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The Link Between Refractories, Slag, and Steel in Ferrous Metallurgy

Refractories are an important constituent of the overall production cost for semifinished steel products, accounting for almost 4% of the cost. Due to the direct contact between the steel melt and the refractories the balance and influence of interactions taking place between the metal, slag, and refractories are constantly targeted to improve steel product quality. Furthermore, the subject of refractory maintenance is also a focus in cases where productivity is limited by the lining life of the metallurgical reactors. This is due to the fact that relining or even refractory maintenance is a nonproductive time in the production process. The complicated triangular relationship is completed by the unavoidable presence of metallurgical slag. Steel quality is processed by reduction and refining oxide components containing iron. Therefore, the accompanying elements and the slag forming agents are also affected. The desired process is that nonuseful elements or components are molten or oxidized into slag. An additional function of the slag is the adsorption of the steel deoxidation products and undesirable elements including phosphorus and sulphur. Furthermore, the slag has an insulating function against heat losses by convection and radiation. Refractories function to avoid the metallurgical vessel body shells from melting. In addition, they are designed to guarantee flow control of liquid steel from one vessel to the other. A further important design function is the prevention of steel melt reoxidation by air. However, refractories are sensitive to mechanical erosion, chemical attack, and thermal shock stresses and as a result of these mechanisms wear is a common effect. Metallurgy is the discipline of avoiding steel contamination by emulsified slag or refractory particles. Where avoiding contaminant formation is not possible techniques to separate the nonmetallic inclusions from the liquid steel have been established and when avoiding and separation are not an option inclusion shape control is a common metallurgical technique to prevent steel product failure during use.

Introduction

Refractories are nonreplaceable in steelmaking, although the acceptance of refractories as a high quality product varies in the worldwide view of the steelmaking industry. Those plants who are consistently committed to increasing their productivity and quality levels are aware of the three-dimensional relation of steel-slag-refractories-(alloys) and consider these issues while optimizing their processes. They investigate the material capacities of the various available refractories to influence their process efficiency and the refractories are integral in the metallurgy. However, for those steelmakers who are mainly in the business of construction materials for buildings, cost competition, and logistic problems are the main focus. Since the quality demands on these products compared to other steel types are rather low, these steelmakers try to decrease their costs by classic purchasing methods used to purchase commodities worldwide. These two different philosophies cause a permanent contradiction in the customer relation to the refractory industry. In one situation the valuable, high-end refractory products are permanently evaluated for their quality and safety aspects by one half of the steelmakers, and in the other refractories are dealt with as essential commodities for steelmaking.

Steel Production

In 2006 more than 1.0 billion tonnes of crude steel were produced worldwide and the boom that started in 2000 is still ongoing. The worldwide growth in production and consumption is at an average of 5–6% per year [1]. The regional analysis of the growth, detailed in Figure 1, indicates that this development is a regional phenomena. China, the other Asian countries (mainly India), and the former USSR countries (CIS) are driving the steel production increase and almost doubled their production in the last 5 years.

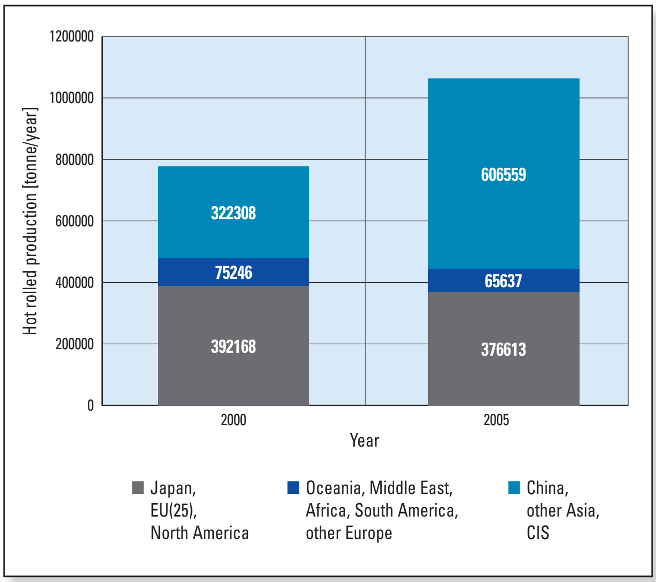

Figure 1. *Regional steel production growth [2].*

In all other regions of the world, for example the European Union (25), the USA, and Japan steel production is static or decreasing due to restructuring effects or overcapacity reductions. In the emergent nations like Africa, Oceania, the Middle East, and South America the output is stable or slightly decreasing. An in-depth analysis of the figures indicates that steel production and the demand for steel products are globally balanced. In the static countries of the world and in the CIS an export surplus exists, and in the growth regions production and demand is almost balanced. Today, China is on the turnaround between import and export, but the overall Asian demand and the demand in the emergent regions sucks the export surplus from the market.

A study of steel production growth in terms of products [1] indicates the overall production of long and flat products is increasing at a similar level (Table I). This effect is very interesting because typically the capacity of long product steelmakers is only between 10–45% the maximum capacity of integrated mills for flat products. Namely, in the global growth regions a large number of new competitors are entering the regional steel market with facilities principally designed for the production of steel for construction applications at the low quality end of the steel product market. Production increases in the flat steel market sector are achieved by enlarging existing capacities or implementing new technologies, including thin slab casting/rolling mills. The target of these steelmakers is the high quality end. The consequence of this situation for the refractory producers will be addressed in the following sections.

Basically, the consumption of refractories will increase in parallel with the steel production growth, which will provide the opportunity for the refractory industry to expand with their existing customers. However, these customers will only represent the smaller portion of the total growth. They produce high value added steel products with a higher monetary value, based on the higher production effort (i.e., high quality raw materials, expensive primary energy, and a high quality working force). These customers consider refractories as a substantial element for steelmaking, guaranteeing production safety, high productivity, and high steel quality. Their relation to the refractory suppliers is based on the principle of long-term partnership. Since these companies recognize that their growth in the industrialized regions is strictly limited, they move forward by adding new capacities in emergent regions or allied in strategic mergers.

In the regions with an increasing steel demand, new steelmakers are entering the market or obsolete plants are being modernized and converted that are producing steel products at the low quality end of the market. As a result the market price for the product is lower and the cost competition is higher. The search for cost reduction is essential for these plants' survival and purchase savings are a typical solution. Since they produce at a commodity level they consider refractories in a similar manner. Whilst refractories are essential for liquid steel production and cannot be replaced, there are a lot of refractory producers worldwide and the steelmakers believe they can reduce costs by selecting an alternative. They often use the benchmark tool to decrease their purchase volume, although the process conditions in the benchmarked sites are not comparable. With this type of customer issues regarding safety, availability, reliability, productivity, and quality are difficult to discuss because the steel products in these cases do not require these characteristics. To supply this type of customer the refractory industry must have cheap and simple to handle products in their portfolio. However, this type of customer is open to the full line service option, an outsourcing concept operated by refractory suppliers.

Hot rolled steel product	Production		Product applications
	2005 %	Growth (2000-2005) %	
Heavy plates	3.7	3.9	Shipbuilding, bridges, large diameter tubes, gas tanks, construction
Hot rolled strip for direct use	15.5	17.7	Automotive, containers, railway wagons, farm goods, wheels
Cold rolled strip for direct use	10.2	10.7	Automotive, household goods, containers, laminations
Electrical sheet and strip	0.9	0.8	Electric motors, transformers
Tin mill products	1.2	-1.8	Cans, packages, perishable goods
Metallic coated sheet and strip	9.3	4.7	Automotive, panels, crash barriers, appliances
Nonmetallic coated sheet and strip	1.0	1.5	Panels, appliance and architectural applications, bathtubs
Tubes and tube fittings	8.2	10.5	Drilling equipment, construction, hydroforming
Welded tubes	5.0	3.6	Automotive systems, cylinders, offshore, construction
Total flat products	54.9	51.5	
Railway track material	0.8	1.0	Railway tracks
Heavy sections (> 80 mm)	2.8	-0.8	Buildings
Light sections (< 80 mm)	4.5	-12.0	Mining, construction
Concrete reinforcing bars	12.0	35.9	Buildings
Hot rolled merchant bars	10.0	13.8	Construction, profiles, drilling equipment, car springs, forgings
Wire rod	12.7	9.2	Tyres, springs, ropes, wire, electrodes, screws, nails
Seamless tubes	2.4	1.3	Offshore, boilers, automotive, hydraulic cylinders, buildings
Total long products	45.1	48.5	

Table I. *Steel production growth by products [2]. Total hot rolled product growth from 2000 to 2005 was 32.8%.*

Cost Structure in Steelmaking

The cost structure for the two main modern steelmaking production routes is depicted in Figure 2. The comparison illustrates clearly that the costs for steelmaking are dominated by the costs of raw materials, which are scrap in the case of the electric arc furnace (EAF) route and scrap and hot metal for the basic oxygen furnace (BOF) route. The raw material costs for electrical steelmaking are approximately 10% lower than for BOF steelmaking. However, this advantage is counteracted by the higher electrical energy requirement and the lower Fe yield caused by the scrap quality, thereby the overall costs for the semifinished products are almost on the same level today. The refractory costs account for 2.0% in the EAF route and 3.4% in the BOF route. By taking only the conversion costs into account the share of refractories increases up to 5.2% and 11.3%, respectively. The difference in refractory consumption in the principal steelmaking routes is understandable due to the aforementioned product quality issues. The difference in market prices for long and flat products is approximately 100 €/tonne (Table II) [1]. The comparison indicates the market prices for the semifinished products are almost comparable, but that market prices for high quality flat products are significantly higher than for rolled long products.

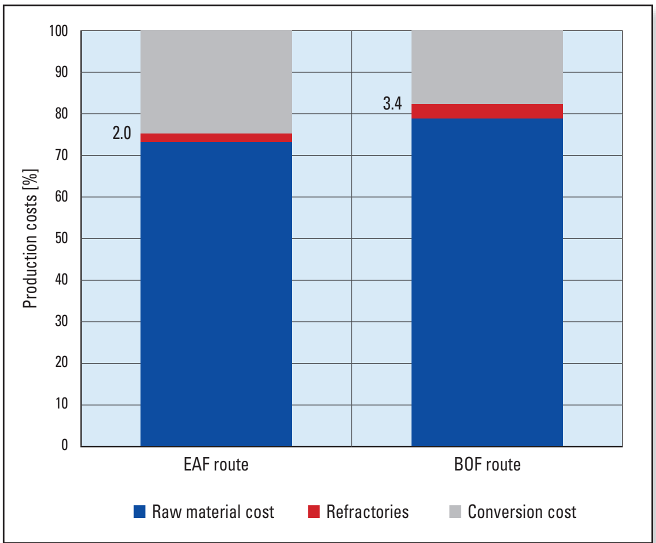

Figure 2. Cost structure of steel production routes.

Product type		Price level [U$/tonne]			
		Average	Domestic	Import	Export
Long products	Billets	516		530	508
	Rebars	527	598	585	556
	Wire rod	554	542	578	550
	Sections	679	761		625
Flat products	Slabs	466		470	466
	HR plates	616	721	590	565
	HRC	560	596	565	543
	CRC	630	688	613	608
	HDG	805	819	825	790

Table II. Price structure for steel products [1]. Abbreviations include hot rolled (HR), hot rolled coil (HRC), cold rolled coil (CRC), and hot-dipped galvanized (HDG).

Specific Refractory Consumption Developments

The specific refractory consumption developments in steelmaking, detailed for Japanese mills in Figure 3, demonstrate that the refractory industry as a partner to the steelmaking industry has always accompanied the request for lower costs and more efficient use of resources by the steelmaking industry. In 1970, the total specific refractory consumption for steelmaking was 30 kg/tonne, and was reduced by the consequent developments of product quality, installation and maintenance techniques, and equipment to 10kg/tonne on average and even lower. The savings regarding energy consumption and CO_2 emission reduction are sustainable.

An additional benefit for refractory consumers is the shift between shaped and unshaped products in the total specific refractory consumption for steelmaking. This effect was supported by the refractory industry with the introduction of new techniques and machines for the efficient use of unshaped materials. The advantage for the customer is in this case a disadvantage for the supplier since the product identities are changed from shaped special products to unshaped commodity products.

Globally, specific refractory consumption is nonuniform. Compared to the average of 10 kg/tonnes, Japan and China as the major steelmaking countries are significantly lower [3]. Other regions of the world are still on their way to improvement, which is mainly caused by a lower structural and technological steelmaking standard, as illustrated in Figure 4. However, this comparison is only a general

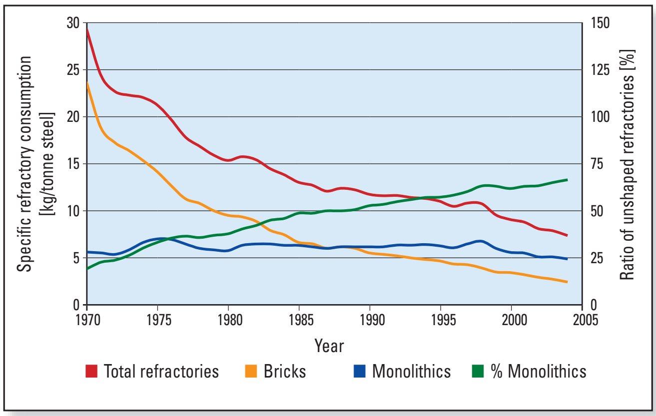

Figure 3. Specific refractory consumption in iron and steelmaking in Japan [3].

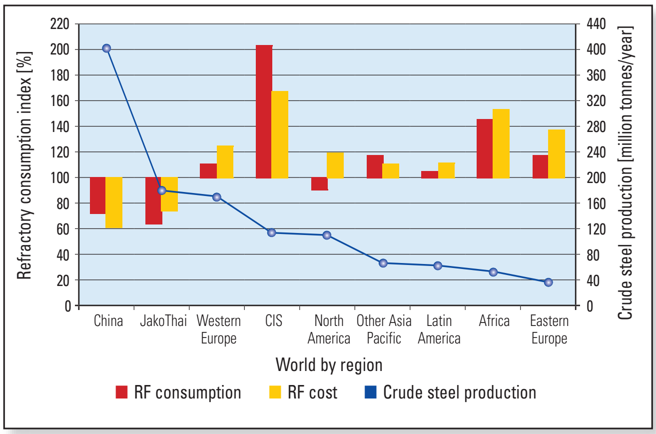

Figure 4. Refractory consumption by world regions [1].

approach to describe the rules of the world refractory market because the refractory consumption of each plant is very individual and dependent on the specific vessels installed and the production programme. An example of this situation can be seen in countries of the former USSR (CIS). In these countries many old production facilities are operated at a low productivity level that results in a high refractory consumption typical of the standard operation in the 1970s. However, the majority of steelmaking companies are on their way to modernization so it can be expected that within a period of 3–5 years the technical standard will achieve that of middle Europe and this will reduce the refractory consumption. If the level becomes similar to that in China or the current average level remains to be seen.

State of the Art in Steelmaking

The continuously increasing demands on steel product capacities, the permanent pressure of the steel consumers for lower raw material consumption, and steady requests for cost decrease and productivity increase, driven by the worldwide competition, have revolutionized steelmaking technologies in the last 30 years [4]. Whilst the steelmaking technology of the 1970s focused on the sequence of melting, homogenizing, and casting units, today there are additional treatment steps integrated in metallurgical processing (Figure 5). These steps include desulphurization, vacuum degassing, heating, inclusion modification, and cleanliness treatment. As a consequence more treatment steps in metallurgical processing require additional melt superheats, which must be carefully combined with metallurgical slag modifications, and result in additional remaining time in the metallurgical reactors. Furthermore these effects cause additional stress on the metallurgical reactor linings. The challenge is for refractories to withstand this additional stress by introducing special and demand designed products for customers.

The challenge for the refractory industry is to optimize economical aspects in parallel with the increasing demand of high quality steelmaking applications. Since refractories have a major influence on the steel chemistry [5], due to the interactions between steel and the necessary additives for steelmaking (Figure 6), they are a focus of metallurgy. Today, the alloying of certain elements is typically controlled. The continually increasing demands on steel grades require increasing limitation of nontolerated elements in the steel melts. The metallurgical task becomes increasingly detective work, where the requirement is to determine differences in the final result and trace them back to the origins and develop preventive steps to avoid pick up.

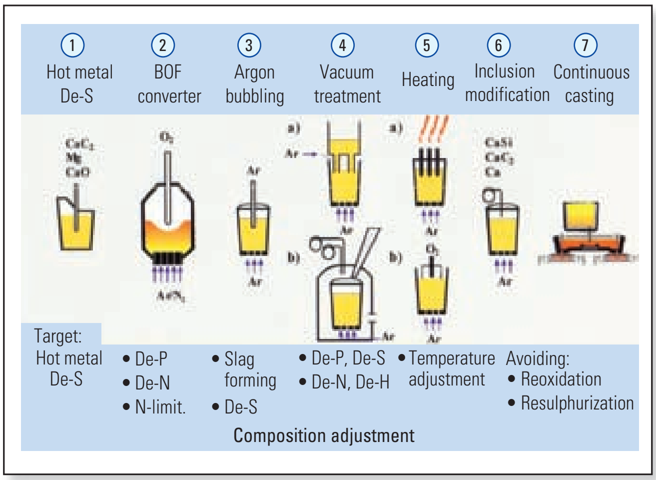

Figure 5. *State of the art in metallurgical processing [4].*

Another very important target of metallurgical operations is to limit the nonmetallic inclusion (NMI) content in the melt in addition to increasing steel cleanliness (Figure 7). NMIs weaken the steel microstructure and cause failures by cracking, breaking, or surface damage [6]. Refractories during casting, together with casting powder and fluxes, are the last materials to be in contact with the solidifying steel. It is well-known that refractories dissolve during metallurgical processing. The important question is where the dissolved microscopic refractory particles are finally deposited or to develop a technical solution to settle out the small nonmetallic particles in the tundish or the mould slag. In applications where the steel product requires additional attention to nonmetallic contamination, steelmakers have developed techniques to modify the inclusion morphology by injecting metallic wires, altering the deoxidation practice, or changing the slag composition during refining.

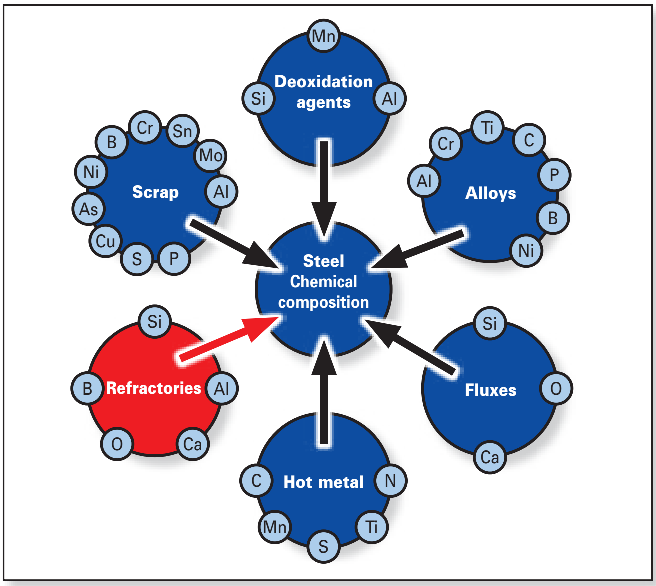

Figure 6. *Effects on the chemical composition of steel products [5].*

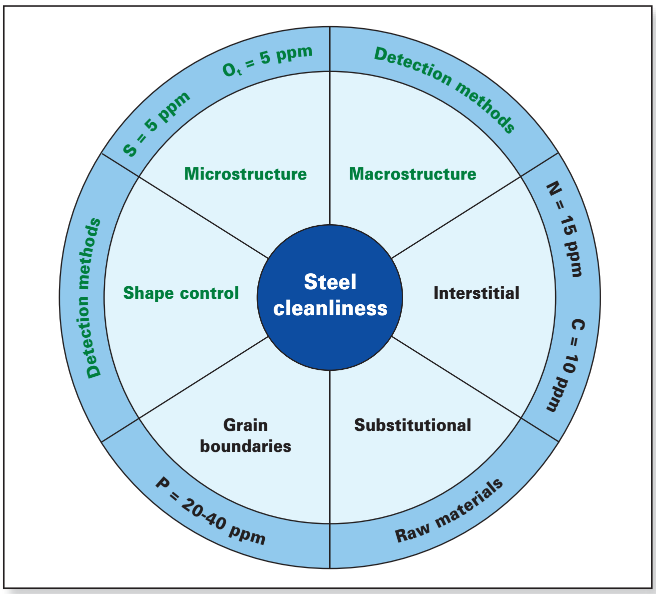

Figure 7. *Effects on the steel product cleanliness [6].*

Refractory Design Aspects

The refractory producer is aware of the capabilities and limits of his products and through direct contact with the steelmaker modifies his products continuously to the customers requirements (Figure 8). For this tailored approach not only the knowledge of the stress factors caused by the melt and the slag are important, but additionally major design influences are indirect stress factors including [7,8]:

- >> Hot and cold cycle logisitics.
- >> Maintenance conditions of the steel shells.
- >> Scheduled repair and break down frequency.
- >> Availability of manpower and machine time for relining and maintenance work.

Namely, for the design of an optimum refractory concept a fundamental knowledge of the individual steelmaking processes is essential. This design process requires a confidential partnership between the involved parties that is based on a mutual target. The partnership today is more important than in the past because the introduction of secondary metallurgy has changed metallurgical processing significantly and the role of common vessels has been redefined.

Melting Unit

Today, the role of the melting unit in the metallurgical chain is to guarantee the availability of liquid steel with the correct composition and the appropriate superheat for the continuous casting sequence (Figure 9). The process operates under oxidizing conditions, namely the process energy is generated by the oxidation of silicon, manganese, and carbon, as well as iron, phosphorus, and titanium. A desired additional benefit of the strong boiling reaction is a decreased nitrogen content in the melt, originating from the hot metal charge, and inhibition of nitrogen pick up during oxygen blowing. By using argon supplied through bottom purging elements the equilibrium content of oxygen and carbon can be lowered to levels only possible by vacuum treatment under normal conditions and homogeneity of the melt at turndown is guaranteed.

It should be highlighted that the process targets of the melting units are defined differently in the various global regions. For example, in Japan it is a common technique to separate the stages of dephosphorization, desiliconization, and lowering the manganese content in the melt from decarburization. Hot metal desulphurization is obligatory. In Japan a two step melting process is established for raw steelmaking, which enables a certain freedom in hot metal quality requirements. In middle European facilities another process alternative was established. In the case of the integrated BOF plants, quality is the focus at the hot metal stage. By selecting the raw materials for the blast furnace (BF) the hot metal burden is adjusted to a low phosphorus and manganese content. Hot metal desulphurization is obligatory and in addition the lowest content of the aforementioned elements is achieved in a one-step process. In other regions of the world the steelmakers try to reduce their costs by using local raw material sources, an approach that was abandoned in Europe 30 years ago. However, these diametral targets always cause extreme process conditions in individual plants, which have to be taken into account while designing the individual refractory concept.

Since refractory relining or maintenance in most steel plants is related to a significant reduction in production capacity, engineers in steelmaking strive to increase the lining life. Today, a number of successful maintenance techniques have been introduced on an industrial scale to prolong the campaign duration of melting units including:

- >> Gunning
- >> Coating
- >> Slag splashing
- >> Patching
- >> Slag metallurgy

Using these methods campaign results between 2500 and 35000 heats have been achieved worldwide. The wide ranging results indicate that more than the main targets of the campaign life increase must be taken into consideration and that there is a significant local influence. Relevant factors include:

- >> Maintenance refractory consumption.
- >> Time requirement for maintenance.
- >> Consumption of fluxing agents.

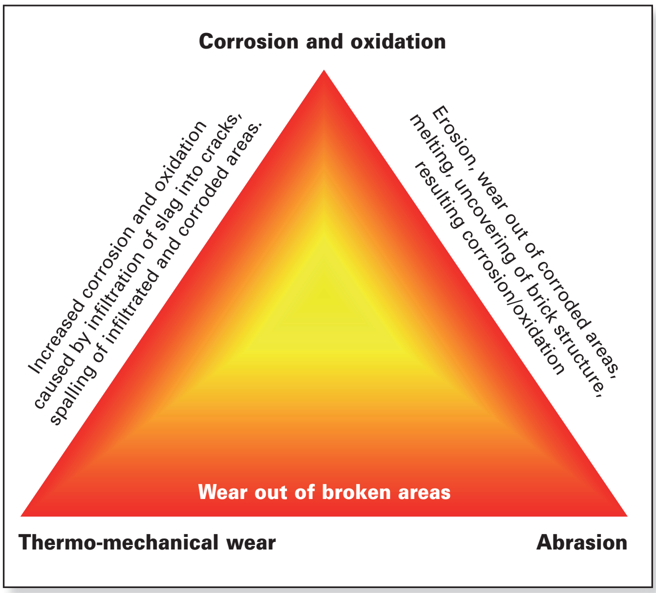

Figure 8. *The refractory wear model [7,8].*

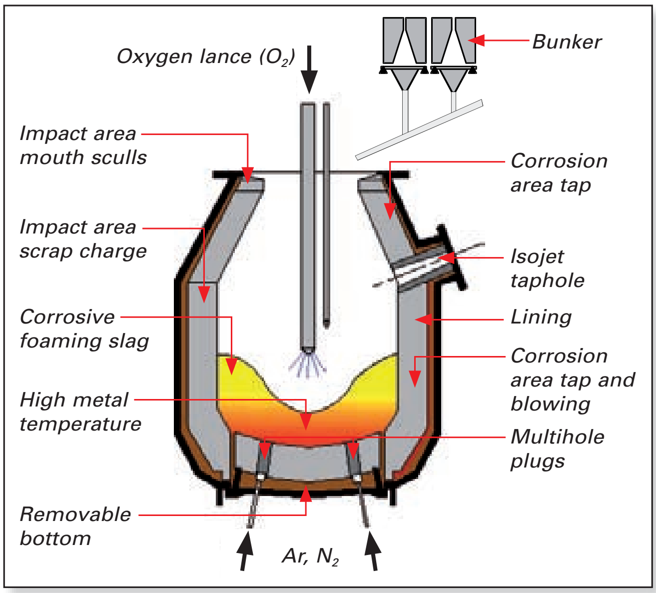

Figure 9. *Primary metallurgy operations.*

>> Slag handling and slag use.
>> Yield losses with the slag.
>> Energy consumption caused by slag.
>> Mechanical shell repair costs.

The right mix between maintenance and relining strategies is in addition to economics also dependent on the operational targets of the individual steelworks. This question can only be answered in intense and confidential collaboration between the steelmaker and the refractory supplier on site. The refractory industry developed and still develops new machines and technologies for standard and special situations and is capable of implementing solutions that can be summarized under balanced lining concepts: Namely, the target is the most appropriate utilization of the resources including refractories, manpower, energy, productivity, and steel product quality while always guaranteeing vessel availability and safety against break outs. This balance is achieved using optimized refractory grades, shapes, and constructions that are adjusted to the vessel wear phenomena. Specific key performance factors can be used to measure the success of the strategy including the quotient of worn out refractories to installed refractories or other indicators. An example of a standard lining concept for a BOF and the main wear zones are depicted in Figure 10.

Ladle Metallurgy Units

Since the introduction of secondary metallurgy in many steel plants the function of the steel ladle has been extended from a simple transport vessel to a metallurgical reactor (Figure 11) [9]. The first target of secondary refining is the deep decarburization of the melts, if required. This reaction is forced by oxygen soluted in the molten steel and the decrease of the [C] x [O] equilibrium at lower than atmospheric pressure. A low carbon content is principally required for deep drawing applications, as well as a low silicon content for annealing demands. Today, several industrial scale vacuum technologies are available to achieve low carbon levels in steel. The next step in the process chain is refinement of the liquid steel which is a treatment under reducing conditions. The elimination of the soluted oxygen in the melt by deoxidation and the removal of the NMIs, followed by generation of deoxidation products is the subsequent main target of secondary refining. The more the steelmaker focuses on deoxidation, the more efficient are the subsequent process steps, starting with alloying to the desired composition. In this case lumpy metallic alloying agents are fed through bunkers, hoppers, weighing units, belts, and vibration feeders into the melt. In addition, pneumatic injection of alloy powder or wire injection are industrial scale techniques employed worldwide.

To create the desulphurization potential and to form an artificial liquid and reactive top slag, flux agents are fed into the heat and melted by its superheat. The composition of the slag must be designed in a way to guarantee the metallurgical requirements, whilst concurrently addressing the requirement for NMI modifications. To guarantee effective and reliable process conditions the prevention of slag carry over from the furnace has to be minimized. Parallel or next step heats are treated at vacuum pressure to remove soluted gases including nitrogen and sulphur from the melt, if required. This process can be used for deep desulphurization simultaneously if a reactive and liquid slag was formed

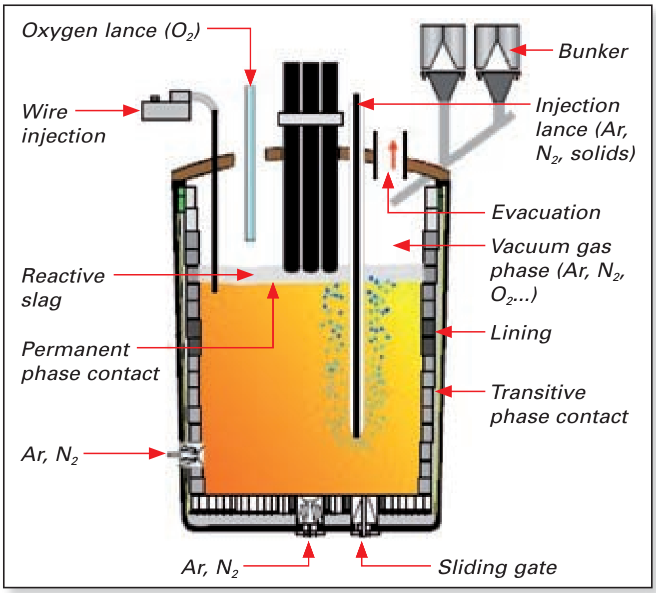

Figure 11. *Ladle metallurgy operations [9].*

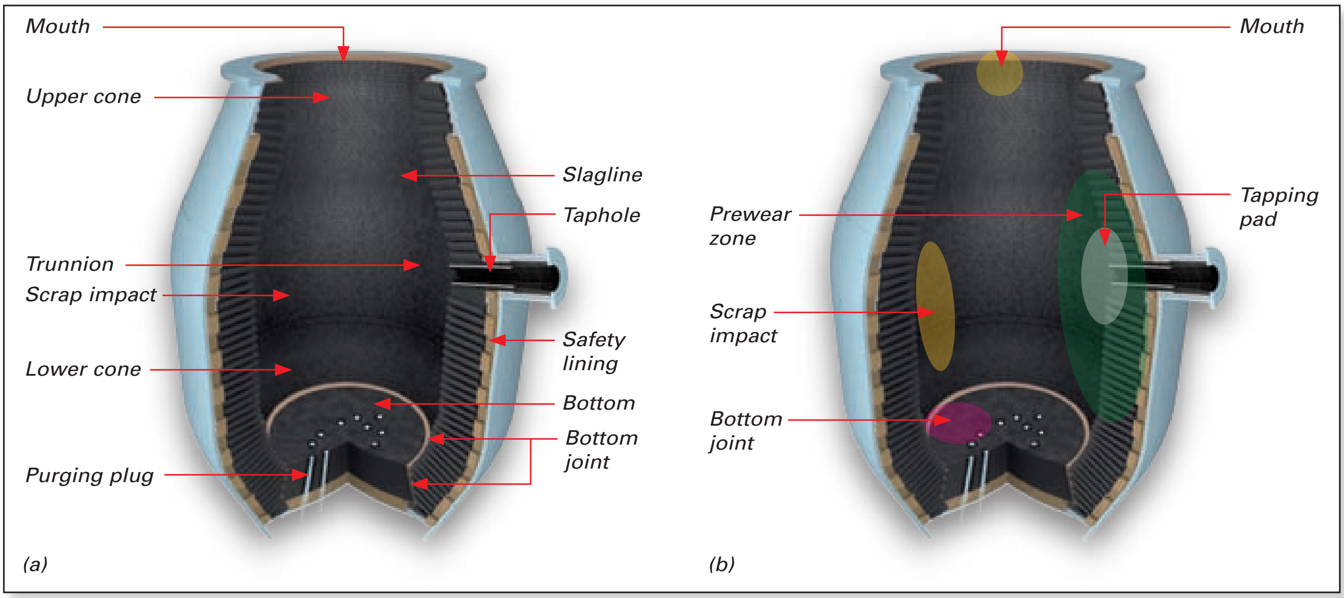

Figure 10. *BOF (a) lining concept and (b) wear zones.*

in previous steps. After the vacuum treatment a careful homogenizing process is required to guarantee the correct and uniform composition and temperature adjustment of the melt. To create the necessary stirring power, inert gases are blown into the melt via porous plugs in the ladle bottom or via lances from the top. Adjustment of the melt nitrogen content is favourable for specific applications because of the positive impact on the tensile strength properties. The alloying of nitrogen is possible by integrating a gaseous nitrogen supply into the stirring equipment.

An additional metallurgical target is temperature adjustment of the melts by using heating or cooling. This step is one of the most important since internal steel properties are strongly related to superheat during solidification. Common techniques on an industrial scale are electrical (i.e., ladle furnaces) or chemical heating devices, where the heat is generated by adding metallic aluminium to the melt which is burned by blowing oxygen on top of the melt. The superheat, which is a result of the strong exothermic reaction of the aluminium with the oxygen, must be transferred to the melt by intense stirring.

A modern and reliable process control must be performed with a suitable steel ladle lining concept (Figure 12). The variety of different steps in secondary refining indicate that the individual stresses caused by the process must be considered for the design of the special lining concept. In addition, the refractory producers must integrate additional key factors in their design strategies to address:

- Thermo-mechanical stress caused by operational temperature deviation.
- Mechanical erosion caused by the tapping stream from the furnace or by the purging stream from the bottom plugs.
- Chemical corrosion caused by oxidizing components (FeO, MnO, and TiO_2) and mixed crystals formation due to reactions with the metallurgical slag components (CaF_2).

Furthermore, the stress on the ladle lining is intensified due to the fact that typically steel plants are serving a wide variety of steel grades, namely ladle lining refractories must be designed to withstand the highest stress caused by the individual processes in the steel plant. This demand explains why the fine tuning of both the metallurgy and refractories are directly linked and must be based on a trusting and constructive partnership between steel and refractory producer. The most important aspect in this relation must be operational safety. More than 40% of all liquid steel break outs happen in the steel ladles, although operational conditions are controlled carefully. In the majority of cases liquid steel break outs not only affect the lining but are accompanied by damage to the vessel steel shell in addition to other equipment. Historical examples show that a ladle break out can cause the entire steel plant to stop for a period of more than a few days. Typical ladle campaign lives are between 80 and 130 heats, depending on refractory quality and metallurgical stress caused by the steel quality and slag. Ladle campaign durations of more than 200 heats have been reported from Japan and Korea.

Tundish Metallurgy Units

The second important reactor in secondary refining is the continuous casting tundish (Figure 13) [4]. Since ladle

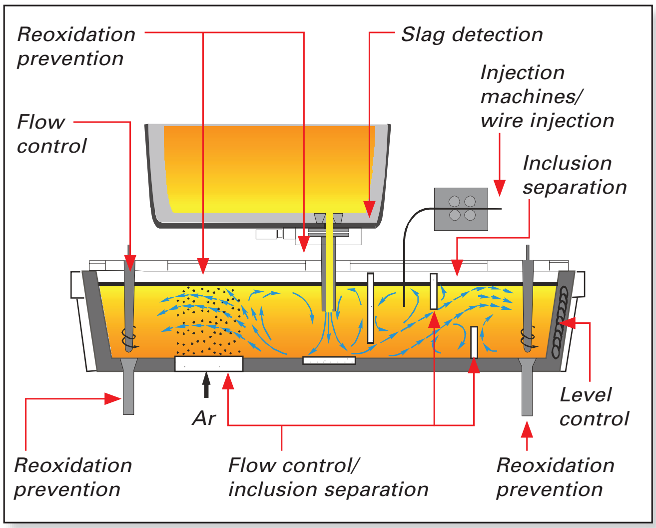

Figure 13. *Tundish metallurgy operations [4].*

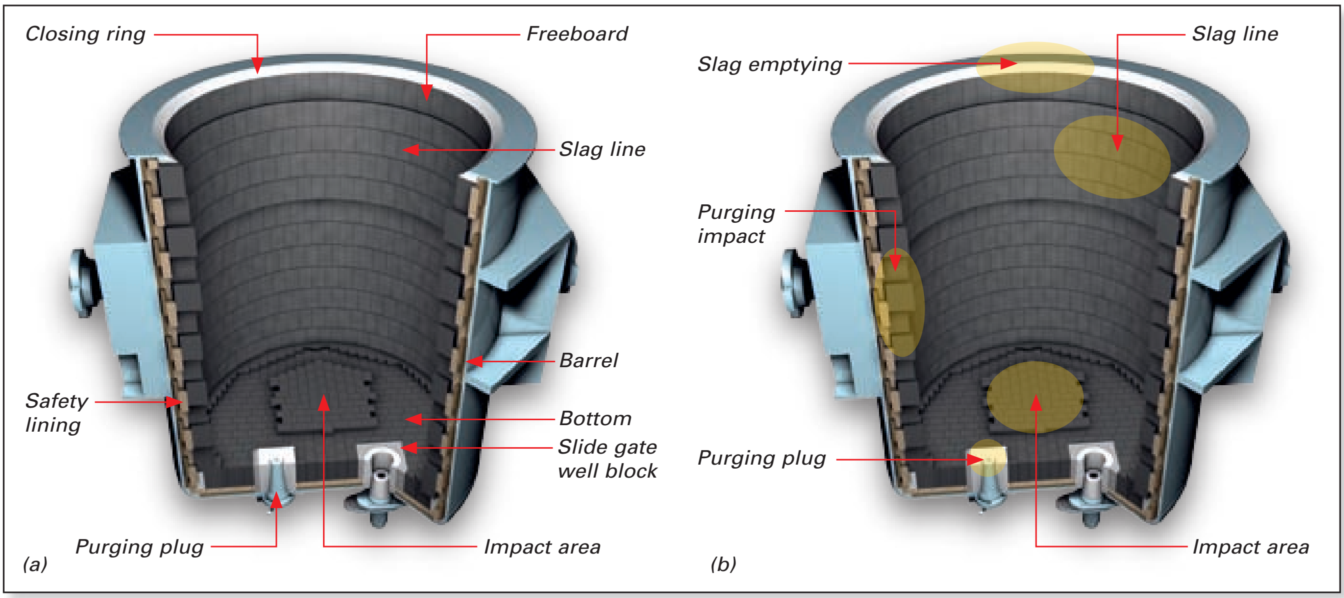

Figure 12. *Ladle (a) lining concept and (b) wear zones.*

operations are currently under control, tundish operations are becoming increasingly the focus of steelmaking quality improvements. The most important tundish function is to convert the liquid steel into different numbers of solid shapes while guaranteeing continuous molten steel flow. The additional important function is prevention of air contact with the molten steel. This function is guaranteed using the shrouded casting technique, namely that the contact of liquid steel and air is prevented using refractory tubes for the transfer from the ladle to the tundish and then to the mould in addition to using artificial slag fluxes to cover the molten steel surface in the tundish and the mould. A secondary effect of shrouded casting is the optimization of temperature losses during casting, which are important for retaining the superheat given to the melt during ladle refining.

The ladle and tundish are equipped with flow control devices including slide gate or stopper rod systems to obtain the required operating conditions. Both systems have the additional function to guarantee a constant bath level in both the tundish and mould during steady state casting mode, which is fundamental for clean steel production.

The use of flow guiding elements in the tundish, including dams and weirs, to direct the steel flow to the bath surface and remove NMIs from the melt by soluting them into the slag is common today. Additional furniture is the argon purging beam, which is installed on the bottom of the tundish between the steel inlet and outlet to the strands and creates a compact haze of argon bubbles which separates the NMIs from the steel melt and brings them to the surface in the covering slag. To process a slag free casting in sequence operation mode the majority of ladles today are equipped with an electromagnetic slag detection device, which operates automatically to prevent slag carry over from the ladle into the tundish by closure of the slide gate. Slag carry over prevention is only one of the multidimensional targets of continuous casting, achieving sufficient yield at casting is another. In the last years tundish metallurgy has been completed by injecting metallic wires for inclusion modification and the required temperature adjustments. Although this technique is difficult to use on an industrial scale, it is the only opportunity to achieve a homogeneous composition because the speed of the wire injection can be adjusted to the casting speed.

The basic lining concept for a one strand tundish with the installed furniture for flow control is illustrated in Figure 14. In addition to the furniture, the wear lining and the impact plate are the tundish cycle time limiting factors. For the installation of the wear lining several techniques are available on an industrial scale including:

>> Conventional gunning with slurry mixes.
>> Dry mixes.

Which option is most appropriate for the steel plant can only be decided by intensive and confidential collaboration between refractory producer and steelmaker. This dialog is very important because the machinery used for the two different techniques is totally different, which means that a switch from one to the other is not easily performed.

Worldwide, more than 30% of steel is produced using open casting technology. This operational practise is used by steelmakers who do not have the high steel cleanliness demands previously described. However, ladle shrouds are used because the hard tapping stream from the ladles would cause very high NMI entrapment if it fell directly through the insulation cover of the tundish.

Refractory Requirements

In summary, the steelmaker's refractory requirements are as illustrated in Figure 15 [10,11]. The most appropriate refractory product concurrently satisfies the demands on quality, productivity, and cost: Where the term quality represents the demands on the accuracy of metallurgy and process speed; the term productivity represents the demands on safety, availability, and reliability; and the term cost represents the expectations of a satisfactory price/result relation and the possibility to achieve overall cost reduction for steelmaking.

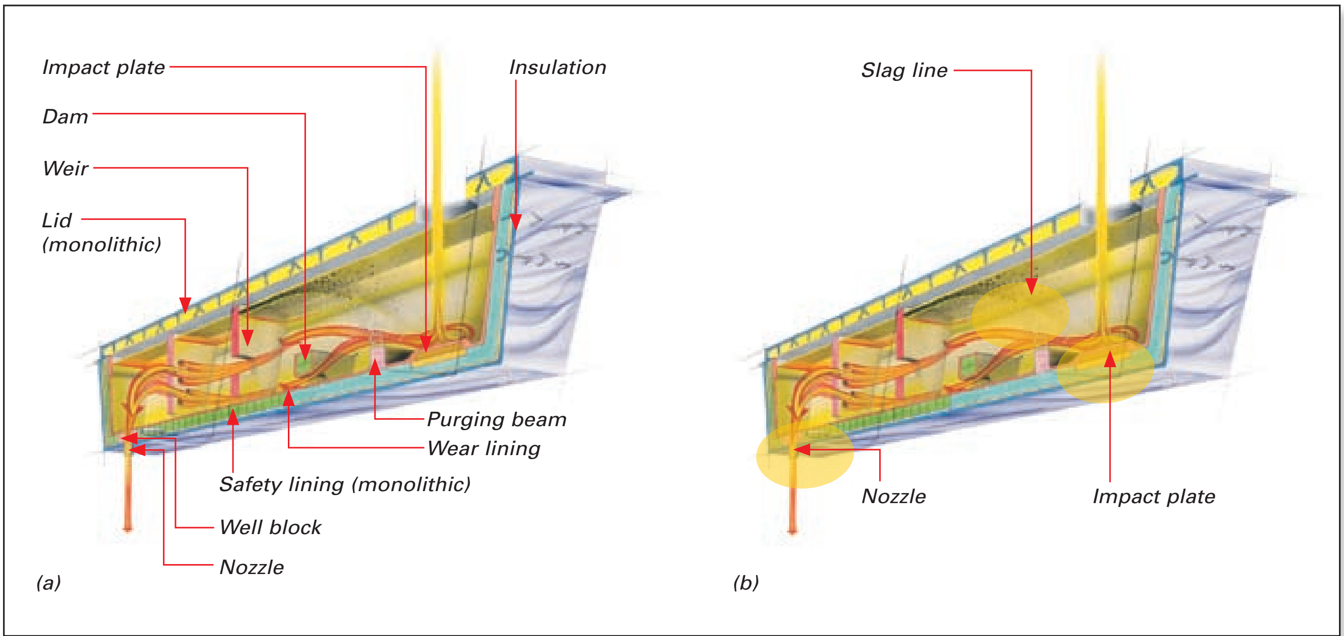

Figure 14. *Tundish (a) lining concept and (b) wear zones.*

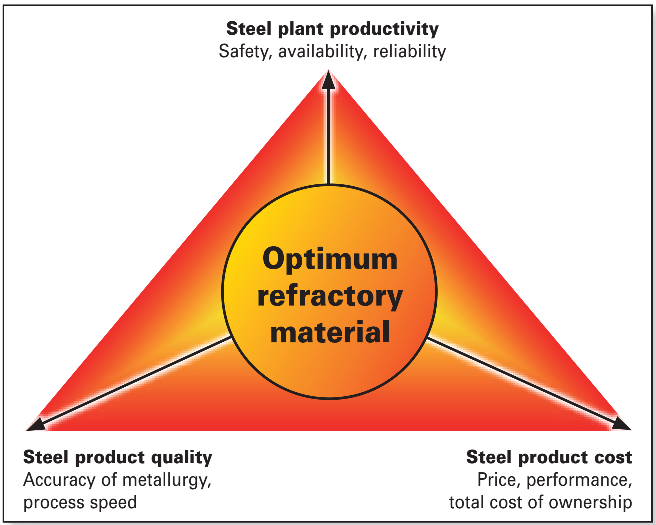

***Figure 15.** Demands on refractory materials [10,11].*

The refractory producers are concerned with the demands of the steelmakers and are committed to continuous improvement. The products offered today are much more than only bricks or masses, but also include the following packages:

>> Wide product range for different application demands.
>> Application consulting.
>> Supply of machines and tools for lining and maintenance work.
>> Supply of lining and maintenance supervision.
>> Education of the customer personnel on site.
>> Optimization of logistics to the customer.
>> Implementation of recycling techniques.
>> Development and support of steelmaking operation techniques regarding the special demands on refractories.
>> Technology consultancy.

For the optimum supply design the recent steel quality production structure of the customer must be taken into consideration. This approach separates the system partners from the commodity suppliers in the refractory business. The first question to the customer is therefore how he would like to be supported. If the steelmaker wants to use the full capability of the refractory producer then the additional benefit creates customer value and should be honoured. Whether this is included in the refractory price by mutual agreement or is paid in the form of special fees is not a question of partnership but of contracting and financing. The most important fact is that both parties agree on the value that has been added to the steelmakers process.

Conclusion

The steel boom occurring since the beginning of the decade has resulted in a steady growth in the steel producing industry of more than 35% worldwide. This positive effect has occurred at different rates in the world regions and was generated by the high demand in China, Asia, and the CIS countries. The growth in the "old world" is almost static and the threshold countries are on their way to industrialization. The refractory industry is growing with its steel customers. A more detailed analysis of the steel market growth divided by products illustrates that steelmakers must be divided into two groups: One that is enlarging existing facilities and another that is starting into the market. Both groups cannot be treated the same way by their suppliers. In particular, the new facilities ask for low cost products because they are working in a highly competitive market when compared to established producers who are mainly working in the field of high value added products. Due to the fact that today the production costs of steelmaking in the two major production routes are almost on the same level but market prices for the standard steel products are significantly lower, the cost competition in the case of long products is greater than in the case of flat products. Refractories have a 2.0 to 3.5% share of the overall production cost.

Analysis of the specific refractory consumption development for steelmaking indicates the refractory industry has provided a significant input into steel production cost efficiency by decreasing on average the specific consumption from 30 kg/tonne to 9 kg/tonne. This development has a regional focus because of different technology standards, different metallurgical approaches, and different production programme structures worldwide. Regarding the function of refractories in steelmaking, it is evident that the refractory requirements are directly linked with the different steel production routes. Therefore, for optimum collaborative efficiency it is essential that the steelmaker and refractory producer are committed to common targets. This is the reason why refractory products have changed from a commodity to a specifically designed product and why the refractory industry is asked increasingly to participate in the productivity increase in steelmaking.

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