Fused-cast technology:
an overview of existing options,
low-cost manufacturers’ positioning,
impact on refractories’ performance
**What are we talking about?**

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<td><strong>A</strong></td>
<td>fused-cast are special refractories</td>
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<td><strong>B</strong></td>
<td>developed in few western places, with remarkable technological differences</td>
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<td><strong>C</strong></td>
<td>said differences have reflections in the technical properties and behavior in glass furnace applications</td>
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<td><strong>D</strong></td>
<td>several low-cost manufacturers have developed their own technological platforms, with relevant consequences on performance</td>
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Introducing fused-cast refractories

- The most widely diffused materials for glass contact and superstructure applications.

- Represent a major investment in furnaces construction and repair.

- Produced by fusing high purity refractory compounds in EAF and pouring the liquid into molds for slow cooling and crystallization.

- Ingots undergo mechanical treatments getting to the final blocks.

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• Fused-cast refractories have independently originated in Europe and North America in the first half of 20th century.

• The raw material fusion with EAF was applied to eventually produce blocks for various applications.

• For some producer, the origin was electrofused mullite to be enriched with zirconia to increase resistance versus various slags, and notably glass.

• For other the origin was various types of fused alumina (alpha, alpha-beta, beta), coming from electro abrasives background.

• In all cases, fused cast refractories represented a huge progress for glass furnaces life and glass quality.
Fused-cast: technology families 1

• In Europe AZS fused cast blocks were developed independently in France (L’Electro Refractaires, 1929) and later in Italy (SIC-Edison, 1960s).

• SEFPRO (SEPR) managed to maintain a quasi-monopoly position in Europe until end of the 80s, when Refel (I) entered the market as independent player, now part of RHI-AG.

• European technology developed the so called “hot-strip process” and the “oxygen top lancing” refining. These technologies, with minor differences are still applied in all European facilities.
In USA Corning Glass Works and Hartford-Empire Co. developed Corhart to produce fused cast refractories in 1927. In 1987 Corhart became part of SEFPRO group, to cease manufacturing in Louisville on 2005.

Monofrax became the trademark for alumina fused cast refractory division of Carborundum in 1933. After various changes in ownership, Monofrax is now part of RHI-AG since end of 2006.

Monofrax fused cast technology evolved in what is called “non-hot-strip” technology and a different, proprietary type of oxygen-refining process.
Fused-cast: technology families 3

- In Japan, two companies developed production based on a licensing agreement with SEFPRO (Asahi) and a JV with Monofrax (Toshiba-Monofrax). The latter was bought and integrated in SEFPRO group in 2003. Manufacturing technologies linked to the relevant “parents”.

- In Russia R&D development in the fused cast area begun in the late 1950s and eventually developed BAKOR brand (now EPO). Chinese development initiated with CBMA in 1955 and the first industrial development was with CSR in 1958; well over 20 Chinese players are now operating in continental China. In India, an initial development based on Monofrax technology evolved in an independent company (CUMI) which, eventually, was bought by SEFPRO group in 2002.

- In all cases the technology was based on “non-hot-strip” process and various simplified oxygen lancing for refining.
Fused-cast: tech. families / summary

• Fused cast operations based in Europe (SEFPRO and RHI-Refel) operates “hot strip process” and top oxygen lancing.

• Monofrax in USA (the only remaining manufacturing unit in the Americas), all presently operating units in Russia and India, all the several purely Chinese players are operating “non-hot-strip process” and a variety of oxygen injection methods ranging from top lancing to the proprietary bottom-injection of RHI-Monofrax.
FC technology: where are major differences?

1. Liquid Refining in EAF, “furnacing”.

2. Molding Technology for AZS and mold staffing.

3. Hot Strip / Non-Hot-Strip and annealing medium.

- While 1) is independent variable, 2 & 3 are strictly connected.
FC technology: liquid refining & furnacing

1. **Top oxygen lancing (EU):**
   - Utilizes sophisticated lance to inject $O_2$ from top at the end of fusion process (high rate, short time)
   - Furnacing must assure a liquid clean top at the end of fusion process, before $O_2$ injection
   - Degassing time necessary before pouring

2. **Bottom injection (USA):**
   - Utilizes a tuyere to inject $O_2$ from bottom all along fusion process (low rate, full time)
   - Cold-top furnacing is possible all along fusion
   - No degassing necessary before pouring (power-on pour possible)
Fused-cast: prod. Layout - furnacing

Simplified layout

- Raw materials weighing and mixing (batch preparation)
- Fusion in E.A.F., refining pouring
- Mold preparation and staffing
- Poured blocks
- Hot strip (when done)
- Naked blocks into annealing box with insulating medium
- Boxes in annealing warehouse for controlled cooling
- Boxes dumping, cool block extraction and cleaning
- First inspection
- Blocks to cutting, grinding, drilling
- Second inspection
- Pre-assembling
- Final inspection and customer inspection
- Dismantling and packaging, shipment
3. Differences on products made under 1) and 2):

- On liquid chemical homogeneity and therefore blocks composition within pouring line-up
- On liquid thermal homogeneity and therefore blocks size/shape consideration within pouring line-up
- On residual oxygen blistering in liquid to be poured
- On risk of batch carry-over from cold top batch blanket
- On risk of disrupting fusion process in case of oxygen stream loss (bottom injection technology)
FC technology: molding & hot-/non-hot strip

- Why these two major technological differences are inter-connected?
Fused-cast: prod. Layout - (non) hot strip

1. RAW MATERIALS WEIGHING AND MIXING (BATCH PREPARATION)
2. FUSION IN E.A.F., REFINING PURING
3. MOLD PREPARATION AND STAFFING
4. Poured Blocks
   - HOT STRIP (when done)
   - NAKED BLOCKS INTO ANNEALING BOX WITH INSULATING MEDIUM
5. BOXES IN ANNEALING WAREHOUSE FOR CONTROLLED COOLING
   - BOXES DUMPING, COOL BLOCK EXTRACTION AND CLEANING
     - First Inspection
     - BLOCKS TO CUTTING, GRINDING, DRILLING
       - Second Inspection
       - PRE-ASSEMBLING
         - Final inspection and Customer inspection
         - Dismantling and Packaging, Shipment
FC technology: molding & hot-/non-hot strip

Mold function:
1. Containing liquid during and immediately after pour (contrasting hydrostatic pressure)
2. Freezing a liquid layer in contact (skin)
3. Modulating thermal flow between refractory body and surrounding medium

Therefore:
• In hot-strip function 1 is short term and the staffing medium is the real contrasting element; in non-hot-strip mold must sustain long term function 1 since staffing medium is mostly insulating
• In hot-strip function 2 is short term to produce “strippable” skin; in non-hot-strip mold stays as long term thermal flow medium, in addition to insulating medium
FC technology: molding & hot-/non-hot strip

Mold composition:

1. For AZS, molds are based on high purity silica sand, bond with inorganic (waterglass) or organic (resins) systems, with or without other elements with structural and/or thermodynamic functions.

2. Molds can be monolithic or made out of glued multiple elements

Therefore:

- In hot-strip process molds can be light, thin and organically bonded since the structural function is temporarily assumed by staffing medium and because, due to subsequent stripping, there is no surface graphitization risk
- In non-hot-strip process molds must be inorganically bond (graphitization risk) and thick due to structural function and intrinsic weakness of the silicate bond at high temperature

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FC technology: molding & hot-/non-hot strip

Staffing technique:

1. For AZS, in most western operations staffing material is silica sand ("black" silica sand)
2. Staffing can be at various thickness around mold and with different degrees of packed density, corresponding to variable support to mold and thermal conductivity

Therefore:

• In hot-strip process molds are individually staffed in rigid assembly of steel frames, leaving a relatively thin space between sand mold and steel frames. This sand is vibrated to the requested degree to contrast deformation of mold due to hydrostatic pressure of liquid
• In non-hot-strip process molds are put into annealing boxes individually or in groups based on assembly plan. Sand is normally poured loose in the thick space between sand mold and box walls. The overall assembly determines the passive cooling curve. In special cases, alumina (or other materials) replaces black sand in box assembly
FC technology: molding & hot-/non-hot strip

**Hot strip / Non-Hot-Strip techniques:**

1. For AZS, EU operations adopt the hot-strip process; poured molds, after a variable (but short) waiting time are de-staffed and the block, having a solid thin crust and a liquid interior, is lifted and quickly transferred to the annealing box, where light insulating medium fills up the space between naked block and box walls, for the whole annealing time.

2. For AZS, USA operation adopt no-hot-strip process; poured molds are already in the final annealing box, surrounded by the annealing medium (sand or alumina or other stuff). Blocks cool down inside its own sand mold.

Therefore:

- In hot-strip process there is one more degree of freedom in driving the initial phases of block cooling. The hot strip process is an extremely delicate phase, conglobating a large amount of know-how and requests a great deal of process control since a large amount of finished product defect can arise from improper management of this process stage.

- In non-hot-strip process molds are left alone after pouring and the cooling down curve is determined by staffing assembly. The system is less dependent on personnel skills, but more dependant on initial parameters.
Differences on products made with or without hot-strip:

- On annealing time for largest blocks
- On feasible chemistry combinations
- On blocks surface crazing (isothermal spider-work)
- On variables dependant on molding chemistry (related to the hot-/non-hot strip):
  - Surface appearance (glazing, annealing media contamination)
  - Sub-skin porosity in the 2-5 mm range
FC technology: overall considerations

Performance differences for AZS made with different technologies:

- Western refractories, made by the few major “historical” players, do not differ a lot in overall performance, but:
  - Hot-strip process permits producing more “difficult” chemistries, with, theoretically, better corrosion behavior in very demanding applications. It must be noted that in the recent years, chemistries have been generally “adjusted” toward better process recovery also by hot-strip manufacturers, so contributing to leveling performances
  - In general terms, a properly operated hot-strip permits better release of residual stresses (tensions) in blocks with critical shape/size or chemistry
  - A perfectly managed hot-strip process makes possible better average process yields, but demands higher degree of process control
FC technology: overall considerations

For a Customer willing to buy from a primary western supplier:

- Price & Conditions, services, support (CATs), delivery, should be determining factors. Competition must be on this ground.
- Quality and expected performance differences are, generally, minor, in spite of substantial technological differences.

Of what said Customer should be concerned?

- Be sure to compare apples with apples when analyzing quotes. Remember, not all casting techniques are alike.
- Be sure you have optimized cost/benefit asset for all quotes.
- Be sure you have a professional approach to inspecting materials and set-ups at the supplier’s premises.

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Low-cost FC technology: what configuration?

- Technology, from a few original sources, has been spread all over (China) due to poor technology protection practices.
- Since 1960’, limited technology injections have arrived from Russia, USA (CE) and moderate know-how leakage out of western manufacturers which established delocalized units or JV in China.
- In general, top technology level is quite balanced, due to remarkable cross-exchange.
Low-cost FC technology: what configuration?
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Low-cost FC technology: what configuration?
Low-cost FC technology: oxygen injection

- All “tier one” manufacturers operate oxygen injection through top lancing (EU style), but with much less sophisticated devices, reduced safety, reduced process control and “furnacing” practice

- The above situation reflects in reduced reproducibility, and less controlled level of products’ oxidation, beside security issue which, per se, have no consequences on products quality

- Poorly controlled level of oxidation is, potentially, source of erratic density (and therefore corrosion resistance) and, in case of insufficient oxidation, higher levels of exudation and therefore defects cession to glass
Low-cost FC technology: oxygen injection
Low-cost FC technology: non-hot-stripping 1

- Hot stripping is a most sophisticated process stage, requiring a great deal of know-how and equipment technique; no one Chinese manufacturer is adopting this technology

- Within the non-hot-stripping technology, there are diversified situations, but in general molding process is the less advanced stage. From this weak point descend manufacturing over-cost, worsened process yields, overloading of the grinding shop

- Several annealing mediums are used and, in some cases, made out of different materials blended which, within the recycling process, can get contaminated and segregate, determine uneven insulating property, and therefore resulting in increased levels of cracking or block tensioning
The peculiar quality of these non-hot-stripping processes is having significant consequences on products overall quality (defects, attributes) and process limitation (feasibility grid) for critical size/shapes.

In spite of that, if the quality control filter works properly, the above issue reflects on process yields (manufacturing cost) more than on risk of shipping defective goods; the average quality level of acceptable products is, in spite of that, affected.
Low-cost FC technology: non-hot-stripping 2
In most cases, as-cast quality of surfaces and overall blocks’ geometry is bad enough to require “six faces grinding”, which has grown into some sort of Chinese standard practice.

Though effective in term of aesthetics, grinding glass contacts surfaces (working faces) is, technically, a bad practice since depriving blocks of corrosion resistant portion, exposing sub-skin porosity and polluting the surface with grinding powders.
Low-cost FC technology: other comments

In addition to the main points above mentioned, we must point out a few more details having practical consequences on the utilization of these materials:

1. Overall process control
2. On-line chemistry control
3. Mechanical treatment manufacturing stage
4. Online QC and blocks traceability
Low-cost FC technology: oth.1 process control

• Overall process control is not the strongest point of low-cost manufacturers; the level of automation during fusion and refining does not generally permit to stabilize adequately the specific energy input, specific oxygen injection and other critical variables, in absence of a thorough “manual” control

• This is one major cause of product variance in properties like redox condition, density, micro (and macro) porosity, having consequence on the product performances
Fused-cast: prod. Layout – proc. control

RAW MATERIALS, WEIGHING AND MIXING (BATCH PREPARATION)

FUSION IN E.A.F., REFINING AND POURING

MOLD PREPARATION AND STAFFING

POURED BLOCKS

HOT STRIP (when done)

NAKED BLOCKS INTO ANNEALING BOX WITH INSULATING MEDIUM

FUSED-CAST REFRACTORIES

Simplified layout

BOXES IN ANNEALING WAREHOUSE FOR CONTROLLED COOLING

BOXES DUMPING, COOL BLOCK EXTRACTION AND CLEANING

First Inspection

BLOCKS TO CUTTING, GRINDING, DRILLING

Second Inspection

PRE-ASSEMBLING

Final inspection and Customer inspection

DISMANTLING AND PACKAGING, SHIPMENT
Low-cost FC technology: oth.2 on-line chemistry

- The feasibility of on-line chemistry control depends on a chain of techniques involving:
  - Liquid sampling at furnace spout
  - Sample preparation and analytical techniques able to render a "complete" chemical analysis in less than one batching time
  - A feedback control routine able to correct the successive batch based on composition drift of a given sample
  - A batching equipment able to produce real-time batches

While most top tier Chinese manufacturers have XRF equipments installed, very few really use it and less (none?) of them utilize a combination of sample preparation able to hit the real-time target

- The unfeasibility of on-line chemistry control is making impossible to prevent out-of-chemistry episodes which, due to the high value of these products, can have devastating financial consequences, or lead to the enticement of enlarging the LCL-UCL fork, or let out-of-specs materials go through the control screen
Fused-cast: prod. Layout – online ch.ctrl

- RAW MATERIALS WEIGHING AND MIXING (BATCH PREPARATION)
- FUSION IN E.A.F., REFINING POURING
- MOLD PREPARATION AND STAFFING
- Poured Blocks
-Hot Strip (when done)
-Naked Blocks into Annealing Box with Insulating Medium

Fused-cast Refractories

Simplified layout

on-line chemistry control

- Boxes in Annealing Warehouse for Controlled Cooling
- Boxes Dumping, Cool Block Extraction and Cleaning
- First Inspection
- Blocks to Cutting, Grinding, Drilling
- Second Inspection
- Pre-Assembling
- Final Inspection and Customer Inspection
- Dismantling and Packaging, Shipment
Low-cost FC technology: oth.3 grinding shops

• The typical “grinding shop” of Chinese manufacturers is equipped with a large number of light (low productivity) domestic machines, equipped with domestic diamond tools. These grinding and cutting machines are quite different from EU or USA machinery, and must be operated at really low productivity in order to guarantee acceptable results in terms of surfaces planarity and roughness, linearity of cutting and so forth.

• Reason for not procuring western equipment is obvious; the cost of one western grinder can be more than one order of magnitude larger than a single domestic piece of equipment. Utilization of a large number of equipment sets is and will stay as a feasible practice until labor cost will be compatible with manning these several low-automation machines.

• Surfaces quality and dimensional accuracy of pieces is generally not at the level of best western manufacturers but it can be well within the real technical need for most glass furnaces applications. This is made possible through utilizing the light equipment at low productivity, so a great care must be applied to ensure the quality of job done, case by case.
Low-cost FC technology: oth.3 grinding shops
Low-cost FC technology: oth.3 grinding shops
Low-cost FC technology: oth.3 grinding shops
Low-cost FC technology: overall considerations

- Mentioning differences between major western fused cast manufacturers, we pointed up the fact that other factors than technological differences should be considered, when choosing a specific supplier.

- We also have noted that, among the large number of low-cost players (mostly in China), we have a group of so called top-tier manufacturers. Among them, the technologic configuration is quite balanced.

- Therefore, when considering the Customers’ point of view, the proper comparison, at least initially, must be done between major western and low-cost (top-tier) suppliers.
Considering to procure Low-cost FC refractories?

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<th>Pluses</th>
<th>Minuses</th>
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<td>• Price</td>
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<td>• Intermediation</td>
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<td>• Price</td>
<td>• Customer service (pre- and post sale)</td>
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<td>• Technological &amp; quality differences</td>
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Low-cost FC refractories: PRICE 1

• Price is the main (only) motivation for considering low-cost fused cast refractory procurement. The prevailing role of financial management in industrial enterprises, is imposing to most organization a serious evaluation of this option.

• Price advantage vs major western suppliers is still important, typically over 20% on a CIF basis, that is including transportation and accessories up to Customer. Referring to AZS fused cast, in most cases the commercial margin for a major western manufacturer can be under 15% (very often single digit); in other words, when the book cost of a Chinese supply is 20% under the best quote of a western manufacturer, the low-cost goods are sold delivered under competition’s manufacturing cost.

• Therefore, Chinese prices, so far, must be considered “unbeatable”. This peculiar situation is obviously harming western manufacturers (the more they are insisting on producing commodities), but also damaging themselves which, in several cases, after paying commissions to commercial intermediation, are selling at no profit, precluding any hope for their own technology improvement.
A very strong price-oriented Clientele (glassmakers) is therefore meeting a low-cost pool of suppliers which are ready to leveraging hard on price of commodities.

So, why these low-cost players are not rapidly monopolizing the market segment?

The answer stays in the right side of the previous slide, where minuses were listed. As a matter of facts, scarcely profitable suppliers have done too few (or nothing) for overcoming these handicaps, in the erroneous convincement that price and only price can overcome any other issue

Though the real situation, in several cases might be not so far from this assumption, it is also true that several streamlined glassmakers’ organizations simply do not have enough resources to properly handle the “minuses” without assuming unacceptable level of risks

Considering to procure Low-cost FC refractories?

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Looking at the “minuses” section it is worth briefly discussing the main points:

- **Communication**: for those used to the communication style of western major manufacturers, direct communication with low-cost manufacturers can be a very different experience. This is one of the major motivation for utilizing various type of intermediation

- **Intermediation**: a various configuration of in-between entities has been developed by top-tier low-cost manufacturers, ranging from commercial agents with almost no technical profile up to refractory organizations without own fused cast production but good introduction and understanding in the glass segment. These entities, depending on the level of technical competence, are providing variable levels of servicing which is not supplied directly by the low-cost manufacturer; in all cases these intermediaries are absorbing some level of competitiveness margin
Low-cost FC refractories: MINUSES 2

- **Customer Service**: mostly supplied by or through the intermediary, can hardly meet the level of service supplied by western manufacturers; for those used to receive great support on the engineering side of the business (drawings, application, CATs) must consider the necessity to reinforce their own technical departments and supply increased details when issuing a RFQ.

- **Technological & quality differences**: we have discussed about these points in details; we know we must be ready to handle the fact that there are quality differences, coming from technological peculiarities. We can assume that, in most cases, the situation is manageable in term of specific application, but potential Customers of low-cost manufacturers must be ready to submit, discuss and somehow enforce a feasible set of technical specifications to be applied to the quoted materials. This is a major difference from western procurement practice.
Low-cost FC refractories: MINUSES 3

- **Procurement process follow-up:** for people used to procure from familiar organization within the same region, following up the procurement process can be culturally and logistically challenging; intermediaries can support, but a direct checking will have associated costs which must be preventively considered.

- **Inspection at Supplier’s premises:** costs relevant to logistics are obvious. We must also consider that the level of confidence developed with traditional suppliers after decades of familiarity can be, here, still to come; the support from commercial intermediary is conflicting with the Customer interest, and we know that only a really thorough and technically competent inspection can detect “hidden flaws” in fused cast materials. Therefore it is fundamental that Customers approaching inspections at low-cost suppliers premises will operate highly skilled, experienced and qualified technical staff; this is not always an easy game to play for streamlined technical organizations of western glassmakers!
Low-cost FC refractories: MINUSES 4

SO... WHAT?

• Communication
• Intermediation
• Customer service (pre- and post sale)
• Technological & quality differences
• Procurement process follow-up
• Inspection at supplier’s premises

For several medium-sized Glassmakers, some or most of these minuses can be a serious impediment to capitalizing a low-cost procurement, also when technical obstacles are manageable.

The good news for these glassmakers is that, today, qualified support is available to the industry in order to preventively assess the feasibility for a low-cost procurement and, when feasible, to support a Customer with professional services through all of these steps and beyond, for a minimal cost compared to the saving opportunities

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CONCLUSIONS (it’s about time!)

• Fused Cast Refractories are manufactured by a small number of western players which developed peculiar technologies and techniques, leading to products appreciably different but generally equivalent in application performance.

• Fused Cast Refractories are manufactured by a large number of low-cost manufacturers (mostly Chinese) which developed slightly different technologies and techniques, leading to products with a variable level of quality and application performance.

• Due to the above point, in view of an important price leverage, feasibility of low-cost procurement must be considered case by case (specific application); associated risks can (and must) be minimized through a deep understanding of the specific supplier’s capability and driving appropriately the procurement process.

• For Companies looking for professional help, independent support is now available through all steps of procurement, making it possible to capitalize the existing financial opportunities.
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an overview of existing options, low-cost manufacturers’ positioning,
impact on refractories’ performance