Refractory Challenges in Furnaces

Ruth Engel* discusses the refractories and issues for glass furnaces expected to stay in continuous service 10 to 15 years or more.

Glass melting furnaces come in many sizes and types. The ones expected to stay in service the longest, present the greatest challenges and are the most demanding of their refractories.

Consequently, many studies and much work has been carried out to address their problems and develop methods for their repair which minimise production disruption.

Furnaces

Glass furnaces have evolved in size and longevity while, at the same time, production temperatures, throughput and product requirements have become more challenging. ***Fig. 1*** shows the changes in campaign length and amount of product as a function of decade of start-up. These improvements can be related to larger furnaces, better designs and refractories, greater control of the process and more timely preventive maintenance.

The most common problem areas for these furnaces are shown in ***Fig. 2*** which also indicates the prevalence of each category.

Refractories

Glass furnaces length of continuous service is ever increasing. To achieve this goal, furnaces are zoned with different types and/or qualities of refractories. Over time, the refractories have undergone many changes to improve their consistency and quality, address environmental concerns, while at the same time, minimise glass defects.

Among the challenges for improved furnace life are refractory wear and its effect on glass quality, repair methods that can be carried out while the furnace is in service, techniques for monitoring refractory wear during operation, energy use and its source, etc.

Appropriate refractory selection should consider that the temperatures for melting and refining glass fall in the 1300ºC to 1550ºC range, and are composition dependent. In addition, the bath's oxidation state (redox) influences the type and severity of the bath's reaction with these refractories. Because the bath is mainly heated by flames through radiation (top down), the temperatures under the crown can reach 1650ºC or higher and the gases in this area are often loaded with alkalies which are detrimental to refractory life. A summary of the most important refractory requirements for each area are listed in ***Table 1***.

A limited number of refractory types are compatible with the conditions listed in ***Table 1***. Their components are plotted on a quaternary diagram (***Fig. 4***). Not shown is chromic oxide (Cr_2O_3) which can also be added to the refractories. Because of the possibility of glass contamination, effect on colour and environmental issues at the time of the refractory's disposal, its use has greatly decreased and it is often not considered.

Crown

The crown is generally lined with silica either as brick or castable. An insulating package is usually added to the cold face to minimise thermal losses. The advantages of using silica are its creep and alkali resitance, and volume stability. Lately, much work has been done to improve the alkali resistance of the brick, a key property that affects their longevity.

Traditionally, silica bricks are manufactured using quartzite. Silica fused grains, based on chemically pure quartz sands, are also used today. For brick production a small amount of a sulphite solution is added as a pressing aid while lime is used as the binder and mineraliser. This lime reacts with the fine silica fraction forming β-2CaO-SiO_2 at temperatures >600oC, and also $3C_aO$-$_2SiO_2$. Around 1000ºC these transform to pseudo wollastonite (α-CaO-SiO_2).

During firing of silica, brick care has

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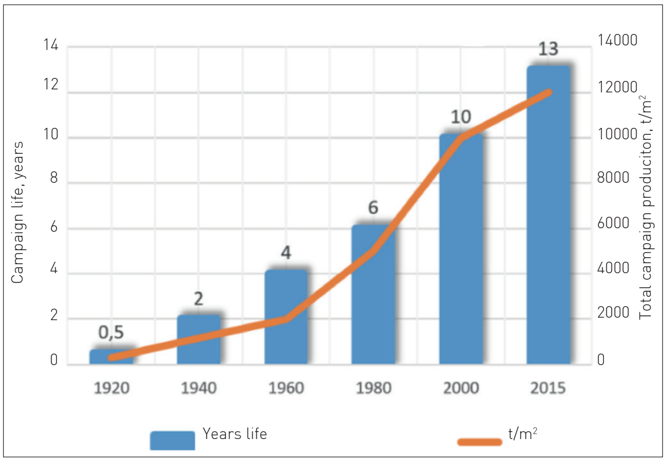

Fig 1. Furnaces Life and Total Campaign Production, in the period 1920 -2015*1

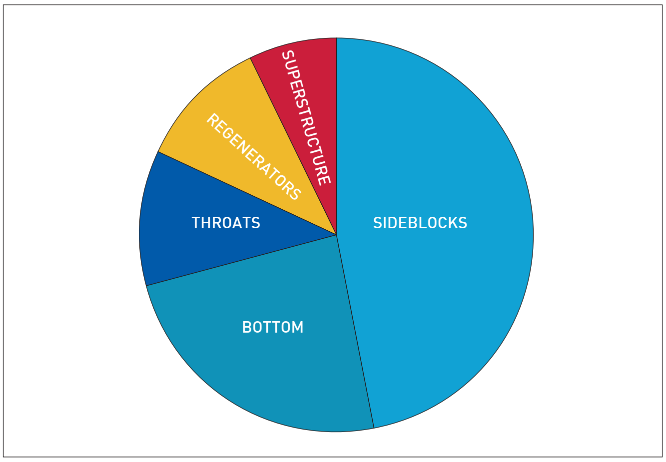

Fig 2. Furnace high maintenance areas*2.

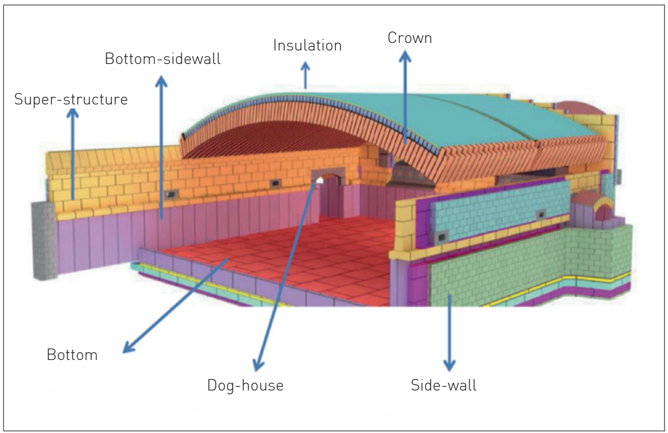

Fig 3 Schematic of the different furnace zones*3

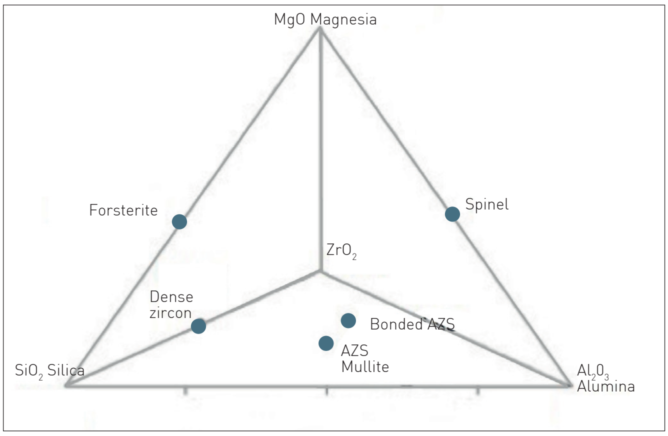

Fig 4 Glass furnace refractory compositions *4

Area	Conditions	Requirements
Crown (working lining)	Alkali vapors high and variable temperatures	Volume stability. Low permeability. Creep resistance Thermal shock resistance
Super structure	Batch carry over High temperature Volatiles: alkali vapors	Thermal shock resistance Corrosion and erosion resistance
Side walls	High temperature Glass corrosion Machinability	Corrosion resistance Chemical compatibility
Bottom paving	Glass corrosion Machinability	High refractoriness under load Corrosion resistance
Safety layer	Glass contact	Corrosion and erosion resistance
Insulation	High thermal load	Low thermal conductivity Good mechanical strength

Table 1. Refractory requirements for the different areas in a glass tank furnace

Fig 5 Silicate drip*4.

to be taken to account for the silica's polymorphic transformations from quartz to tridymite and/or crystobalite, which are accompanied by a linear expansion of about 4%. This is less than theoretical based on the volume changes associated with the silica transformations and is due to a pore size decrease with temperature.

Use of fused grain does not require attention to these transformations but, at temperatures > 1470°C, the amorphous silica will convert to cristobalite while the refractory remains volume stable. Unfortunately, once the silica has undergone this transformation thermal cycling from temperatures >1000°C to room temperature lead to cracking.

Crown refractories have to withstand alkali attack, thermal shock as a result of burner cycling and localised high temperatures. Work has been carried out to improve the alkali resistance of silica brick by decreasing or eliminating the amount of lime added during production.

This has lead to brick with low flux content, high densities and a small amount of viscous melt phase which can be attacked. Alkali attack of silica refractories is considered a greater problem when using oxy-fuel rather than air-fuel burners because these burners have a higher flame temperature. In addition, the nitrogen in the air is removed, thereby decreasing the diluting effect of the combustion products which leads to an increase in the concentration of the alkalies. This increase can range from three to six times of that present when using air-fuel burners.

Alkalies, in particular NaOH, and to a lesser extend KOH, react with the CaO in the amorphous and the wollastonite phases in the refractory, decreasing their viscosity (equation 1).

In addition, the higher temperature together with increased alkali concentration result in a low viscosity alkali silicate liquid which can easily penetrate the brick's open porosity through capillary action weakening the bond phase and attacking the silica grains (equation 2). This reaction takes place at relatively low temperatures (<1400-1450°C). The liquid can also run down the superstructure picking up alumina and/or zirconia. If this drips into the bath it can lead to glass defects (***Fig. 5***).

$2NaOH(g) + (CaO\text{-}SiO_2)(s) = Na_2O\ (CaO\text{-}SiO_2)(l) + H_2O(g)$ (1)

$2NaOH(g) + SiO_2(s) = Na_2O\text{-}SiO_2(l) + H_2O(g)$ (2)

Another crown refractory problem is ratholing. It is the result of sodium sulfate (Na_2SO_4) penetrating the refractory along joints and condensing when it reaches the region between 785°C to 955°C. The addition of an appropriate insulation package can move this region out of the crown refractory and into the insulating layer thereby avoiding the problem.

Colloidal silica (sol gel technology) bonded silica castables can also be used to line the crown. Their advantage is the absence of calcium that alkalies can react with and the absence of joints which affect the ability of these alkalies to penetrate into the lining. They also bond to existing refractories, do not form ratholes and can quickly be brought to use temperature as they contain no chemically bonded water. Their disadvantage is that they require construction of forms, and material costs may be higher than using brick.

Although the discussion has focused on silica refractories to line the crown, some installations use fused-cast alumina because they show better resistance to

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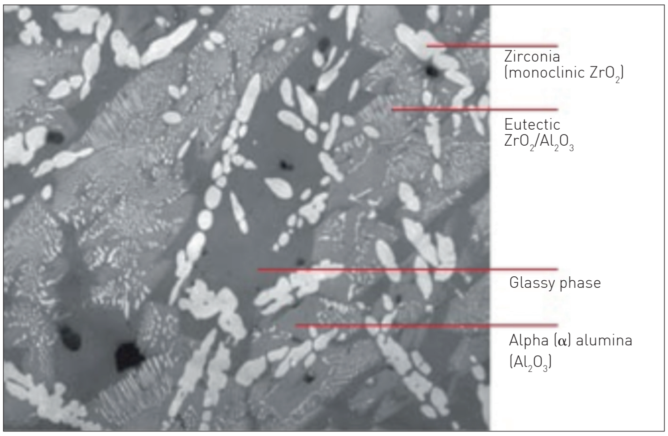
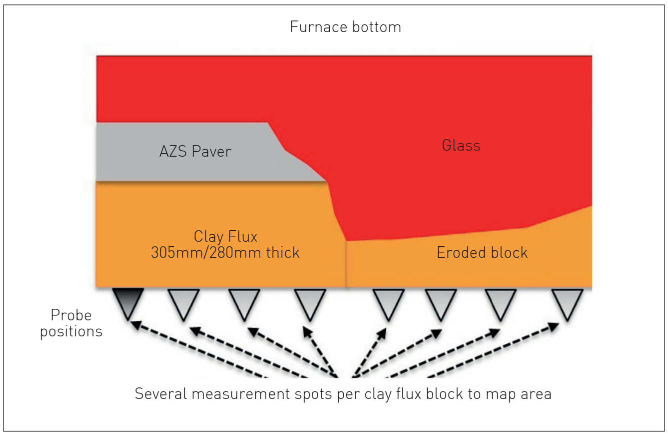


▲ Fig 6 Typical fused-cast AZS microstructure*5.



▲ Fig 7 Radar imaging: schematic of bottom wear determination showing layout of measurement spots*6.

alkalies. Nevertheless, the alumina can also be attacked as shown in equation (3)

$NaOH + Al_2O_3 = NaAl_9O_{14}$

Superstructure

A variety of refractories can be found in this area: sintered alumina-zirconia-silica, also called sintered zirconia-mullite, silica or fused-cast alumina. Wear issues are similar to those of the crown.

Side wall/bottom

The sidewall and bottom refractories in contact with the molten glass are generally some type of fused-cast alumina-zirconia-silica (AZS) block. The sidewall's area of highest wear is at the glass line where refractory-glass-air come together. The bottom refractories in contact with the glass are generally exposed to slightly lower temperatures and higher glass viscosity than the sides due to temperature stratification within the melter. The exceptions are the areas close to bubbler, stirrers and electrodes.

Fused-cast AZS blocks are manufactured by melting mixtures of highly refractory raw materials in an electric arc furnace and casting the melt into moulds for cooling. The process leads to a fill cavity, shrinkage voids and/or density variations even if undergoing controlled cooling. Their locations are dependent on the fill direction of the block and the cooling process itself. The fill cavity may be removed if the block is to be used in a critical application.

Fused-cast AZS refractory's corrosion resistance is the result of low to non-existent apparent porosity, the block's microstructure and its glass phase. The crystal phases are mainly α-alumina, monoclinic zirconia and a zirconia-alumina eutectic co-precipitate, which can be seen as interlocking dendrites in the glassy matrix. (***Fig. 6***). This glass phase is rich in silica, has some alumina and contains most of the impurities from the raw materials (alkalies and others). It is deformable at high temperature thereby absorbing the zirconia volume changes due to its polymorphic phase transformation. Because it is considered a source of glass defects, formulations have been developed that increase the amount of ZrO_2 and minimise the glassy fraction so as to improve erosion resistance and minimise exudation.

A furnace bottom and sidewall has other refractories in addition to fused-cast AZS blocks. The bottom should have a safety layer which can be brick, monolith or both and both areas have insulation as the outermost layer.

Exudation

Exudation is the migration of the glassy phase of the AZS block to its hot surface where it comes in contact with the melt.

It takes place in two stages: the first occurs when new block(s) undergo initial heating. Its magnitude is a function of the care taken during the fused-cast manufacturing process such as quality of raw materials, oxygen lancing and degassing to minimise the gases left in the product. The amount and composition of the glassy phase in the blocks will subsequently control the amount of exudate generated. In addition, once it is on the refractory's surface, its viscosity is affected by the redox state of the surrounding materials.

Repairs

Furnace refractory conditions should be monitored on a routine basis. The effect of refractory wear can sometimes be seen from the outside, glass oozing or shell/refractory glow, but it is often hidden from view. To monitor the hidden high wear areas, several non-destructive approaches have been developed. Among them are endoscopy, thermal imaging of the interior or exterior of the furnace and the latest one, radar imaging (***Fig. 7***).

The information obtained should be used to plan repairs to slow the rate of wear and prevent breaching. They can be carried out while the furnace is in operation or hot and can consist of overcoat installation, addition of external cooling, ceramic welding particularly of the crown and replacement of sidewall blocks.

Conclusion

Long furnace life can be obtained by the selection of appropriate refractories for the different areas in the melter and carrying out preventive maintenance. These activities have been aided by the development of more wear resistant refractories and the ability to monitor the condition of all areas in the furnace.

References

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