Refractory Zone

Fused cast refractories: science or craft?

P. Carlo Ratto discusses the more technical approach to fused cast manufacturing methods and how the advent of new modelling techniques is greatly enhancing the process.

In the age of “virtual” technology, when processes, including manufacturing, seem to be predictable to the point where optimization of process variables (and introduction of new ones) can be reliably performed through computerized models, it is rather surprising having to admit that some manufacturing technology is not, in the age of communications and social media, completely under the reassuring control of “science & technology”.

While refractories in general are among the oldest materials handled by the mankind, and one among the most ubiquitous materials that supported the Metal Ages of men, it is to be admitted that only in less than a couple of centuries the production of refractories has switched from empiric practice to a complex and branched field of science.

While sinter refractory materials, produced through a range of different forming and firing techniques, have been studied and understood enough to be able of predicting, with a reasonable margin of error, the behavior of a given refractory under operational conditions, there is an area where the large amount of independent and connected variables and the technical difficulty of collecting (measuring) some of them has been, so far, a challenge that several have faced but none has completely defeated.

Odd combinations
Well in the middle of this area, fused-cast represent a peculiar combination of refractory science and foundry practice, transferred in a field of temperatures where most of the traditional foundry rules are subverted.

The huge amount of technological parameters, and among them some of very difficult quantification, have made, so far, impossible a sufficient degree of scientific definition; as a result some capability stays in the area of empiric “know-how” or, if you prefer, well within the domain of craft or art.

To the skeptics should be enough to say that, for example, the physical condition of a fused refractory inside the EAF furnace, just before the pouring process, is far from a complete understanding... For example it is generally acknowledged that in the case of a typical AZS (alumina-zirconia-silica composition) we deal with a liquid ceramic but, is it an homogeneous mono-phasic liquid, in other words a “real” liquid? And at which temperature are we operating and therefore referring when studying the characteristics of this peculiar liquid?

“when the temperature measurement provide a number within a given range, then it is OK for a proper casting temperature”.

Sticky references
Of course, the consequence is that for each company and each furnace, “experts” are managing reference numbers that are not easily transferrable to another company, another furnace, another expert. In other words, experiences are not automatically applicable as general practices, and this is one of the root cause for a difficult diffusion of the fused-cast refractory manufacturing technology.

Another section of the manufacturing process, consequential to the pouring stage, is also dealing with a remarkable complexity and a large number of parameters of very difficult measurement: the liquid ceramic (citing for example the case of an AZS) poured in a cold mold flasked inside a cooling (or annealing) medium initiates a cool down process in a thermal field and, simultaneously, the crystalline species precipitate, while single crystal nucleuses grow at a speed determined by complex diffusion processes. The chemistry of the liquid phase therefore changes during the precipitation process, leaving a residual amorphous phase having a composition well different from the initial whole liquid ceramic.

For an AZS fused-cast, the final crystalline phases are alpha corundum (Al2O3) and baddolelyte (ZrO2), partially as independent phases and partially as a pseudo-eutectic co-precipitation. The residual amorphous phase is a soda-silicatic glass, saturated with alumina and zirconia.

In the age of “virtual” technology, when processes, including manufacturing, seem to be predictable to the point where optimization of process variables (and introduction of new ones) can be reliably performed through computerized models, it is rather surprising having to admit that some manufacturing technology is not, in the age of communications and social media, completely under the reassuring control of “science & technology”.

While refractories in general are among the oldest materials handled by the mankind, and one among the most ubiquitous materials that supported the Metal Ages of men, it is to be admitted that only in less than a couple of centuries the production of refractories has switched from empiric practice to a complex and branched field of science.

While sinter refractory materials, produced through a range of different forming and firing techniques, have been studied and understood enough to be able of predicting, with a reasonable margin of error, the behavior of a given refractory under operational conditions, there is an area where the large amount of independent and connected variables and the technical difficulty of collecting (measuring) some of them has been, so far, a challenge that several have faced but none has completely defeated.

Odd combinations
Well in the middle of this area, fused-cast represent a peculiar combination of refractory science and foundry practice, transferred in a field of temperatures where most of the traditional foundry rules are subverted.

The huge amount of technological parameters, and among them some of very difficult quantification, have made, so far, impossible a sufficient degree of scientific definition; as a result some capability stays in the area of empiric “know-how” or, if you prefer, well within the domain of craft or art.

To the skeptics should be enough to say that, for example, the physical condition of a fused refractory inside the EAF furnace, just before the pouring process, is far from a complete understanding... For example it is generally acknowledged that in the case of a typical AZS (alumina-zirconia-silica composition) we deal with a liquid ceramic but, is it an homogeneous mono-phasic liquid, in other words a “real” liquid? And at which temperature are we operating and therefore referring when studying the characteristics of this peculiar liquid?

“when the temperature measurement provide a number within a given range, then it is OK for a proper casting temperature”.

Sticky references
Of course, the consequence is that for each company and each furnace, “experts” are managing reference numbers that are not easily transferrable to another company, another furnace, another expert. In other words, experiences are not automatically applicable as general practices, and this is one of the root cause for a difficult diffusion of the fused-cast refractory manufacturing technology.

Another section of the manufacturing process, consequential to the pouring stage, is also dealing with a remarkable complexity and a large number of parameters of very difficult measurement: the liquid ceramic (citing for example the case of an AZS) poured in a cold mold flasked inside a cooling (or annealing) medium initiates a cool down process in a thermal field and, simultaneously, the crystalline species precipitate, while single crystal nucleuses grow at a speed determined by complex diffusion processes. The chemistry of the liquid phase therefore changes during the precipitation process, leaving a residual amorphous phase having a composition well different from the initial whole liquid ceramic.

For an AZS fused-cast, the final crystalline phases are alpha corundum (Al2O3) and baddolelyte (ZrO2), partially as independent phases and partially as a pseudo-eutectic co-precipitation. The residual amorphous phase is a soda-silicatic glass, saturated with alumina and zirconia.
Anaylsis

The crystals morphology (acicular or isometric corundum) and the crystal size, the glassy-phase distribution among crystals changes in different zones of a refractory block, generally following the isothermal surfaces; the amount of co-precipitated or independent crystalline phases also depends on the cooling down process.

The intensity of this macro inhomogeneity, depends on the size of a specific block and the thermal flow through the mold, that, in turn, depends on the cooling/annealing package thermo conductivity.

We are not referring to minor changes, in fact it is to be known that, for example in a 36% ZrO2 AZS you can have zones with 32% and other with 42% ZrO2, depending on these segregation processes.

As a result of several studies, it is confirmed that the quality of crystalline phases and the way the glassy phase is distributed are closely related to the corrosion, resistance performance and tendency to generate glass defects, ultimately, to the refractory quality in application.

Computer modelling?

Once more, the amount of parameters related to the above mentioned range of results is so large (including molds quality, cooling/annealing medium, casting configuration for specific size/shapes, pouring velocity and liquid temperature, liquid chemistry and crystals nucleation parameters, ...), that a computer model capable to provide reliable results on how to operate to effectively manufacture a specific size/shape is far from being produced.

When a new shape/size of block, significantly far from known practice, is to be produced, “experts” have nothing to do but estimating proper initial parameters and go through a trial-and-error routine to optimize the results.

It is to be stressed that also tracking back observed manufacturing malfunctions (e.g. the occurrence of a higher than wished level of cracks) to the primary causes is not a univoque neither an easy exercise; it is a game where good technologists perform better than not-so-good “experts”.

No one fused-cast refractory manufacturer will ever easily admit, but every player, even the “best western” have, from time to time, episodes when production has bursts of defectiveness, as if the manufacturing process was momentarily out of control. These alarming and expensive episodes, of course, trigger immediate and worried corrective actions based on previous experiences. In my long and diversified experience, I must admit that in some cases the problem disappears (or does not) without a clear connection with the corrective actions. Sometime, as a consequence of the long manufacturing cycle (cause and effect can be separated by more than a month time), fortunately the problem has already disappeared when we detect the issue at the tail of the process.

This is another evidence of the incomplete scientific definition of the manufacturing process; it explains the unpleasant feeling of having the process not completely under control, and that, therefore, you can potentially have something going wrong without complete knowledge of the occurrence.

This kind of discomfort is something the experts of this technology do sometime experience, though will not be glad admitting.

Control freaks?

Is it all this enough for saying that we should give up the attempt to put our manufacturing processes under better control?

Surely not; it is obvious that the more we know, the better we measure, the more we keep under control with a reproducible process has already disappeared when we detect the issue at the tail of the process.

We must convince ourselves that fortuity has nothing to do with the observed episodes and that, on the contrary, it is always a matter of our lack of knowledge in the area of parameters and their inter-connection.

Case-Based-Reasoning (CBR) has been tentatively applied to build a better organized database of experiences to be utilized when a new situation or a not new undesirable occurrence appears, in order to improve the problem-solving process and make it less dependant to the so-called experts’ know-how.

Every advanced company has gone through various experiences in order to organize the technology and know-how in something more scientific and less reliant to the “craftsman experience”.

Though the results of such attempts have been, (so far and to my knowledge) not completely satisfactory, it is out of doubt that the reached stage of this continuous improvement is one of the most important (should say “the” most important) traits that differentiate a good and well experienced Company from others that manage a much less controlled process.

If a nice company can have once a year an episode of significant deviation in the final products quality, other producers can have multiple episodes or even can be systematically in that condition. Some, of whom I have got direct experience, do not even have knowledge of being under such condition!

Now, it is clear that having a higher scrap rate due to bad quality of products in your process, it is not only unbearable in terms of costs, but also largely undesirable in terms of average quality of the “acceptable products” sold.

Establishing an efficient tracking system, properly connecting a given product to the manufacturing condition through a multi-weeks production cycle, the adequate collection of manufacturing parameters (from raw materials to finished goods) and the deep knowledge of the quality of finished goods are, in fact, the only way to reliably collect “cases” that stay at the base of accumulated manufacturing know-how.

Building know-how

Building this “book of knowledge” is a continuous improvement process, the main way to reduce costs (the average scrap rate is a major cost factor) and improve quality.

Now we must stress that most of this know-how is site-specific, due to sensitivity to certain variables related to raw materials and equipments, as a consequence, transferring (and therefore selling/buying) know-how from one Company to another is an almost impossible operation, unless the whole manufacturing configuration is transplanted, a practice that often turns out to be unrealistic due to the need to procure locally some of the materials.

In other words, the know-how cannot be simply transferred from one to another Company; on the contrary what can be done is applying operational concepts that stay at the root of building the specific “book of knowledge” for each particular situation.

The journey from handicraft to science and technology is a work in progress for everybody making fused-cast refractories, but the way to go is different for different players, and there is no guarantee for eventually reaching a final target.

To think of it, this must be the reason for people like me to stay in this business, old and yet ever new, where art and science come together in an intriguing world of stones and fire.