CAMPAIGN EXTENSIONS FOR FERROALLOY FURNACES WITH IMPROVED TAP HOLE REPAIR SYSTEM

C. Coetzee[1], P.L Duncanson[2], P. Sylven[3]

[1]GrafTech Refractory Systems, South-Africa, E-mail: colette.coetzee@graftech.co.za
[2]GrafTech Refractory Systems, US E-mail: Peter.Duncanson@graftech.com
[3]GrafTech Refractory Systems, Sweden, E-mail: Sylven@telia.com

ABSTRACT

Driven by the ever-increasing need for more cost effective and productive manufacturing methods, operators are re-evaluating traditional approaches to furnace relines. The ferroalloy industry is realizing that the small initial savings of conventional refractories are more than offset over time. Buying refractory systems which have proven to fail prematurely and which cause significant downtime for maintenance, especially around the tap holes, no longer makes economic sense. A new paradigm has emerged: install refractory systems and materials which ensure long life, reduce maintenance, and increase productive uptime. This articles revolves around the usage of the GrafTech ChillKote™ lining system not only for complete furnace relines, but especially for tap hole repairs. This campaign extending technology has been used with great success on worn big block carbon linings, ceramic insulated type linings as well as on rammed carbon linings. Examples from ferromanganese, silicomanganese and ferrochrome tap hole repairs will be explained in great details.

The ChillKote™ lining system combines effective furnace wall cooling with carbon and graphite refractories of higher thermal conductivities to "chill" the refractory lining by transferring heat from the furnace. This engineered combination lowers the temperature of the refractories to below that of the molten process materials. The fact that small HotPressed™ bricks are used, make the installation very flexible and greatly facilitates using this system for partial wall and tap hole repairs. The end result: extended campaign lives.

1 INTRODUCTION

For decades the Ferroalloy industry suffered with poor lining and tap hole performance. Typically, traditional insulated type linings gave lifetimes of 5-6 years, which included regular major tap hole repairs. Several of these furnaces, equipped with traditional refractory linings, had major break-outs putting personnel at risk and resulting in massive production losses. The aim of this paper is to give a brief overview of different types of linings and tap hole designs. The same phenomena was seen for big block carbon linings worldwide, where major breakouts were seen within the first 3-5 years of operation, especially on ferrochrome furnaces. The disadvantages of each technology will be discussed and how the GrafTech technology was used to rectify the problem. Section 2 will discuss the different types of lining technologies used in the ferroalloy industry and section 3 will give a brief overview of the GrafTech technology. Section 4 will show some case studies from the industry for various types of lining technology and failures. A more detailed overview of GrafTech's latest improved tap hole configuration will be supplied in section 5.

2 TYPICAL TYPES OF LINING DESIGN IN THE FERROALLOY INDUSTRY

Traditional submerged arc furnace linings consist of a variety of lining types and configurations. Often, these configurations consist of composite linings, comprised of combinations of amorphous carbon blocks, various types of ceramic bricks and carbonaceous ramming pastes of various compositions. The main types of lining technologies employed for ferromanganese, ferrosilicon, silicomanganese and ferrochrome furnaces are discussed in detail below.

2.1 Insulated type ceramic and rammed lining with and without water cooling

The actual configurations employed mostly comprise an "insulated" refractory concept. The wall philosophy utilizes a cold face ceramic lining, usually in combination with carbonaceous ramming paste or large size carbon blocks. Often, additional ceramic inner walls are utilized to contain the pastes or protect the carbon. In the bottom pad lining, the same concept of a cold face ceramic in combination with carbon paste or block is utilized, often with air convection cooling to protect the furnace bottom shell. All too often, operators of such furnaces have been forced to endure a variety of lining problems, degradation and wall and bottom breakouts. Productivity losses, high maintenance costs, production interruption and facility damage seriously hamper profitability and endanger personnel. However, certain concepts and philosophies that combine water cooling, highly thermal efficient carbonaceous refractories and traditional ceramic refractories into a lining-cooling "system" can be utilized to end these lining failures [1].

The lining "system" so configured utilizes low thermal resistance and water cooling to "super chill" the refractory hot face and thus retain an insulating layer of hot face ceramic refractories and solidify a protective layer of process slag and metal. This enables the lining system to achieve a true thermal equilibrium, and, thus, minimize heat losses and prevent lining degradation, refractory loss and provide long life.

This is possible because once thermal equilibrium is achieved refractory temperatures are maintained significantly cool to prevent chemical attack from occurring. Additionally, the protective accretion or "skull" of process slag and metal protects the refractory mass from thermal shock, abrasion and erosion. Contrast this situation with the conventional concept of utilizing thick refractory mass to outlast degradation and erosion in a "wear versus time" contest that all too often results in breakouts and high maintenance. Figure 1 illustrates the basic refractory configuration of an insulated type ceramic/rammed lining. The results of this lining type are: poor conductivity materials, long start-up, high temperatures, chemical attack, penetration and dissolution. These all inevitably to break-outs and the only benefit is initial cost.

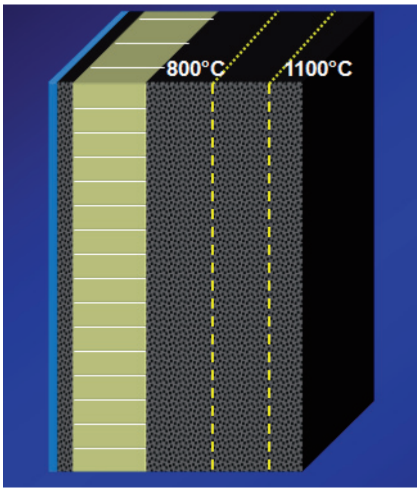

Figure 1: Insulated type ceramic and rammed lining with resultant isotherms

Figure 2 shows the same type of lining technology for a silicomanganese furnace, with figure 3 showing the resultant break out next to the tap hole. History has shown that break outs on ferromanganese furnaces occur mainly through the hearth of the furnaces due to lower resistance and longer electrode operation, whereas ferrochrome furnace break-out occurs mainly in the tap hole and areas across the electrodes. Drawing #2 is only for illustration purposes to indicate depicted hearth wear and not for a detailed refractory outlay. The PCD and power inputs also contribute significantly to the above mentioned failures, and with poor lining design contributing even more. Figure 3 also shows the typical metal penetration seen on a silicomanganese furnace designed in the 1970's not built on grillage beams. Severe penetration below the shell plate below the furnace can also be seen. Today all ferroalloy furnaces are being built on grillage beams with proper air convection cooling via fans.

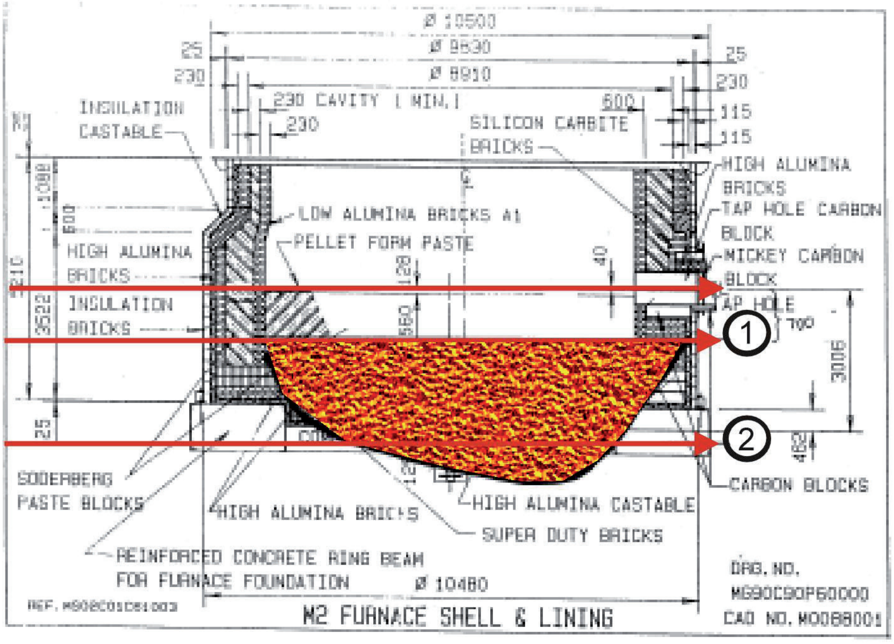

Figure 2: Typical silicomanganese furnace lining showing severe metal penetration in hearth

Figure 3: Break-out on a silicomanganese furnace next to tap hole

2.2 Big block carbon linings

Figure 4 shows the typical big block lining layout. This technology has been used extensively on ferroalloy furnaces, with resultant break-out occurring as early as 2 years after start-up. Big block linings are mostly water cooled, and, due to the relatively high thermal conductivity of the lining materials prior to installing and operation, are regarded as “freeze linings”. These linings typically consists of thick walls, long blocks, tight joints and a rammed annulus next to the furnace shell.

Sidewall problems can be traced to a combination of factors: lack of thermal expansion relief, high thermal gradients across the wall block and inability to accommodate differential thermal expansion. All of these factors promote cracks with subsequent metal and chemical attack. Attack of the wall by metal and chemicals most often is a result of the cracking problem.

Proper “freeze” lining wall design requires a high thermal conductivity refractory that will minimize thermal gradients through the wall, and, consequently, promote the formation of a protective layer of solidified materials on its hot face. Proper wall design incorporates provisions for radial thermal expansion of the wall, but, more importantly, it also incorporates provisions to accommodate differential thermal expansion. Differential expansion occurs because the wall hot face temperature is higher than the wall cold face temperature. This differential can be as high as 1700°C (3100°F), especially when an accretion of solidified materials is absent. As a result, the hot face of the wall grows at a faster rate than the cold face. The differential induces high stresses in the blocks which are restrained from bending or bowing. Typical cracks result parallel with the hot face.

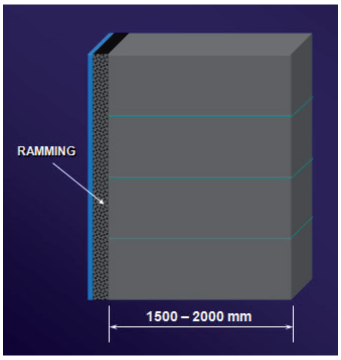

Figure 4: Typical big block lining configuration

Cracks interrupt the ability of large blocks to convey heat and facilitate cooling because each crack acts as an air gap which is a barrier to effective heat transfer. Once the ability to convey heat away is lost, the protective accretion can no longer form; and, therefore, carbon will be attacked by the metal and chemicals. This is because the carbon temperature will be above the critical reaction temperature for attack by these mechanisms [2].

In addition, the rammed layer required between the shell and the cold face of a large block carbon wall also insulates the carbon from the cooling system. This is because ramming materials shrink when cured and possess thermal conductivities that are significantly lower than baked carbon. The lower conductivity and shrinkage combine to provide additional barriers to heat transfer and result in high hot-face carbon temperatures above the solidification temperature so that skulls cannot form on block walls. So called micropore and even super micropore large carbon blocks are typically used in Europe and Asia in an attempt to increase the life of big block carbon walls. Because of differential expansion and bending, and close fit due to precision machining and the lack of thermal expansion provisions, these stronger blocks are prone to stress cracking, pinch spalling and thermal shock. Thermal shock is particularly size dependent. The larger the exposed hot face cross-section, the more likely thermal shock is to occur. Walls composed of smaller cross-section hot pressed pieces are unaffected by thermal shock.

Figures 5 show the above mentioned wear mechanism on a big block lining. Figure 6 shows the failure on a large FeMn furnace before being relined with GrafTech lining technology.

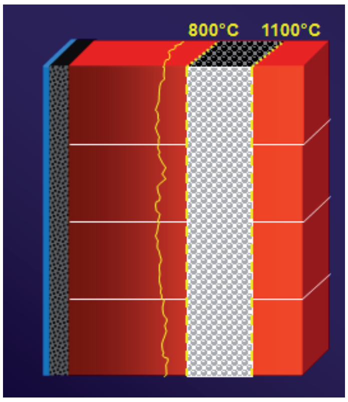

Figure 5: Big block lining where cracks allow penetration and lining cooling is prevented with resultant chemical attack.

Figure 6: Crack on big block lining on ferromanganese furnace

3 A DESCRIPTION OF THE GrafTech ChillKote™ LINING CONCEPT

The GrafTech ChillKote™ lining concept combines wall cooling and thermally conductive carbon and graphite refractories to "chill" the refractories by transferring heat away from the furnace lining [2]. Effective water sidewall cooling, together with the efficiency of the heat dissipating conductive refractories, lowers the temperature of the lining below that of the molten materials. This causes a layer of slag and process metal to solidify or "freeze" and forms a protective "skull" which completely coats the refractory hot face. Once formed, the slag skull insulates the refractories, reducing heat loss and protecting the lining from erosion, chemical attack, thermal shock, and other stresses. The result: extended life and greatly improved refractory performance.

The ChillKote™ lining concept allows significant reductions in lining thickness and mass. As a result, the working volume and capacity of the furnace is increased, installation and commissioning time is shortened, and profit-robbing downtime is reduced. The distance between the electrodes and the refractory wall is also increased. In addition, capital costs are lower. ChillKote™ linings combine engineering with low thermal resistant carbon, graphite, and semi-graphite materials with various ceramic refractories especially selected for thermal insulation, electrical insulation, and steel shell temperature control. Within a ChillKote™ lining, each component provides the properties required for its application and which work together in a cohesive system to enhance lining performance. An added advantage is that, should the protective skull be lost during upset conditions, self healing and the replacement of the skull will occur quickly due to the low refractory hot face temperature. GrafTech's proprietary Hot-pressed™ method of manufacturing produces carbon and semi-graphite refractories with low permeability, superior resistance to chemical attack, and outstanding and consistent thermal conductivity.

4 GrafTech TAPHOLE REPAIR CASE STUDIES TO IMPROVE LINING LIFETIME ON DIFFERENT TYPES OF LINING CONFIGURATIONS

4.1 Repair on a 48 MVA ferrochrome furnace with water cooled insulated type lining

This case study discusses a 48 MVA FeCr producing furnace with a 13m inner diameter. This furnace was originally built with a conventional lining as described in section 2.1.The furnace had to undergo an emergency repair in 2001 due to a tap hole burn through. The furnace operated well up to 2006, but after thermal scans showed very high temperatures in the tap hole area, it was decided to install a GrafTech type tap hole.

Before the installation commenced, a shell plate of approximately 3 x 3 m was cut out around the tap hole area. The burden was excavated and the area cleaned. In order to do a quality installation, the shell plate was sand blasted beforehand to remove all skull and dirt. Existing castable and ramming next to the proposed area of repair were left untouched. Figure 7 shows the design of the GrafTech type tap hole. Initially, building was supposed to commence 696mm below the tap block, but the plant only excavated material up to a level where the installer could fit in 1 course of carbon underneath the tap block. A leveling castable was poured underneath this layer of carbon to ensure a proper level was achieved to build on. GrafTech's CBY™ graphite tiles were put against the shell and HotPressed™ Bricks were used for the wall. See figure 8 below. GrafTech type GradeD™ carbon taphole block and lintels were also used.

In order to tie in with the existing lining, anchors were welded onto the shell and gunnited. Existing castable against the shell as well as carbon in front of the castable were installed again. Castable is a low conductivity material and would not be recommended for any type freeze lining. In this case, due to time limitations and instruction from customer, this was used to tie-in with the old lining.

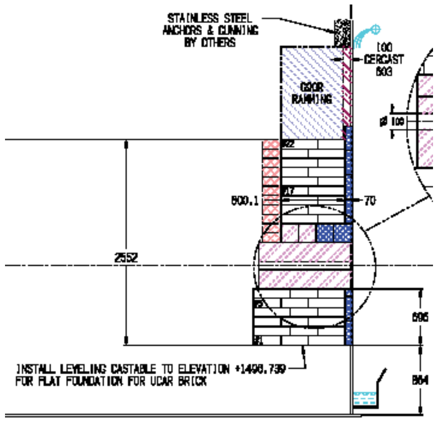

Figure 7: GrafTech tap hole configuration on a ferrochrome furnace

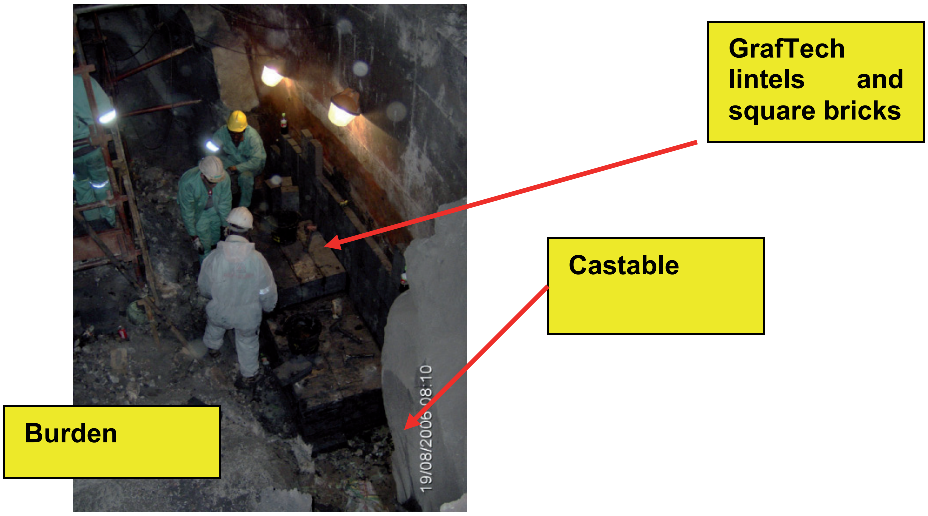

Figure 8: Area of repair

4.2 Repair on 75 MVA ferromanganese furnace with a big block type lining

This 75 MVA FeMn producing furnace has been built with a conventional big block lining as seen from the drawing below. The furnace has an inner diameter of 15500 mm and has two metal tap holes and one slag tap hole located 1 meter below the metal tap holes. During the last couple of years, the furnace had numerous problems with hot spots and the shell has lifted 80mm from the grillage beams. The furnace had more than one burn through at the slag tap hole, both at the top and bottom left side. The last time the slag tap hole had a breakout, electrode paste was loaded into the cavity above the tap block. Figure 9 below shows the slag tap hole after shell removal and excavation of burden. Very little of the big block lining was left on the sides of the tap hole. Graphite tiles and carbon bricks were used to tie into the little bit of what was left of the big block lining as shown in figure 10. The GrafTech repair resulted in this tap hole life being extended with another 3 years before complete furnace rebuild using the ChillKote™ lining technology.

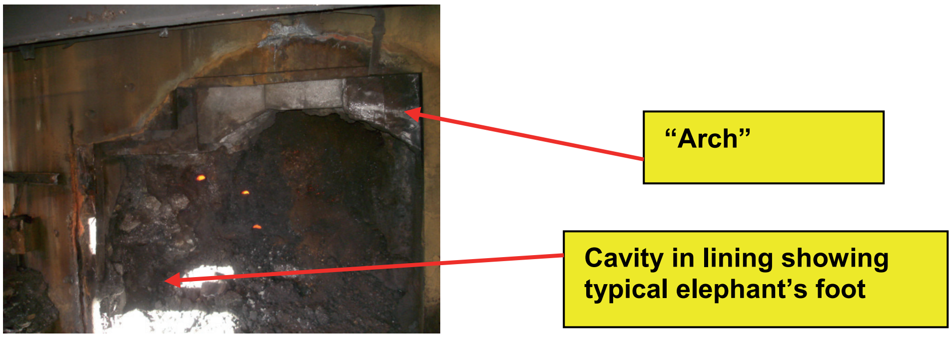

Figure 9: Area excavated before building

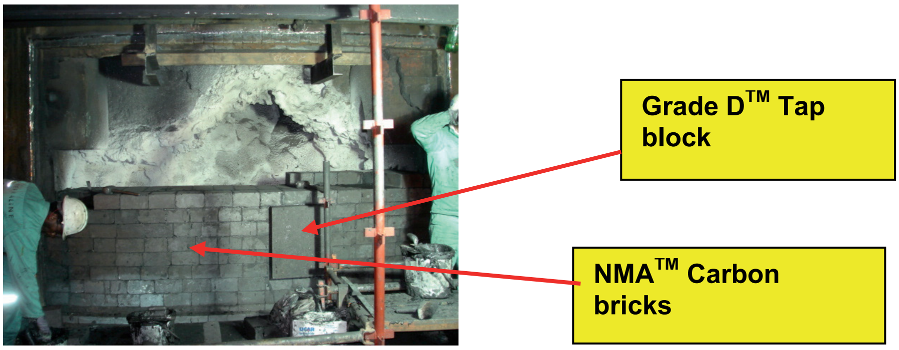

Figure 10: Building progress

4.3 Repair on 42 MVA furnace with GrafTech Freeze lining

This case study shows an actual repair done on 12m diameter FeCr furnace installed with a GrafTech freeze lining after 3.5 years. Figure 11 shows the original lining design and furnace dimensions. The furnace has shown exceptional performance since start-up with an average daily availability of 98%. During July 2007, a large repair was done in the tap hole area. This area has shown premature wear due to excessive lancing practices. The furnace was melted down properly and prepared for the repair to be made from the inside of the furnace. Though very little of the existing tap block was left over, the rest of the lining was in a superb condition. Most of the bricks in the abutment were still intact and no lifting of any sidewall bricks could be seen. This can be attributed to excellent water cooling on the furnace, good lining monitoring, stable metallurgical operation and electrode control, as well as the superior lining design and materials used. Figure 12 shows the tie-in on GrafTech materials with the existing sidewalls surrounding the tap hole area.

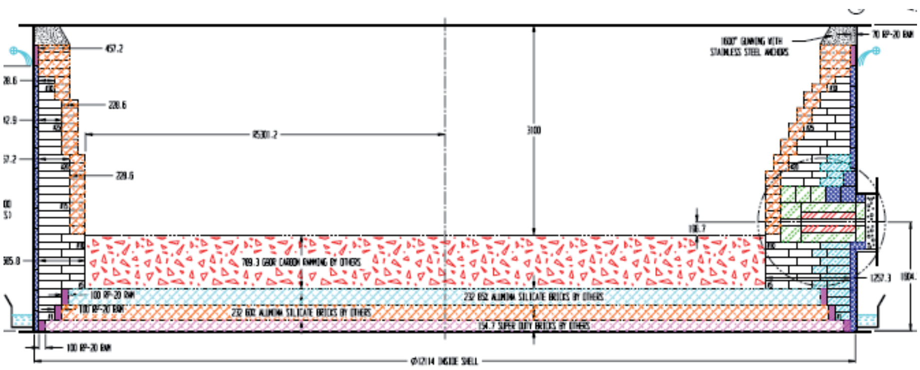

Figure 11: GrafTech ChillKote™ lining in a ferrochrome furnace

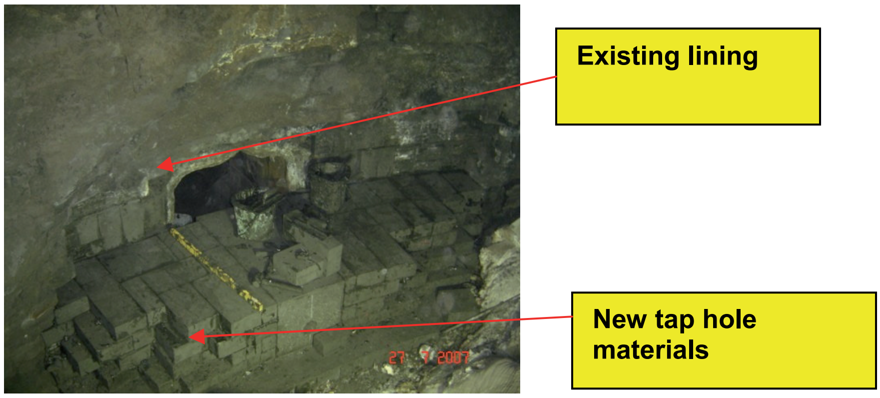

Figure 12: Tap hole abutment showing new tap block and bricks tying in with existing lining

5 GrafTech IMPROVED TAP HOLE CONFIGURATION

Even with a GrafTech ChillKote™ lining, tap holes will wear faster than the rest of the refractory lining, especially when tap hole procedures are unfavorable, e.g. excessive oxygen lancing. Tap hole repairs on any type furnace can take anywhere from a few hours to up to 3 weeks . To assist the operators with easier and faster tap block changes, GrafTech reconfigured the current tap hole to significantly shorten the repair times and prevent damage to surrounding areas. Figure 13 shows the improved tap hole configuration as seen from above. The tap block is split in 2, with surrounding side blocks preventing damage to the sidewall bricks during excavation. A rammed gap between the side blocks and actual tap hole also allows for less breaking and easier removal of the tap block. This new configuration was implemented first on FeCr furnaces with GrafTech linings in India during 2008 and today, all new ferroalloys furnaces, especially ferrochrome furnaces will utilize this new and improved configuration.

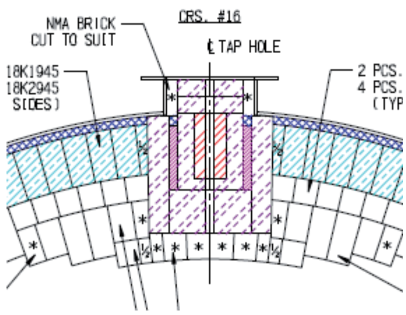

Figure 13: GrafTech improved tap hole configuration

6 CONCLUSION

An old furnace operator we know once said, “No tap hole, no furnace”. The tap hole is the most critical component of any furnace refractory lining. This paper discussed the reasons for failure of tap holes for different types of lining technologies and how these can be repaired using GrafTech technology. Case studies from industry illustrated how the ChillKote™ tap hole concept improved tap hole lifetime on various types of refractory linings. This lining concept has proven to provide improved life and performance in submerged arc furnace applications all over the world. ChillKote™ linings have been proven to perform far superior to conventional insulated carbon linings in ferromanganese, silicon-manganese and ferrochrome applications in Europe, India, Tasmania, South Africa and in North and South America. They result in low refractory temperatures, minimal heat loss and improved productivity, resulting in improved profitability. Lining thickness and composition can be configured to optimize performance potential, reduce capital expenditures, reduce re-line downtime, eliminate lining maintenance and improve safety and profitability [3].

7. REFERENCES

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