The SLAG-REC® project for an innovative direct dry granulation of EAF slag

R. Roberti[1], F. Uberto[2], M.Svanera[2], G. Altenburger[3], F. Cabra[4]

[1] Dept. Of Mech. Eng, University of Brescia, via Branze 38 – I-25123 Brescia, Italy
[2] ASO Siderurgica, via Seriola 122 – I-25035 Ospitaletto, (Bs), Italy
[3] MFL - Maschinenfabrik Liezen und Gießerei - Werkstrasse 5 - A-8940 Liezen, Austria
[4] CABRA Engineering, Via S.Anna, 2 – I-24060 Rogno, (Bg), Italy

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Abstract
The iron and steel industry has since the most remote times produced emissions and waste products which sometimes have been successfully used in different fields of application. A good example are Etruscan metallurgical slags, tens of meters thick in some places, which extended to the coastline in the Gulf of Baratti in Tuscany and which were used more than two thousand years later as the metallic charge for the blast furnace in Piombino during the first half of the XXth century. Further examples are the steel slags from the Basic-Bessemer (Thomas) process which were used as a phosphatic fertilizers since the introduction of the basic converter in the 1860's, while more or less in the same period the blast furnace slags were suggested for road construction and are still today being successfully used for that and other purposes.
In effect the iron and steel industry has investigated blast furnace slags continuously, taken care of suitable processing and if necessary modified the iron smelting processes to get slag products which fulfill the requirements of the specific standards and regulations.
The same did not happen for Basic Oxygen Furnace or for Electric Arc Furnace slags which still to day pose some problems for their handling and processing, even when intended for dumping, or encounter difficulties in being used notwithstanding their proven valuable characteristics for some proposed fields of application.
The present paper describes a new system, the SLAG-REC® machine, for the direct dry granulation of Electric Arc Furnace (EAF) slags, its advantages in handling slag directly out of the furnace and in modifying its characteristics in order to comply with the end use requirements.

Introduction

The industrial processes involved in the production of iron and steel have always given rise to a number of different kinds of materials which were at one time simply referred to as waste. Nowadays, however, it is somewhat difficult to find the correct term to cover these materials, as work has progressed on converting them into marketable products and some of them have become objects of separate business activities. Terms such as waste, product, by-product, co-product, recycled product, raw material, secondary material, etc., are problematic to define as, according to the situation, different terms may be used for a correct description of the same material. It is nevertheless important to be able to select the proper term in each instance, for many reasons. The most evident adverse impact of the incorrect choice of term is clear in those cases where some law or regulation may prevent a material from being used at all if classified in that way. As far as the marketing of the resulting products is concerned, the choice of the appropriate term can have a considerable effect on their image and the extent to which they are accepted by the public opinion.
The terms used by the steel industry for its products and for those materials generated alongside the production processes have become fairly firmly established over the years, and their use continues to reflect the viewpoint of the steel producer. Consequently, the terms used for the materials generated alongside the steelmaking processes do not in general promote their marketing where attempts are being made to create a high-quality "by-product" image. A good example for this is the term "slag", which is still popularly equated with waste.
Waste products from the iron and steel industry have been sometimes successfully used in different fields of application also in the past. A good example are Etruscan metallurgical slags,

tens of meters thick in some places, which extended to the coastline in the Gulf of Baratti in Tuscany and which were used more than two thousand years later as the metallic charge for the blast furnace in Piombino during the first half of the XXth century. Further examples are the steel slags from the Basic-Bessemer (Thomas) process which were used as a phosphatic fertilizers since the introduction of the basic converter in the 1860's, while more or less in the same period the blast furnace slags were suggested for road construction and are still today being successfully used for that and other purposes.
The same did not happen for Basic Oxygen Furnace or for Electric Arc Furnace slags which still to day pose some problems for their handling and processing, even when intended for dumping, or encounter difficulties in being used notwithstanding their proven valuable characteristics for the proposed fields of application.
In the case of blast furnace slag, it has to be considered that the production of molten iron involves the conversion of iron oxide feed materials by reduction at high temperature. During the smelting operation, a slag is formed from the non-ferrous components (gangue) of the iron oxide feed and the ash content of the carbon based fuels. The composition of the slag is not only controlled to specific metallurgical requirements, so that the iron composition meets the required compositional specification, but it is also engineered so that, as well as meeting the iron making compositional requirements, it also meets the chemical specifications required of the blast furnace slag by-products. In addition, blast furnace process is maintained as far as possible in steady state conditions and this facilitates the subsequent treatment processes of the slag as it flows regularly out of the furnace, with almost constant properties, i.e. temperature, chemical composition, viscosity, etc.
This is not the case of EAF slag, as it flows intermittently out of the furnace with large variation of temperature, viscosity and foaming conditions and with a chemical composition that is mainly adjusted according to the steel to be produced and not taking into account the possible use of the slag as a by-product of the steelmaking process.
Furthermore, in Europe as well as in other continents there is a great demand for aggregates mainly from civil engineering industry, especially in the field of road and concrete constructions as well as for hydraulic purposes, like stabilization of river banks. Every human activity in these field however must comply with expectations by public opinion and with the declared targets of industrialized countries Governments:

1. to protect the environment and to improve its quality;
2. to serve the protection of the human health;
3. to guarantee a cautious and efficient use of the natural resources.

The last statement holds us responsible to save natural resources by using industrial co-products and to increase their utilization rate wherever their technical and environmental properties are suitable concerning the relevant application field.
Electric Arc Furnaces are commonly used for steel production from scrap. In Europe electric-arc furnaces produce about 86 million tons of steel and as by-product about 20 million tons of slag every year, the 60% of which (12 million tons) is simply dumped with easily deducible negative impacts for the environment; in addition, slag dumping is a cost for the electric arc steel industry, which has also to face frequent dump capacity problems.
Recycling of slag in road constructions is the most interesting possible use (1-3); to this purpose slag has to meet specific parameters, either from the mechanical, environmental, and stability point of view. EAF slag is not usable in the conditions as it is produced, but only after several treatments and even after sometimes it may still be subjected to swelling or present environmental problems given by excessive leachate release, due to the fact that the today established treating processes, very long and not always environment friendly, cannot avoid a certain level of free lime content of slag or take under strait control all the characteristics of the slag.
ASO has recently developed a new, eco-innovative system for slag collection by means of a dry granulation treatment, which can simplify the handling of the slag out of the EAF and keep under control the structural constitution of the slag thus making possible a 100% recycling of EAF slag after only one treatment process, completely eliminating the risk of swelling and elements leaching to the environment. The system which has been named SLAG-REC® is hereafter described and its advantages highlighted.

The present State of the Art treatments of EAF slags

Handling of slag out of the EAF is not a simply and safe task even when slag is intended for dumping. The slag is discontinuously discharged from the electric-arc furnaces and is let to cool down to room temperature. Solidification in blocks occurs in air, and the process is often accelerated by water sprinkles. Today EAF slag is simply poured on the ground or is gathered in large pots before being poured on the ground in a separated area (Fig. 1), and water sprinkles are mainly used to avoid excessive uncontrolled foaming reactions rather then to take under control the cooling rate of the slag. Actual slag handling practices pose the following problems:

- Slow or uncontrolled cooling rate
- Explosion hazard due to water sprinkles
- Need for further handling, in adverse conditions (handling hot liquid slag, tilting slag pits to pour slag on the ground, etc.) also when slag is to be dumped
- Crushing and milling to final size (dust emissions) if slag is to be re-used

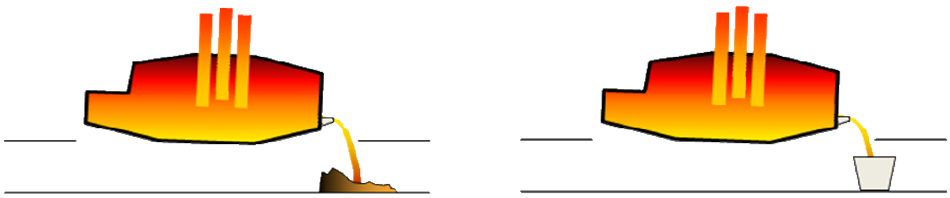

Fig. 1 – Schematic representation of the actual system for EAF slag handling.

Slag solidified in large size pieces or in blocks is not re-usable, and needs at least to be crushed and milled.
The direct obtainment of a readily usable slag as in the case of blast furnace slags is not possible as water granulation, i.e. pouring the slag into a large mass of water, cannot be applied due to the large variation of EAF slag parameters.
In addition to size requirements which can be complied with by crushing, milling and sieving, the volume stability and leaching behaviour are decisive criteria to make practicable any pretentious applications of steel slags
When it is not possible to obtain a glassy structure by means of water chilling, in order to avoid swelling, the free lime content has to be reduced to max. 2-3 %, otherwise slag cannot be used for road construction, and it makes necessary further treatments. Slags with excessive free lime content should be stabilised by a seasoning period which can take months (depending on piece sizes). Weathering of the solid slags outside the slag pits for a certain period of time at free atmosphere transforms the free lime into calcium hydroxide. In some cases the slag is also sprayed with water to accelerate the hydration of free lime and/or MgO. The actual process is not only needing a long time, but it is not even completely environment friendly since the moving operations produce dust, and the drained water has a pH around 10.
As far as the environment implications are taken into account, it must be considered that the assessment of the environmental compatibility of aggregates as a building material is not determined by the content of environmentally relevant elements in the solid material but by the potential leaching behavior.
Therefore, the major element analysis and the mineral composition that are usually measured on EAF slags are essential but not sufficient for an evaluation of their environmental impact. To get information about the effect on the ground water and soil, it is of more interest to know the concentrations of those environmentally relevant components which can be leached out.
To simulate the leaching of aggregates in a laboratory during the last decades many leaching tests methods have been developed. Notwithstanding all the detailed test parameters have not yet been harmonized the tank leaching test is officially used as a controlling method for factory production and third party control when slags are applied as aggregates for road construction and hydraulic structures.

The leaching test results have shown that except for the pH value, which is affected by the partial solution of the slag lime, and the closely-related electric conductivity, the leaching of other elements is insignificant in terms of environmental impact. The greatest attention is paid towards chromium which may occur in somewhat higher amounts as a mineral component. In any case the concentrations in leachates are low provided that the chromium ions are bound within stable crystalline phases, and this is usually taken under control by a properly adjusted chemical composition and by rapid cooling.

The SLAG-REC® system

For electric-arc furnace slag no dry granulation solution has been proposed yet. Contrary to the constancy of the production process in blast furnaces, in EAFs slag production is discontinuous (slag is being eliminated from steel periodically, and its temperature and fluidity vary from heat to heat), thus for EAFs it is impossible to use of the wet granulation systems proposed for blast furnaces.
ASO is the first to develop a complete solution for dry granulation to solve slag handling and treatment in EAFs.
Fig. 2 is a schematic representation of the original idea (4-5) at the basis of the SLAG-REC® system.

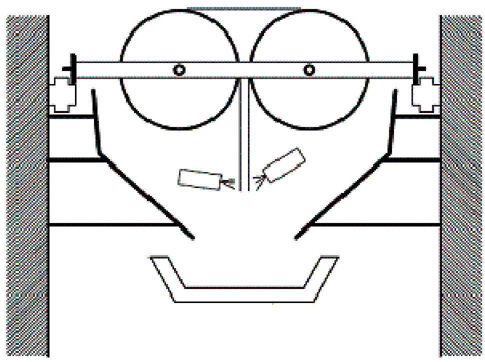

Fig. 2 – Schematic representation of the SLAG-REC® system.

ASO has developed a new system for EAFs for dry granulation of slag, using two contra-rotating cylinders which make the slag to granulate and vitrify because of the rapid cooling. Air sprays below the rotating cylinders contribute to the dry granulation and rapid cooling The continuity of the process is finally assured by a continuous evacuation system of the granulated slag using a series of oscillating tanks or a belt conveyor.
The new system rapidly cools down and disaggregates the slag either directly received from the slag door of the furnace, or poured from a slag pit, solving at the same time its collection and its movement with no need for any further operation.
The system is made up of a couple of side-by-side contra-rotating cylinders, rotating on respective axes and located in a containing structure; two heading refractory plates, not shown in the figure, assure the lateral containment of the liquid slag.
The rotating cylinders are fixed horizontally on supporting beams and they are moved by an engine in opposite senses. They are placed in order to limit between them and the heading refractory plates an upper gathering basin for the slag to be treated, to canalize it in between for lamination, and to outlet it towards the gathering conveyor.
The inter-axe distance of cylinders can be regulated in order to be able to vary the rolling width responding to different needs (slag temperature, viscosity, foaming state, etc.).
Under the cylinders, on the opposite sides of the slag trajectory at the rolls outlet, nozzles are located for the ejection of compressed air sprinkles towards slag.

In practice slag falling out from the furnace deslagging door or poured from a slag ladle is gathered in the upper basin between the rolls and begins to cool down when it enters in contact with the roll surfaces; then it is roiled to an adjusted thickness passing through the space in between, to be then further cooled by the compressed air sprinkles. Over the cooling function these air sprinkles have also the role of disaggregating the slag falling down from the gap between the cylinders. Slag is then collected in the gathering conveyor, ready to be transferred, without any need for further manipulations. Moreover, the load of slag to be treated can be regulated depending on its characteristics, also by the adjustment of a suitable rotation speed of the cylinders.

The planned three phases for the realisation of the eco-innovative first SLAG-REC® system are the following:

a) Engineering phase. This phase is based on previous positive empirical experiments carried out on two small, manually operated cylinders. The phase is presently almost concluded and the result is schematically presented in Fig. 3. Designing of the machine has been focussed on both structural and thermal aspects and has used sophisticated simulating instruments in order to define exactly all engineering parameters of the system; both geometry and size of the various parts have been defined according to the needs of the ASO EAF.

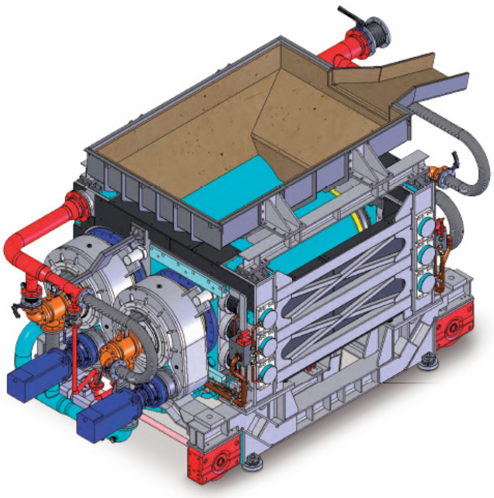

Fig. 3 – 3-D representation of the SLAG-REC® machine

b) Construction of the SLAG-REC® machine. The engineered system designed for the ASO furnace, will be fabricated and put on trial.
c) Validation and production start. In this phase the new system operation will be started. In the initial validation and practical testing phase eventual necessary modifications will be identified for the improvement of the system to be proposed to the market.

Conclusions

A new system for EAF slag dry granulation has been developed. The new SLAG-REC® machine would be practically applicable to all EAFs; it will contribute to save slag from dumps and make it re-usable mainly for road construction and for cement conglomerations, resulting in

- less problems in handling hot slag for the steel works
- less waste transported in dumps from EAFs,
- less use of natural gravel for road construction (saving up natural resources),
- no transport and dismissing costs of slag to dumps,
- less water used in the overall electric arc furnace process,
- less emission of contaminant substances of slag to soil and atmosphere,
- “cleaner” steelmaking industry – healthier environment.

Acknowledgments

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References

1 – H. Motz, J. Geiseler, Waste Management 21 (2001) 285-293

2 – M. Frıas Rojas, M.I. Sanchez de Rojas, Cement and Concrete Research 34 (2004) 1881–1888

3 – L. Muhmood, S. Vitta, D. Venkateswaran, Cement and Concrete Research 39 (2009) 102–109

4 – R. Roberti (2008). Impianto per il trattamento delle scorie del forno elettrico ad arco. Italian Patent n. n. BS2008A000143

5 – R. Roberti (2009). Equipment for the treatment of slag from electric furnaces. European Patent n. 09425294.7-1215