EAF SLAG RECOVERY TURNS A WASTE DISPOSAL PROBLEM INTO A BUSINESS OPPORTUNITY[1]

The treatment of metallurgical slag allows for a 100% landfill diversion rate and generates revenues from the sale of the recovered products

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Abstract

The melting of steel scrap with the EAF (Electric Arc Furnace) produces metallurgical slag amounting from 12% to approximately 20% of the steel, thus the production of this by-product is very important and the traditional on-site piling method is not a solution any more. Danieli has developed the Ecogravel® Process, the slag recovery system which produces various sizes of aggregate having mechanical properties better than those of natural aggregate. The system is able to magnetically separate ferrous materials from the EAF slag, the recovered scrap metal is approximately 3%-4%. The process is completely automated and its operation requires personnel only for feeding the processing line and removing the end products. Danieli is flexible in designing a process which takes into consideration the specific requirements of each project. The phases of the process are crushing, grinding, screening and magnetic separation, by special equipment. The process recovery rate is 100%, because no waste or other by-product is generated. The main product is Ecogravel®, a fantastic industrial aggregate, but the recovered metal scrap is economically even more important. Depending on the EAF operations and slag pre-treatment, up to 3%-4% of the slag is recovered as scrap. The markets for aggregate product is bituminous conglomerate for road pavements and in the concrete like aggregate for industrial and civil application. The return of the investment could be less than 1 year, depend from the disposal costs of the slag. Ecogravel® Process is very attractive, in fact it can turn a bulky environmental problem into a business opportunity.

Key words: Steel slag; Recycling and utilization; Asphalt mixture; Concrete.

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1 INTRODUCTION

The melting of steel scrap with the EAF (Electric Arc Furnace) or production of steel by BOF (Basic Oxygen Furnace) produces metallurgical slag amounting from approximately 12% to 20% of the steel, thus the production of this by-product is very important and the traditional on-site piling method is not a solution any more.

Figure 1. Danieli Electric Arc Furnace .

Figure 2. Deslagging process.

Danieli has worked with ABS, an electric steel meltshop having a capacity of 1 Mtpy, to adjust the metallurgical process in order to facilitate the production of recoverable EAF slag.
Ecogravel® is the trade name of the main product of the Danieli slag recovery system which, through a combination of grinding and sieving, produces various sizes of aggregate having mechanical properties better than those of natural aggregate (gravel).

The system is able to magnetically separate ferrous materials from the EAF slag. The process is completely automated and its operation requires personnel only for feeding the processing line and removing the end products.
Since December 2006, when the plant was started-up at the ABS electric melt shop in Udine, more than 600,000 tonnes of EAF slag have been recovered and successfully marketed for road asphalting and for the production of concrete.
In ABS, the recovered scrap metal is approximately 3% of the processed material and is recycled back to the meltshop.

2 MATERIAL AND METHODS

2.1 EAF Slag Characterization

The slag produced by the EAF is suitable for recovery and can be processed after a seasoning period, during which the waste is exposed to the weather precipitations for stabilization.

Figure 3. Compact and porous EAF slag.

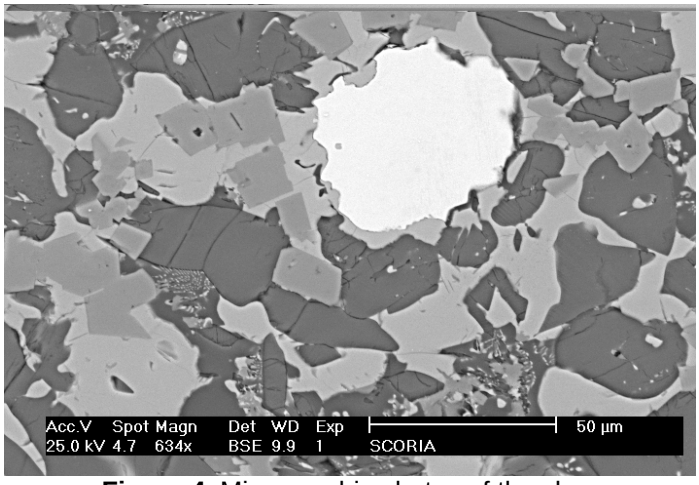


Figure 4. Micrographic photos of the slag.

The above pictures show samples of compact and ABS porous slags and the enlargement made with the electronic microscope (the white area is an inclusion of steel).

The following diagram is an example of chemical analysis made by pointing a specific area of Figure 5.

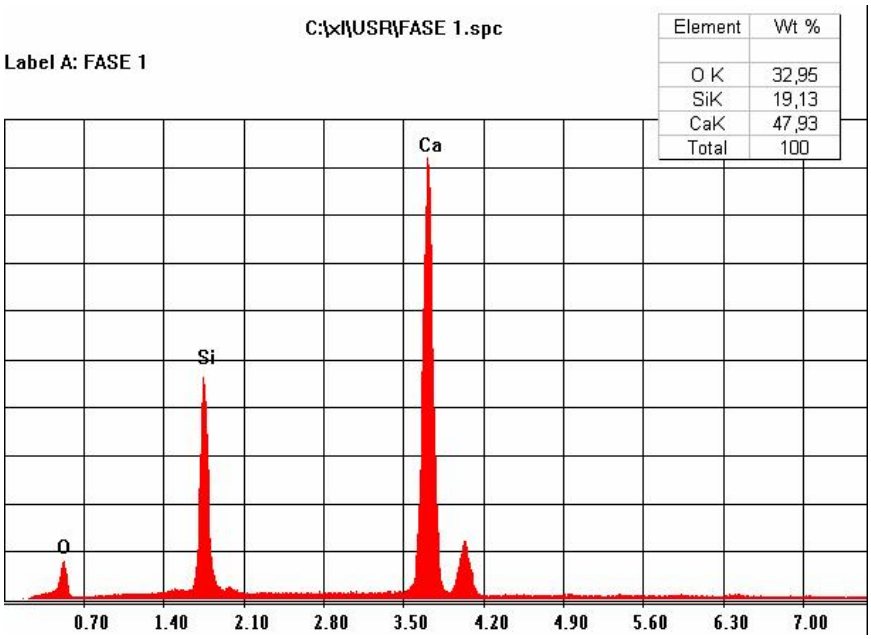
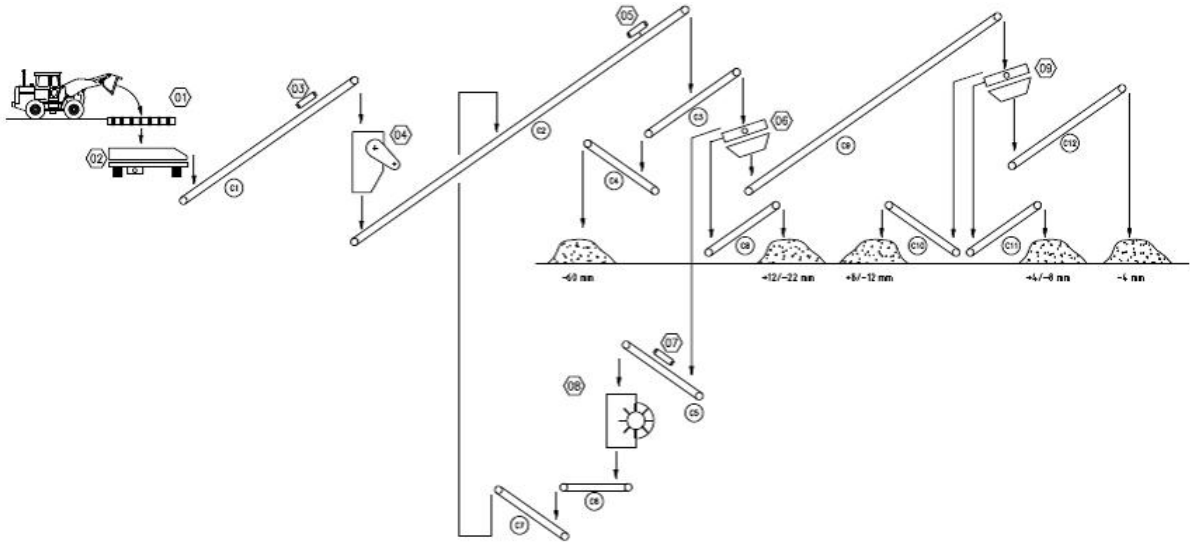


Figure 5. Chemical analysis of a phase of the slag.

2.2 The Global Blue Process

The process depends on the number and specifications (particle size) of products. Danieli is flexible in designing a process which takes into consideration the specific requirements of each project. A process diagram, suitable for the production of five different aggregate sizes, is provided in Figure 6.



1	*Static Scalper*	*6*	*Primary Screen*
2	*Vibrating Feeder*	*7*	*Tertiary Magnet*
3	*Primary Magnet*	*8*	*Hammer Mill*
4	*Jaw Crusher*	*9*	*Secondary Screen*
5	*Secondary Magnet*	*C1-C12*	*Belt Conveyors*

Figure 6. Global Blue Process Diagram

The slag is handled by a wheel loader, which feeds the plant by unloading the slag into a static scalper, having the function of separating any bulky material. The material passed through the scalper is processed by a special vibrating feeder which doses it to the following treatment equipment.
A magnetic separator (primary magnet), with self-cleaning belt, is installed over the lifting conveyor taking the material from the scalper to a jaw crusher, which is the first size-reduction equipment of the line.

Figure 7. Danieli slag recovery plant in A.B.S. Italy; and detail of slag recovery plant.

A secondary magnet processes the material treated by the jaw crusher which, by means of a reversible conveyor, is transported to the primary screen. By reversing the direction of this conveyor, it is possible to complete the treatment without additional processing, as it is required when the market demands for a coarse aggregate to be used as unbound material for road construction.
The primary screen is of two-deck type, thus it generates three different fractions:

- A coarse fraction, which is further processed by a hammer mill and recycled back to the primary screen inlet;
- A mid-size product (for instance > 12 mm and < 22 mm);
- A fine fraction, which is sent to the secondary screen.

The secondary screen, also of two-deck type, generates three different products:

- A coarse product (for instance > 8 mm and < 12 mm)
- A mid-size product (for instance > 4 mm and < 8 mm);
- A fine product (for instance > 0 mm and < 4 mm).

A second wheel loader is used to load a truck, which conveys the products to their storage bunkers.
All sieving mats can be changed in a few hours to produce aggregate with different size.

2.3 Recovery Rate

The process recovery rate is 100%, because no waste or other by-product is generated.
The main product is Ecogravel®, but the recovered metal scrap is economically even more important. Depending on the EAF operations and slag pre-treatment, up to 3%-4% of the slag is recovered as scrap, with consequent saving on the cost of raw materials required by the meltshop.

Figure 8. Recoverable scrap within the slag.

2.4 O & M Costs

The plant requires only four operators per operation shift and the other operation and maintenance costs are moderate. The most important cost components are shown in the Table 1 (all amounts are indicative only).

Table 1. Requirement per Tonne of Processed Slag

Requirement per Tonne of Processed Slag		
Electricity	4.50	kWh/t
Spare parts	1.50	Euro/t
Diesel fuel	0.35	Litre/t

2.5 Plant Throughput Capacity

The capacity of the slag treatment plant is defined by the quantity of EAF / BOF slag produced and by the possible need of treating material generated in the past and stock piled at the site.

The throughput capacity of a treatment line varies from 50 to 200 tph, depending on the number and specifications (particle size) of the aggregate products.

In general, a system with a single processing line is adequate for processing an average of 100 tph of slag. With an operation based on 8 hours/day and 5 days/week, the resulting plant capacity is 200,000 tonnes, enough for a meltshop producing 1.5 million tonnes of steel per year.

Of course, the capacity of the plant depends on the hours of treatment and, when required, two shifts per day can be arranged. The critical maintenance consists in the replacement of the wear parts of the jaw crusher and hammer mill, which must be serviced weekly to make sure that the plant performance is not negatively affected.

2.6 Land Requirement

In the case of a single treatment line, the equipment foot print is approximately 50 m by 80 m, but the total land requirement depends also on other factors. In general, to allow for an adequate stabilization of the slag. The markets of the products are seasonal, or depend on the weather conditions, thus it is important to have a few months of product storage capacity.
The picture below shows the ABS slag recovery plant, which includes also a plant for the preparation of concrete mix. The area taken by this plant, which treats 200,000 tonnes of slag per year, is approximately 5 hectares.

Figure 9. Slag processing area in A.B.S. Italy.

3 RESULTS

3.1 Road Asphalting Application

Ecogravel® is an ideal product for the construction of the wearing course of road pavements. This is principally due to its high degree of adhesion to road surfaces, a fundamental traffic safety prerequisite.
The product is fully compliant to the European standard EN 13043 "*Aggregates for bituminous mixes and surface treatments for roads, airports and other traffic areas*".
Ecogravel® is particularly appreciated in the top layer, where the hardness and wear resistance of the product are superior to those of the natural aggregate (gravel). Extensive testing has allowed the certification of the aggregate product for this application. With the use of Ecogravel® increases the durability of the road.

Figure 10. Ecogravel®; Road application; and a sample of the final product bituminous conglomerate.

3.2 Concrete Application

The particular characteristics of the EAF process allow for producing slag with low sulphur levels, thus the slag derived aggregate can be used in making concrete.
While the use of Ecogravel® for structural concrete is still being studied, its use for the construction of pavements is already an established practice. The result is excellent, particularly for pavements subject to heavy traffic or wear by loaders handling materials with the bucket.

Figure 11. The A.B.S. concrete plant in Italy, that utilize slag in the concrete like aggregate.

Figure 12. Concrete produced with Ecogravel like aggregate inside; and industrial concrete floor made in concrete with Ecogravel.

The diagrams in Figure 13 show that the concrete mixes made with Ecogravel® (3, 4, 5 and 6) have a resistance to compression, traction and shear higher than those of mixes produced with natural aggregate (1 and 2).

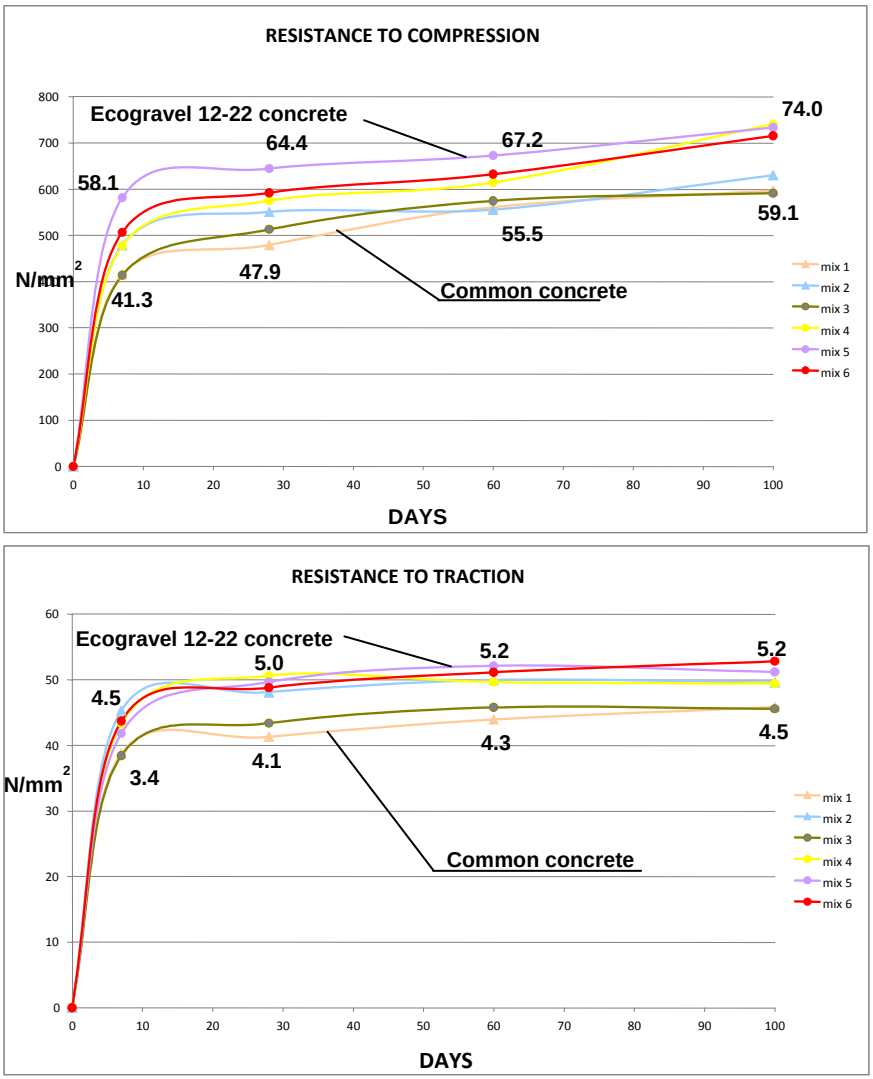


Figure 13. Ecogravel® Resistance

Ecogravel® complies with the European standards EN 12620: "*Aggregates for concrete*" and EN 13242 "*Aggregates for unbound materials and materials bound with hydraulic binders for use in civil works and road construction*".
Ecogravel® concrete is used mainly for the bearing layers of roads and large transit, parking or deposit areas, surfaces which require high mechanical characteristics in terms of capacity and resistance over time. In this case as well, Ecogravel® has shown that its characteristics allow it to be used with excellent results as an industrial aggregate for concrete.
Various precast articles made of concrete can be manufactured using Ecogravel®. The most popular products are wells for sewer systems and other products to be installed underground.

4 DISCUSSION

4.1 Plant Revenues

A plant recovering EAF slag has two flows of revenues deriving from the sale of the Ecogravel® and scrap. When the recovered scrap is used in the same meltshop that

produces the slag, as usually happens, instead of sale revenue there is a saving in the purchasing of this primary raw material.
Many electric steelmakers pay substantial disposal fees for having the slag transported and disposed at a permitted landfill, thus there is an avoided cost amounting to the entire disposal fee.
For an Italian steel meltshop producing one million tonnes of steel per year, and 120,000 tonnes of EAF slag, the expected revenues are as in Table 2 (all amounts are indicative only).

Table 2. Ecogravel® Feasibility Study

Product	Tonnes per Year	Price/Cost per Tonne	Revenues per Year
Aggregate	116,000	€ 5.00	€ 580,000
Steel scrap	4,000	€ 250.00	€ 1,000,000
Avoided cost of slag disposal	120,000	€ 22.00	€ 2,640,000
TOTAL REVENUES AND SAVINGS			€ 4,220,000

4.2 Ecogravel® Service - Full Service Management of Secondary Materials in the Meltshop

A turnkey global service of management and handling secondary materials in the meltshop through men and equipment.

Figure 14. Slag Management and Handling

5 CONCLUSIONS

The slag recovery plant is environment friendly, due to the following reasons:

- EAF slag is recovered for beneficial uses and no solid waste is generated, thus the landfill diversion rate amounts to 100%;
- The product of the plant replaces natural aggregate and therefore the plant operation contributes to saving natural resources;
- Ferrous material, which otherwise would be wasted, is also recovered from the slag and used for the production of steel;
- The plant has no negative impact on the environment, because the emission of dust and noise are negligible.

It takes only common sense to understand that EAF /BOF slag, regardless of its waste classification and current disposal cost, cannot be piled up for ever in the backyard, because the accumulation of waste is associated with the assumption of liability. The material recovery option must always be preferred to landfill disposal.

Environmental sustainability alone cannot be the only driving factor when an industrial enterprise has to invest in waste recycling equipment, but slag recovery is also economically feasible, because it allows for cancelling disposal cost, saving on the procurement of scrap and it generates revenues from the sale of Ecogravel®.

Based on the above considerations, the plant is very attractive, in fact it can turn a bulky environmental problem into a business opportunity.