Repair Action of Refractory Linings in High Temperature Reactors

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Over the last years repair operations in several plants and facilities (e.g. chemical plants, incineration and gasification plants) were realized, which still are permanently in operation.
In this paper the authors describe some examples of efficient repairs on refractory linings of different high temperature reactors (HTR).

1 Introduction

HTR are often operated under extreme service conditions like high and varying temperatures, increased pressure, hot abrasion and chemical attacks. Operational dependability and availability of the furnaces are of extreme importance. A breakdown of the reactor typically causes a shutdown of the whole plant. Such aspects have to be taken into consideration already during engineering.
In general there are two categories of repair works:
- "regular" scheduled maintenance operations and
- sudden as well as unscheduled repair works including emergency repairs.

The described examples are focussed on the second category: repair works as emergency operations, which are normally combined with a high pressure of time.

2 Failure types and repair actions

Reasons for break downs can be manifold, but main reasons are thermal overstress in connection with the accumulation of unforeseen circumstances, design imperfections or mistakes and/or assembly or maintenance mistakes and omissions.

After inspection of a damaged reactor first question of the plant operator will be: "When we can start up again?" This has to be answered by a new question: "How long the reactor shall be in operation after repair?" The discussion between user and producer of refractories determines the volume of repair actions, since it makes a difference if the replaced lining has to be in service until next scheduled regular maintenance turn in some months or durably for the originally planned lifetime like the not defected surrounding lining or as long as possible.
It will be reported about five different and extraordinary ways of repair works in HTR:
- repairing of local damages with "original" brickwork
- repair of partial damages with tailor-made pre-cast shapes
- repair with "muxing" method
- application of plastic fiber-mastic
- "repair" by "doing nothing" as a special case.

2.1. Repair of a brick lining in a gasification reactor in Vresova (CZ)

The first case was a hot spot in a reactor which was lined with bricks. There was a demand to repair partially destroyed bricks in the hot face layer like shown in Fig. 1. The damage was caused by a burner defect and the best method had to be found for repairing in this case. Thinkable were:
- installation of original brickwork
- installation of pre-formed shapes made of castable refractories
- regular gunning of appropriate refractory gunning mixes
- "shotcreting" with especially designed refractory mixes.

Regular gunning is fast and productive but it has following disadvantages:
- lower strength than dense bricks and pre-cast shapes
- higher porosity than dense bricks and pre-cast and pre-dried shapes
- additional problems with dry-out and heating-up of the lining.

Fig. 1 **Local damage of the hot face brickwork in a high temperature reactor (HTR)**

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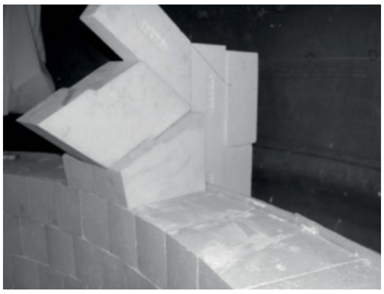

Fig. 2 Repair by bricklaying with high alumina dense bricks for the hot face and bubbled alumina LW-bricks for the backup insulation

Fig. 3 Damages of supporting bricks inside a HTR, positioned on alloyed steel-consoles

Fig. 4 Special cutting equipment for careful demolition (especially for dense bricks)

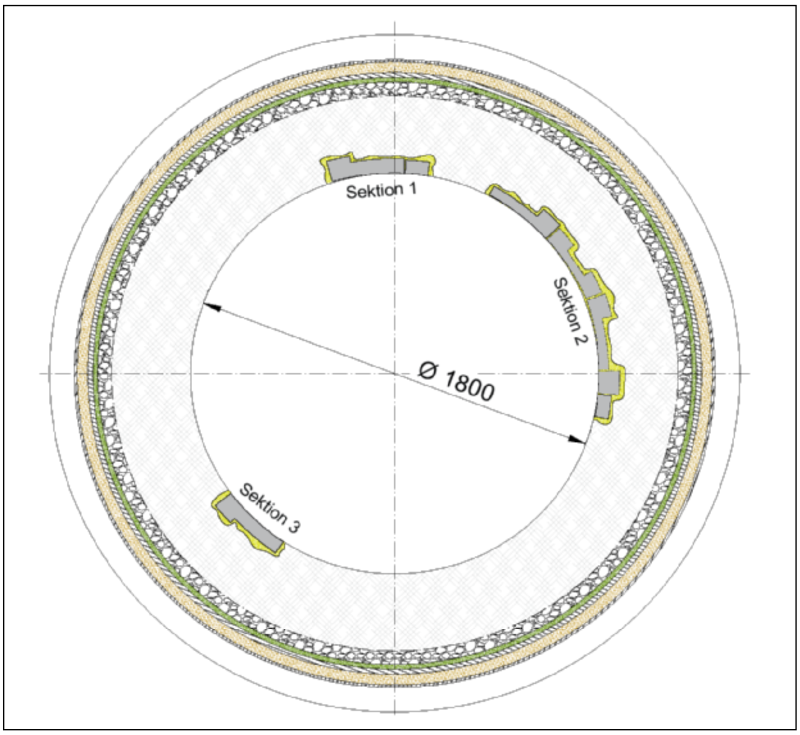

Fig. 5 CAD drawing for the arrangement of the shapes

"Shotcreting" (= wet gunning) requires a too high effort of equipment and machinery. So this possibility seems to be ineffective for the described case, even though the properties regarding chemistry, density and strength could be sufficient. The so called "high dense gunning" was not taken into consideration due to big amounts of rebound which is often combined with this technique. Finally the repair was done more or less on a conventional way in different steps:

- identification of the damaged area
- analysis of the failure reasons
- breaking out of the relevant area included insulation layer
- assembly of original and still available spare bricks as shown in Fig. 2.

2.2 Repair of partial damages with tailor-made pre-cast shapes

Sometimes replacement bricks are not available within a short time. In such cases the application of pre-formed shapes can help to realize proper repairs in very short times. The following example will explain the experience with tailor-made shapes made of a castable refractory (Fig. 3).

Due to a little design imperfection the brickwork in the console-area (for carrying the upper brick-layers) has been damaged. The customer needed a very quick repair.

For removal of the damaged brickwork a special cutting technology (Fig. 4) was applied successfully, which is known and widely used in civil engineering and road construction. By use of this method a careful demolition could be made by minimizing destructive vibrations, which usually are developed by applying other break-out methods (pneumatic hammer, etc.). This advantage was necessary for avoiding any destructive shocks, which could loosen the residual brickwork structure.

Further repair steps were:

- a detailed profile of the damaged area could be obtained by using a laser distance meter after removal of involved damaged bricks (Fig. 5)
- with CAD-3D technology individual sizes for pre-cast shapes were designed (Fig. 6)
- the resulting electronic drawings could be used directly from the CNC-machines of the mould manufacturer.

Due to this technique the drawings, moulds and formwork for manufacturing of pre-cast

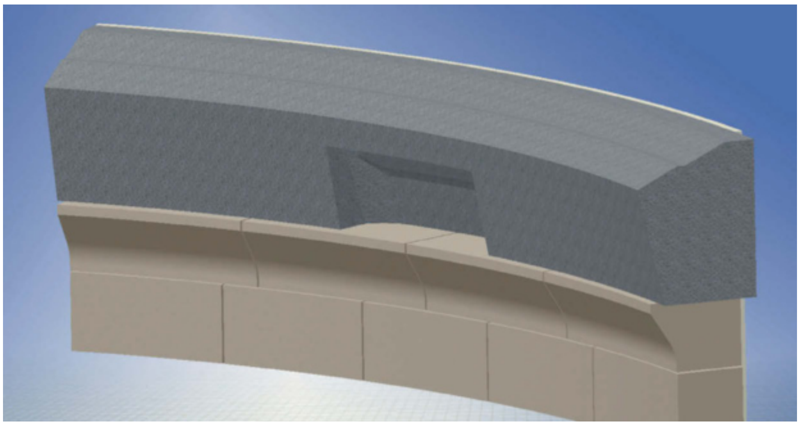

Fig. 6 3D-CAD-visualisation

Fig. 7 Example for the installation of preformed shapes

Tab. 1 Demand of working environment on material properties

Service Conditions	⇒	Important Properties of Refractories
type of HTR, geometry, etc. high temperature aggressive slag high gas velocity red./ox. atmosphere	⇒	type of material sufficient max. service temperature adequate raw material composition density + pore size distribution abrasion resistance + strength

shapes could be realized within a very short time.

The reader of this article may be surprised and could ask: "Why so much effort?" The answer is: "Extraordinary conditions demand extraordinary material properties (and efforts) and the following comparison may explain Tab. 1".

Pre-formed shapes and preferably dehydrated or dried ones, made in a professional and well-equipped shop have distinctly better physical (and partially also chemical) properties than dry or wet applied refractory gunning mixes (Fig. 7). Their properties come mostly very near to the ones of the original lining materials, especially as far as physical properties are concerned.

2.3. Stopping of vagrant gases by "muxing" technology

"Muxing" or grouting is the injection of refractory materials through steel shell behind and into an existing (but defective) refractory lining by using high pressure pumps. The process is shown in Fig. 8 principally. Steps for muxing are as follows:

- localization of cavities in the lining
- detection of their shapes and sizes
- determination of a suitable pattern of input holes
- drilling the holes into and fixing nipples on the shell
- pressing the refractory materials through the nipples with pressures more than 20 bar
- closing the holes or nipples.

Main criteria for material selection for muxing repairs are:

- furnace type (e.g. HTR, blast furnace, etc.)
- geometrical conditions of detected cavities
- reducing or oxidizing atmosphere during service
- presence of aggressive components (Na, K, S, Cl, F, etc).

Typical materials for application in HTR and incinerators are mainly high alumina mixes based on corundum or tabular alumina (>90 % Al_2O_3). In case of aggressive slag with low viscosity addition of chromium oxide to mor than 40 % and free of silica can be necessary.

2.4 Application of plastic fibre-mastic

Thermal insulating materials such as lightweight bricks, calcium silicate boards, vacuum-shaped ceramic fibre boards or ceramic fibre blankets and modules are predominantly used in the backup insulation as well as in the hot face or in areas of man-

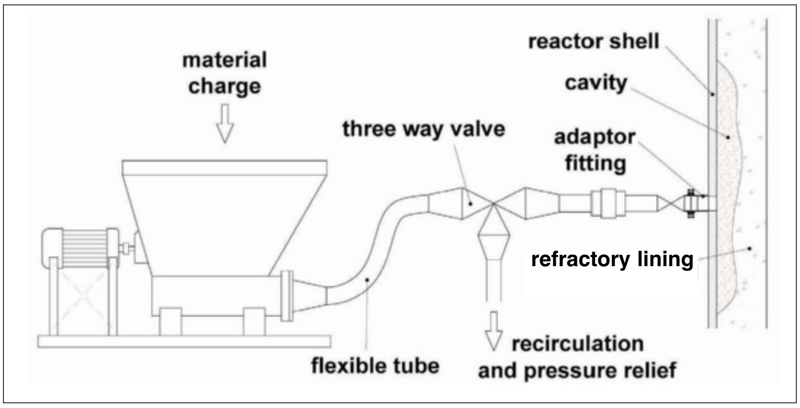

Fig. 8 Principle outline of high pressure injection (muxing)

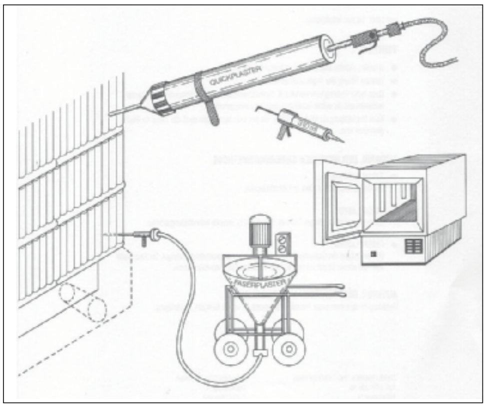

Fig. 9 Maintanance with plastic fibre-mastic

Fig. 10 **Hot spot repair of a BF of a hot blast duct by injection of fibre-mastic with a Quickplaster**

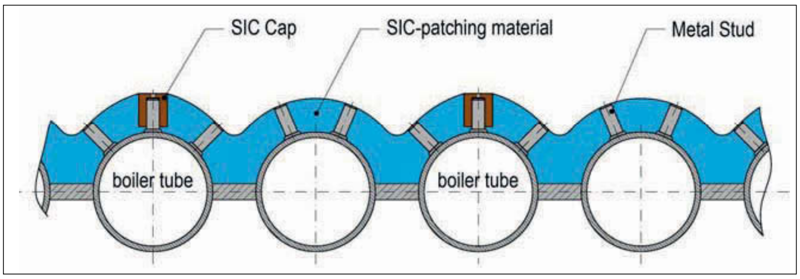

Fig. 11 **Boiler tube coated with phosphate bonded SiC patching material**

holes and other apertures of industrial furnaces. Such insulation materials tend to shrink and erode over long time service periods. Fibre mastics can be used to fill existing shrinkage gaps.

Fig. 9 shows different possibilities for this repair method:

- cartridges with a corresponding hand press, if smaller quantities were applied
- compressed air driven plunger press for amounts up to ca. 400 kg (Quickplaster) or
- fiber-plast machine for quantities more than 400 kg.

The repairing of a hot spot on a hot blast duct of a blast furnace at *Arcelor-Mittal* shall be described as an example.

In the back-up insulation a formation of holes were detected and a dangerous temperature increase occurred at the metal shell. To prevent a shutdown of the duct, the holes and gaps in the lining were filled with fibre mastic for 1500 °C service temperature. After drilling several holes into the steel shell the product was injected by the so called Quickplaster like shown in Fig. 10. The holes in the shell have been closed by welding and an untroubled operation of the furnace could be avoided.

This repair method is effective a well experienced one and similar to the muxing technology.

2.5 Repairing "by doing nothing" – a special case

Finally a very special "damage case" will be described, which is related to an incinerator for firing ammunition components. The side walls were water-cooled tubes coated with phosphate bonded SiC-patching material like shown in Fig. 11.

The plant stood for several months without proper and sufficient pre-heating. During this time the phosphate-bonded material picked up moisture and lost strength as expected. Due to this lost on strength there was a demand to break out the refractory material and to install a new lining.

However, test results show that the loss on strength of unshaped refractories – especially phosphate-bonded materials – caused by moisture pick-up – can be regained by drying and heating up only [2]. So the exchange or renewing of the refractory lining could be avoided.

3 Trends for material improvement and development

The application of direct-bonded, high-compacted and at high-temperature fired bricks seems to be the best choice in any case for the first lining of strongly stressed HTR, especially for furnaces where aggressive slag is part of the process. This should also refer to repair actions. But many incinerators and reactors usually are unique and designed for certain material charges, processes or even part of R&D-projects sometimes. Consequently bricks are not always available due to costly stock keeping.

An exchange of a certain brick by a so-called "equivalent" castable refractory should always be taken into consideration. However, it has never to be forgotten, that unshaped refractories are mixtures of certain raw materials, which will get the final physical and

Tab. 2 **Technical data of a corundum based ULCC containing 5 % chromium oxide**

Chemical Composition [%]	
Al_2O_3	94
SiO_2	0,1
Fe_2O_3	0,1
CaO	0,45
Cr_2O_3	5,0
Required water for vibration [l/100 kg]	4,2
Physical Properties after 1600 °C Pre-firing	
Bulk density [g/cm³]	3,20
Permanent linear change [%]	–0,15
Apparent porosity [%]	15,5
Modulus of rupture [MPa]	18
Cold crushing strength [MPa]	90

mineralogical properties after a certain time in service. High quality bricks are ready for use right from the beginning and don't need a "soaking time" for getting the right properties. In cases of certain HTR this may be more important than fast supply and other facts which are normally advantages of monolithic refractories.

It is favourable in any case to have equivalent unshaped refractories in the range of products. This should include the relevant knowledge and facilities for the production of pre-formed shapes, for example made of castable refractories, which refers especially to cases when damaged bricks have to be substituted shortly. Therefore improvements and/or development of special monolithics with high purity like bricks are interesting targets. NCC's or chemically bonded unshaped refractories could be promising steps for R&D in this direction. Tab. 2 is showing exemplary technical data of a corundum based chromium-oxide containing ULCC having a maximum service temperature of more than 1800 °C.

"Conventional" refractories based on alumina and/or andalusite often are overstressed in HTR especially when slags with frequently changing chemical composition and melting behaviour causing strong wear are part of the process.

Historically first field tests with shaped refractories for such applications started with corundum bricks. The addition of 5 % Cr_2O_3 showed improved performance. At the end bricks with high contents of chromium oxide (10–40 % and more) appeared more effective. On the other side the addition of ZrO_2 to chrome-corundum-bricks for improving certain properties like thermal shock resistance and corrosion resistance is looking promising too. In Tab. 3 typical properties of a high-purity corundum brick and a chrome-alumina-zircon brick can be seen.

Nevertheless, beside all technical advantages regarding performance with chromium containing bricks there is a strong need for a rigid reduction or even a substitution of chromium oxide in refractories due to environmental reasons. It is well-known that demolished refractories out of such HTR or incinerators belong to hazardous wastes and have to be stored in special deposits. But it seems not to be necessary to increase the environmental problems with hexavalent chromium-oxide which could be avoided by using chrome-free refractories.

One contribution to such aspects could be a Sialon-bond SiC-brick for certain cases (Tab. 3). Non-oxidic nitride-bond bricks have high alkali resistance, high thermal conductivity and mechanical strength. However, under oxidizing conditions the maximum service temperature should be lower than 1100 °C. But not all brick shapes are yet available like known from conventional bricks.

Tab. 3 **Typical technical data of high grade bricks for hightemperature reactors**

	Corundum Brick	Chrome-alumina-Zircon-brick	Sialon-bond SiC-brick
Chemical Composition [%]			
Al_2O_3	99	17	13,3
Cr_2O_3	–	62	SiC: 71
ZrO_2	–	12	Nitride matrix: 27
			N_2 (included): 6,2
Physical Properties			
Bulk density [g/cm³]	3,15	3,84	2,69
Apparent porosity [%]	16	10	15,5
Cold crushing strength [MPa]	80	210	200
Modulus of rupture at 1500 °C [MPa]	4	5	(1350 °C): 45
Thermal conductivity at 1000 °C [W/m·K]	3,4	2,9	15

4 Conclusions

The above mentioned results show shortly summarized that considerable improvements regarding the operational availability of HTR can be achieved by intelligent concepts of repair and maintenance actions.

The most important precondition for successful new refractory linings and repairs is an intelligent concept and the right refractory material. Finally mutual understanding between all involved parties (plant operator, producer of refractories and installer) seems to be a "conditio sine qua non".

One remark at the end may be allowed. It would benefit all involved parties, when the process- and furnace-engineers would involve refractory experts right from the beginning of planning and engineering. Following this rule an optimised refractory solution could be found by avoiding of – sometimes – simple reasons for bad performance and early maintenance. Not often the quality of the chosen refractory was responsible for a bad performance. In most of the cases the real reasons are others like unforeseen ups and downs during service, unknown process-parameters, so called "low price solutions" and other facts, which are normally not belonging to refractory products.

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