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# DEVELOPMENTS IN THE REFRACTORY DESIGN OF LIDS FOR LADLE PREHEATING IN DUNKIRK STEELWORKS

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## Introduction

In June 1997, the International Agency for Research on Cancer (IARC) issued an updated ruling on the carcinogenicity of crystalline silica. They concluded that "crystalline silica, inhaled in the form of quartz or cristobalite from occupational sources, is carcinogenic (Group 1) for humans". The National Institute for Occupational Safety and Health (NIOSH) Centre for Disease Control and Prevention has determined that crystalline silica exposures may lead to irreversible lung disease, although the observable effects may follow a lengthy latency period (time from exposure to the onset of disease).

Even if it is proved that ceramic fibres, as produced, do not contain crystalline silica, these amorphous synthetic vitreous fibres may devitrify following sustained exposure to high temperature (> 968°C) (1). The health concern over crystalline silica is associated with the inhalation of extremely tiny particles that can do damage to the lungs. These fine particles, referred to as breathable dust, are smaller than the diameter of the human hair. When inhaled into the lung, crystalline silica can cause long-term, irreversible lung disease. For this reason, workplace exposures to fine airborne crystalline silica containing dust must be minimised.

The European Union legislation of December 1997 classified ceramic mineral fibres as a category 2 carcinogen ("substance which should be regarded as if they are carcinogenic to man"). The legislation was to be transferred to national law by end of 1998. Accordingly, ceramic fibre blankets will require a label showing a skull and crossbones and information including "may cause cancer by inhalation" (Figure 1).


**Figure 1 Label for RCF's**

Besides the need to mark fibre goods adequately, to follow strict working guidelines and apply protective measures, this legislation encourages the substitution of fibres with safe alternatives.

In this case, ceramic fibre producers attempt to find new solutions (2)(3), especially proposing fibres with a larger diameter (> 6 μm) or products in which the fibres are bound in a matrix and are not available to become airborne. These products offer a solution to the legislation, excluding the new ceramic fibres from the breathable hazard classification scheme; however, they offer only a partial solution to the hygiene and health conditions of operators during installation, use and removal of fibres.

The health and safety of personnel played a major part in the developments of the refractory design for ladle preheater covers.

Indeed, even if it is possible to substituμte a part of the fibres considered as potentially dangerous to health by others fibres, it seems important to consider the removal of all fibres if at all possible.

## Ladle Preheater Covers

For some considerable time, lids for ladles have been built with refractory ceramic fibres (RCF's).
In Sollac Dunkirk steelplant, the centre of the dome is made of zircon fibres, as are the fume extraction ports. For two years, the burner pipe lining has been constructed using andalusite / chamotte based castables.

The disadvantages of the actual configuration are numerous:

- Problems of hygiene and health conditions of operators due to handling, installation, maintenance, and removal of the lids.
- Huge consumption of RCF's : 9000 square metres in 1998 and 9200 square metres from the beginning of 1999

- More and more difficulties for the storage of fibre wastes after use plus increasing costs. Consumption of burner pipe linings. (Figure 2)

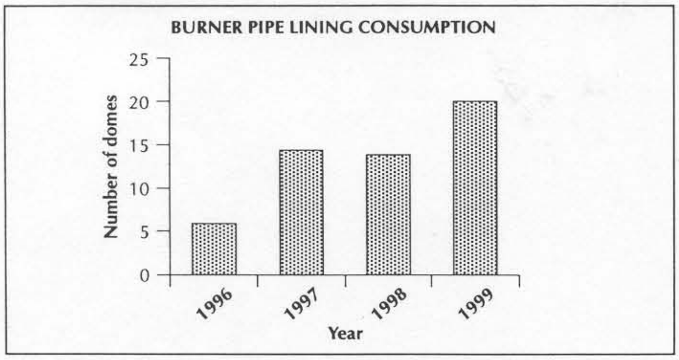


**Figure 2 Burner pipe lining consumption**

- Damage to the periphery of the lid due to the contact of the wool with the top of steel ladles, often clogged up with scrap and slag.
- Resultant from the above, reduced availability of the preheating lids

## New objectives, new constraints

### Objectives

The Dunkirk steelplant aims at the following objectives :

- Total removal of drawbacks due to handling, installation and removal of RCF's.
- Increasing the life of ladle preheater lids.
- Increasing the availability of ladle preheater lids (francs/tonne)

In answer to the previous objectives, the solution of "Monolithic refractory approach" was considered.

### Constraints

This solution needed to take into account the mechanical aspects of the installation, thermal and thermomechanical constraints for the refractory components.

### Mechanical constraints

The acceptable constraints of the lift system for the lids are directly linked to the potential power of the hydraulic equipment.
The pressure required to lift the standard lid is 120 bars. The stress on the hydraulic jack is then twenty tonnes, giving a leverage on the arm of 4.3 T maximum . The application of safety coefficient of 15% infers that the weight of the lid should not exceed 3.8 T.

The maximum acceptable pressure is, at Dunkirk, 200 bars. After calculation, the maximum weight of the shell + refractory, could reach 6.1 T.

One of the main aims of the investigation was then to obtain a lid of less than 6 tonnes ; indeed, the necessity for the inclusion of a new mechanical system would have induced a cost of Euros16000 per preheating lid.

### Refractory constraints

These constraints are due to mechanical and thermomechanical aspects. In fact, the refractory material needs to have good mechanical characteristics, coupled with reasonable thickness and correct installation.

Due to the large surface area of the lid, a relatively significant thickness is necessary in order to resist flexing during lifting.

It is important to take into account these constraints due to the mechanical aspect and the total weight of refractory and shell.

In parallel, the refractory material must offer good insulation properties, not to cause overheating of the shell.

Finally, the periphery of the dome must resist the mechanical constraints, caused by the contact between scrap and slag on the top of the steel ladles.

## Ladle Lid Design

### Technical principles

During handling, a lot of mechanical and thermal shock appears on the surface of the ladle lid.
To protect them against failures or cracks, precast shapes are placed around the periphery of the lid.
These pieces are manufactured by the SIFCA™ process in the precast shop at TRB (Figure 3).

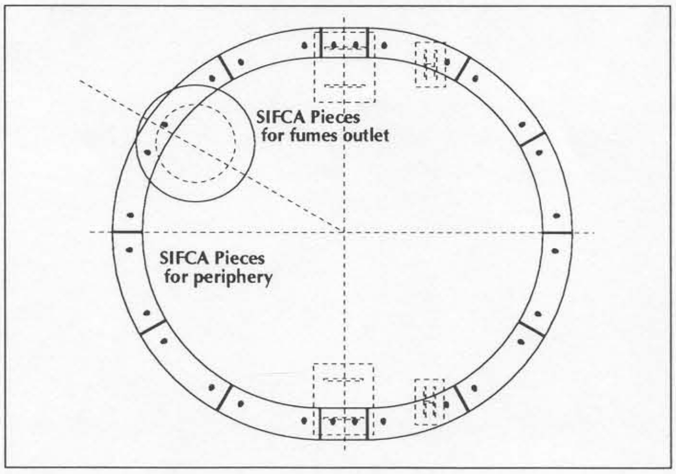


**Figure 3 SIFCA™ pieces**

Another ring of SIFCA™ shapes protects the fume outlet port against gas attack.(Figure 3)
The burner is a precast shape cast in the TRB precast shop and fitted on the lid steelwork.

Finally, an insulating castable is cast into the remainder of the lid.

## Installation on site

### Installation of SIFCA™ Rings

During the assembly operation, the lid is turned upside-down.
Initially, each SIFCA™ item of the exhaust port is fitted on the shell. After fitting, each set of nuts and bolts is protected against gas attack with an alumino-silicate ramming mass.

The same procedure is followed for the assembly of each SIFCA™ ring in the lid.

### Anchors

Before installing the insulating castable , stainless steel anchors are welded onto the shell.
For increased efficiency, anchors were chosen with a Y shape, round base, zigzag form, and their heights were calculated[4] to be 80 mm.

For this application, the TWU 8-080(40) - 310 anchor was used.

A calculation made first to optimise the distance between anchors and second, to limit the weight of the lid concluded that the spacing should be 198 mm (with a safety factor of 40% assumed)[5].

In practice, anchors were welded with a spacing of 200 mm; paraffin wax and plastic caps were also installed on the anchors.

### Centre of the Lid

The centre was cast with an insulating castable (see §5).

## Central part of the lid

### Castable

Furthermore, the constraints discussed have only been solved by the appearance on the market, of a new family of insulating castables, with the aggregates being developed by the ALCOA company (6) .

That raw material, called SLA-92, has the base mineral composition of a calcium hexaluminate (CA6), which exhibits the most excellent thermal properties of the calcium aluminate system with a melting point above 1850°C. Some other properties of CA6 are high thermal shock resistance, thermal expansion and fracture toughness KIC similar to alumina, moderate flexural strength due to anisotropic grain growth, and stability in reducing atmosphere.

The product chemistry (Table 1) of SLA-92 is, compared to pure $CA_6$(91.6% $Al_2O_3$, 8.4% CaO) - on the alumina - rich side in order to suppress the formation of hydratable calcium aluminate phases (CA, $CA_2$). The bulk density is around 0.65 - 0.70 g/cm³.

| SLA-92 | Typical | Unit |
|---|---|---|
| $Al_2O_3$ | 92.5-93.5 | % |
| CaO | 6-7 | % |
| $Na_2O$ | 0.2-0.4 | % |
| $SiO_2$ | 0.05-0.07 | % |
| $Fe_2O_3$ | 0.03-0.04 | % |
| MgO | 0.05-0.3 | % |
| Bulk density | 0.65-0.7 | g/cm³ |

**Table 1 Chemical composition of SLA-92[4]**

| Quality | Réfrisol 1600°C | Unit |
|---|---|---|
| Bulk density | | |
| At 110°C | 1.05 | g/cm³ |
| At 1000°C | 0.97 | g/cm³ |
| HMOR | 1 | Mpa |
| Thermal conductivity | | |
| At 400°C / 5h | 0.35 | W.m⁻¹.K⁻¹ |
| At 800°C / 5h | 0.37 | W.m⁻¹.K⁻¹ |
| At 1000°C / 5h | 0.40 | W.m⁻¹.K⁻¹ |
| At 1300°C / 5h | 0.41 | W.m⁻¹.K⁻¹ |
| At 1400°C / 5h | 0.43 | W.m⁻¹.K⁻¹ |
| Mechanical resistance | | |
| after curing at 110°C / 24h | 20 | kg/cm_ |
| 1000°C / 5h | 40 | kg/cm_ |
| 1500°C / 5h | 38 | kg/cm_ |
| Permanent linear change | | |
| after cooking At 1000°C / 5h | -0.10 | % |
| At 1400°C / 5h | -0.46 | % |
| Limit temperature for use | 1600 | °C |
| Chemistry | | |
| $Al_2O_3$ | 87/90 | % |
| CaO | 9/11 | % |

**Table 2 Characteristics of the insulating castable**

The SLA-92 aggregate was introduced into the formula of a castable in cooperation with a local supplier, and shows the physical and insulating properties of the refractory products produced from this aggregate (Table 2).

### Castable drying

After casting, the refractory material was dried for 24 hours at room temperature, followed by heating with a gas flare in order to obtain 600 °C on the surface of the castable.

Full mechanical behaviour of the castable will be obtained after using the lid on the first ladle.

### Removal of RCF's from the standard lid

The removal of RCF's in the standard lid was achieved by following actions :

- extensive water spraying on the lid before removal from the hydraulic system
- removal of the lid
- lid placed upside down, then flooding of the fibres with water
- elimination of fibre blocks with a spade and packaging in large bags, in accordance with recommendation on site and the legislation.

## Technical solutions

SIFCA™ Lid Lip Ring :
The SIFCA™ items were designed in accordance with Figure 4.

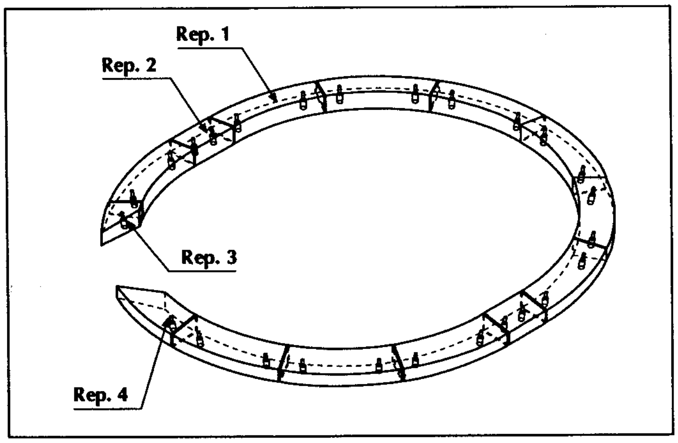


**Figure 4 SIFCA™ pieces for the periphery of the lid**

Four different kinds of precast shapes are required to make up the total ring of the lid, having a total weight for the set of about 1.4 tonnes. Each item is bolted to the shell with 2 HR (high resistance) nuts and bolts, 100mms in length so that, in case of problems with one of the precast shapes, it can easily be removed and replaced. This kind of technical solution has been tested before on the ladle lip ring covers with great success. (More than 2 years in service for certain ladle covers).

**SIFCA™ Fume Offtake Ring**

All around the fume offtake, SIFCA™ precast items have been designed in accordance with Figure 5.

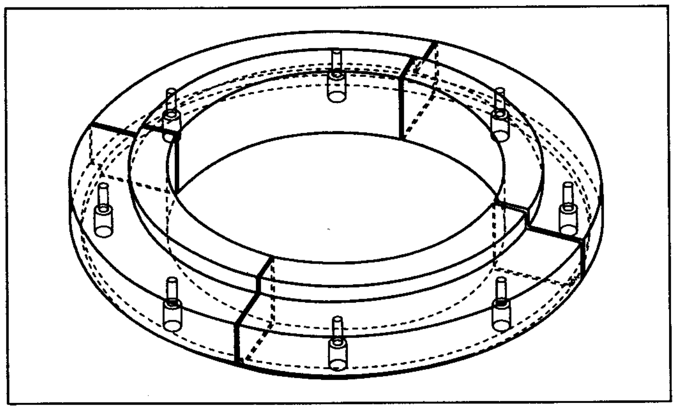

**Figure 5 Precast Shapes for fume offtake**

This ring consists of 4 identical precast shapes made with SIFCA™ Process.
Each piece is fitted on the shell with 2 nuts and bolts (M20, High Resistance) with a dry joint between each item of the set.
A chair joint has been designed on the surface of each piece in contact with the insulating castable.

On the top of each shape, a 50 mm step of SIFCA™ protects the shell against gas attack.

**Why is the SIFCA™ Process Used?**

SIFCA™ ("Slurry Infiltrated Fibre Castables ") is a patented precast refractory composite composed of :

- 6% volume percent of stainless steel fibres,
- 84% volume percent of low cement refractory slurry.

SIFCA™ is a revolutionary process for producing refractory precast shapes.

The unique characteristics of this product are :

- high thermal shock resistance :
- high impact resistance :
- exceptional compressive strength:
- at elevated operating temperature: the precast shapes can have a service temperature range up to 1650°C, under appropriate conditions.

(See all characteristics of SIFCA™ in the graphs Figure 6 (a) to (c)).

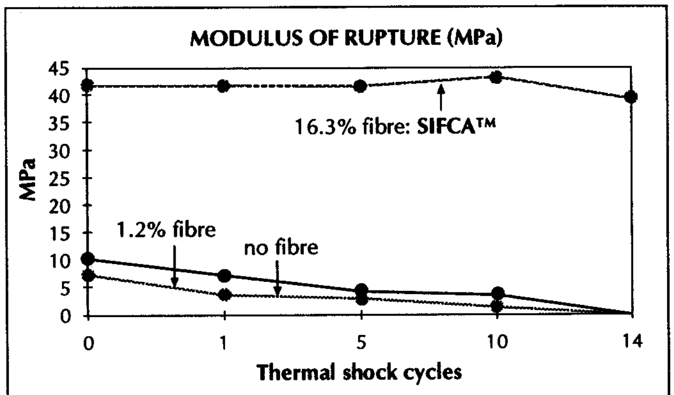


**Figure 6a Thermal shock resistance**

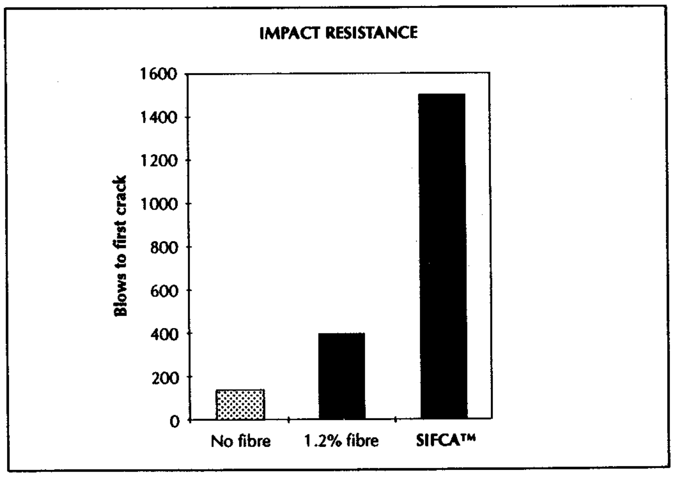


**Figure 6b**

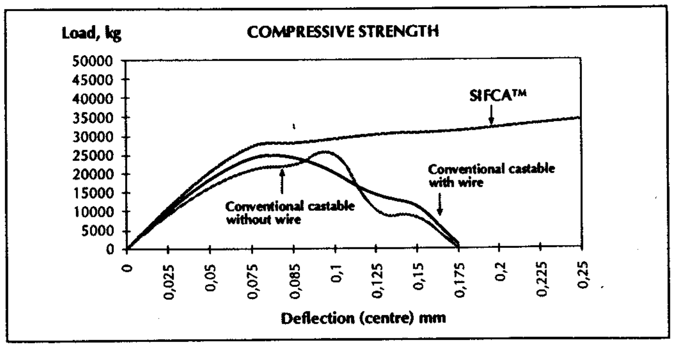


**Figure 6c**

### Some figures

After the total installation of refractories, the lid has a total weight of 4.300 tonnes, which is compatible with the standard hydraulic system.
The price of the castable solution is 54% more than the ceramic fibres solution but, in first approximation, the relative price (F/tonne) will be less than the RCF's solution.

## Conclusion

All the materials used in the design of the lid had health and safety data which presented much smaller risks than the RCF's solution.Our experience has proved that it is now possible to ensure the safe replacement of RCF's for the lids for preheating ladles.

The recent development of castables with both good pyroscopic resistance, low density and improved mechanical characteristics as compared to standard insulating castables, allows new applications, especially in the case of installations overhead without modifying existing mechanical installations. Whilst initial costs are higher with the monolithic approach the indications are that the life of the lid will be increased by at least 100% without repair. In addition the manpower requirements during the initial installation of the monolithic system are approximately 50% of the requirements when installing the ceramic fibre approach.

New applications are still being studied, in Sollac Dunkirk, for tundish preheaters and in hot rolling mill furnaces.This work constitutes a new step in the substitution of refractory ceramic fibres in our workshops and, as a result, an improvement in health and safety conditions in the work place.

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