Refractory Considerations for Structural Components of Coreless Induction Melting Systems

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ABSTRACT

Coreless furnaces utilize a significant number of refractory-based structural components that are often overshadowed by the discussion of molten metal contact refractory materials. Structural components are seldom in contact with molten metal; these materials support the working lining and are critical for a successful melting operation. Structural components include upper and lower ring segments, push out blocks, coil grout, slip plane materials, as well as other furnace areas including the pour spout and cover.

This paper reviews the specific structural components utilized in coreless induction furnace refractory systems. The required mechanical properties and compositions required for each refractory item are discussed along with typical lining material selection used within each area.In cases where improper materials or component designs are utilized, the resulting lining performance is shown to be less than optimal. Improvements in refractory products and design considerations are also highlighted in several case studies.

Refractory requirements for upper and lower support rings of the coreless furnace

There are several factors for short lining life and for catastrophic events in coreless furnaces. Often the first thing most look for is defects in the working lining. Few consider how deep an impact the structural stability of the furnace is in determining the working lining performance, furnace operation and safety. The structural refractory components are designed with certain mechanical properties that make them ideal for supporting the furnace and the working lining. Important factors will be discussed in this paper.

STRUCTURAL COMPONENTS OF A CORELESS FURNACE

Figure A upper support ring

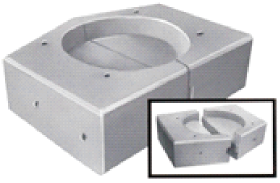


Figure B Lower support ring

Castable for structural blocks of the coreless Furnace

Castables used for structural integrity of the furnace require certain characteristics to provide the stability and resistance required. The most important properties to look for in this application are :

1. Strength
2. Volume stability
3. Ease of casting/placement
4. Ability to cast when mixing with 3% to 7% stainless steel fiber addition
5. Ease of drying
6. Good flexibility of water additions

Strength is important for castable material used to re-build or repair the rings on coreless furnaces. These rings experience impact due to charging and removal of worn linings. The castable rings also need to have high resistance to shearing. When the furnace pours metal, high tension develops on the support rings. As the furnaces gets older and the shunts start to loosen, this puts pressure on the rings to hold the furnace in place.

Volume stability is another major factor to consider when recommending a castable for this application. The rings of the furnace often experience severe thermal shock. The rings should last one to two years depending on the amount of re-lines that occur. Reducing the amount and severity of cracks will extend the lining life of the rings and provide stability for the top portion of the working lining. Cracking will reduce strength, provide an uneven surface for the refractory lining to expand against and contract and possibly will allow the unsintered refractory to leak.

Ease of casting is required depending on the size and type of furnace. Often there is a need to cast through very small openings. This requires a castable with good flow at low water additions. Long working times are often required for this type of installation.

The ability to cast with an addition of 3% to 7% stainless steel fibers is also necessary. Different furnace designs and capacities require the use of stainless steel needles to improve the strength, volume stability and thermal shock resistance. The steel fibers will stop the cracks from going deep into the refractory. They also provide very good strength for added support during the tilting of the furnace. As stainless steel fibers are added the flow of the castable will be greatly reduced. It is important to use a castable that is designed for good flow with SS needle additions.

Ease of drying is critical. If the blocks are cast in site it becomes very difficult to remove all the chemically combined water from the castable. If the castable retains large amounts of water after casting and drying then the castable will release large amounts of water during the first sinter of the working lining. This can cause a slow sinter heat, shut the furnace down due to grounding problems, can cause the castables to crack due to steam pressure and can cause condensation on the copper coils resulting in arcing.

Good flexibility of water usage is important due to the difficulty in casting some of the smaller sections of the rings. Most castables will start to lose strength properties after exceeding the maximum recommended water content. Higher additions of water results in lower strength, increased expansion and cracking and make drying the blocks very long and costly. To avoid these problems it is recommended to use a low moisture castable with additions of organic fibers for drying, and special additives that provide good flow at low water content.

Precast shapes are an alternative to casting in place. Precast shapes provide the foundry the ability to dry the blocks away from the furnace at higher temperatures for longer periods of time. The advantage is that blocks are constructed with minimum water content, the ability to completely dry the blocks prior to installation and fast turn around when blocks are replaced. Prefired shapes are the preferred method to reduce down time, eliminate moisture from the refractory system and to provide a smooth start-up of the furnace.

The proper construction and dry-out of the top and bottom support rings cannot be overstated. These blocks play a vital role in the performance of the lining and safe operation of the furnace. The following are some case studies of poor upper and lower ring construction and the effect on lining life :

Figure C

Figure D

Foundry A is a large automotive plant with 2 – 23 mt coreless furnaces for melting ductile iron. Furnaces were installed new, but after just 1 month of operation castable upper rings became damaged. Ring were made from conventional 90% alumina castable from a local manufacturer. The lining lasted run for 80 to 100 heats before showing ground. Personnel removed the top cap to find that metal had penetrated the cracks in the upper 1/3 of the furnace. Repairs had to be made to the upper rings and the grout in the top portion of the furnace. This caused delayed sinter and slow initial melt times due to reduced power caused by ground fault. It was determined that cracking was due to insufficient structure of the upper support castable ring. The Allied Mineral Products proposed a new material better suited for the application and a new design.

The castable was changed from a high alumina to a mullite based low cement castabe. The ring was constructed with 4 different sections. The two side sections used an addition of 3.5% 310 SS needles of varying lengths. The pouring spout and del sagging spout sections used 7% 310 SS needles of varying lengths. By changing the material used, by adding stainless steel fibers for improved thermal shock and by modifying the design of the upper rings, foundry A now achieves two years life from the upper rings with minimal cracking and no effect to the working lining. Foundry A was able to increase the lining life from 80 heats to 200 heats. Most important was decreased down time, reducing repairs required to the coil due to metal penatration and increased safety of operation.

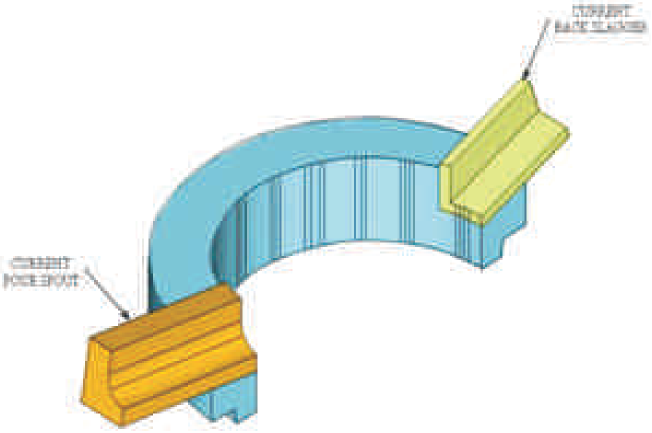


Figure E

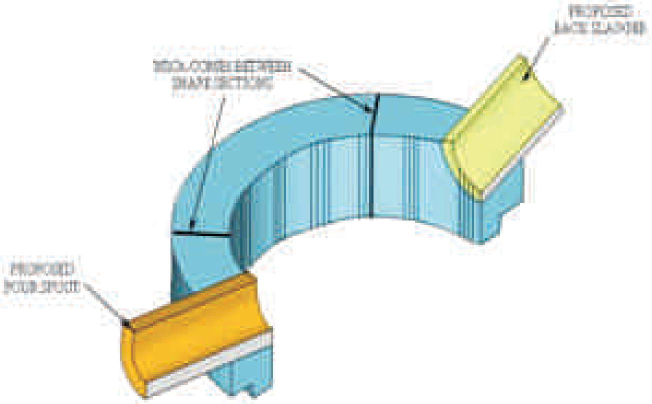


Figure F

GROUT

Figure G Proper Selection of Grout

Grout is another area that most coreless melting shops overlook. This is a key component to the success of any lining used. If the grout is not properly installed and maintained, many types of lining problems can occur. Foundries often use a conventional castable designed for use in ladles. The user will often sift the coarse grains from the castable, mix the refractory, and apply the finer material as coil grout. This is not a proper proceedure and can result in short lining life and difficulties when sintering new linings. These products are designed for high temperature applications. They contain very high amounts of calcium aluminate cements. This forms multiple hydrates and will not allow moisture to evacuate from a castable until at least 45°C. Furnace coils are not recommended to operate higher than 15°C temperature the epoxy and insulation on the coils will begin to burn. Allied Mineral Products recommends materials that are meant for coating coils only. They are specifically designed for use at lower temperatures yet still have the ability to stop molten metal if penetration occurs. There are several advantages of grouts over standard castable for this application.

1. Grout contains binders and additives that allow the material to be applied by hand smoothly without slumping. When viewing the coils that use standard castables, you will note very uneven surfaces and often see the contour of the coils at each turn. This uneven surface can shorten lining life and create a potentially dangerous condition. The lining whether silica or high alumina needs a smooth tapered surface. When the furnace is heated and cooled the lining will expand and contract. If the coil grout is not smooth the working lining can hang up during this expansion and/or contraction and cause the lining to crack or spall. All refractory will crack during heating and cooling and will seal again with proper cold start procedures. However, if the cracks occur due to hanging up on the coil grout (tensile stress) they will not seal and leave a potential area for metal penetration causing the lining to fail, possible damage to coils and putting worker health and safety in danger. Using a proper coil grout is quite possibly the second most important component to the coreless furnace after the working lining.

2. Grout has organic fiber additions that allow the grout to dry faster with less cracking. Use of conventional castables will again have very high CaO (Cement), causing the grout to hold the chemically combined water for a longer periods of time and to a higher temperature. This remaining water results in ground detection problems, cracking due to excess steam pressure and lower strength. The repairs after each reline on castable vs a Grout material is quite high.

3. Allied's grout contains very low amounts of CaO to allow for easier and lower temperature drying. Grout is designed to have high strength at 250°C, designed to give up the chemically combined water with greater ease and designed to stick to the coil during application.

4. Grout can also contain a special ceramic fiber that provides even greater strength and volume stability. These ceramic fibers hold the grout together during operation of the furnace and during repairs and replacement of linings. High powered coils create substantial vibration. This vibration can and will begin to crack the grout over time. Allied Mineral Products designs grout specifically for this application. The ceramic fibers hold the grout together providing a more stable and stronger grout lining.

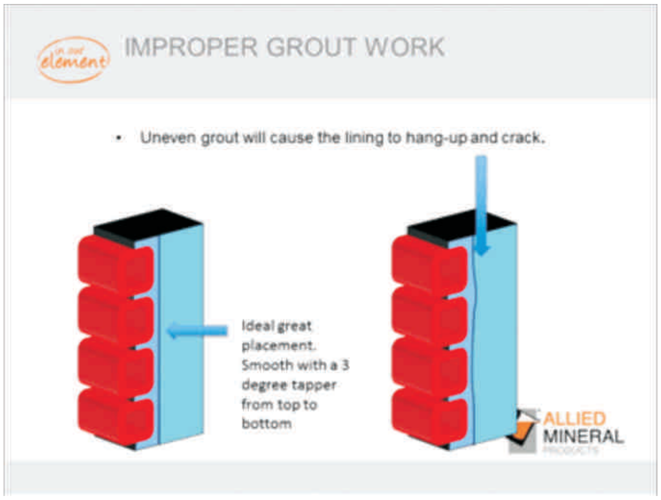
5. Grout has special additions that gives the material some stickiness. This allows the grout to be applied to the coils with minimal waste (fallen material) and allows the applicator to apply the grout smoothly. Grout has very good working times, so the operator can apply carefully and maintain a concentric cylinder.

Using a proper grout material is one of the most critical components to the safe and consistent operation of the working lining. Whether using silica, alumina or magnesia, the quality of the grout, the quality of the grout installation and the proper curing and drying of the grout will have a profound effect on the lining life of the working lining and the safe operation of the furnace. Below is an example of poor grout condition that had a negative impact on the lining life, operation of the furnace and safety to the equipment and the operators.

In **Figure H** you can see that the furnace has an improper transition of the upper ring to the grout surface. This has resulted in a ledge being created at the area where the two come together. The resulting ledge has restricted the movement of the working lining during heating and cooling. During heating and cooling of the working lining

Figure H Ledge between the coil grout and the upper ring

Figure I Cracking as the result of the lining hanging up the refractory will expand and contract in a vertical plane. Any irregularity in the surface of the grout or the rings can cause the lining to hang-up during this process resulting in horizontal and random cracking due to stress. This type of cracking is the result of mechanical stress and will not seal upon re-heating. This can lead to metal penetration and possible damage to the furnace and put operators in harm. **Figure I** is the result of this improper construction of the grout and rings. The top portion of the lining could not contract naturally once cooled. This resulted in severe metal penetration in the top portion of the furnace. Not only did this create long and frequent down time but also damaged the top block. **Figure J** below also illustrates the need for a smooth grout surface. A smooth grout surface is very difficult with a standard conventional castable. It can only be achieved consistently with a refractory designed specifically for coil coating.



IMPROPER GROUT WORK

- Uneven grout will cause the lining to hang-up and crack.

Figure J

PUSH OUT PLUG FOR AUTOMATIC LINING REMOVAL

Castable blocks used to extract linings from coreless furnaces are a common source for lining problems, mainly associated with the floor and taper section. These castable blocks are cast from conventional or low cement castable. Blocks are often overlooked as an issue with working lining material due to the position and limited function it has with the furnace. These blocks do however contain very high amounts of water. The water must be removed before use for various reasons. Depending on the castable used, drying will give the proper strength needed to resist damage during lining removal. These plugs often fall out of the furnace with the lining, causing damage from impacting the floor. They also need to be dried to prevent moisture from penetrating the working lining on the initial heat. Water in the refractory can cause spalling of the refractory, saturation of the refractory and in some cases growth. Drying the push out plug will ensure safe operation of the furnace and provide a more consistent lining life. The following is an example of one foundry that did not dry the plug and the results.

The photograph in fgure K is an example of one foundry that never considered drying the push out plug. There reasoning was that the moisture will be driven down and away from the working lining. Although that may be true in principle but at the initial stages of the sinter temperatures are not high enough and the steam rises before higher temperature and pressure force it down. This is a 10mt furnace for melting iron. In every new lining approximately 2" of the lining would spall resulting in an early patch and lower lining life. It was found that the steam generated by the push out plug was forcing the top layer of the refractory to peel off. The foundry was given a controlled sinter cycle for drying the plug before use. After the proper process was followed the spalling was eliminated.

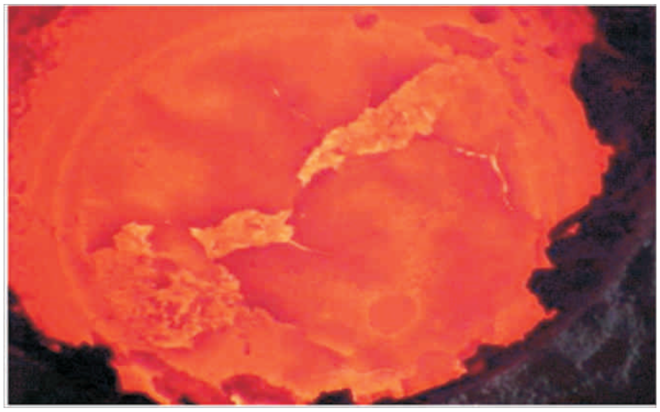


Figure K

Any moisture left in the structural components can react with the refractory matrix or the bonding system and cause early lining failure or worse, catastrophic failure. Had this foundry practiced liquid sintering the results could have been much worse.

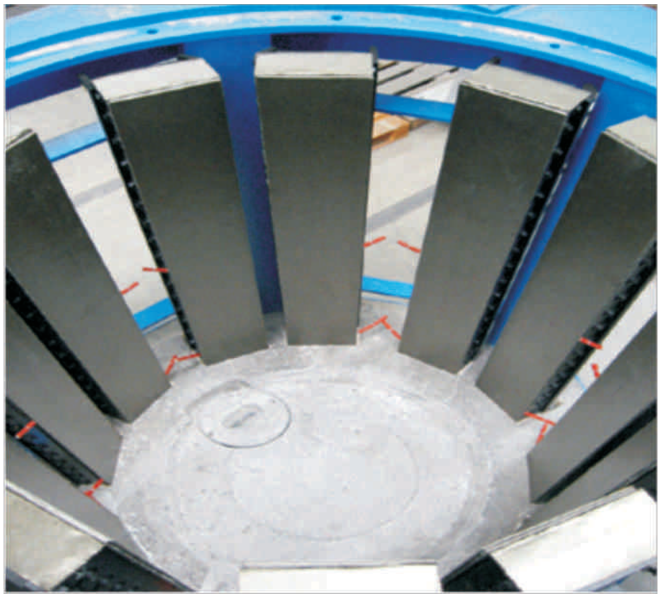


Figure l

The Yokes/Shunts

The Yokes and Shunts consist of stacked columns of thin strips of highly magnetic silicon steel held in compression by stainless steel clamps.

Function of the Yokes and Shunts

1. Acts as an efficient electromagnetic flux return path preventing the field from coupling and heating the furnace steel shell

2. Provides mechanical support for the coil assembly, refractory system and charge. These components are sized to carry the electromagnetic field without saturating and also to minimize hysteresis loss. The thin strips are insulated from each other so that they act as individual loads and are so thin that eddy currents cannot be efficiently induced.

Figure L

The Yoke and shunts will have a very negative impact on the working lining if not properly maintained and adjusted. If the Yokes and the Shunts become loose, the coil is no longer under sufficient pressure and can move or expand. As the coil shifts this movement will cause severe cracking of the working lining. The resulting cracks caused by loose Yokes and Shunts will never seal upon re-heating. These cracks are a potential source of metal penetration and/or catastrophic furnace failure.

Yokes and Shunts need to be adjusted and tightened according to the furnace manufacturer recommendation. This should be part of the foundries' monthly preventative maintenance program. At that time, the condition of the laminations of silicon steel that make up the yokes should be checked to ensure they are not conducting electricity. Any deformation or separation of the laminations can cause the furnace to lose melting efficiencies. This also can have a negative impact on the working lining of the coreless furnace.

When the insulation between the laminate layers of silicon steel break down they lose the ability to contain the metal flux lines within the furnace. This allows the electromagnetic flux lines to extend outside the furnace. This results in several severe issues effecting the furnace, but also having a negative effect on the refractory working lining. The following are the results of such breakdown in the construction of the yokes and shunts :

1. The furnace will require greater energy input to melt a ton of metal.
2. There is the possibility that the structure of the furnace can now draw power and heat up. This can cause costly damage to the equipment.
3. Can cause hot spots within the working lining and active melt zone.

These hot spots that are created in the active melt zone will affect the working lining refractory in a number of ways. These hot spots are not isolated to the metal - they are also transferred to the refractory. These hot spots can cause the following problems.

1. Faster erosion in the area of the hot spot. The higher the temperature the faster is the erosion of any refractory material. These hot spots will cause the refractory to erode in isolated areas of the lining while other areas remain in good condition.

2. Due to the loss of energy the furnace now requires more power in order to melt. The increase in power will also increase the stirring effect of the furnace. This additional force created due to the higher stirring action will also prematurely erode the lining material.
3. Can cause differential expansion which leads to cracking. As an isolated area is heated more than the surrounding area there is a potential for the material to expand or contract differently. This can result in random cracking and eventual penetration of the lining. The two pictures below will give a good indication of the strain the yokes and shunts are exposed to.

The yokes and the shunts need to maintained and replaced on a regular basis in order to maintain the efficiency of the melting furnace, but is also important for the longevity and safety of the refractory working lining.

Figure M represents new yokes and shunts

Coreloss (Hysteresis Heating) is the straining of the grains in the laminations trying to allgned themselves with the field. Since the field is AC frictional forces are generated within the laminations. Heat removal and brackets/clamping method can reduce this problem.

Figure N represents shunts and yokes that have not been maintained properly

Below is a case study of one foundry that experienced a sudden runout. Immediately their attention turned to the refractory quality. After a lengthy investigation by the customer, Allied Mineral Products Technical Team and the Furnace manufacturer, the problem was determined to be loose shunts.

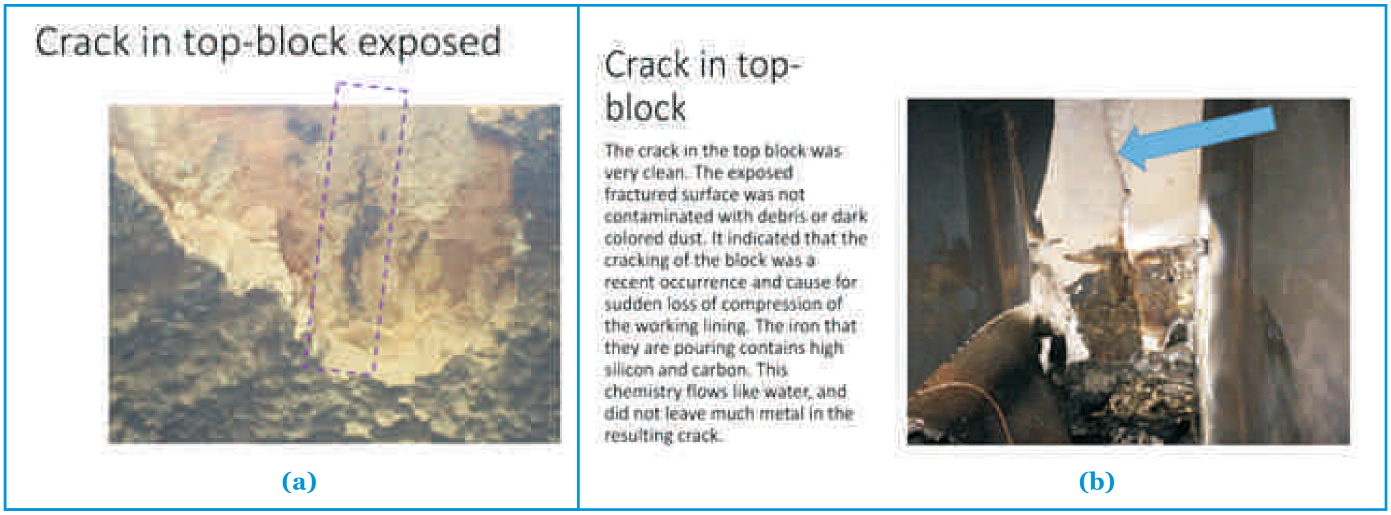
Foundry D operates a 5mt coreless furnace for melting iron. Recently the furnace experienced a sudden and unexpected runout in the top of the furnace. Lining was running great, no GLD notifications, no increase energy consumption and no signs of a problem. Suddenly metal ran through at 3 O'clock position .

(a)

(b)

Fig O (a) Metal Run Out **Fig O (b)** Metal Run Out

The exit point of the metal was directly behind the expected problem area.



The crack in the top block was very clean. The exposed fractured surface was not contaminated with debris or dark colored dust. It indicated that the cracking of the block was a recent occurrence and cause for sudden loss of compression of the working lining. The iron that they are pouring contains high silicon and carbon. This chemistry flows like water, and did not leave much metal in the resulting crack.

(a) (b)

Fig. P (a,b) : Cracks in Top Block

After removing the top portion of the silica lining a crack in the upper support block was noticed. This crack had not been seen during the lining of the furnace.

Once the refractory had been completely removed the crack on the inside of the upper block was inspected. The crack was found to be very clean and newly formed. The OEM checked the shunts and found they were loose.

It was the conclusion of the OEM, the customer and Allied Mineral Products that the shunts had loosened to a point that the lining shifted, cracking the top block and the top portion of the refractory. Shunts were tightened according to OEM specifications. They were found to be very loose. Top Block was replaced and the furnace has been back in service for months with no issues.

CONCLUSION

It is very important to keep in mind that there are many factors that affect lining life. Most operators only consider the type or quality of the working lining, but if the furnace is not constructed with good structural refractories, then lining life and safety are compromised. By ensuring the right products are used for the structural blocks and grout and by ensuring the materials are installed and dried correctly the effect is longer and safer lining life for the working lining. By including frequent inspection of the shunts and yokes into the monthly preventative maintenance plan, the foundry can avoid working lining issues related to stray electromagnetic flux lines. The vast majority of the time, working linings do not fail due to quality issues, they fail due to an external force or problems in the operational process.