaO \cdot Al_2O_3 \cdot SiO_2$ and akermanite $3CaO \cdot MgO \cdot 2SiO_2$. The only crystalline compound in slow cooled slag which has cementitious properties is β-$2CaO \cdot SiO_2$. Thus crystallized blast furnace slag has little or no value as a cementing component. Crushed BF slag for use as aggregate, ballast and light-weight building material has been an important industry for many years. The concrete made of BF slag as aggregate has the similar properties compared to the conventional aggregates. The BF slags are also used as glass raw material, mineral wool, lime fertilizer and soil stabilization and conditioner[4].

From utilization point of view, the volume stability and/or the slag porosity are important properties which influence the resistance to impact strength. For the aggregate in road construction, a dense slag with high impact strength is very important. For the aggregate in making concrete, a porous slag requires more addition of binding agents. Porosity is formed by the gas release from the molten BF slag during cooling. The solubility of the gases, e.g. N_2, H_2 and O_2 decreases with lower temperature. However, due to the higher viscosity at lower temperature gas bubbles may not all escape. During the slag solidification, the entrapped gas bubbles decrease the impact strength of the cooled slag[5].

Steel slags

Steel slag is a by-product of the steelmaking from iron with a wide range of chemical and mineral compositions, resulted by different feeding material and smelting conditions. In comparison to BF slags, BOF and EAF slags are produced from an oxidation process, thus have higher iron oxides contents. It contains several valuable components: Fe 2–8%, CaO 40–60%, MgO 3–10%, MnO 1–8%. The slag basicity from BOF slag is in the range of 3.5, which is higher than the basicity of EAF slags with a basicity of about 2.0. The SMP slags often have an even higher basicity of around 4[6].

Steel slag is a secondary resource of raw material in metallurgical plant. It can be directly taken back to sintering, ironmaking and steelmaking, and used as flux, from which the useful elements can be recovered[7]. It is advantage that the premelted flux is more easily remelted than the raw flux.

On the other hand, steel slag can be used as construction material, pavement material and engineering material. The remainder is either stored or used for landfilling. Steel slags have been utilized successfully as a construction material, due to their good technical properties. Through proper quality control, the steel slags aggregates can reach a stronger bearing capacity, permanently stable if the requirements for the volume stability have been fulfilled, and do not influence the environment by leaching[3]. The potential problems associated with utilization of steelmaking slags are volume-stability and leaching of heavy metals such as Cr and V. The high free CaO leads to hydration and causes cracking in structures[8]. The stress leads to aggregate deterioration and ultimately pavement failure. Thus reuse of steelmaking slag as a high-quality asphalt aggregate is hampered by the hydration of free lime. To eliminate the expansion problem, the slag is allowed to age out of doors for several months, then the slag should not be crushed again after ageing. Powders of steel slag are also patented for treating wastewater, whereby environmental contamination due to the slags can be prevented and the cost for treating wastewater can be reduced[9]. In general, slag compositions determine the application of the slags. Higher free lime and magnesia are required in fertilizer production by hydration. In order to produce dense aggregates suitable for road and waterway construction and concrete structures, it is necessary to avoid free lime and magnesia formation in the slag.

SMP slags are more difficult to recycle, largely on account of their highly variable chemical and physical properties. The secondary slags are mostly used for various purposes of landfilling, and that their heterogeneous properties and the relatively small volumes generated have, so far, not inspired much research into possible modification techniques. Desulfurization slag has been partially recycled via the sintering plant and blast furnace, and there are some references to its utilization outside the mill, e.g., as a raw material for the manufacture of cement and as a soil improvement agent in agriculture if it has a high lime content[10]. SMP slag has high inclusion absorptivity and high sulphide capacity (regarded as good physical properties), and can be used as desulfurizing agent in hot metal pretreatment.

Stainless steel slags

AOD slags from stainless steel making have almost no utilization due to high content of chromium and poor physical properties. In recent years IPBM process (EU's Plant By-product Melting process) has been developed for slag reduction and for up grading of the slags in a separated plant. The principle is to reduce the less stable oxides into metals such as Fe, V, Cr and Ni etc. The stable oxides remain in the slag and can be converted into various slag products through modification and quenching for application in cement industry, hydraulic binder etc.[11]. At about the same time, Kawasaki Steel Corporation applied a patent for using stainless steel refining slag as a material of a pavement base which is free from the danger of environmental pollution. The slag was treated to have a basicity of 1.4 to 4.0, then mixing the slag in molten state with a substance containing sulphur having a valence of zero or a negative value in an amount of 0.2wt% or more, in order to modify the slag so that Cr^{6+} does not elude from the slag product significantly[12].

Kilau and Shah[13] tested leachability of chromium-bearing slags under acid precipitation conditions, and found that the CaO/SiO_2 ratio and MgO content are the two critical factors to control the chromium leachability and to prevent any environmental pollution. If $CaO/SiO_2 > 2$, chromium exists in slag as $CaO \cdot Cr_2O_3$, which can be vulnerable to leaching by acid precipitation, especially if oxidized to $CaCrO_4$ when exposed to the environment over an extended period. Maximum chromium leachability occurred when the composition of slag has about $CaO/SiO_2 = 2$. If $CaO/SiO_2 = 1–2$, in the presence of sufficient magnesium, $MgO \cdot Cr_2O_3$ was formed, which is very resistant to oxidation and to dissolution by simulated acid precipitation.

Ferroalloy slags

Ferroalloys are mostly smelted using submerged electric furnaces, and small number of operation is using blast furnaces or converters. A large amount of slag is produced from the Fe-alloy production. Most ferroalloy slags are currently landfilled, only a small proportion is recycled and treated for application in inner plant recycling, cement mixture, and as armour stones. Therefore, the need for recycling and utilization of ferroalloy slag is high.

Disposal of these slags will not only need large landfill area, but also pollute the atmosphere, underground water and soil. For example, chromium and manganese containing slags is harmful to human health, if not handled properly. Therefore, reasonable utilization and treatment of these slags are essential to reduce the environmental impact and to recover the valuable materials from the material sources.

The chemical composition of the ferrochrome slag includes three major oxides: SiO_2, MgO and Al_2O_3 which account for up to about 85% of the slag compositions. The physical properties of ferrochrome slag were found to be very suitable as road construction material[14]. However, the influence of the chromium bonded in the slag on the environmental is not very clear.

The low MnO slags are low in CaO and Fe_2O_3 contents and high in SiO_2, Al_2O_3, MnO, MgO, Na_2O and K_2O. The granulated slags are non-crystalline and can be used in making blended slag cement with ordinary Portland cement (OPC), however, addition of the slags lowered the compressive strength of the blended cement as compared to that of OPC used. High MnO(>15%) and MgO(>8%) containing slags were considered unsuitable for blended cements because of their deleterious effects. Air-cooled lumpy slag was evaluated for use as aggregate in concrete[15].

Slags from nonferrous metallurgical industry

Unlike ferrous slags, the slags from base-metal smelters contain 3 main components of FeO-CaO-SiO_2 of over 75–85%. The discarded slags after cleaning operation are normally used in cement, insulation material, fertilizer etc. Due to high Fe content nonferrous slags can be a comparable low grade iron ore, and could be used as ironmaking raw materials in rotary kiln process. Nonferrous slags also contain a certain amount of potentially toxic elements, for example Pb, Zn, As, Cd, which are a possible source of environmental contamination. Smelter slags are normally considered inert because many of the toxic elements are contained in low solubility silicates, oxides and glass. The environmental effect of the long term slag disposal may be serious, especially when the slags are in contact with acidic ground water (pH<4)[16].

Copper slags

Copper is produced mainly via pyrometallurgical processes, which composed of matte smelting, copper converting, fire- and electro-refining. Large amounts of slags are produced due to relatively low grade of the copper concentrates (20–30%). Copper slag is a by-product during matte smelting and converting. Smelter and converter slags differ remarkably on their mineralogical composition and morphology. Converter slags are more inhomogenous and often contain solid particles, and the copper content is higher than in matte smelting slag[17]. The type of slag in copper smelting is exclusively the iron silicate or fayalite slag with the iron to silica ratio of about 2.3 on average, which may contain 1–7% CaO and few per cent of Al_2O_3 and MgO, and varying quantities of residual heavy metals. In copper smelting, minimization of solid waste generation is receiving increased attention with more stringent environmental legislation and lower disposal space availability. The generation of slags during copper smelting is very high, about twice as much as produced cathode copper. Due to the valorizable characteristics, it is important that slag can be valorized as a by-product, rather than to be disposed of as a waste product. Converter slags require cleaning in all cases, either by returning the converter slag to the matte smelting furnace or by a separate slag cleaning method. For slag cleaning operation, the slags must be slowly cooled with a more crystalline nature, particularly above 1000°C, to promote the coalescence and growth of the metallic copper and matte particles. The recovery of other non-ferrous metals in the oxidized state, such as Pb and Sb, is almost not possible.

Similar to the BF and steel slags, the mineralogical composition and morphology of solidified copper slags are of interest for slag utilization and for environment. The slag may be quenched, resulting in a more amorphous vitreous phase in which heavy metals are locked up and become immobilized. Therefore, the vitrified iron silicate slag is characterized by its good environmental stability and by attractive properties for construction industry. If CaO content increases, it can exhibit cementitious properties under the activation of NaOH. The granulated copper slag enhances the strength of concretes[18].

Arsenic is present in the copper minerals in concentrations up to around 1wt%, and is a toxic pollutant to the environment. Because of its high vapor pressure,

most of the arsenic is removed by volatilization. In reverberatory furnaces with more than 0.2% arsenic in the feed, 10% to 25% was reported to the slag. In an electric furnace with an open bath, less than 11.2% was slagged off. In flash furnaces, 7% to 17% of arsenic comes to the slag. During conversion, typically 70% of the arsenic is volatilized, with about 16% reporting to the slag[19].

Lead- and zinc- containing slags

Lead is produced through pyrometallurgical processes, dominated by the conventional blast furnace process and new lead smelting processes such as QSL, Kivcet and Ausmelt. However, all the lead smelting slags are essentially a CaO-SiO_2-FeO-ZnO four component system. It contains about 1–3% Pb and 6-17% of Zn. Compared to copper slags, lead slags have high CaO and low SiO_2 and extra ZnO. Due to high content of ZnO and PbO, the lead slags are first cleaned to recover Zn and Pb through fuming process. The fuming are carried out in fuming furnaces and Waelz kilns[20], where lead and zinc oxides in slags are first reduced with carbon reductants to metallic vapours and, further, collected in as ZnO and PbO in the flue dust, and finally returned to the zinc processing plant. The cleaned slags are dumped or used in a number of applications similar to copper slags.

Zinc is partially produced by hydrometallurgical process (the dominating roasting-leaching-electrowinning route), and partially by pyrometallurgical processes. Particularly pyrometallurgical extraction of lead-zinc complex ore through Imperial-Smelting-Furnace (ISF) process generates similar zinc and lead containing slags. They are treated in the same way as lead smelting slags: slag fuming with submerged combustion slag fuming or with Waelz kilns. Cleaned ISF slags could be used with care in a number of applications similar to copper slags, or dumped.

Recovery of zinc as high grade oxide gives the best economic return from zinc containing slags. Pb- Zn- slags can contain environmentally hazardous heavy metals, which can be leached into ground water if not properly disposed. Even disposed or in landfill sites or chemically stabilized, they may carry an ongoing liability[21]. Therefore, the lead- and zinc- containing slag disposal, used in cement and concrete production can be hazardous.

Granulated phosphorus slag

Phosphorus slag is a by-product during the production of elemental phosphorus, and composed of mainly CaO and SiO_2. The amount of slag is rather high, about 7.5 ton slags are generated for production of one ton phosphorus. The minor components in the slag depend on the nature of phosphate ores used, are 2.5–5% Al_2O_3, 0.2–2.5% Fe_2O_3, 0.5–3%MgO, 1–5%MgO, 1–5% P_2O_5 and 0–2.5%F. The CaO to SiO_2 ratio ranges from 0.8 to 1.2.

For the air-cooled slag, the main crystalline compounds are $CaO \cdot SiO_2$; $3CaO \cdot 2SiO_2$ and $3CaO \cdot 2SiO_2 \cdot CaF$. It has no cementitious properties and can be crushed for uses as ballast or aggregate for road construction. For quenched slag, the glass content of granulated phosphorus slag is high, thus the slag can be used as a cement material. However, it is less reactive than the granulated BF slag due to its lower alumina content.

Slags containing phosphorus can be utilized as phosphorous fertilizer, depending on the CaO and P contents and other mineral occurrences in slag. The slag can be modified by addition of lime. P content will affect composition of phosphate mineral and the mineral constitutes will affect utility of the slag and solubility rate in the slag. In addition, the phosphorus slag should not be used as light weight building material, due to the radioactive elements from the phosphate rock.

Waste incineration slag

Waste incineration represents the total oxidation process of the combustible materials present in the municipal and industrial wastes. During the incineration about 300 kg solid residuals/t waste is generated, in which roughly 250–300 kg/t slag and 20–30 kg/t ash are produced for landfilling or reuse[22]. The slag constitutes of mainly SiO_2, Al_2O_3, CaO and NaO. The ash contains significant amount of heavy metals and trace amounts of organic pollutants, and is considered hazardous[23] and must be treated or landfilled with careful control of the effluents. An alternative recovery option is necessary from an environmental and economical perspective. The incinerator residues can be reused through high temperature melting and controlled solidification as road construction materials, concrete aggregate, or cement materials[24–25]. Good and safe quality stones can be produced from MSW incinerated residual[26].

To better utilize the incinerator slag, Reich et al.[27] added limestone in the slag to improve the slag quality, and found that different soluble heavy metal species are formed in reactions of heavy metals, slag components and lime(stone). The pH of the leachate increases with rising CaO-content of the slag. A lower melting temperature raises the content of molten phases in the slag at constant kiln temperatures, and heavy metals are better fixed in the matrix. In comparison to post-treatment of waste incineration residues, such as stabilization with concrete or fusion processes, this procedure is integrated in the process, demanding only limestone as an additive.

Salt slags from secondary aluminium smelters

The commercial process in Europe for Al recovery from scraps involves crushing, sizing and melting the metal from the scrap in rotary furnace under a salt flux protection. The salt flux absorbs the oxides and contaminants from the scrap and protects the aluminium melt from oxidation. It consists mainly NaCl and KCl, and some additional cryolite or CaF_2. After melting, aluminium metal and salt slag are tapped from the furnace. Depending on the scrap type, usually a large amount of salt slag is generated, which contains mainly oxides, nitrides, chlorides and some residual aluminium metal or alloys. High salt flux factor is used to reach a higher metal recovery for melting lower grade scrap, which leads to an increased quantity of the salt slags. Due to the high consumption of the salt flux and thus high generation of salt slags, it has to be cleaned and recycled. Salt slags are treated in a series steps: separation of the entrapped aluminium metal; leaching and filtering to separate the soluble salts and the residues; crystallizing to regenerate the salt fluxes; and heat treatment of the non-metallic residues for reuse. The salt slag actually is not a slag but a slurry, which contains the salt flux and the products from the chemical reactions that occur between the scrap and the salt flux during melting.

Since the properties of the salt flux affect the separation efficiency of the metal from salt slags and the metal loss, research was carried out to understand the relationship of amount of entrapped metal with slag compositions. Due to the important role of the slag viscosity in the sedimentation of metal drops in salt slags, the viscosity of lab-synthetic

slags with different compositions was measured. Industrial slag samples were taken at Konzelmann Metallschmelzwerke GmbH, Germany from the slag stream during the slag tap. These samples were analysed on their salt, non-metallic components (NMC) and aluminium content[28].

Viscosity of salt slags or salt slurries

In general, the most important parameters that influence the salt slag viscosity are temperature, salt compositions, and properties of entrapped NMC. The compositions, amount, size and shapes of the NMC are related to the scrap charge and furnace operation.

The viscosity of salt with composition of 30 mol% KCl-70 mol% at 800°C was calibrated against the data in literature (1.13 centipoises)[29]. The NMC particles added in the synthetic slags were obtained industry, which has an average density of about 3.0 g/cm³. Effect of NMC size (10 μm and 30 μm) on viscosity was also investigated. The results are illustrated in Figure 1. It is clear that the presence of NMC particles increases the molten salt viscosity, especially at higher volume per cent of NMC. The viscosity increased dramatically when the volume per cent of NMC reached about 10%. For the same volume percentage of NMC with particle sizes of 10 and 30 μm, the number of NMC particles with an average diameter of 10 μm is 27 times higher than the number of NMC particles with diameter of 30 μm in a distinct volume of molten salt. The viscosity of the slag with 30 μm NMC particles was a bit lower than the viscosity of a slag with 10 μm particles, however, the difference is almost invisible. Based on sedimentation calculations in the slag phase, the amount of aluminium entrapped in the slag is increased by the NMC particles smaller than 21 μm. These small NMC particles increase the viscosity of the salt slag that influences the settling velocity of the aluminium droplets.

Analysis on industrial slag samples

To study the metal entrapment in the salt slag, industrial slag samples were taken from melting aluminium granulates. The number of metal beads and weight per cent of the entrapped metal were analysed, as shown in Figures 2 and 3. It can be seen that the slags contain large amounts of metallic beads with size smaller than 2 mm. Higher NMC in the salt will lead to somewhat higher metal loss in the salt slags. This may be the result of the increased slag of viscosity at high NMC content. According to the sedimentation calculation[28], the smaller NMC particles have more significant influence on the salt viscosity, and further, on the settling rate of the aluminium droplets from salt slag into the metal bath. Therefore, the higher the viscosity the larger is the aluminium droplets that remain entrapped.

In general, the viscosity of the slag is increased with addition of NMC particles. After a critical volume percentage (about 10%) is reached, the viscosity starts to increase radically. It can be concluded that the data from analysing the industrial slags are very scattered. The amount of metal entrapped in the slags was measured 4.6 wt% on average. Some parts of the slag contain only 0.5 wt% aluminium and others 18.5 wt%. The amount of aluminium entrapped in the slag may be affected not only by the NMC/Salt ratio in the slag samples, but also by the operation conditions and NMC particle shapes. About 40% of the NMC particles are fine enough to remain suspended in the slag. When the furnace stops rotating NMC particles and aluminium droplets start to settle, the salt slag can therefore, be considered to be a slurry. The NMC particles form a sedimentation layer that blocks aluminium droplets reaching the slag/metal interface and further agglomerating into the metal phase. This has significant influence on metal recovery and yield.

Environmental impact

The environmental conformity of the slags and their byproducts has been investigated for years, which is normally to be judged by the leachability of the slags. Due to the very low solubility of the most mineral phases of the BF and steel slags in water, the BF and Steel slags do not affect the environment if there is no free lime and the slag is volume stable. High free CaO content in steel slag may cause volume expansion, which will be harmful for the use e.g. in the road construction.

Most slags contain impurities of toxic elements, such as As, Pb, Cd, Co, Cr or Ni. Since these substances can be leached to some extent from the slags, possible
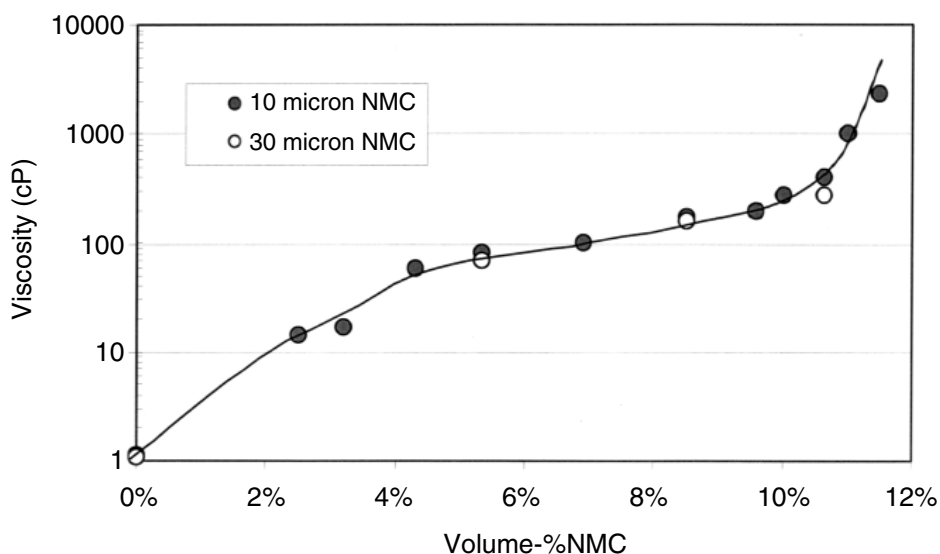

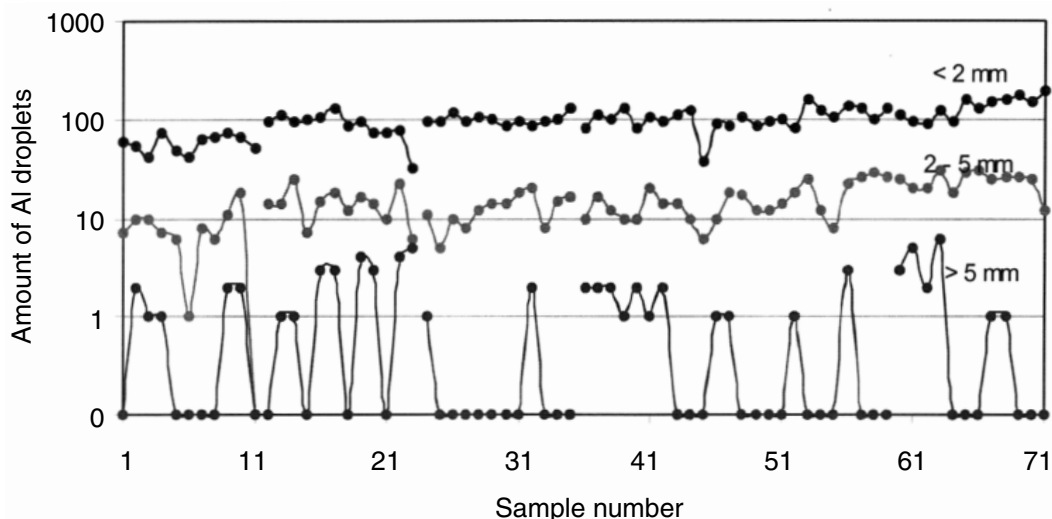**Figure 1. Influence of amount and size of NMC on slag viscosity**

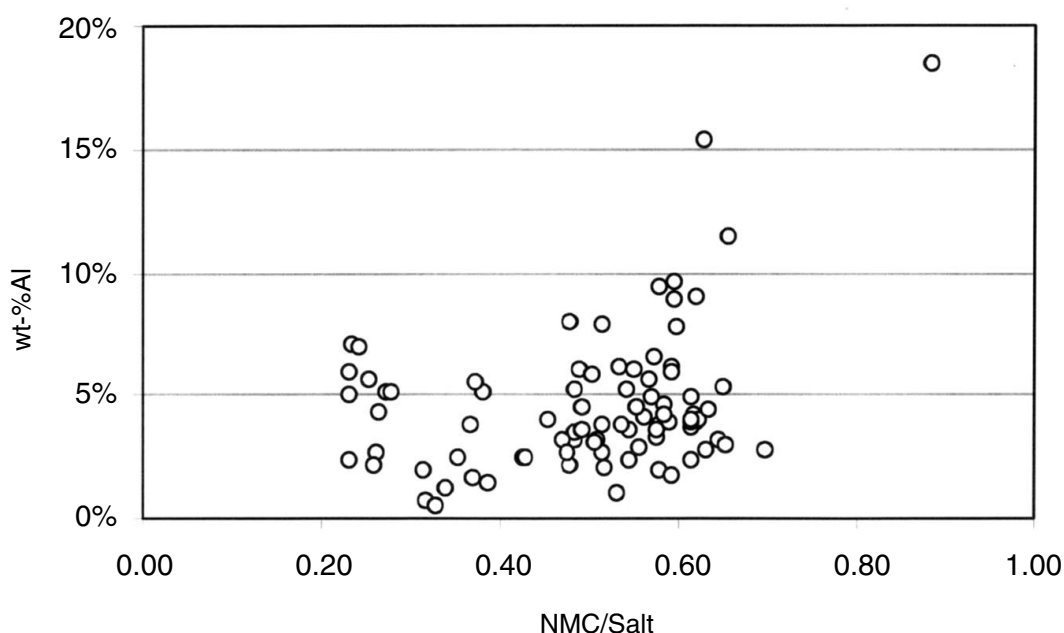**Figure 2. Amount of aluminium droplets in certain size class**

Figure 3. Weight-% Al entrapped in salt slag versus NMC/Salt ratio

environmental hazards cannot always be excluded. Several investigations of water, soil, and plant pollution by slags are available[30]. Environmental test on smelter slags containing dissolved arsenic up to 23.5% show that the release of arsenic is minimal, and that solid slag is a safe means for storing arsenic[31]. Incinerator residues contain hazardous substances such as heavy metals and dioxins. To recycle these hazardous material, long term safety aspects must also be considered for the sake of future generations.

The gaseous emissions from the salt slag (slurry) that result from contact with water are of great environmental concern. In the leaching process, the components in the slags react with water and generate explosive, poisonous and/or with unpleasant odour gases: Al metal fines liberating hydrogen (H_2); carbide producing methane (CH_4); nitride forming ammonia (NH_3); and phosphorous developing highly toxic phosphine gas (PH_3). Because of the soluble residues and the hazardous gas evolution, the

salt slag cannot be simply dumped. So far the best way is to recycle the salt, to utilize the residues and to recover the generated gases. Non-metallic components (NMC) including oxide, carbon and cryolite or fluorite are not water soluble, and they are filtered and dried. After calcinations, the NMC can be further processed for application, for example, in cement industry[32] or for making refractory bricks[33].

The responsibilities of the metallurgists are not only to produce high quality metal products, but also to protect the environment and, further, to protect human health. Through improving the quality of the industry by-products and increasing the utilization rate of metallurgical slags, the living environment can be protected, and an economic use of the natural resources can be guaranteed.

Summary

Through surveying the literature, the research work

developed during the last a few decades informs us that utilization of slag has a long history. Further, to explore the high potential of using slags to produce those products which are competitive in the respective market is still a challenging task. Many relationships were found between the application of the slag and its link to smelting process. As the slags have more or less a similarity to natural stones, they can have the same applications in most of the fields, especially in civil engineering. To increase the re-utilization of the slags, sometimes it is necessary to modify the slag properties by introducing additives and by applying suitable heat treatment. Besides the technical description of the slag, there is an increasing demand for more environmental information. The product development can not simply be separated from the environmental research.

It is time to develop an appropriate technology to guarantee the quality of slag-containing products, in order to promote their use. The effective reuse standards have to be established based on the environmental issues. It is clear that treated slags under controlled conditions are more useful than unprocessed slags. Products shaped like bricks would leach smaller amounts of hazardous substances than shapeless slag under similar environment, due to decreased surface area and less permeability.

Specifically for aluminium scrap melting, salt slag properties play an important role in metal–slag separation. The experiments carried out in the laboratory show that the viscosity of the salt flux in compositions of NaCl 70 mol% - KCl 30 mol% is increased with addition of non-metallic components. After the amount of solid particles reaches to about 10 volume%, the viscosity increases rapidly with further increasing the amount of non-metallic particles. The amount of aluminium entrapped in the slag may be affected by multi-factors: the NMC/Salt ratio, the operation conditions and NMC particle shapes. When the furnace is at rest, the NMC particles form a sediment layer that hinders aluminium droplets to settle into the metal phase. This retains the metal but also affects the retention of other less environmentally favourable compounds that enter the furnace due to unclean scrap.

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