Innovative Refractory Technology for Coreless Induction Furnaces

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Abstract

In recent years, there has been industry pressure to provide larger and more powerful coreless induction furnaces for melting both iron and steel alloys. Production demands and electrical costs have driven many foundries and steel mills to invest in larger, faster, and more flexible batch melting furnaces. These technological advancements in induction furnaces have put a greater demand on refractory suppliers to provide innovative advancements in both acid and neutral based refractory for these applications.

This paper will discuss a completely new generation of refractories and address care of structural components, installation, sintering and optimal operation of coreless induction furnaces to significantly improve the lining life. This reduces total melting costs while providing great consistency in refractory lining performance.

Specific case studies where new technology refractories have been used will be referenced, and an overview of refractory properties and compositions that are best applied in specific melting applications will be provided.

Silica-Based Refractories for Iron and Steel Melting

Silica-based refractories have long been the standard for foundries using coreless furnaces to melt iron and iron alloys. Traditional lining materials include a high purity silica aggregate with a boron-based, heat-set binder, generally in the form of either boron oxide or boric acid. In the past, this binder was mixed on site at the foundry, prior to installation. Technological advancements then allowed the binder additives to be pre-mixed by the refractory producer and shipped to the foundry in a ready-to-use form. Silica-based refractories have essentially maintained the same composition for the past several decades, with only minor design changes and mineral additions.

Figure 1 – Iron melting coreless furnace with silica lining

Silica-based linings have many advantages for the traditional foundry:

- Low cost mineral base (in comparison to alumina-based/neutral refractories).
- Non-wetting to iron and to most iron slag compositions.
- Excellent thermal expansion properties for batch melting operations, limiting metal penetration through thermal cracks.
- Refractory-grade silica deposits are in multiple sites around the world.
- Silica-based refractories can also be used in copper alloy melting furnaces and furnaces melting some grades of steel alloys.

While silica-based refractories have many advantages, there are some deficiencies in the product range:

- The silica grain can be reduced by some common alloying elements at metal melting temperatures.
- Rapid bottom erosion (known as elephant's foot erosion) due to mechanical, chemical, and thermal factors occurs during the production of ductile iron, limiting lining life.
- Naturally high acidity of silica results in chemical erosion of lining when exposed to basic slags.
- Mineral transformation and subsequent expansion that occurs with silica (quartz transformation to tridymite) around 870°C extends sinter time during startup.

Technological Advancement in Silica Linings

A new range of silica based lining materials (Reference Figure 1) has been developed utilizing advanced large grain technology (ALGT). The material employs a grain size of up to 12 mm in diameter, which is 60 to 100% larger than the maximum grain sizing of traditional silica-based refractories. The increased grain sizing results in a substantial reduction in the total surface area of the refractory grains, and combined with new binding technology, provides a more effective and repeatable sinter process. Additional benefits of the new technology are as follows:

- Large grains provide better particle packing, resulting in increased installed density of the lining.
- Improved abrasion resistance in service at metal melting temperature.
- Binder system designed for liquid sintering of larger furnaces.

Case Studies for Improved Silica Linings

Foundry A operates 3 coreless furnaces with a capacity of 7 MT each. Installation utilizes traditional form vibration and sintering is completed with liquid metal charging. This foundry produces normal grades of iron, as well as special grades melted above 1600°C. This special iron production results in rapid, unpredictable erosion in the bottom of the furnace.

Results at Foundry A: Silica linings with ALGT have been installed for the complete lining, resulting in a 10 to 20% increase in lining life over traditional silica for regular iron production. However, for the high temperature special iron alloy production, an increase of up to 50% has been achieved due to better sintering properties and increased abrasion resistance of the ALGT silica lining in the taper and bottom section of the furnace.

Foundry B is a large automotive foundry melting traditional gray and ductile iron in medium frequency coreless furnaces. The facility operates multiple 3 MT and 5 MT furnaces on a single 12-hour shift resulting in daily thermal cycling of the lining. The foundry already achieves excellent lining results of 350 heats per lining with minor repairs to the floor, taper and top cap.

Results at Foundry B: A silica lining with ALGT has been used for the complete lining, resulting in a record campaign of 675 heats with one minor patch of the floor and taper area. All furnace linings have been successfully converted to take advantage of the extended campaign life.

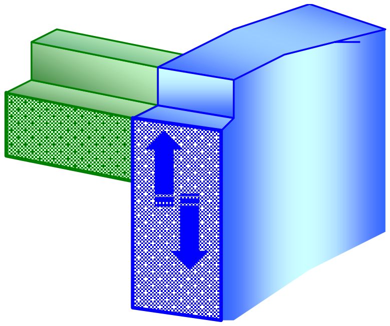
Structural components (Top and Bottom Blocks/Spout/Grout) of coreless induction furnace: To achieve consistent lining life of coreless induction furnaces, these play very important roles.

- **A-Top/Bottom Blocks:** Need to check every time before lining to make sure it has tightened properly and in good shape/condition.

Figure 2 - Bottom block cracked

Bad Condition of both top and bottom blocks (Reference Figure 2) directly affects the performance of lining life. If it is cracked and not tightened properly, it creates impact on lining during operation (tilting) and results in lining cracks and leads to metal fining in lining through cracks.

- **B-Spout:** Always Install the Spout before the main lining (Reference Figure 3/5/6). It is important to maintain the vertical plan Refractory, to allow free movement, minimizing cracks and penetrations below the spout.



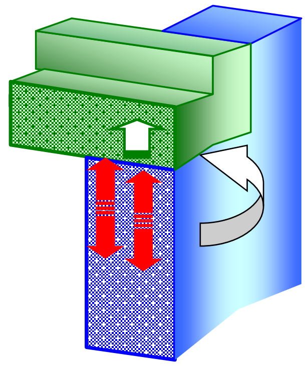


Figure 3 - Correct Spout Installation Procedure

Figure 4 - Incorrect Spout Installation Procedure

Figure 5 - Installed Spout with SP 83CR

Figure 6 - Installed Spout with A 7055

It is incorrect procedure to install the spout above the working lining (Reference Figure 4) which inhibits the free movement of the working lining and adds stress that results in cracks and metal penetration.

- **C- Coil Grout:**
  - Must be smooth and concentric to allow the lining to expand and contract freely and avoid hang up of lining which leads to cracks and eventual metal fining.
  - Should be strong enough to hold well upon lining demolition
  - Before installing the refractory, make sure the grout is completely dry.

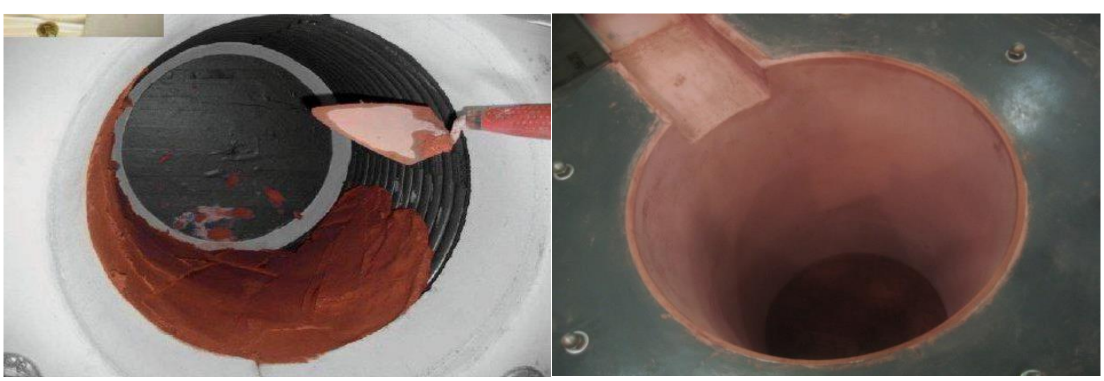


Figure 7 - New generation pigmented Coil Grout 563

Pigmented grout (Reference Figure 7) gives a visual reference between the lining and the grout to avoid damage during manual removal of old refractory. Specially designed fine-grain products allow 100% use, low shrinkage after air set and require less water and demonstrate easy dry out and high strength.

- **SLIP PLANE:** Use a good quality SLIP PLANE between working lining and coil grout, i.e., Mica sheet (Reference Figure-8). The Mica sheet should be adhered properly to the grout; there should be no space between the mica sheet and grout. Secure the mica with quality adhesive tape. Never use adhesive like sodium silicate or fevicol to secure mica sheet with grout.

Figure 8 - Mica Sheet Installation

- **FORM:** One of the important components which plays a vital role in determining the lining life of the coreless furnace.
    - Adequate thickness of form is preferred and varies as furnace capacity increases.
    - The form should be designed to maintain its integrity for as long as possible, avoiding localized deformation (Reference Figure 9) which could impair the density and saturation of the metal or promote slag.
    - A thin sheet former might be damaged before hot face formation, thus reducing lining life. This will be good enough for taking the vibrator.

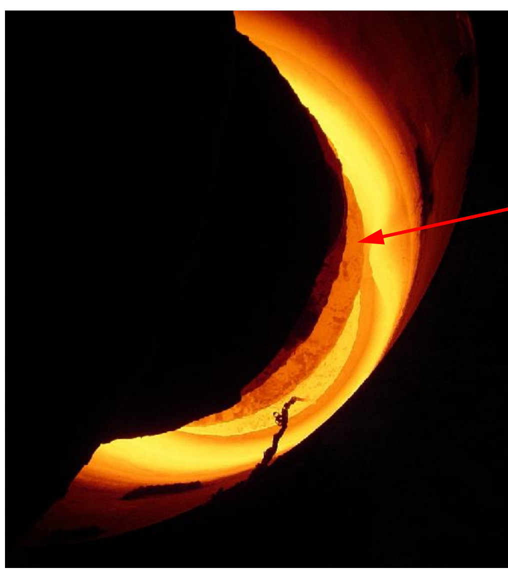


Figure 9 - Deformation of Former

Refractory Alternatives in the Top Cap Area:

There are many ways to make a top cap (Reference Figure 10) and many kinds of materials that can be used. Our recommendation is always what will be safest and work longest. Different operations and conditions require different materials.

Most customers do not use anything special for the top cap. The typical procedure is mixing sodium silicate with whatever they are using. Since most facilities use silica, they do not mind remaking the top cap every day. They must do shave repairs after every 15 to 20 heats, so this does not present a problem. This is the same with local MgO lining users.

We recommend a top cap material with a long life for steel and iron melting. We aim to extend the life of the entire lining, and to achieve this, we must use an equally high-quality material for the top cap. This is the difference between running 15 heats and running 100 heats.

Although several different products can be used for the top cap, we generally recommend a dry material. There are many reasons that dry is better than a wet material.

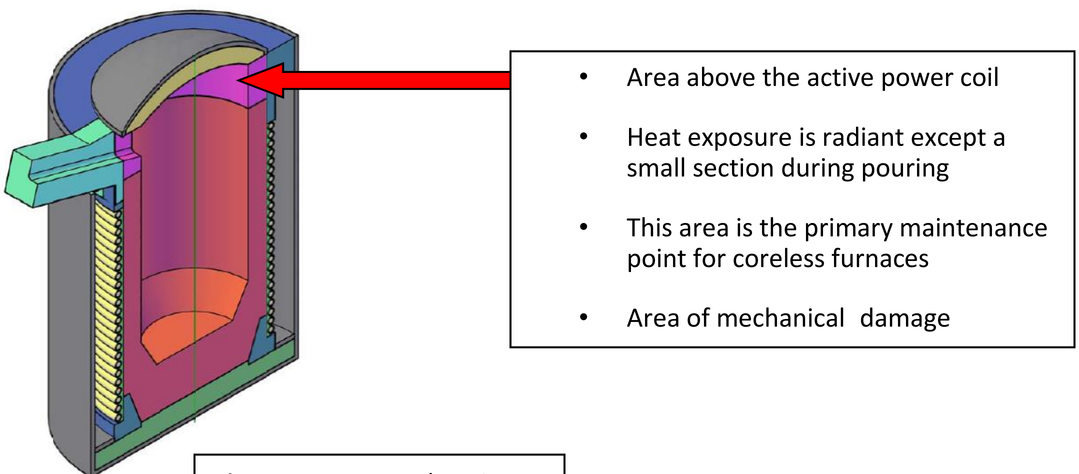


Figure 10 - Top cap location

Exposure Conditions: Impact from charge; thermal shock cracking (temperature difference); separation of top cap lining from primary lining.

Temperature Difference / Separation: Large pollution systems cause a difference in temperature at the top of the furnace (Reference Figure 11). Large temperature differences result in cracking and seam separation. Different material classifications and minerals do not always bond completely (Reference Figure 12).

Figure-11 Temperature difference

Figure-12 Separation

<u>ADVANTAGES OF DRY TOP CAP MATERIALS **(DV 231XB for Iron / DV 493 for Steel)**:</u>

1. Easy to install. Material is installed using the same method as the working lining.
2. No separation plane between the working lining and the top cap. This greatly reduces the chance of metal penetration between the working lining and top cap, especially when the operation requires the furnace to be heated and cooled repeatedly during campaigns.
3. Products are stronger than mixing the lining material with sodium silicate.
4. Higher resistance to erosion caused by chemical attack. Sodium silicate is a glass binder and will begin to deteriorate at high temperatures.
5. Dry materials are more volume stable and will not expand and grow due to hydration of the refractory. When mixing material with sodium silicate, you add almost 25% water. The bond in silica will absorb this moisture and grow, often lifting the top cap material a few inches over the top of the upper castable ring. This problem worsens on linings with MgO; MgO hydrates easily and growth can be quite high, especially during the heating of the furnace. MIXING SPINEL BONDED OR PURE MgO LININGS WITH SODIUM SILICATE IS NOT RECOMMENDED.
6. No pre-drying required since there is no moisture in the material.
7. No hanging up of lining during heating and cooling as the lining and top cap are one monolithic part and will move together. Plastic top caps will expand and, once cooled, the working lining will drop down and the plastic will remain stationary. This creates a gap between the working lining and top cap that must be patched with each heat (Not a problem if the furnace runs continuously).

Sintering of lining:

- For proper sintering, always use K-Type thermocouples to achieve desired sintered lining.
- The end point of k-type thermocouples should touch the form to get an accurate temperature reading.
- Do not steps out the holding temperature period given in sintering procedure.
- If possible, use ceramic blanket to cover the furnace top until melting starts. This will help achieve a properly sintered lining from the bottom to the top of the furnace.
- Always fill the furnace to the top during sintering heat (Reference Figure 13/14).

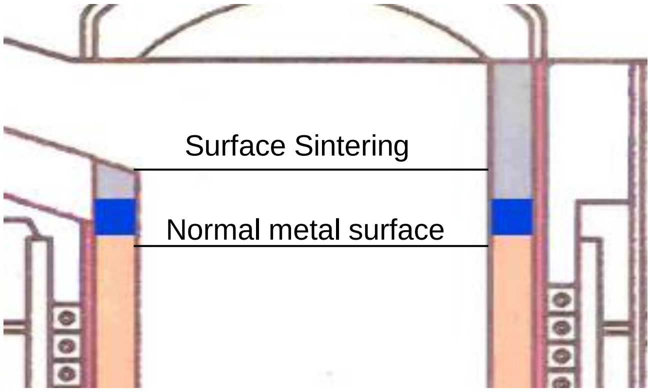


Figure 13 - Schematic Sintering / Normal heat metal level

Cool Down Practice:

- Best practices in cooling down minimize the depth and size of thermal cracks. When cooling down of a lining is necessary, rapid or forced cooling is the preferred method <u>(Reference Figure 15)</u>
- Rapid cool down creates numerous small and shallow hot surface cracks which will close quickly upon subsequent reheating. This will eliminate the fewer large, vertical cracks that occur in “slow” cooling.
- Rapid cooling balances the rate of heat loss at the hot face and the coil side of the lining, resulting in a reduction of stress planes in the lining.
- A fan/air hose should be placed at the opposite side of spout to allow air flow down the sidewall, across the floor and up to the spout side.
- An Alternative to rapid cooling is keeping the lining temperature above 1600ºF (871ºC) with a gas torch.

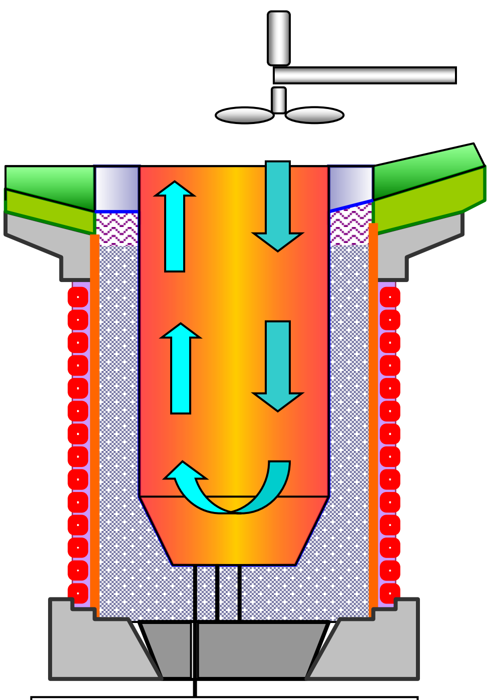


Figure 15 - Rapid Cooling

Re-Heat/Cold Start-Up Procedure:

- Charge furnace densely and ramp up the heat to 1000-1050˚C using thermocouples to monitor temperature.
- Hold 1 hour at 1050˚C (no molten metal!).
- Reason for hold: Cracks that have been generated by thermal cycling will seal upon heating to around 1000˚C. Continuous increase in kilowatts does not allow time for the critical areas to reach 1050˚C and transfer enough heat to close the cracks. Therefore, a hold time is required.
- Make sure the furnace is completely covered during the cold start which aids heat soaking.
- Proceed to melt the charge using normal procedures.

Summary

As the foundry evolves to meet the growing demand for metal castings around the world, new melting equipment that is more powerful and energy efficient is being developed. This equipment tests the limits of traditional refractory systems. New refractory products that extend campaign life, increase the speed of relines, and lower the overall cost of melting are a necessity.

New product concepts for silica and alumina-based linings that provide economical, safe, and consistent production of iron and steel alloys are available.