THE TREND OF MONOLITHIC REFRACTORY TECHNOLOGY IN JAPAN

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1. INTRODUCTION

In the past 10 years, refractory industries in Japan have been suffering from loss of production and reduction of unit prices due to reduction of unit consumption of refractories and increase of imported refractories. In this severe situation, Japanese refractory industries are fighting to survive by corporate restructuring and technological development. This report details the general trends in monolithic refractories in Japan.

2. OUTLINE OF REFRACTORY AND STEEL INDUSTRY

2-1. Refractory and steel production

Refractory production has been decreasing for the past 10 years in Japan. In 1991, the refractory production was 1.71 million tons and it was reduced to 1.32 million tons in 2000 (Figure 1). And, the unit consumption of refractories has largely decreased. In addition, amount of refractories imported is increasing. On the other hand, crude steel production by Japanese iron and steel industry has not changed much and has been shifting around 100 million tons annually over the past 10 years (Figure 2). Also the average unit price of refractories produced in Japan has been reduced by about 30% over the past 10 years. Therefore, Japanese refractory companies have made various corporate efforts to restructure including the transfer of their production to foreign sites and the improvement of their domestic plants' productivity.

2-2. Corporate circumstances

In Western countries, active plant integration is underway through the merger and alliance of refractory companies. Japan is not the exception, KROSAKI Corp. and HARIMA Ceramics Ltd. were forced to merge in April 2000 and as a result KROSAKI HARIMA Corp. was born. In May 2000, Krosaki Harima, acquired Kyushu Refractories Company Ltd. Further changes are expected in near future.

3. GENERAL TRENDS IN MONOLITHIC REFRACTORIES IN JAPAN

In spite of the fact that the total refractory production has greatly decreased, the production of monolithic refractories has only slightly decreased. It is due to the wide application of monolithic refractories for furnace refractory linings, which has increased extremely to save labor and energy, especially in the iron and steel industry. As a result, ratio of monolithic refractory production has become approximately 60% of total refractory [2, 3].

4. DEVELOPMENT OF MONOLITHIC REFRACTORY

4-1. Taphole mixes for blast furnaces

4-1-1. General

A great deal of improvement has allowed the unit consumption of taphole mixes to be reduced more than 20% in Japan over the past 15 years. It is well known that taphole mixes play an important role to maintain the stable operation of the blast furnace. Recently, there has been an increased requirement for high productivity through the stable operation of blast furnaces.

4-1-2. Requirement for taphole mixes

It is necessary for the stable operation of blast furnaces to ensure a reliable plugging of tap holes and a stable and long-time tapping. Furthermore, the longer service life of the blast furnace has led to a greater requirement for the protection of its hearth with taphole mixes. To meet the requirements, there have been various studies made so far to improve taphole mixes for higher strength, abrasion resistance and corrosion resistance through the addition of metallic silicon, ferrous silicon nitride and the blending of alumina silica grain into taphole mixes.

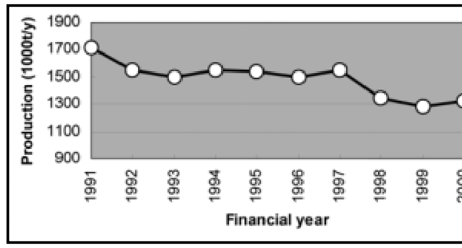


Figure 1. Refractory production in Japan [1].

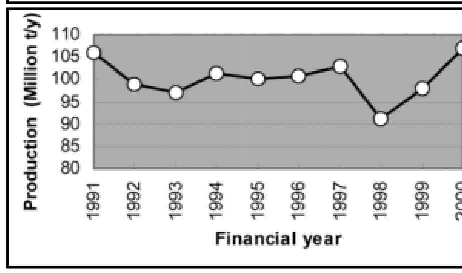


Figure 2. Crude steel production in Japan [1].

4-1-3. Roseki (pyrophyllite) aggregate

We have some experiences that the type of taphole mixes containing roseki aggregates may have the same, or in many cases, better durability as the type of taphole mixes containing alumina aggregates in the blast furnaces, in spite of the fact that roseki aggregates are thought generally to be inferior to the alumina aggregates in chemical corrosion. This indicates the microstructure of taphole mixes formed under the hot and constrained condition is more important than the mere chemical composition.

4-1-4. Tar addition and properties of taphole mixes

The viscosity characteristics of tar greatly affect the hot plasticity. Therefore it is necessary to select the tar with the relevant viscosity in accordance with the operation condition. As illustrated in Figure 3, the use of tar with a high viscosity has an effect of maintaining the plasticity of taphole mixes in the hot condition. Crack generation of taphole mixes charged into tapholes and heated rapidly is affected by the vaporizing behavior of tar and the amount of its volatile materials content. Therefore, the tar viscosity and the control of the amount added are of great importance. If more tar is added, the apparent porosity of taphole mixes becomes larger. However, it is considered that a higher densification of taphole mixes is basically effective to improve their durability. To reduce the amount of tar addition, there are studies concerning the addition of ultra-fine powders such as silicaflour and carbon black. Figure 4 shows the effect of the addition of silicaflour. It indicates that for this type of taphole mixes, an addition of a percent of silicaflour results in the largest reduction of tar addition.

Figure 5 shows influence of carbon black on the amount of tar addition. An addition of the carbon black powder with the less ability of DBP (Di-butyl phthalate) oil absorption, the less tar is added, and thus making the taphole mixes denser and stronger.

4-2. Blast furnace main troughs

4-2-1. General

Figure 6 shows the change in refractory consumption for all kinds of troughs (including main trough/slag/iron runner) and for main troughs over the past 15 years in Japan. In Japan, hot metal treatment by troughs and runners started in 1980 and the rate of such treatment increased each year. Furthermore, its influence led to a large increase in refractory consumption for troughs and runners until 1990. Now, however, the unit consumption is as low as that for the year 1985 because of various improvements in both materials and repair methods.

4-2-2. Wear mechanism of main trough refractory

There are multiple factors for wear in main trough refractories for each slag and metal zone. The slag zone is worn by (A) slag corrosion, (B) oxidation, (C) spalling, and (D) hot metal abrasion. And the influence of these factors on wears in the slag zone increases in the order of A, B, C, and D. Therefore, the improvement of corrosion resistance of the refractories for the slag zone requires;

A) Improvement of slag resistance,

B) Improvement of oxidation resistance,

C) Control of thermal expansion and the prevention of excess sintering, and

D) Increase in physical strength.

On the other hand, the metal zone is worn by A) corrosion mainly due to FeO, and B) abrasion. Consequently, improvement of the corrosion resistance of the refractory for the metal zone requires;

A) Improvement of FeO resistance,

B) Improvement of abrasion resistance.

Particularly the improvement of corrosion resistance against FeO is the more effective.

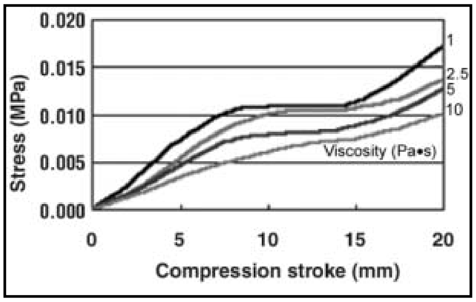


Figure 3. Relation between tar viscosity and hot plasticity.

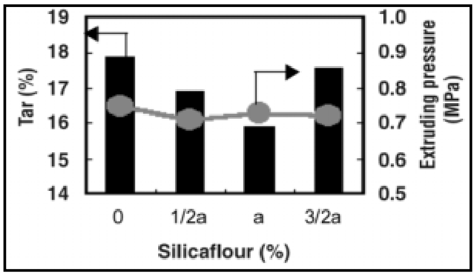


Figure 4. Relation between silicaflour and tar content.

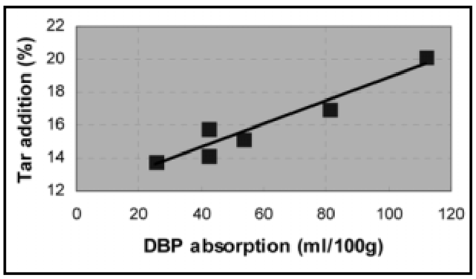


Figure 5. Relation between DBP absorption and Tar content.

4-2-3. Material lining configuration of main trough

Figure 7 shows the configuration of the main trough lining. Conventionally, main troughs in Japan had been entirely lined with Al_2O_3-SiC-C material containing 20 to 30% of SiC. The lining method was easy to install as one of its advantages. However, the lining method had a disadvantage of making it difficult to prolong the life of the main trough, as wear mechanism is unique in slag and metal zone. So, suitable materials were then developed for each zone individually. Each of these zones was then lined with a refractory of a different type. This is called zone lining. The lining method has allowed the substantial increase in the performance and is now in use at most of the blast furnaces in Japan. And also suitable testing methods are selected to evaluate the individual characteristics of materials.

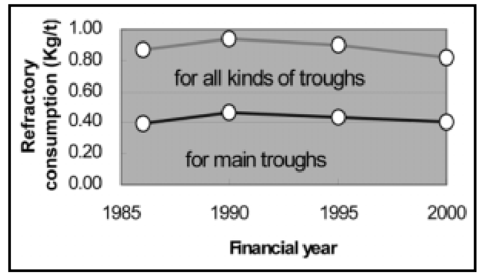


Figure 6. Refractory consumption of trough castable.

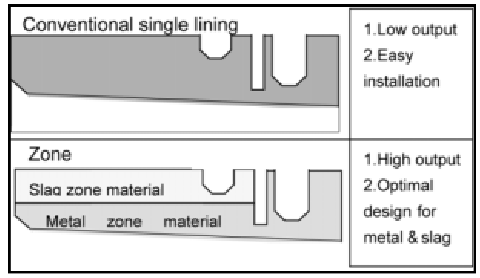


Figure 7. Material design configuration of main trough.

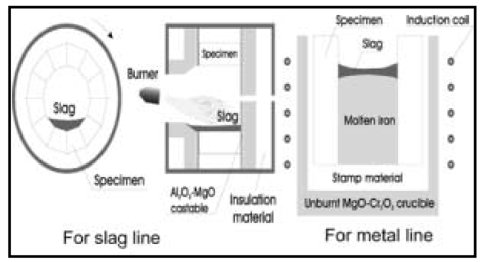


Figure 8. Evaluation method of slag & metal zone material.

4-2-4. Evaluation methods of each material

The rotary slag corrosion test is applied to the evaluation of slag zone materials since the wear in the zone is mainly due to slag corrosion in the oxidizing atmosphere. On the other hand, the corrosion test using a high frequency induction furnace is applied to the evaluation of metal zone materials since the wear is due to the corrosion at the slag-metal interface in reducting atmosphere. Each testing method is illustrated in Figure 8.

4-2-5. Material design concept for slag/metal zone

For slag zone material, the influence of SiC on corrosion resistance was studied by both rotary slag corrosion test and high frequency induction furnace corrosion test. The rotary slag corrosion test shows that the wear decreases with the increasing SiC content,

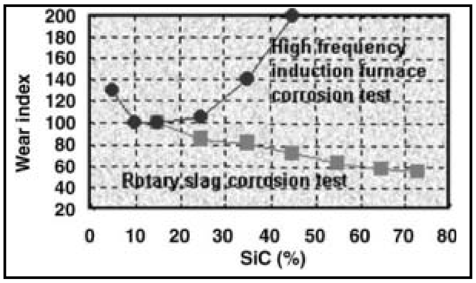


Figure 9. Relation between SiC content and corrosion resistance.

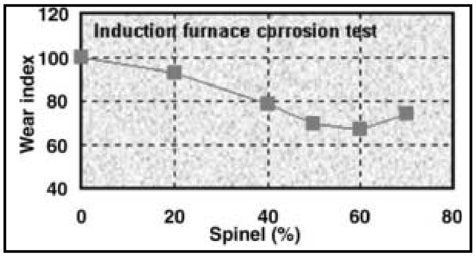


Figure 10. Relation between spinel content and corrosion.

while the high frequency induction furnace corrosion test shows the opposite (Figure 9). As it is obvious from the figure, materials with good slag resistance generally require the adoption of the zone lining method for the main trough because of their poor wear resistance in the metal zone.

For metal zone material, the influence of spinel addition on wear resistance against FeO was studied by high frequency induction furnace corrosion test (Figure 10). Based on these results, different materials are lined for the slag and metal zone in the trough.

4-2-6. Field performance of BF trough in Japan

During campaign troughs are repaired four to five times by casting method, wet gunning method, and dry gunning method. The total tapping pig iron during a campaign is in the range from 125,000 to 140,000t under severe operational and lining condition, i.e. high hot metal temperature, narrow trough width and thin lining thickness.

4-3. Torpedo ladles

4-3-1. General

The rate of the monolithic refractory usage in torpedo ladles has been increasing every year, while the unit consumption has been increased. Despite the large increase in the rate of hot metal pretreatments in torpedo ladles, the total unit consumption has increased slightly because of various improvements in repairing methods and materials over the past five years.

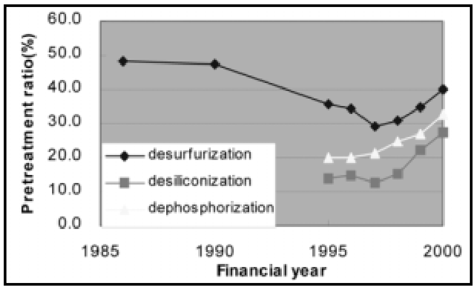


Figure 11. Ratio of hot metal pretreatment in TPL.

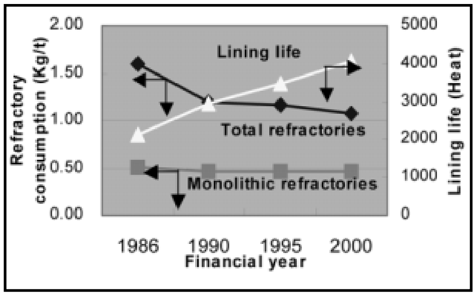


Figure 12. BOF life and refractory consumption.

4-3-2. Hot metal pretreatment

Since 1980, Japan has seen the start of hot metal pretreatments such as de-sulfurization, de-siliconization, and de-phosphorization, which cause notable damage to torpedo ladle linings. As a result, the consumption of refractories for torpedo ladles has increased remarkably. Figure 11 shows the change in the rate of hot metal pretreatments in torpedo ladles in Japan. The rate for the pretreatments has been increasing every year since 1995. Therefore, the improvement of initial lining bricks has become important and at the same time, the improvement of monolithic refractories for intermediate repairing has also become remarkably important.

4-3-3. Repair methods for torpedo ladles

The repairs have been generally conducted by partially exchanging lining bricks, dry gunning, and partially casting using a vibration plate. In recent years, wet gunning repair has often been used. The wet gunning repair has become more popular because of the following advantages;

1) Improvement of working conditions, low rebound loss and less dust generation.

2) Obtain high durability through a dense repaired body equivalent to the casting.

3) Obtain same material thickness as castable.

Since the repair material is attacked by chemical and physical corrosion due to slag and hot metal while in use, the wet gunning mixes are naturally required for high corrosion resistance. Besides they are also required to have high resistance to peeling-off, since the generation of peeling-off from the residual lining is one of major causes of the wear. In recent years, therefore, improvements in resistance to peeling off have been increasingly important for such materials in addition to corrosion resistance. It has led to the development and practical use of such materials to optimize the thermal expansion and the hot softening and shrinking properties under the load by the addition of silicaflours and mullite aggregates on the base of a low addition of alumina cement.

4-4. Basic Oxygen Furnace

4-4-1. General

Figure 12 shows the change in the refractory consumption of the BOF and its service life in Japan. The service life of the BOF has approximately doubled from 2100 heats to 4100 heats over the past 15 years, at the same time the refractory unit consumption for BOF has greatly decreased. For the period, the increase in hot metal pretreatments, particularly de-siliconization and de-phosphorization of hot metal, has led to a reduction in BOF slag generation and in blowing time, thus resulting in a reduction in load to BOF lining refractories. The fact may have led to reduce refractory unit consumption and may have increased the service life of the BOF. But improvements in monolithic repair materials have also played a major role in reducing the unit consumption and the increased service life.

4-4-2. New MgO-C gunning mixes

As BOF repair materials, mainly phosphate bonded gunning mixes have been used so far. Recently, however, totally new MgO-C type of gunning mixes with resin and pitch bond have been developed and adopted in Japan as high performance repair mixes. The MgO-C type gunning mixes have remarkably improved the corrosion resistance by giving excellent slag penetration resistance, and high hot adhesive strength compared with conventional phosphate bonded gunning mixes. Consequently, performance of the MgO-C gunning mixes is improved by 40~60% compared with phosphate bonded type.

4-4-3. Hot casting repair mixes

In addition to the gunning mixes, the hot casting repair mixes are adopted to repair the lining of BOF except trunnion-side. They are available in two types, namely the aqueous and the non-aqueous type. At present, the type using powder pitch is in common use in Japan. The influence of pitch properties and pitch addition on the hot fluidity and the hardening rate is shown in Figure 13. Since the type with powder pitch emits a lot of smoke in operation, the material with liquid and powder phenol resin is used at the steel making shops in which the emissions are undesirable.

4-4-4. Flame gunning technology

Flame gunning technology is a highly advanced repair method applied mainly for partially worn area as an emergency repair. This system melts refractory powder in a flame and creates a monolithic body providing dense structure and consequently high performance of 15~20 heats. Typical property of flame gunning mix is shown in Table 1.

4-5. Steel ladles

4-5-1. General

Over the past 15 years there was a substantial drop in the refractory consumption in Japan despite severer operating conditions. These conditions include increased steel holding time and an increased molten steel temperature in ladles due to increasing the continuous casting ratio and secondary refining ratio. On the other hand, there was a large increase in the rate of monolithic refractories use at the same time. This means exactly how much advances in monolithic repair technologies have helped to obtain the substantial drop in refractory consumption in steel ladles.

4-5-2. Installation method and kinds of monolithic refractories

High siliceous zircon castable was replaced by alumina spinel castable for the sidewall except slag line area since 1987. The application of the monolithic refractories using the alumina spinel castable to the bottom of the ladle was started in 1988. In 1992, the slag line has been lined for the first time by the castable using magnesia zirconia clinker. As a result, the ladle lined entirely with the monolithic refractories appeared for the first time in the world.

4-5-3. Alumina-Magnesia castables

Research and development of alumina magnesia based castables started around 1988. Their application to sidewall, except the slag line and the bottom, was studied. However, they were not put into the operation for a long time. The alumina magnesia castables have excellent corrosion resistance but are extremely damaged by the structural spalling due to slag penetration. For this reason the material was not put into the operation. In 1994, however, the application of alumina magnesia castables to the sidewall of ladles proved to be successful. This success was made possible by a good balance between corrosion resistance and slag penetration resistance through a reduction in the alumina cement addition and an application of silicaflour, for the purpose of an optimization of thermal linear expansion and thermal stress under the load. This type of castable then was improved in several ways, as a result, the application spread rapidly and widely in Japan.

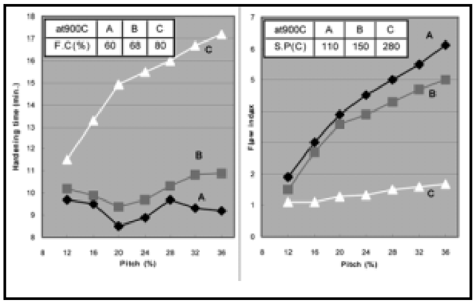


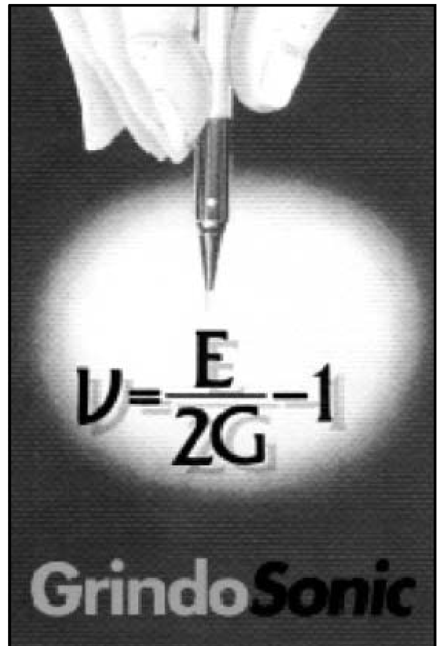
Figure 13. Relation between pitch and flow/setting [4].

Table 1. Properties of flame gunning material.

Material Type	MgO-CaO
Chemical composition	
SiO_2 (%)	5.5
Al_2O_3	0.7
Fe_2O_3	7.1
CaO	25.2
MgO	58.7
Grain size (mm)	0.5-0
Refractoriness (C)	>1800
Bulk density	3.3
Apparent porosity (%)	6.3
Performance (Heat)	>20

4-5-4. Material lining configuration of steel ladles

The typical ladle-lining configuration currently adopted in Japan is illustrated in Figure 14. The slag line is lined with MgO-C bricks. Sidewall is lined with alumina-magnesia castable in most cases. Sidewall is mainly worn by chemical corrosion and also worn by structural spalling due to slag penetration. Therefore, for the sidewall lining castable, it is required a good balance of corrosion resistance and slag penetration resistance. On the other hand, the bottom of the ladle is lined with alumina-spinel castable containing stainless needles in most cases. Bottom is mainly damaged by structural and thermal spalling. Therefore, it is required that one bottom lining castable has excellent vol-



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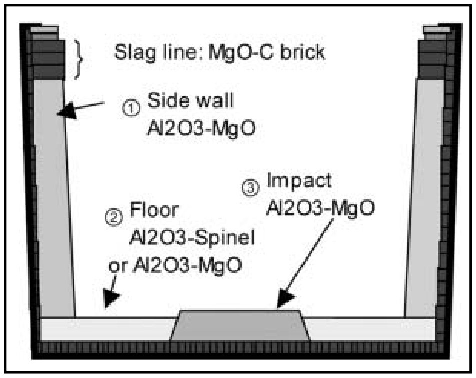

Figure 14. Material configuration of steel ladle.

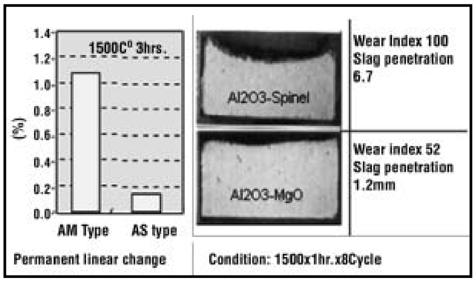

Figure 15. Comparison of Al_2O_3-Spinel and Al_2O_3-MgO.

ume stability and slag penetration resistance. In addition, the impact area of the bottom is lined with alumina-magnesia castable; which is required to have excellent volume stability and slag penetration resistance. Impact area is damaged by abrasion and cracks due to mechanical shock of molten steel. Therefore, as impact area lining castable, it is required to have appropriate amount of magnesia and silica flour to relief the mechanical shock.

4-5-5. Comparison of alumina-spinel and alumina-magnesia castable

Figure 15 shows the comparison of both alumina–spinel castable and alumina-magnesia castable. Generally speaking, the alumina-spinel type is superior to the alumina-magnesia type in volume stability and spalling resistance, but inferior in slag corrosion resistance and relief characteristic of thermal stress. Based on these differences in characteristics, the alumina-spinel and alumina-magnesia type are selected depending on the operating conditions.

6. SUMMARY

As mentioned earlier, in Japan, total refractory production has been greatly decreasing; however, the importance of monolithic refractories is increasing as not only repair materials but also as initial lining materials. And it is expected that the ratio of monolithic refractory will further increase in the future.

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The Back Cover Continued From Page 1

The north-facing trilithon is equipped with a Polaris window through which the North Star can be viewed. This feature and the analemma were not part of the original Stonehenge and were added so that visitors can make use of UM-Rolla Stonehenge throughout the day. Sun/moon rise and set tables for this Stonehenge model are posted monthly at the site.

A marker bearing the inscription "UMR-Stonehenge" has been placed in the center of the monument. This marker identifies the spot as an official triangulation point in the National Geodetic Survey's North American Triangulation Network. (Such points are used for mapping and control purposes.)

Approximately 160 tons of granite were used in the monument. The rock was cut to the proper dimensions by UMR's Waterjet equipment. This equipment used two waterjets cutting at a pressure of 15,000 pounds per square inch traversing the surface just like a conventional saw. The cutter moved at a speed of about 10 feet per minute and cut between one-quarter and one-half inch on each path.

In addition to its astronomical functions, UM-Rolla Stonehenge serves as a monument to man's past achievements through its blending of cultural and scientific influences. Just as the ancient site stands as a tribute to the ingenuity and talent of ancient engineers and cultures, so the campus site serves as a reminder of man's technical and humanistic potential and the importance of the history of science and technology in understanding that potential.

Every year the National Society of Professional Engineers makes up to 10 awards for outstanding engineering accomplishment. These awards are given for completed projects and typically go for such items as the space telescope. In 1984 the University of Missouri-Rolla received one of these 10 Outstanding Engineering Achievement Awards for its Stonehenge model.

Industry News Continued from Page 9

lines such as Boron Carbide and Green Silicon Carbide. Additionally, he instituted new processes to expand, refine and increase silicon carbide production.

Electro Abrasives grew from 15 employees to 25 at the time of his death.

Expansions occurred in 1995 and 2003 with continual quality improvements in the plant and to the product line.

"He was a well respected innovator and leader in the industry," stated Kristine Ramming, General Manager. "He listened to the customers and made sure we produced a high quality abrasive product to meet their needs."

After serving Electro Abrasives as a Product Manager for six years, Kris Ramming was appointed General Manager at Electro Abrasives six months ago. "My father ran an honest company with high quality products and I was proud to have been able to work under him for six years."

"Electro Abrasives will continue to be a leader in Silicon Carbide and Boron Carbide production for use in aerospace, coatings, composites, compounds, lapping, polishing, wire sawing and more."

September 11, 2001
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