A REVIEW ON RECYCLING OF REFRACTORIES FOR THE IRON AND STEEL INDUSTRY

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ABSTRACT: This paper reviwes the efforts of the steelmaking and refractory industries to increase reuse and recycling of spent refractories. After an introduction to the problem, cases from Europe, Asia, North America and Latin America are presented.

KEY WORDS: Refractories; Reuse; Recycling

INTRODUCTION. Refractory materials are essential for the production of iron and steel. They are used in the direct reduction modules, coke oven batteries, blast furnaces, hot metal transport and pretreatment, oxygen converters, electric furnaces, steel ladles, recirculation degassers, tundish, casting systems, reheating furnaces, heat treatment units and other downstream equipment. Global demand for refractory materials has been estimated in 46 Mt for the year 2016. The steel industry consumes about two-thirds by weight of refractory production. It is estimated that the refractory material remaining after use is 30% of the material applied. This means that around 9 millions tons of spent refractories per annum are available for recycling or land refilling.

Taking the second half of the twentieth century as a parameter, while steel production quadrupled, the total consumption of refractories fell by half. This has been influenced by the adoption of new processes for the production of steel and improvements in the quality of refractories and application technologies. The generation of millions of tons of refractory waste materials is a major challenge for the environmental performance of the steel and the refractories industries. The adoption of recycling practices, due to their complexity, is site-specific. Experience has shown that strong internal or external incentives are required for them to be put into practice. This paper discusses the current characteristics of the recycling of refractory materials for steel use and presents various successful experiences of recycling in steel companies of Europe, Asia, the USA. and Latin America.

The steel industry consumes mostly magnesitic, dolomitic and silico-aluminous refractories. There is a great variety of types, manufacturing ways, vessels or furnaces to be lined, and broad scope of operating practices. All this makes recycling a complex issue [1]. During use, part of the material is dissolved in slag, hot metal and steel. After use, the remains may be recycled internally or externally, or may be deposited. For instance, in Europe this distribution was determined by means of a mass balance (Tab. 1).

Tab. 1. Distribution of refractory material after use in the European steel industry [2].

Destination of refractories	Share
Dissolution in hot metal, steel or slags	33 %
Internal recycling	25 %
External recycling	37 %
Landfilling	5 %

Internal recycling may imply the use of the waste refractory within the steel plant. For instance, as a slag conditioner in the blast furnace, BOF or EAF. External recycling means that waste refractory is sent back to the refractory plant or to specialized recyclers. Landfilling refers to material being sent to deposit directly by the steel industry.

It is considered that bricks are easier to recycle than monolithics. Monolithics are more prone to contamination; they present difficulties in beneficiation, they may not be fully burnt, they may have large size (complicating trituration) and may have anchors. But at the same time, production of monolithics is the main exit for recycling of recovered refractories. The design criteria of refractories is managed in order to obtain maximum performance; aptitude for recycling is not taken into account [1].

To implement a recycling program, an assessment of type and amount of refractories entering to the plant must be carried out, including the areas where they are employed, current practices for disposal, and corresponding cost. Options for reuse or disposal should be considered, as well as process changes that could achieve a decrease in the material waste. This assessment should be carried out following these priorities: 1) reduction of consumption; 2) internal reuse; 3) external reuse; 4) treatment; 5) landfilling.

The largest consumption of refractories corresponds to steel ladle and BOF lining, as well as blast furnace / cathouse. In Fig. 1 the distribution per equipment is presented, for European integrated mills.

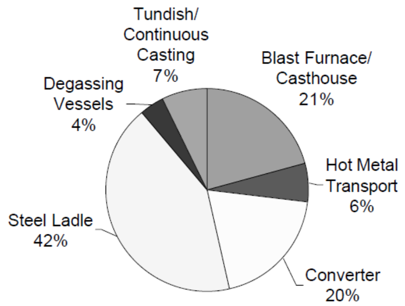

Fig. 1. Percent distribution of refractory consumption in different iron & steelmaking equipment, for the integrated European mills [2].

In Tab. 2, a summary of recycling path for the different iron and steelmaking process units is presented, based mostly on the European experience. Regarding recycling as slag conditioner, several projects have been developed. For example, the one carried out by the Albany Research Center and the Steel manufacturers Association in the USA [3], oriented to obtain a model of EAF slag saturation, to adequately control content and type of solids precipitated in the slag at working temperature, a factor that matters to achieve slag foaming.

In the following, some recycling cases from Europe, Asia, North and Latin America are commented.

EUROPEAN CASES. Among the specific cases published, it is worth to mention the Swerea MEFOS project [4]. SSAB Lulea used ground and sized MgO-C converter bricks (5-25 mm) as a partial substitute of calcined dolomite. The charging was of 300 kg per heat, in big-bag, together with the scrap charge. 600 kg dolomite were saved; lime was added to replace lost CaO. There were no difference in slag and steel chemistry and metallic yield.

Another case in Swerea MEFOS program was in CELSA Armeringsstål, Norway. It is an EAF-based plant, producing rebar. Norsk Ildfast Resirk (NIR). In this case, dolomitic ladle bricks were recycled as slag formers in the EAF. NIR is located close to the plant, and prepares the bricks through crushing, magnetic separation and screening. 1.000 tpa are treated, returning to CELSA's silos for further charging in the EAF [4].

Tab. 2. Recycling path for the different iron and steelmaking process units.

Iron-making	Coke plant	Reuse of silica bricks for ceramic welding
	Blast furnace stoves	Most of the refractories may be recovered and reused in the refractories industry relatively easy
	Blast furnace	Furnace lining endure 20 years, with intermediate repair; most of the refractories are incorporated to the slag; the taphole material is consumed with the use; most of BF through is eliminated with the slag
	Hot metal transportation	High alumina torpedo car lining life extended from 400 to 1,200 heats in last two decades; recyclable as slag ladle addition
Steel-making	BOFs	Longer lining life. Up to 60% is dissolved in the slag; 20% recycled as BOF refractories; 20% recycled as ladle slag addition
	EAFs	Reutilize in part in the EAF or ladle, for EAF slag or for concrete
	Ladles	Most of the lining dissolves in the slag; some part is recycled in the refractory industry (MgO-C bricks) and other part (dolomitic bricks, non-shaped Al_2O_3) is recycled for furnace or ladle slag, or as a flux in the blast furnace, or in other industries
	RH	$MgO\text{-}Cr_2O_3$ refractories with limitations for reuse or recycling; use as gunning material
	Caster	Repair and reuse of slide gate plates, or use as filling sand; recycling of shrouds, stopper rods and SEN for ladle slag or concrete

Two Italian plants equipped for refractories recycling are Ferriere Nord [5] and Stefana [6]. Both are electric meltshops producing steel for rebar and wire rod. In both cases, spent refractories are recycled together with ladle slag (Fig. 2). Refractories come from dolomitic ladle lining, tundish lining and EAF hearth. EAF bricks are recycled in the refractory industry. Both in Ferriere Nord and Stefana there are special injectors for the introductions of the mix ladle slag / refractories in the EAF.

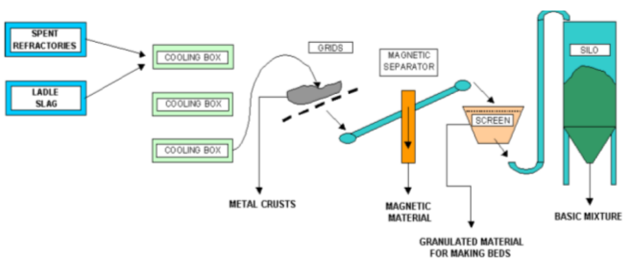

Fig. 2. Layout of equipment for recycling of steel and slag in the EAF at Ferriere Nord [5].

ASIAN CASES. This problem was early tackled in Japan, due to the space restrictions for landfilling. The experience of Daido Steel in Chita has been published [7]. This is a special steel plant, producing 1.7 Mta at the time of the publication. The plant uses EAFs for melting, and AOD, LF and RH degassers for steel refining. 70% of the steel is continuously cast and 30% is ingot cast. Monthly, 900 t of spent refractories are generated, of which 650 are recyclable (their composition is known, not having relevant mix or contamination). Some of the recyclable refractories are used as they are, while others are process for crushing and composition adjustment.

Two of the "as such" uses are addition to ladle slag and EAF slag. For ladle slag, the addition was 3 kg/t. This addition made possible a decrease in fluorspar consumption and the elimination of dolomitic lime addition, but the lime addition had to be increased (Fig. 3). Regarding slag attack on slag line refractories and desulfurization refractories, results were comparable to those without recycling.

For the dolomitic bricks of AOD lining a use was found as flux for slag formation in the EAF, without changes in Cr_2O_3 in the slag, a key factor in the economy of this process. The upper plates of ladle slide gates are repaired by working of the hot face and introduction of an insert in the worn hole, and reused. MgO-C and MgO bricks of some zones of the EAF with lower heat load are recirculated in the same furnace, after elimination of slag and metal adhesions. Finally, with the tundish working lining magnesitic concrete is prepared, and with spent ladle porous plugs, aluminous casTab. is prepared. Both are employed in steel ladles, in non-critical zones (Fig. 4). With these actions, 58% of internal recirculation of refractories is achieved.

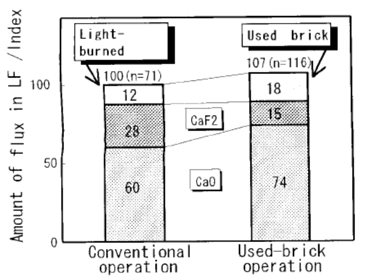

Fig. 3. Flux consumption in the ladle furnace, for conventional operation and operation with spent refractories [7]. n: number of heats.

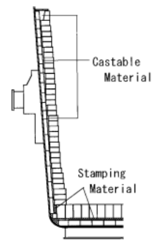

Fig. 4. Daido Steel Chita plant ladle: use of recycled refractories and casTab. [7].

Another interesting case is that of Nippon Steel & Sumitomo Metals Corporation. With base in the aim of totally eliminate residues, through the three R approach (Reduce, Reuse, Recycle), a project was developed from 2001 to 2005, focused in the recycling of refractories. The recycling starts with the classification of the materials in several categories: MgO, Al_2O_3, refractories with C, refractories without C, etc.. The classified refractories may be divided in different types, and slag and metal needs to be separated. They are crushed into lumps of 200 - 400 mm; then, a new hand and magnetic separation is carried out.

NSSMC adopted the magnetic suspension separation system to remove iron. There are two types, one for small lumps and other for large lumps, or when the separation process is long. To define the required power, a definite amount of 5-10 mm iron lumps was mixed with ladle refractory lumps of the same dimension. They we re subjected to magnetic separation, varying the power. Total iron was decreased to 2% or less with a magnetic force of 12,000 Gauss or more [8]. Each NSSMC plant adopted a system type, according to its operating conditions and the refractory type processed [8].

For slag separation, a system used in the food industry to separate foreign material from grains or beans, was introduced, based in differentiation by color. The system uses compressed air to classify materials with a strong contrast between white and black. This system is particularly effective to remove pig iron, steel or slag. Of dark colors, from aluminous lumps, of light color (Fig. 5). In the next step, the material to be recycled is crushed to obtain a size of less than 20 mm. According to type and size, impact, compression or shear energy is employed (Fig. 6).

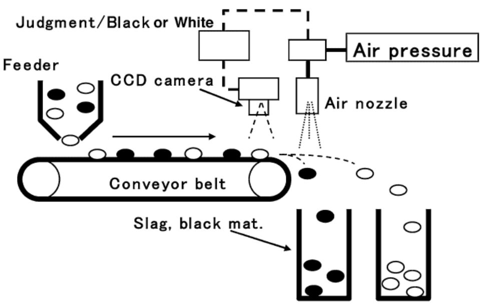

Fig. 5. Scheme of the system for slag and metal removal by color [8].

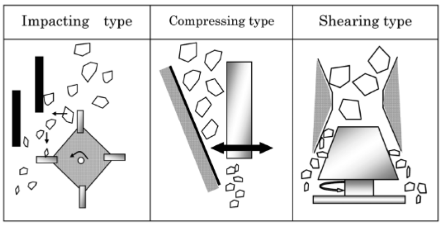

Fig. 6. Equipment for crushing the spent refractories, depending on material type and aimed size [8].

For separation into predetermined size fractions, standard systems of screens with simultaneous horizontal and vertical vibrators are available. A critical problem is dust generation in the different process steps. All the equipment is covered to prevent emissions; there is a system for dust collection.

Once crushed, the materials are temporarily stored. When added on-site to monolithic refractories, previous drying is not necessary. But those used for instance for hot repairing, are dry mixed and stored in a tank for the hot repair machine. If the material to be recycled were humid, there will be risk of hardening reactions in the waiting time before use. Because of this, a kiln is employed for drying the material to be recycled, before mixing [8]. Management of size is as follows: the larger fraction corresponds to the recycled material (Fig. 7). For concrete, depending on application, 5-20 mm or 1-5 mm are employed. For humid gunning material 1-5 mm is applied; instead, for dry gunning, <1 mm is added.

As the proportion of recycled material increases, in case of concrete, more water is required and the material obtained is more porous, with less resistance to wear. This brings to determine a maximum content of recycled material, that seems to be around 20%. As when the recycling is repeated, the percentage of impurities is larger, a criteria is followed of recycling for less demanding applications (*one rank down*).

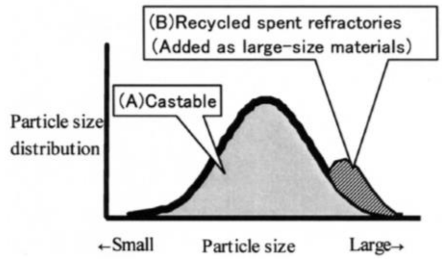

Fig. 7. Concept of addition of recycled material to refractory concrete [8].

In Fig. 8 the evolution of refractories recycling from 2001, when the company started the project, to 2005, when it was completed in Muroran, Kimitsu, Nagoya, Yawata and Oita. Landfilling of refractories was eliminates, and utilization for pavement was reduced. As can be deduced from the description of the installations, for this result a heavy investment in equipment was necessary.

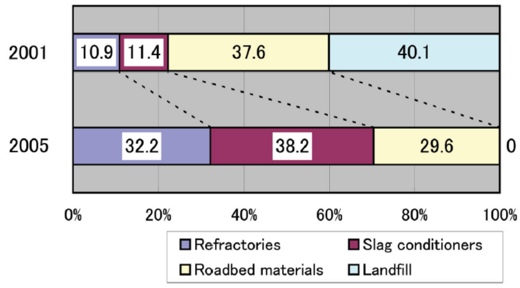

Fig. 8. Evolution of destination of spent refractories in Nippon Steel plants, between 2001 and 2005 [8].

The Chinese steel industry, given its huge production volume, has a big challenge in this issue. BaoSteel has given some steps. For many years, they recycled $MgO-Cr_2O_3$ bricks from RH lining for gunning material for repairing of the same equipment, in a proportion of 20% [9].

USA CASES. The Department of Energy, jointly with the Steel Manufacturers Association and twenty steelmaking and refractories companies, have developed a research focused in the use of spent MgO-C breaks as slag modifiers in electric arc furnaces [1]. Although several service companies tried this recycling way in the USA, in many cases the practice was discontinued due to problems with dust suppression. The material should be fine enough to dissolve easily in the slag, but no so fine that it could be dragged by the dust collection system, modifying dust chemistry and decreasing its value, given by the zinc oxide content.

Several refractory recycling schemes have been surveyed in the American industry [1]. In Fig. 9 the cases of an integrated plant and a scrap based EAF plant are presented. In this last case there are fewer recycling options. In this market, some companies specializing in refractory recycling are operating, as for instance Maryland Refractories Co.

LATIN AMERICAN CASES. The situation is influenced by market characteristics. In segments where refractory producers and users are fragmented in medium and small companies, services has been created to concentrate and classify spent refractories for further derivation for reutilization. In segments where both refractory producers and users are large companies, the recycling is more straight, being part of the service offered by the refractories suppliers [10].

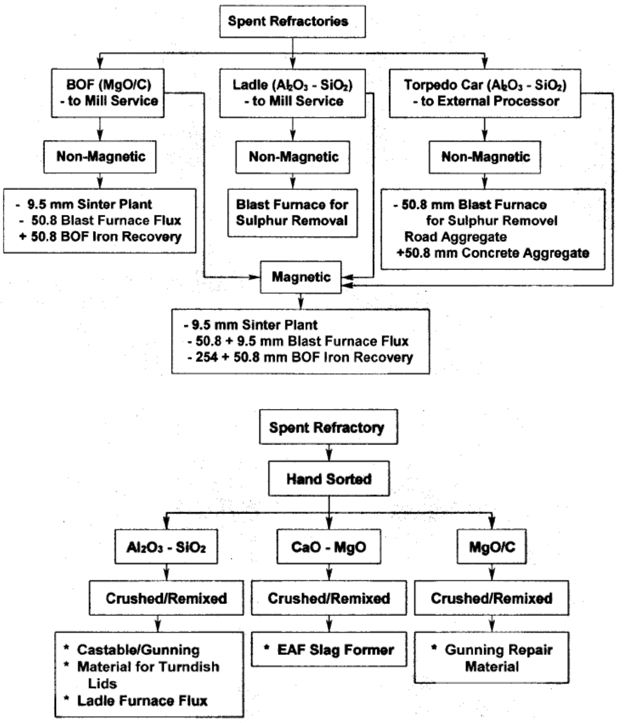

Fig. 9. Flow diagrams of refractory recycling at unidentified American steel plants. Top: integrated mill. Bottom: minimill [1].

The larger steel producer, Brazil, has a specific refractory consumption that has been estimated in 8.4 kg/t by the year 2004 [11]. In this country, integrated plants dominate production (76%). In Fig. 10, the distribution of spent refractories by chemical features or function is presented, for both integrated and electric plants [12]. Some of the routes adopted in Brazil for reuse or recycling of refractories are summarized in Tab. 3.

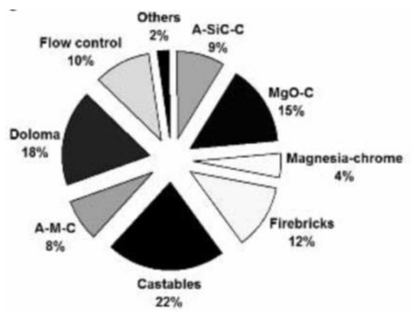

Fig. 10. Distribution of steelmaking and ironmaking refractories by function or chemistry, for integrated mills and minimills of Brazil [12].

Among the experiences of other Latin American countries, that of ArcelorMittal Lazaro Cardenas have had big diffusion. They recycle crushed MgO-C bricks form the four EAFs in one of them [13]. At the time of implementation, 5,000 tpa of spent refractories were generated (EAFs 1,200 t; ladle 3,800 t). The aluminous ladle bottom is separated manually and not recycled. The magnesitic material is crushed to less than 3 mm. Up to one t is charged together with DRI, coke and lime, through the fifth hole, in the first minutes of the melt. The benefit, after discounting 0.12 USD/t for material preparation, is 1.25 USD/t [13]

Tab. 3. Reuse and recycling of some types of spent refractories in Brazil [12].

Refractory type	Origin	Utilization
Dolomite	Steel ladle in electric meltshop	Hydration and disintegration when cooling in contact with air humidity. This complicates separation of slag line MgO-C bricks. Internal recycling as slag conditioner. External use as pavement base or inert for concrete (previous mixing with slag for stabilization).
Magnesia-carbon	BOF and ladle slag line	Slag conditioner for BOF or additive for slag foaming in EAF, due to basicity and carbon content
Magnesia-chrome	RH / VOD	Recycling by electromelting; high cost, but it guarantees removal of impurities and grain regeneration
Chamotte concrete and bricks	All areas	Very heterogeneous and contaminated. Complicated (at times impossible) separation and classification. Recycled in lower quality concrete for pavement blocks

CONCLUSIONS. There is a growing interest in reuse and internal/external recycling of refractories spent in the iron and steel industry, driven by regulatory and economical aspects. There are companies that achieved full elimination of landfilling in own or third party land. The steps in this direction require investment to succeed and to continue along time.

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