The Record Breaking Shougang, Benxi & Baosteel Hearth Campaigns

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ABSTRACT

Since 1991, the Shougang group in the Peoples Republic of China has installed 10 blast furnace hearth linings based on the UCAR® Refractory System design and HotPressed™ Bricks. This paper is highlighting four of these, namely the very large refractory lining in Shougang Jingtang #1 in the Hebei province, a 15.5m furnace blown-in 2008, as well as Shougang #1, 3 and 4; the three blast furnaces that (March 2010) have broken the Chinese records on both service years and accumulated production per cubic meter working volume. Other leading BF operators that recently have reported record breaking numbers are Baosteel and Benxi and we will discuss the performance of their hearth linings in this paper. In addition to describing the refractory fundamentals of these large furnaces, the paper will describe the proven hearth lining concept and design used to enable these records to be achieved.

1. Introduction

Figure 1: Shougang Iron making; state-of the-art technology

The Shougang Group, one of the leading steel makers in China, installed their first UCAR® Refractory System freeze lining in 1991. For an iron maker, changing the fundamental concepts for their hearth lining is a major commitment; much of the plants profitability relies on the production level and availability of the blast furnace. In addition, the reliability of the hearth lining is a critical safety issue. For Shougang the decision was based on references from around the iron making world and on their own troublesome experiences with large carbon block hearth walls. For instance, prior to 1,726 m^3 Shougang #2 blast furnace being relined with a UCAR® lining in 1991, the two previous large carbon block liners lasted only 3 and 6 years. 10 years after installation the HotPressed™ bricks were found to be in good condition. It was therefore decided to reline the hearth using the same US made refractories. This was also an excellent indicator that Shougang had made the right lining decision for all their other furnaces, where they had decided to rely 100% on the performance of UCAR® linings.

The proven UCAR® Refractory System freeze lining technology, unlike big carbon block technology, relies on small HotPressed™ carbon and semi-graphite bricks with tightly cemented joints. These details are critical to ensure good heat transfer to the water cooled staves over the full campaign of the furnace. The lining technologies will be discussed in more detail in section 2 and 3 below.
Baosteel is another leading iron maker that has broken records with their 4,360 m^3 blast furnace. The hearth material and technology is similar to the ones utilized by Shougang and we will elaborate further in section 4 in this paper. At the ICSTI congress in 2009, Benxi Iron and Steel published a paper describing how they now have "applied UCAR® carbon bricks long life technology" on all their four blast furnaces, moving from 5 year campaign lives to over 15 from one campaign to the next. More details from this paper will be quoted later in section 5 of this paper.

2. Hearth Wear Mechanisms

Hearth wall wear in conventional and micropore large carbon blocks is the result of thermal stress induced cracking, high mechanical stress induced cracking, ram deterioration and shrinkage, chemical attack and consequential reduction of thermal conductivity over time. This wear is the result of many contributing factors including excessive wall thickness, no or insufficient provisions for thermal expansion or differential thermal expansion, thick and deteriorating insulating ram layers and inappropriate material properties. As a result, high mechanical stresses from thermal expansion and temperature differentials result in cracking of the large block hearth wall. Cracks interrupt the ability of the blocks to transfer heat to the cooling system. Therefore, the temperature of the blocks increases throughout their thickness, especially on the hot face. This permits the block temperature to exceed the critical reaction temperature for zinc and alkali attack of approximately 800 °C, which initiates chemical attack of the block. Additionally, the rammed mass at the cold face usually shrinks or is eroded by steam/gas tracking and is a barrier to effective heat transfer, which further contributes to the temperature increase of the blocks.

When alkali and zinc attack carbon, the binder system is destroyed, which cause a loss of strength and thermal conductivity and volumetric "swelling" resulting in abnormal vertical wall growth. Many blast furnace operators with large carbon block liners in their hearth have witnessed the expanding hearth wall cause tuyeres/coolers to lift! As chemical attack progresses, the blocks further lose their ability to transmit heat, which causes even higher temperatures within the block, including the hot face. Note that when the walls are excessively thick, the hot face temperature of the carbon will be the same as the hot metal and slag in the furnace.

When the above described failures occur, the pressure in the furnace and the Ferro static "head" of liquid will force molten materials/gasses/alkalis into the porosity of the hot carbon. This is possible only because the carbon and the molten materials are at the same temperature because cracking of the large, thick blocks prevents proper cooling of the carbon. To combat the penetration of molten materials into the hot carbon, some manufacturers produce carbons blocks with a high percentage of very small pores (micropore, super micropore, ultra micropore, etc.). However, carbon block with the micropore feature are still susceptible to cracking**.** Micropores only prevent molten material penetration of carbon block which are properly cooled. But because of cracking, property deterioration and ram shrinkage the carbon block temperatures can not be kept cold enough to prevent such penetration.

Figure 2 shows typical cracks seen in large carbon blocks after a few years of operation.

Figure 2. Typical wear and cracks in a micropore carbon large block hearth wall, also referred to as "Ring Crack" (In this case after an 8 year campaign).

Figures 3-5 describes this wear process. Figure 6 shows the typical "elephants foot" wear pattern in big block linings – the lining has been consumed down to a point where the furnace has to be stopped.

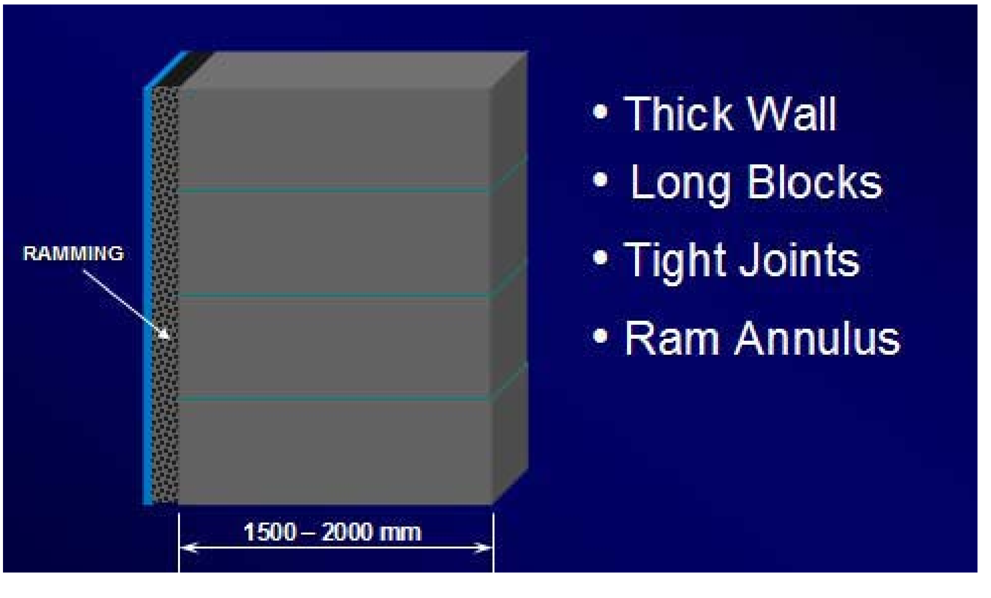

Figure 3: Typical large micropore carbon block hearth wall design

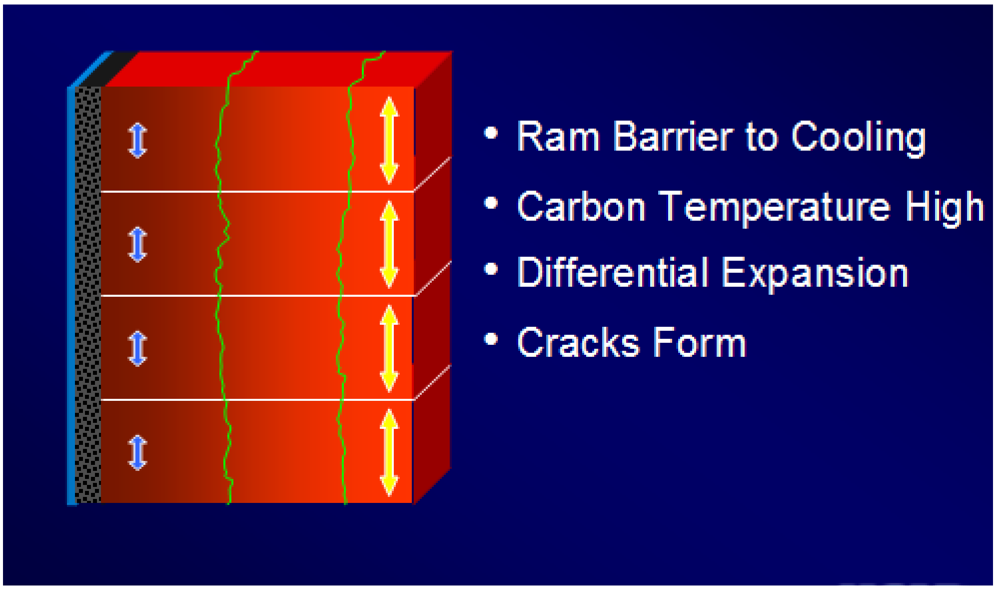

Figure 4: The wear process of the micropore carbon block lining

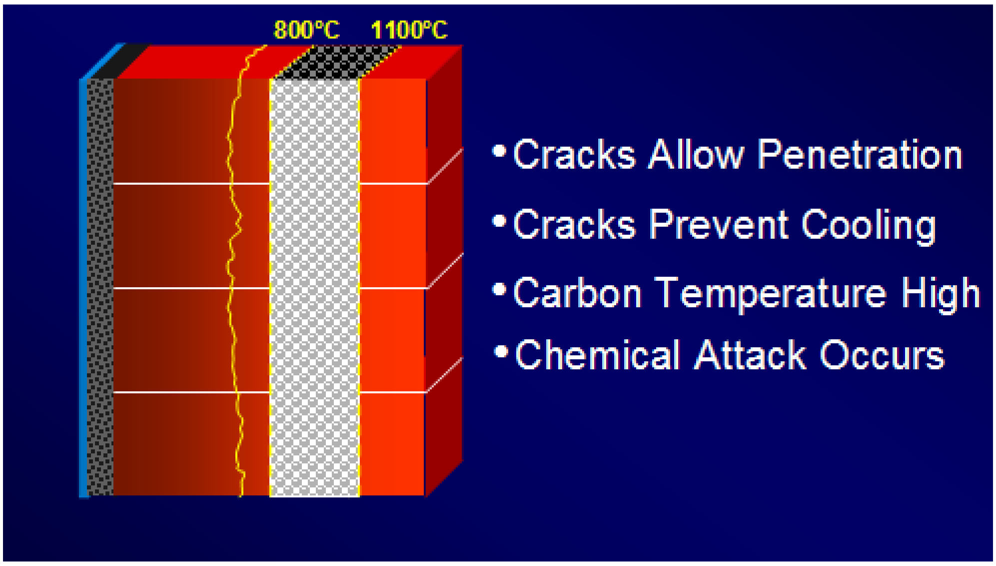

Figure 5. The wear process of the micropore carbon block lining – material is lost

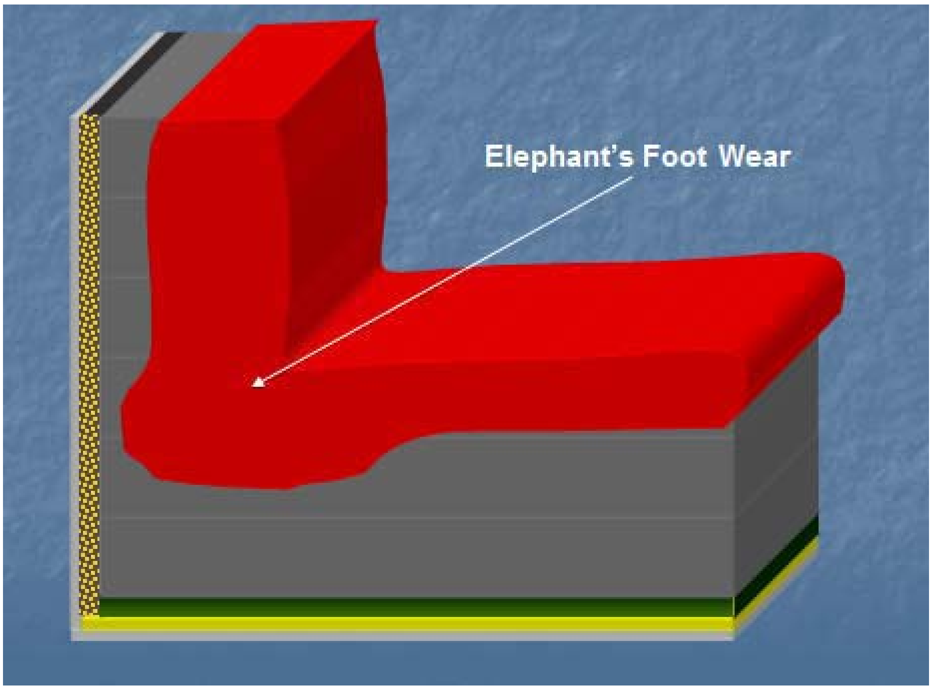

Figure 6. Elephant's foot wear pattern in big block lining

It should also be realized that the installation and long term characteristics and properties of the ramming material between the carbon block cold face and steel shell/staves is critical. Unfortunately the use of ramming materials **is a requirement** when utilizing large carbon block shapes to fill the void in the radius between the block and steel shell.
Optimal densities are never achieved in the field during installation and it is very common to find material deterioration over time.

Ram density and ram baking temperatures are directly related to ram conductivity. Ramming that is not fully rammed and properly baked can not achieve optimal densities and thermal conductivity. The ram, because it is installed against the steel shell, which is water cooled can never properly bake because of the low initial temperatures experienced thus lowering the conductivity value and an increase in the carbon block hot face. This ramming layer therefore eventually becomes a heat transfer barrier and not a high thermal conductivity zone as planned.

It should also be noted that iron will eventually dissolve any carbon that it contacts. It is only a factor of time/temperature and, exposure to the iron. If the molten iron is in contact even with micropore carbon, the iron will relentlessly dissolve the carbon, until wall thickness is reduced to a point where a breakout occurs or until an artificially induced temporary titanium coating can be established on the carbon hot face, to shield the carbon from the iron. Long campaign lives using conventional block carbon or micropore carbon in a high productivity blast furnace are impossible without the continuous inducement of costly titanium accretions for protection, or changes in operating practice like the closure of tuyeres and/or reduced production levels etc.

However, this requires considerable operating expenses for the special ore and fuel rate penalties coupled with reduced production levels that result from this practice in an effort to reduce lining wear and temperatures. Many operators will report long lining life, but virtually never report the cost of charging ilmenite ores, cost of reduced production levels and costs incurred for grouting, repairs etc.

3. The UCAR® Freeze Lining Concept

The UCAR® hearth wall system is based on the fact that all significant hearth wear mechanisms are related to high temperature. Alkali attack only occurs above 800 °C; thermal stress is a result of extreme thermal expansion; and erosion occurs when iron contacts the carbon refractory directly for extended periods. Therefore if temperatures can be maintained at a relatively low level, wear is prevented.

There are four key elements of the UCAR® hearth wall system (Figure 7):

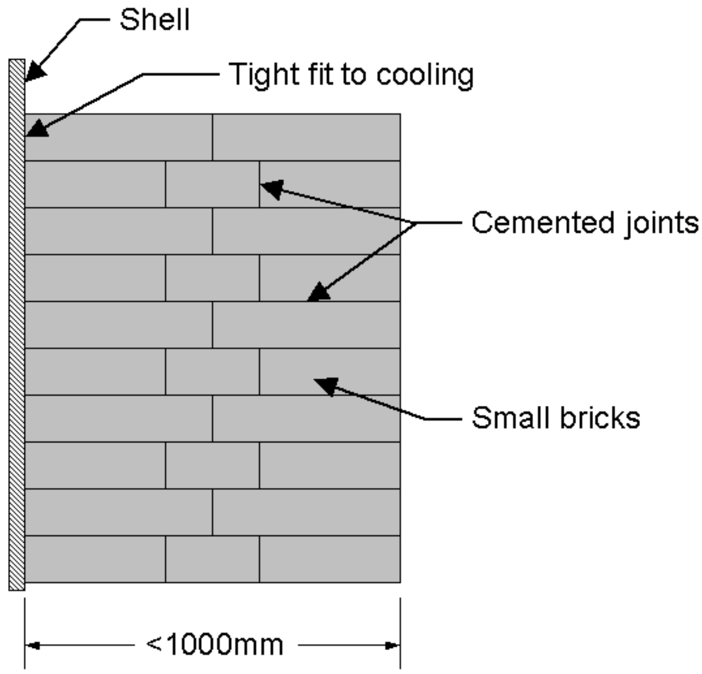

Figure 7. The UCAR® Refractory Concept hearth wall

1. The wall is thin compared to traditional block designs, typically less than one meter thick, which promotes more efficient heat transfer and lower temperatures at the hot face.

2. Small HotPressed™ bricks are used instead of large blocks. Small pieces have small expansion, and hot face rings can expand independently of cold face rings, reducing internal stress. It is NOT recommended to cut small pieces out of a large carbon block and refer to these as "bricks"; the properties of any baked carbon block is well known to vary from one end to the other, and from the center to the surface. Just as a chain is only as strong as its weakest link, all bricks in the hearth wall system must meet the highest standards. The HotPressed™ bricks have superior thermo-mechanical properties, and have proven their superiority in many long furnace hearth campaigns worldwide.

3. No ramming is required between the brick rings and the cooling elements (shell or stave). Ramming paste has poor conductivity compared to baked carbon refractories, and can over time become dry and granular or separate from the refractory, causing an interruption in heat transfer.

4. Special cement is used on all brick surfaces to fill the joints, bond bricks together, transfer heat, and most importantly, absorb expansion without creating stress. When these principles are followed, the hot face temperature of the hearth wall is below the freezing temperature of slag and iron, and a protective skull is formed on the face of the wall. The skull insulates the brick, pushing temperatures even lower, and protects the brick from iron contact and erosion.

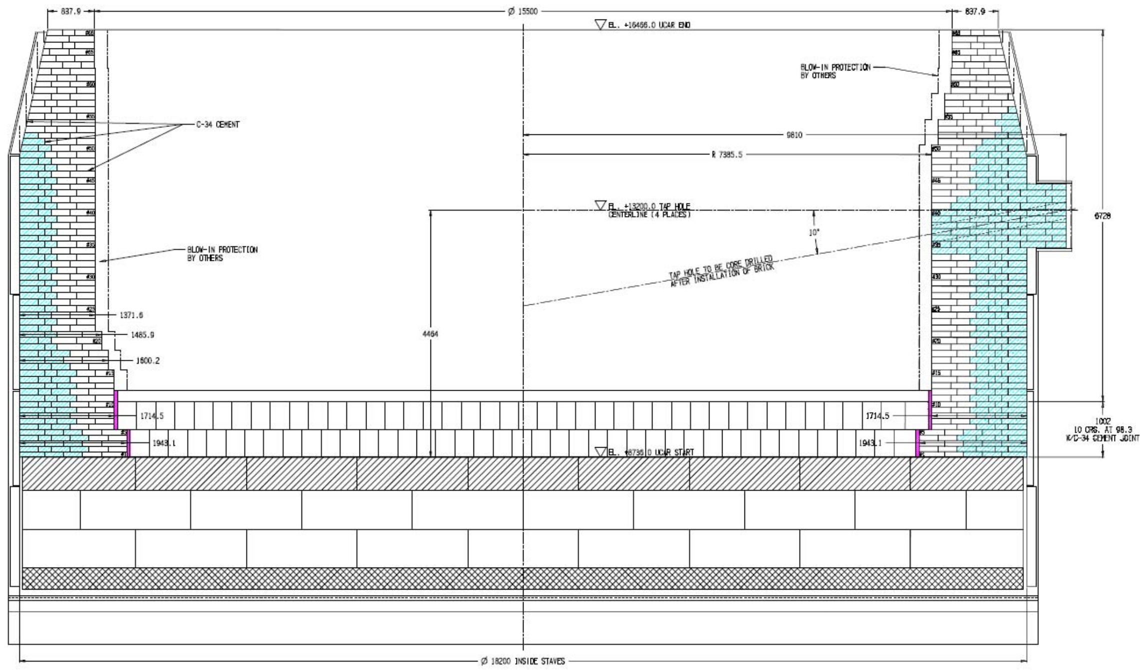

Figure 8. Shougang Jingtang #1 with a UCAR® hearth lining, NMA™ and NMD™ HotPressed™ bricks in the walls.

4. The Shougang blast furnace campaigns - the longest so far in China

The drawing in Figure 8 shows the hearth lining installed in the Shougang Jingtang #1 blast furnace in 2008. Shougang Jingtang is located in Caofeidian port in northern China's Hebei province and Jingtang #1 is an enormous 15.5 diameter high productivity iron making machine with an annual capacity of 4.5M tons. The furnace was commissioned in May 2009 and has a UCAR® hearth lining. As previously discussed, this decision was based on this furnace operator's long term experiences from achieving superior performance from this hearth lining product. These iron makers reported in March 2010 that they have broken the Chinese records on both service years and accumulated production per cubic meter working volume with three of their other blast furnaces**.** Installing HotPressed™ bricks in the hearths was obviously the right decision. Here are some more details about these record furnaces;

- Shougang #1 (2,536 m^3), blow-in August, 1994, Production: 12,500 MT/m^3. Operating at full speed.
- Shougang #3 (2,536 m^3), blow-in June, 1993, Production: 13,200 MT/m^3. Operating at full speed.
- Shougang #4 (2,100 m^3), blow in May, 1992. Stopped in December 2007, as the plant was required to move out of the city of Beijing. Production: 12,467 MT/m^3

In a paper published by Shougang in 2009 the authors conclude that:

"Shougang BF#1, #3 and #4 have all been operating safely for more than 15 years (#4 BF was forced to shut down due to the relocation). All these furnaces are still in good condition." They continue:

"The hearth lining design adopted UCAR® HotPressed™ bricks (NMA™, NMD™ bricks), which has excellent properties of thermal conductivity, anti-slag attack, anti-erosion from hot metal, and solve the problem of poor and unstable properties of domestic materials. In the mean time, the high thermal conductivity of small HotPressed™ bricks reduced the temperature gradient of the hearth bricks lining that together with the lining design and engineering reduced the lining damage caused by cracks or shrinking caused by thermal stress. This concept ensures the hearth security".

Shougang Jingtang plant plans to commission its second blast furnace and four converters during the second half of 2010. The new facilities will lift the company's total crude steel capacity to about 10M tones/year by the end of this year. BF #2 will have the same inner volume (5,500 m^3) as BF #1 and it will have a reliable UCAR® HotPressed™ hearth lining installed. Currently (August 2010), Shougang is running two hot strip mills with a total capacity of around 10M tones/year.

Figure 9. Baosteel #3 blow-in September 1994

Baosteel, another leading Chinese operator published a paper in 2009 regarding their 4,360 m^3 (WV) BF #3. This furnace was first blown-in 1994 and here are some of the key statements from the paper:

- "...the furnace has been in stable operation for over 14 years, accumulated iron production 50.75 million tons and a productivity of 11.66 MT/M^3, highest among the Baosteel blast furnaces..."
- "...the furnace hearth is in good condition and the sidewall temperatures are safe and under control..."
- "...since 2004 BF#3 has achieved a PCI rate exceeding 200kg/t continuously for 4 years with a productivity above 2.4. During November 2004 to April 2005, this number was above 2.6 and the record was broken in May 2005 with a productivity of 2.636..."
- "...with the current hearth condition, the campaign of BF #3 is expected to be ended after 18 years. That will result in an accumulated iron production exceeding 14,500MT/M^3. This will be a new record in China…"

The hearth refractories installed in BF #3 furnace in 1994 were HotPressed™ NMA™ and NMD™ Bricks and C34™ Cement in the hearth wall, combined with GradeD™ Carbon Blocks, RP4™ Ram and GrafTech graphite in the bottom.

Next in line of large iron makers in China that are reporting record campaigns and high productivity, is Benxi Iron and Steel Co. Ever increasing demand for higher productivity, combined with the need for increased campaign life, resulted in a decision to install their first UCAR® lining in BF #5 in 1991. The paper published at the 2009 ICSTI congress explained that the longest lining life, prior to this important step, had been 5.5 years, with worn carbon block linings showing the typical "elephant foot" profile, and with very little carbon left in the wall ("only 50mm"!). All four blast furnaces now have UCAR® hearth linings installed, including NMA™ and NMD™ bricks. The linings in #4 and #5 are now 11 and 13 years old respectively and are showing no signs of wear. Compare this with the previous carbon block campaigns and it is evident that Benxi is a very pleased furnace operator. In summary, the UCAR® hearth linings have proven to be a superior refractory solution for those operators that plan to push their large blast furnaces very hard for a very long time.

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5. Conclusions

Operating a blast furnace is an art. It takes many years to acquire the expertise to run a furnace at high productivity by balancing the ever changing parameters affecting the result. Much of the knowledge has been passed down through generations of iron makers around the world, learning from science, experience and each other. Many will claim that the most critical part of this large furnace is the hearth lining, as it many times determines the campaign length. Producing the iron, confident that the hearth lining will not let him down, allows the operator to concentrate on producing the metal required at the right specification and quantity. This paper describes the main differences between the two most common lining concepts used in blast furnaces today. It explains why the UCAR® freeze lining concept utilizing small and unique HotPressed™ bricks has proven to offer superior performance for many furnace operators around the world, including very large blast furnaces owned by Shougang and Baosteel in China. The authors would like to congratulate the Shougang as well as the Baosteel and Benxi iron makers to their record breaking achievements. GrafTech is pleased to have played a part in the achievements and will continue to provide dependable refractory products in to the future!

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