REFRACTORIES FOR THE STEEL INDUSTRY - A DIAGNOSIS AND PROGNOSIS

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INTRODUCTION

The domestic steel industry has changed dramatically in the past decade and will continue to do so. As the industry changes, so must that part of the refractory industry which serves it. This talk will summarize some of these changes and identify some of the ways that the refractory industry has changed to meet those new needs. It will also attempt to look into the future and provide some guidance with regard to those areas of technology which could most aid in the survival and resurgence of a domestic steel industry.

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THE STEEL INDUSTRY OF TODAY

Armco provided overviews and extended challenges to the refractories industry in 1973 and again in 1980. It should be noted that in 1973 over 140 million tons of steel were made in the U.S.A. and all steel plants were profitable. Some notable quotes from the 1973[1] paper include:

- "One of the major obstacles the steel industry faces is the fact that refractories are not generally developed according to the needs of the steel industry. Refractory companies continue to generate products on the basis of available raw materials and manufacturing techniques seemingly regardless of customer needs. There is no doubt that such a product is occasionally successful.

- "There are other specific applications where improved products will be of utmost importance for the steelmaker in the next few years. In the area of iron making for example, the development of a lining material for blast furnace boshes that will reliably extend blast furnace campaigns over and beyond todays limits will be a necessity to accomplish iron production needed for the BOF process. The bosh of the blast furnace is a very complex system. The answer to the lining question cannot be arrived at without considering the cooling system and geometry of the furnace, the type of lining material used in the stack, and the raw materials charged.

- "In the past, to pour a certain steel tonnage might have required something like 10-15 open hearth furnaces with the corresponding number of blast furnaces and their auxiliary equipment to provide hot metal for part of the charge. Today the same tonnage is produced by two or three large BOFs and perhaps two blast furnaces.

- "The challenge is this. Quality control procedures in the plant of the refractory producer must be improved to make sure that no substandard material is shipped out of the plant. These procedures will have to be followed very strictly and standards raised so it will be virtually impossible to ship faulty materials. It must be realized by the manufacturer that if there is even one percent of poor quality brick then an otherwise perfectly satisfactory lining can fail prematurely and cause major disturbances in the production schedule of the steel manufacturer.

- "The paucity of hot strength data in high alumina brick, speciality refractories, phosphate bonded alumina brick and many other products indicates that the industry must believe that these products are never used at elevated temperatures. In ninety percent of the cases, cold properties are completely meaningless yet cold properties dominate all suppliers data sheets. In an industry where a significant contribution to company profits is made by substantial sales of specialty products, the lack of work in development and characterization of hydraulically bonded products is deplorable."

And from the 1980(2) paper when over 120 million tons of steel was made and most steel plants were profitable:

- "The refractory industry became more responsive, spending considerable sums of money to develop products specifically for areas like A.O.D.'s, electric furnaces, particularly hot spots, blast furnace boshes, blast furnace stoves,and heating furnaces. In a general sense, improvements in aluminosilicate products through "materials engineering" is also noteworthy. For ironmaking applications, semi-graphite and silicon carbide have moved to the forefront as blast furnace bosh brick, replacing carbon and aluminosilicate products. Vastly improved specialty products have been developed for troughs and runners as the need for these products has arisen. The advantages of stability under reducing conditions, good alkali resistance and superior thermal transfer properties clearly exist in these new products.

- "Economic success has not been and likely will not result by going to MgO levels exceeding 96-97%. The anticipated growth of pitch bonded or chemically bonded products at the expense of burned ones in the 80's will result from a better understanding of pitch chemistry and influences of additives such as sulfur.

- "In addition to product research, new inroads were made in understanding refractories in their working environments. In particular, delineation of the effect of reducing conditions on brick properties was approached. An acceptance of thermal shock damage as a major wear mechanism and an understanding of this phenomenon could be observed in the 70's. Continued work in these two areas will have very dramatic influences on product development and refractory utilization in the 80's.

- "A better understanding of and greater utilization of statistical sampling techniques has arisen in the past decade. However, the payoff to the consumer has not been as high as hoped for. This has led to an increase in buying to more rigid specifications and more on sight inspection by steel plant personnel. In some cases, considerable premiums have been asked by the refractory manufacturer to obtain closer tolerances. The use of nondestructive techniques like sonic-velocity measuring devices has recently become feasible in some areas. Certain manufacturers of special shapes examine every body shipped using this technique.

- "Continuing efforts to educate each other and to work together will result in an even more optimistic outlook once the 1990 summary will be written."

In both of those talks, the writers as well as most readers, expected the steel industry and the refractory industry with it to continue to be a highly profitable, healthy business team. How wrong we all were! Dramatic changes in production capacity and structure have taken place.

In January of 1986, America's raw steelmaking capacity was estimated at 127.9 million tons, compared to 133.6 million tons for 1985. Since 1981, steelmaking capacity has dropped 17% or about 26 million tons.

Meanwhile, during both 1984 and 1985, foreign steel accounted for more than one-quarter of the total U.S. market for steel. This compares with 14.1% market penetration in 1976. Aluminum, plastics, and composites are getting more of each car as well. In the past decade, steel industry employment has fallen by more than one-half, from 454,000 in 1976 to 208,000 in 1985. And between the beginning of 1982 and the end of 1985, domestic steel companies lost nearly $7.4 billion on their steel segment operations. In 1985 the industry suffered a net loss of well over $1.7 billion.(3) Over the next five years, an average production of 75 million tons of U.S. steel is being predicted.(4)

A startling way to picture the change in integrated steel plant impact on the refractory industry is to consider the demise in numbers of the symbol of the plant, the blast furnace. In the last 1/2 decade, the number of operating blast furnaces has dropped from 130 to 35. Blast furnaces built in 1975 were expected to have lining lives of three to four years. Blast furnaces built in 1985 are expected to last eight to ten years without major refractory repair. At Armco, we have passed from a five blast furnace company in 1984 to a two furnace company.

The industry will continue to shrink. At the 1986 General Meeting of the AISI, a panel of steel company CEO's gave the formula for recovery of the domestic steel industry.(5) These were:

- Further cost reductions are needed.

- An additional 25 to 30 percent of liquid steelmaking capacity must be shut down.

- Import restrictions, environmental regulations, and tax policies must be left in place for a couple of years so that intelligent plans can be made.

The refractory companies which can contribute most to the first point will be least affected by the second.

One highly respected investment newsletter has written off non-Chicago located integrated steel mills.(6) Armco has dedicated its future to steelmaking, so, having no steel plants in Chicago we hope he is wrong. We think there is a future for steelmaking in the U.S. and we feel the domestic refractory industry will play an important role in bringing this to fruition. In the next few pages will be reviewed some high points which have occurred in the refractory industry in the past 1/2 decade. Through these we will try to show why we are optimistic that the industry will continue to apply the latest ceramic technologies to heading off (not solving) the problems we foresee because of a changing approach to steelmaking. As these are reviewed, it should be kept in mind that refractory assessments today and in the future are more complex than in the past years. Today's Refractory System Success Measure = Refractory Price + Installation Cost + Steel Quality Impact + Contribution to Continuous Operation/grade of steel.

REFRACTORIES FOR THE BLAST FURNACE

As the 1970s drew to a close, the standard procedure of repairing blast furnaces and hot blast systems every three to five years became totally unacceptable. Increasing cost of repairs and the impact of relatively frequent and lengthy outages on production capability has driven ironmakers toward more sophisticated and expensive designs capable of long dependable service. Better process control and instrumentation has increased our knowledge of the operating environment which has helped us to better understand refractory failure mechanisms and the need for a system approach to lining design.

The modern blast furnace with a "state-of-the-art" lining design, operating controls and instrumentation can expect twenty or more years from its air and/or water cooled hearth and seven to ten years from the bosh and stack linings. Refractories found in these furnaces include amorphous carbon, semi-graphite, graphite, high alumina, alumina-chromia, silicon carbides with various advanced bonding systems and fireclays. These materials are combined with proper cooling and zoned to provide a cost effective lining capable of withstanding the chemical and thermal environment of the process. The success of these new designs depends on in-depth knowledge of the physical, chemical and mechanical properties of the lining refractories and unprecedented dimensional control and quality assurance.

One state of the art design employs a dry fit with no mortar joints or ramming materials between bricks or between bricks and cooling elements. This, of course, requires machining of refractory and cooling elements surfaces to insure a tight fit capable of resisting iron penetration while promoting efficient heat transfer across the dry joints. This design opens a new dimension in precision and accuracy for refractory manufacturers as well as installation personnel. During the building of this system, brick layers and inspectors use feeler gauges and sophisticated laser leveling devices instead of the common wooden rulers used in the past.(7)

Blast furnace hot blast systems have traditionally been the most expensive refractory structures in the steel mill due to their mass and complexity. The better designs have been able to produce twenty-year campaign lives with cleaning and repairs every three to five years.

In recent years, the demand for higher hot blast temperatures, operating pressure and uninterrupted operation equal to the longer blast furnace campaigns have made the previously acceptable designs and some of the refractory materials obsolete. To solve this problem, larger stoves with more complex and expensive refractory designs have been developed. To increase the dependability, new, and improved gas cleaning systems capable of increased efficiency and reliability at higher operating pressures have been built.

The hot blast system designs of today place far greater demands on the refractories than previous ones. Precision control of dimensions and of the physical and mechanical properties of refractories is essential. Quality assurance in the refractory plants has been raised to new levels employing the most modern techniques and measuring equipment to satisfy the demands brought on by these designs. The materials used are not exotic; silica, high alumina and fireclay, however, the need for quality and consistency is unprecedented. (The cost of retrofitting an existing facility with a new hot blast system and all of the associated controls, gas cleaning and other auxiliary equipment can easily exceed $30 million).

Some of the most dramatic refractory development work in recent years has occurred in the blast furnace cast house. The traditional graphitic high alumina ramming mixes used in the blast furnace trough five years ago are being replaced by high quality low moisture castables based on fused alumina and silicon carbide. The advanced bonding systems employed in these materials allow them to form a strong bond to old castable with only a minimum amount of cleaning.

An important and interesting part of this technology is the use of reactive metals to form gas bubbles in the presence of moisture which create a pore structure, and/or the use of organic fibers which melt out at low temperature to form a network of small vent holes. These techniques allow casting into hot troughs (600-900°F) and relatively rapid heating from casting to use temperature without danger of steam explosion.

Development of these materials has made it possible to hold iron in today's deep pooling type iron troughs for a week or more without draining for maintenance. This improvement has reduced delays, maintenance frequency and cost on high production furnaces with multiple tap holes, and has made more casts per day possible.

Hot Metal Treatment

In North America, hot metal treatment has become common place in most integrated shops, principally for sulfur control. Although the process was tougher on conventional linings, changes to different types of existing refractories and changing approaches to ladle rotation helped minimize the problem. Desiliconizing and dephosphurizing have not been necessary in most North American shops, but these processes could appear. When these processes come on line in a shop, refractory challenges will appear there as well as at the BOF shop where the operation will have changed due to flux and blowing requirements.

REFRACTORIES FOR THE BOF

Refractories for the BOF have seen dramatic changes since 1980.[8] The introduction and continued development of metallic and graphite additives to magnesia brick has considerably improved performance while presenting new problems in installation and maintenance of linings. These materials have not reached their full potential and their success has been somewhat obscured by the increasing demands due to process changes.[9] The introduction of bottom stirring, combined blowing and demand for consistently higher tap temperatures to support secondary metallurgical processes and continuous casters, without the aid of reheating equipment, have considerably increased lining wear potential in some shops.

A family of pitch bonded magnesia refractories with one or two metals added have been developed. These materials are considerably less expensive than the resin bonded magnesia graphites. However, they display some of the enhanced high temperature strength and oxidation resistance of the magnesia-graphites while retaining the forgiving low temperature pyroplasticity of pitch bonded refractories. These materials are now available for zoning along with traditional pitch bonded and burned magnesia refractories, as well as the ever increasing family of resin bonded magnesia-graphites.

With this array of materials available to the lining designer, he needs only to properly define the operating environment and have a means of accurately measuring wear rate in order to be able to build the most cost effective lining. This statement was somewhat ridiculous a few years ago and may be a little humorous today. However, the development of the proper tools to accomplish this task is well underway.

Development of rapid laser mapping techniques has improved understanding of refractory wear rate, determined precisely the effect of zoning changes, and allowed more efficient management of blowing practice and gunning maintenance of linings.

Intelligent use of computer charge models and rapid sampling techniques have reduced variability in steel and slag chemistry and allowed steelmakers to consistently hit aim chemistry and tap temperature with few reblows. The presence of metal treatment on either side of the BOF will have everything to do with appropriate refractory selection.

As with most processes, it is difficult if not impossible, to isolate and examine refractory performance as a separate entity from the BOF operating improvements. Today's improved refractories have contributed to cost reductions in shops where major process changes such as bottom stirring or a change from ingot to caster practice have taken place. However, concurrent development of process control which certainly affects refractory wear rates must be recognized as part of recent successes.

To take full advantage of emerging refractory and process control technology, the "system approach" to refractory design must be employed in order to provide the low cost and high reliability that are essential for today's and tomorrow's super competitive steel industry.

REFRACTORIES FOR ELECTRIC ARC FURNACES

From a refractory viewpoint, the electric furnace is no longer an area in which significant cost savings can be generated for the steelmaker or can the refractory supplier develop a good market for materials.[10] Most of the roof is water cooled and only the delta section still contains refractories. The use of 70% Al_2O_3 brick is the cheapest way to line the delta section and it requires limited masonry labor. Usually a spare delta section can be laid up and set aside as a replacement which can be rapidly installed with little lost production time.

Three piece fired castable shapes occasionally get tried as delta sections in steel plants, usually on a guaranteed performance basis. However, the key point to be made is that this refractory application saves little money and both the steelmaker and refractory suppliers have far more important problems to solve.

Similarly, the sidewalls of arc furnaces are predominately water cooled leaving only the slag line area and bottoms for refractory installation. Slag lines of arc furnaces are divided into two types depending on the type of steel produced. Furnaces which melt stainless steels use magnesia-chrome brick. Magnesia graphite is a better choice in most carbon steel furnaces. In all cases, the banks are maintained by using gunning mixes and the campaign life is more a function of gunning practices and maintenance than it is a function of refractory brick type. Typically, slag line brick are consumed at two to four pounds per net ton of steel produced while gunning mixes are consumed at about ten pounds per net ton of steel produced. These rates have remained constant for almost ten years and the only refractory change has been the marriage of water cooled sidewalls and magnesia-graphite brick. However, further refractory improvements will effect little cost savings to the steelmaker and only in those furnaces where energy input becomes so high, due to oxy-fuel burners and high powered transformers, that reliable day-to-day operation becomes threatened will better refractories be required.

Currently, refractory brick consumption in sidewalls is about $1.00-2.00/NT while gunning mixes cost $2.50/NT at the 10 lbs. per ton gunning rate. Clearly, decreasing gunning mix consumption offers the most savings to the steelmaker. This also carries over to the electric furnace bottom where brick may be only replaced once per year and brick cost might be $.20-.30/NT. The major bottom cost in this area is again the gun mixes used extensively to fettle the bottom and fill holes.

REFRACTORIES FOR "SECONDARY STEELMAKING" PROCESS

The term "secondary steelmaking" applies to processes such as AOD, VOD and vacuum degassing. Decarburization, alloying, homogenization and temperature control are all achieved in these types of units. The use of tuyeres, predominately used only in AOD vessels during the 70's, is now being widely applied to BOF's and vacuum degassers and experiments are being run in electric arc furnaces. The operation of tuyeres in a secondary steelmaking vessel strongly influences the refractory performance. Often, special grades of tuyere brick or tuyere brick panels are necessary in attempts to even out the wear rate of the refractory linings. The reactions occurring and the wear mechanisms of tuyere brick are not clearly understood and therefore present considerable challenges to the refractory technologist. Several individual properties of refractories can be maximized by refractory manufacturers but which properties are necessary to give improvement in tuyere performance must still be defined. Slag attack is also a wear mechanism in AOD vessels and studies of slag basicity versus lining wear have generally shown that as the slags have become more basic through the years, lining life has improved.

In vacuum degassing units refractory life has improved primarily by small subtle design changes. In some cases, particularly hot grades of steel degassed for caster sequences have caused premature snorkel-nozzle wear. A new design for snorkels-nozzles which can incorporate better cooling of the steel interior, has potential for lowering costs and improving reliability. Many times snorkel-nozzle life is interrupted by steel penetration between the connecting flanges. This requires extreme care during snorkel-nozzle exchange to be sure that a good joint is maintained.

REFRACTORIES FOR LADLE METALLURGY PROCESSES

Ladle metallurgy is the new superstar of steel processing and clearly is a profitable area for refractory technologists to concentrate their efforts in cooperation with steelmakers. In these processes the steel is sampled, bubbled, stirred, homogenized, heated, cooled, purified and brought to an exact temperature required to continuously cast the highest quality steel at the proper casting speed. The reliability of all parts of these ladle systems is quite important when measured against the costly problems encountered in interrupting a caster sequence, or burning a hole in a ladle bottom or slag line. Further, the need for reliability of "standard" refractory components in the ladle, i.e., pocket blocks and nozzles is even more important than in the past. Only a few years ago, almost all ladles were lined with bloating fireclay in alumina spiked fireclay brick. Today, zircon, doloma, magnesia, mag-chrome, high alumina, and a variety of impregnated or resin toned refractories are being tried on lades. Materials thought to be "for expansion" in the past are cost effective today. Confirmed balancing of these and other "super" ladle brick with individual steel shop needs will provide many challenges for the future.

Many new ladle metallurgy systems are associated with a porous plug in the bottom of the ladle. It is easy to understand that porous plugs must be break out free, and 100% reliable as to gas flow at a particular pressure. This gives refractory technologists tremendous leeway in materials development.

The refractory technologist must know the typical slag chemistry of the steels being produced in order to understand slag line reactions and to be sure that the most suitable refractory is used. Often this can be quite complex since a steel plant may make several grades which have widely differing slag chemistries. Similarly, the refractory supplier must have a good understanding of slag-brick reactions often based on laboratory slag tests. Knowing only the lime/silica ratio is not enough information when FeO, MnO and TiO_2 may be the primary chemical components involved in the slag attack. The following partial list of ladle changes all present opportunities for refractory contributions to keep the steel processing steps being taken at a steady and even pace.

		Ref. Cost
1.	Ladle insulating covers	\$0.02-0.05/ton
2.	Ladle refractory covers - (CAS, CAS-OB)	\$0.02-0.05/ton
3.	Top blown lances (CAS, CAS-OB, ASEA, CAB)	\$0.02-0.05/ton
4.	Porous plugs	\$0.10-0.90/ton
5.	Slide gates	\$0.40-1.00/ton
6.	Ladle pouring pads	\$0.04-0.10/ton
7.	Argon stirring rods	\$0.90-1.20/ton
8.	Ladle to tundish shrouds	\$0.20-0.50/ton
9.	Ladle slag line brick - artificial slags	\$0.05-0.20/ton
10.	Overall ladle cost	\$3.50-5.00/ton

REFRACTORIES FOR SLIDE GATE SYSTEM

In slide gate technology the Japanese have pioneered the use of alumina-carbon refractory materials and demonstrated that superior refractory materials can be justified if the resulting performance is achieved. What better place can be found for the application of "high tech ceramics" than slide plates for ladles or continuous casting slide gate systems.

After the steel leaves the ladle proper, it is usually delivered to the tundish via a shroud. Most shrouds are of alumina graphite composition. Fused silica is still used when the steel chemistry permits it. Both shroud compositions can accommodate gas purging which is used more and more often.

Caster Refractories

Historically, all that was needed for a vertical caster was a tundish lined with fireclay brick, a pocket block into which stopper rods fit and a submerged entry tube. Current tundish lining practice encompasses a great variety of designs.(11) These include the historical design and also systems comprising insulation (board or IFB), safety lining and a working lining of high alumina brick. The advent of precast tundish liners which may be one or several pieces has become common. Even though higher quality lining materials are being used, the steel is not in contact with them, but with boards or a gunning mix. New and more stringent steel cleanliness requirements[11] will make it necessary to closely look into the properties of these boards and gunning mixes so as to minimize their role in creating inclusions. This will be aided by the more intelligent use of dams and weirs in the tundish. Intricate designs and new materials will need to be applied to this use. Another newcomer to the tundish is inert gas stirring via a porous element which helps in preventing temperature stratification and allows inclusions to float out.

With the advent of automatic mold level control, the use of stopper rods has been greatly reduced in favor of slide gate systems. These slide gates differ from the ladle gates in that they generally are three plate systems with the center one doing the throttling. More wear resistant center plate materials are being considered for more corrosive grades and longer caster sequences.

The steel leaves the tundish through a submerged entry nozzle (also called a pouring tube). The current material of choice is alumina graphite with a zirconia band which protects it from mold powder flux attack. Although zirconia is quite resistant to the chemical attack, better materials will have to be found. Too often, the interior of the pouring tube is clogged with precipitates. Elimination of this problem is of paramount importance.

The new technology which will probably be installed in the tundish is filters. These refractory pieces will catch most inclusions and aid considerably in the steel cleanliness. The problem is that as of now, we do not know how to use them for more than a few hundred pounds of steel.

So far, this discussion has centered on vertical casting. Horizontal casting avoids some of the above mentioned problems, but creates others. In horizontal casting, the tundish and mold are intimately linked. There are no slide gates, i.e., no throttling, and no pouring tubes. Instead, the tundish opens directly into the mold with a few refractory pieces bridging the tundish and mold. These refractories are currently made out of zirconia because of its thermal properties and inertness to steel. Probably the most important component, refractory or otherwise, of a horizontal caster is the break ring.[12] This ring provides the uncoupling surface between the barely solidified steel and the mold through which it is traveling. In general, it is made out of boron nitride (BN), but other materials, particularly SIALON, and silicon nitride have been used successfully when casting certain grades of steel.[12] New materials with high thermal shock resistance, and low thermal expansion will be needed for this application.

Tundish design considerations are identical with those of a vertical caster.

In summary, the extensive use of gas shrouding for atmosphere control and to minimize clogging will undoubtedly continue. Also, the tundish will be the next metallurgical treating vessel after ladle treatment techniques have been perfected. This means that new refractory systems will be needed to cope with these conditions. When strip casting becomes a commercial reality, several more designs will exist. New approaches will be needed in order to cope with the challenges each of these casters will present.

Finishing End Refractories

The finishing end is one of the most energy intensive operations in a steel mill. It is also one where a lot of energy waste can occur. Before the Arab Oil Embargo, not much attention was paid to this area, but once energy prices started escalating and scarcity became a real threat, all sorts of insulating schemes were pursued. At that time, insulating fiber blankets or modules came of age. Due to their great insulating power, they were indiscriminately installed in many reheat furnaces leading to expensive failures. Most of the problems were related to the lack of knowledge on how to install them properly and in their actual service limitations.

Thanks to human ingenuity and persistence, most of these problems have been overcome and insulating fiber veneers or through to the shell module applications are now common. Nevertheless, the current continuous service limit still hovers around 2500 F, generally due to the occurrence of excessive shrinkage. It is expected that this problem will be overcome in the future as technologists find new chemistries or designs to meet even higher temperatures. Different designs may permit the application of the current fiber blankets to higher temperatures. New installation systems will have to be designed so as to greatly decrease the downtime needed for installation.

Castables

During the last few years, there has been a virtual explosion in types of castables available in addition to those designed for ironmaking applications. These range from conventional high cement, high water castables to no cement content and minimal need for water. The new castables make extensive use of rigorous sizing of their components and new bond systems which brings about higher hot strength and lower porosity than conventional castables. This permits their use in highly demanding environments. The advent of the rapid firing technology castables permits timely and problem free dry out of the new castables.

Farther Into the Future

We will continue to see the division of steel refining "responsibilities" as the demands and capabilities to make cleaner steels more cost effectively (tied into continuous casting) are gained. Additionally, there will be attempts to more directly tie the steelmaking and hot rolling process together. New concepts in direct rolling are now being explored overseas and in the U.S.A. New technologies to replace the blast furnace coke plant complex are getting closer to reality. Each of these areas will require refractory materials and lining concepts different from anything else. A myriad of challenges awaits.

SUMMARY

In summary, the refractory system economics will be different in every shop. A very expensive refractory system will be the appropriate one for Shop A but totally inappropriate for Shop B. Clean steel of consistent quality, made continuously requires major efforts from some of you. We applaud the Refractory industry for the accomplishments made in the last 1/2 decade. You must recognize with us that to continue to meet the new challenges toward survival and world competitiveness, we must work together to develop and apply state-of-the-art discoveries more quickly than in the past. Specifically, we must:

1. Develop and design refractories and refractory systems for specific plant needs requiring increased emphasis on research and development and understanding of the steelmaking or treating process.

2. Tighten in-plant quality standards to prevent the shipment of any substandard products to the customer's plants using up-to-date SPC teachings.

3. Develop product characterization to establish factual material use limitations, and potential benefits under appropriate simulation.

4. Work as a team with steel company technologists so that problems can be avoided before they need to be solved as new approaches to steelmaking or treating come on line.

REFERENCES

1. Baker, B. H., Schroth, P. H., and Shultz, R. L., "Refractory Challenges for the 1970's." Presented at the 1973 Annual Meeting of the American Ceramic Society, April 30, 1973 - Cincinnati.

2. Shultz, R. L. and Schroth, P. H., "Refractories in the 1970's - Review and Outlook for the 1980's." Presented at 1980 Annual Meeting of the American Ceramic Society, April 30, 1980 - Chicago.

3. AISI Report - June 1986.

4. McAlson, T. P., "Down But Not Out." I&SM, July, 1986, pp. 21-25.

5. Ibid.

6. Kiplinger Newsletter, July 25, 1986.

7. Brenneman, R. G., "Improving Campaign Life of Armco Blast Furnaces," presented at AIME, I&SS meeting, April, 1983.

8. Baker, B. H., Brezny, B., and Shultz, R. L., "Role of Carbon in Steel Plant Refractories." Am. Cer. Soc. Bull. 55 (7), 1976, pp. 649, 654.

9. Hart, R. L. and Michael, D. J., "Magnesite-Carbon Brick for Steelmaking," I&SM, June, 1986, pp. 35-39.

10. Baker, B. H. and Fedock, M. P., "Electric Arc Furnace Refractories," Chapter 5 of Electric Furnace Steelmaking, C. R. Taylor, Editor, AIME Publ., 1985, p. 63-70.

11. The Birth of the High-Tech Tundish, 33 Metal Producing, March 1986, p. 25.

12. Engel, R. "Laboratory Testing of Boron Nitride Break Rings," Proceedings of the Electric Furnace Conference, 1985, p. 329.

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