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RAPID AND DURABLE REPAIRS OF BLAST FURNACES SHAFTS WITH JETCASTING®: ASSESSMENT AND INDUSTRIAL UTILIZATION[1]

Tobias Dyck[2]
Cristobal Feliciano[2]
Mike F. Struzik[2]
Joachim Dörr[2]
Bertram Kesselheim[2]

Abstract

There exist diverse methods of repairing the shaft of a blast furnace, they all present advantages and limitations. For instance, bricks lining can be a durable solution but requires long downtime periods, which limits its economical attractiveness. Traditional dry-gunning has been used to reduce downtime, but attainable physical properties and performances are comparably low. In this sense, the Jetcasting technology has been developed to provide iron makers with a refractory material durable and rapid to install. The present works start with a review of the principal wearing mechanisms in blast furnaces and available methods for shaft repairs. Later a presentation of the fundaments and equipment for Jetcasting is presented to continue with a laboratory assessment of the chemical and mechanical properties. The laboratory analyses are complement with a study of the campaigns of 21 blast furnaces around the world that demonstrate the superior resistance of Jetcasting material and its feasibility to minimize downtime and guaranty economical effectiveness of blast furnaces repairs.

Key words: Blast furnaces; Jet casting, Refractory material; Nanobond.

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[2] *Refratechnik Steel GmbH, Schiess-Strasse 58, D-40549 Duesseldorf, Germany*

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1 INTRODUCTION

As depicted in Figure 1, the different blast furnace stack zones are attacked by several wearing mechanisms, such as erosion (upper stacks), thermal shock (lower stacks), heat load (bosh) and chemical attack (all shaft),[(1)] therefore different types of application and material are possible. Before choosing a material for shaft repairing, maintenance status, required physical/chemical properties and atmospherical conditions must be considered. A reliable refractory supplier may be able to provide all material and installation alternatives, putting plant operators and refractory consultants in a position to discuss all available options objectively.
The refractory lining of a blast furnace shaft normally consists of high alumina bricks. Repairs are either done by replacing the brickwork or by applying conventional dry gunning concretes. Burned bricks guarantee highest quality, but may be very time-consuming. Hence, it may take several weeks to install a completely new refractory lining in the blast furnace shaft.
Looking for a faster installation method, conventional dry gunning concretes were firstly applied, nonetheless the properties did not meet the requirements, due to their high rebound rates and the lack of sufficient mechanical resistance, dry gunites were only suitable for use as repair materials. Even the development of physically improved medium cement gunning could not fully meet the blast furnace operators' high demands. However, due to their enormous time saving potential dry gunites have become the standard solution world-wide for intermediate repairs and start-up protection linings in blast furnace shafts.

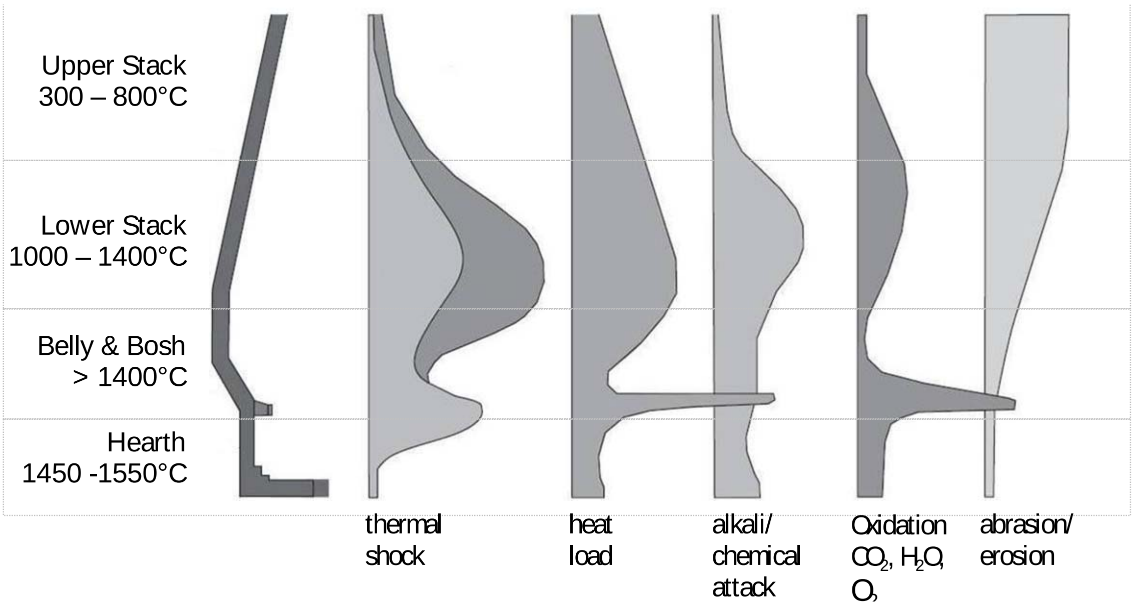

Figure 1. Basic BF refractory wear mechanisms.

Further attempts to solve both, the time and quality issues, by using thixotrope or self-flowing castables did not succeed either. Although the refractory quality could be improved further, the formwork to be placed took too much time and was too expensive. The very high quality of castable mixes however meant a first step forward in the right direction.
According to this, the best solution would be a "gunnable" casting material - and that exactly describes what is meant by Jetcasting®. The experiences gained at Refratechnik Steel GmbH in Jetcasting®, often also known as shotcreting or

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shotcasting, are explained in the following. Refratechnik is able to provide several lining concepts for the most common applications, from our production plant in Bendorf/Germany.

- Throat
  - Refrajet F-55 R - start-up protection, CO-resistant, gunning.
- Tuyeres
  - RefrajetCast LC F-60 AR/R - alkali-/CO-resistant jetcasting, cold repair hearth;
  - RefrajetCast Nanobond S-60 R - CO-resistant, cement-free jetcasting (hearth repair);
  - Refraram B-70 S-15 - ramming mass for gap filling.
- Upper Stack, Lower Stack, Belly, Bosh
  - Refrajet MC F-58 AR/R - alkali-/CO-resistant, MC gunning;
  - Refrajet MC F-58 R - CO-resistant, MC gunning;
  - RefrajetCast LC F-60 AR/R - alkali-/CO-resistant jetcasting, cold repair;
  - RefrajetCast LC F-60 R - CO-resistant jetcasting, cold repair;
  - RefrajetCast Nanobond F-60 AR/R - alkali-/CO-resistant jetcasting, hot repair;
  - RefrajetCast Nanobond F-60 R - CO-resistant jetcasting, hot repair;
  - RefraselfCast LC F-50 R fine staves back-filling, CO-resistant, self-flowing;
  - Refralusit 63 R - CO-resistant alumina brick.

2 JETCASTING® PRODUCTS

To achieve optimum results in cold or hot repairs under tight schedule conditions, blast furnace operators will prefer shotcreting products rather than choosing conventional gunning mixes, due to their higher mechanical resistance and durability.
There are two binding systems of blast furnace stack shotcreting materials available in the market:

- the hydraulic bond: using calcium aluminate cement;
- the sol-gel bond: using colloidal silica.

Most companies producing shotcrete materials for blast furnace stack re-profiling projects have specialized in one binding system only, i.e. either exclusively favouring the hydraulic bond (with calcium aluminate cement); or solely providing the sol-gel bond (cement free, with liquid chemical binder).
Regardless the preferred type of repair, a cold manual repair or a hot repair by means of a robotic pod, Refratechnik Steel is able to offer both binding system options:

- “Refrajetcast® LC”: hydraulic bond, low-cement;
- “Refrajetcast® Nanobond”: sol-gel bond.

In this sense, Refrajetcast® LC is recommended for cold (manual) repairs from a working platform (Figure 2 left). The material is mixed with water, has excellent heating-up properties with extremely good strengths at temperatures below 800°C. Being installed it shows a perfect adherence to already existing surfaces (for instance worm brickwork).
On the other hand, Refrajetcast® Nanobond is ideally used for hot repairs with robotic shooter (Figure 2 right), but is also suitable for cold repairs (e.g. with warm climatic conditions). Mixed with liquid binder, it shows excellent adherence to already existing surfaces. Due to lower quantity water present in the crystal structure, it may be

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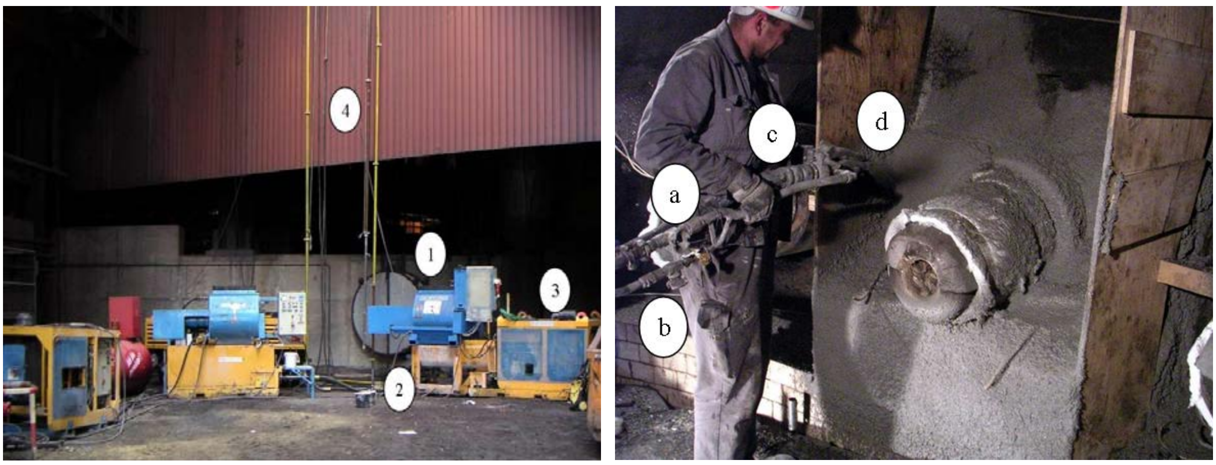
heated with over 100°C/hour. Refrajetcast® Nanobond develops a significant strength at temperatures above 800°C.

Figure 2. Cold manual jetcasting from working platform (left) and hot robotic jetcasting (right).

The quality and lifetime of a Jetcasted lining is naturally influenced by proper installation. Although Jetcasting gives us excellent control over the material's properties, there are important elements to consider, one of them is the correct "nozzle-to-wall distance", which should ideally come to 0.5 m maximum. Values exceeding the 0.5 m, may considerably impair the properties of the product. The extendable lance of the robotic shotcreting however ensures a perfect "nozzle-to-wall distance".

3 INSTALLATION OF JETCASTING

Since the introduction of Jetcasting products on the market in early 2004, Refratechnik Steel has been successfully completing a large number of installations in blast furnace shafts throughout the world (Figure 9). The shotcrete equipment developed and supplied by Messrs. Montanbüro in Bochum (Germany) has mainly been used to do these jobs, Figure 3 presents an illustration of the components of the shotcreting equipment.



1 - paddle mixer;	2 - hopper/dual piston pump	a - pressurized air supply	b - accelerator supply
3 - hydraulic unit	4 - material line	c - material line	d - nozzle

Figure 3. Shotcreting equipment: left pump and mixer; right nozzle.

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Dyck et al.[2] argued that practical experience shows that up to 10 tons of material per hour can be applied, though the ideal installation rate is about 6 to 7 tons per hour. The lining rate per hour however can still be multiplied when using two machines simultaneously. According to industrial experience, the rebound rate in case of a remote-controlled installation by means of an automatic shooter is less than 2%, in case of manually applied mixes on a working platform it is even less than 1%.
Statistical data of a typical blast furnace relining with jetcasting material:

- blast furnace shaft height: 30.0 m (tuyere level to throat armour);
- blast furnace shaft diameter: 13.2 m (tuyere level) to 8.2 m (throat armour);
- layer thickness refractory lining: 350 mm;
- jetcasting material: 200 tons;
- jetcasting installation time: 46 hours (incl. set-up/dismantling of equipment).

Following this idea, Figure 4 presents a comparison of the attainable installation velocities with diverse relining methods, for instance a hot repairs using a robotic shooter with Jetcasting or torcreting (traditional dry gunning) may take up to 70 hours to complete (lines blue and green in Figure 4), however as industrial experience and previous investigations[3] demonstrate with Jetcasting material longer campaigns are reachable than with traditional dry-gunning mixes. In the case of a manual repair a jetcasting installation can be completed in 170 hours (red line in Figure 4), in this case there is higher control of spray which minimizes rebounds (<2%). Contrasting to the velocity of repair of Jetcasting and torcrete, brick lining can take 2 or 3 months due the inherent amount of work, dismantling of worm lining, installation, preheating, etc. Repairs using bricks are currently only reserved to complete revamping of blast furnaces.

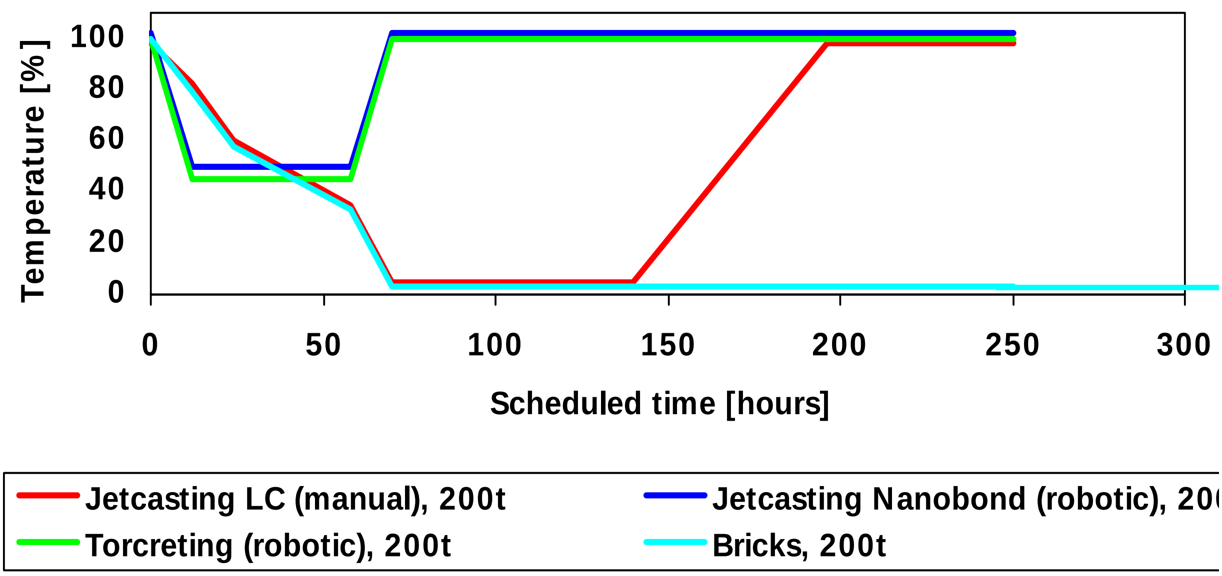

Figure 1, Repair schedule of different installation methods

4 JETCASTING MATERIAL ASSESSMENT

This work commences with an illustration of principal wearing mechanisms in blast furnaces (Figure 1), it shows a significant influence on the refractory lining and can determine the lifetime of the refractory. Therefore a successful lining ought to resist simultaneously the mechanical loads (erosion and abrasion), chemical attacks (CO

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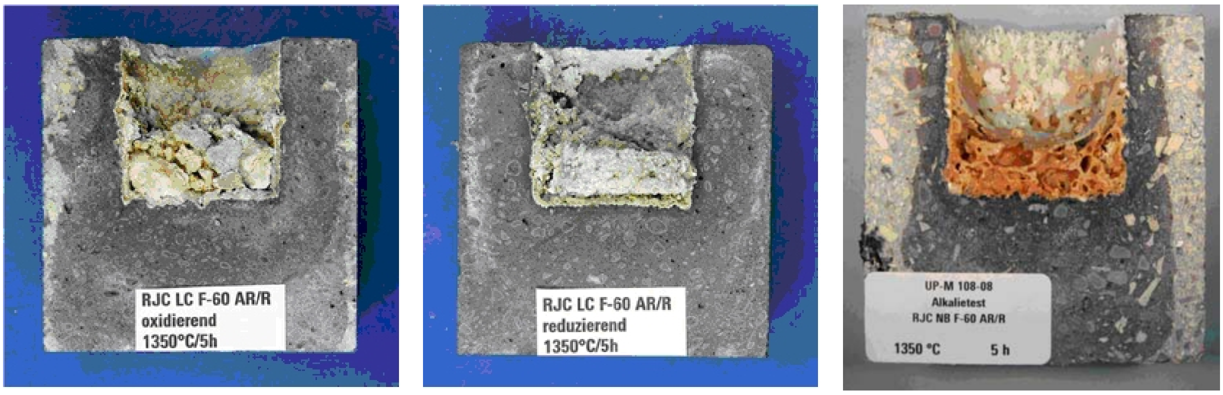
atmospheres & Alkalis/Zn vapours) and thermo-shock.(4) In this section, an assessment of the properties of jetcasting materials will be provided
The alkali resistance is key importance to iron makers, as alkalis may infiltrate the refractories generating cracks and diminishing the performance of the lining. Laboratory crucible test examined the resistance of Jetcast materials (LC and Nanobond), under reducing and oxidizing atmospheres (BF operates under reducing atmospheres), the crucibles were filled with 64 grams of K_2CO_3 at 1.350°C for 5 hours. As shown in Figure 5, the material presents low infiltration of alkalis providing an excellent resistance against alkali both in oxidising and reducing atmosphere. This results were later corroborated on an studied performed by Salzgitter-Mannesmann laboratory (Gronebaum 2004).(5)



LC (oxidizing atmosphere) LC (reducing atmosphere) Nanobond alkaline test

Figure 5. Crucible alkali resistance test with Jetcast.

To complement the assessment of the properties, independent laboratory experiences were carried out at DIFK (Bonn), in which key mechanical properties of the Jetcasting materials (LC & Nanobond) were determined.
The cold crush strength (CCS) is defined as the stress under which a failure in a refractory material occurs.(6) This refractory test provides an idea of the strength and mechanical resistance. As depicted in Figure 6, in the laboratory studies both materials Jetcasting presented a dissimilar behaviour at temperatures between 110°C and 1.200°C the Low Cement variant exhibit higher CCS values (upper green line), >100 N/mm^2, whereas the Nanobond improves its strength with the temperature (lower orange line). Both reached values of 120 N/mm^2 at common shaft temperatures (1.300°C-1.500°C).

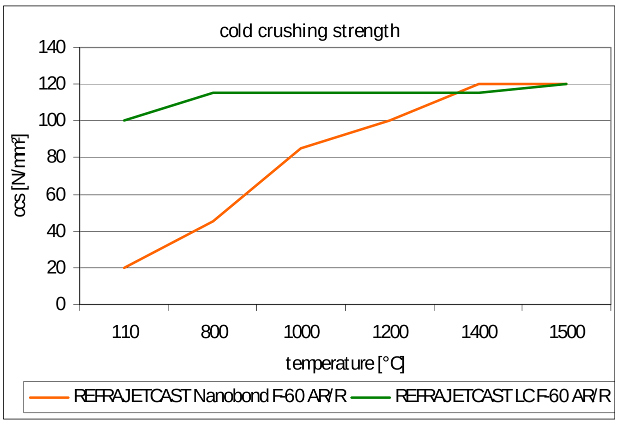


Figure 6. Jetcasting cold crushing strength.

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Similar behaviour was observed in the cold modulus of rupture (MOR) analysis (Figure 7), in which low cement Jetcast (green upper line) surpassed 10 N/mm^2 at 800°C, while Nanobond achieved this value after at temperatures superior to 1.200°C. As depicted in Figure 8 both variants of jetcasting present low permanent linear change at elevated temperatures, observing values lesser than -0.4% at temperatures bellow 1.200°C. This reverts into minimum elongation or shrinkage during the setting and pre-heating reducing the risk of crack formation.

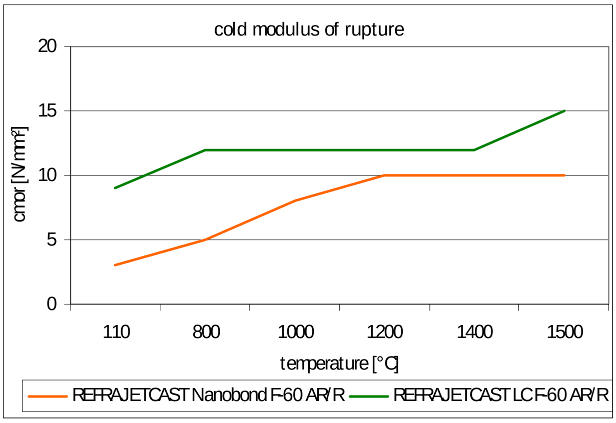

Figure 7. Jetcasting cold modules of rupture.

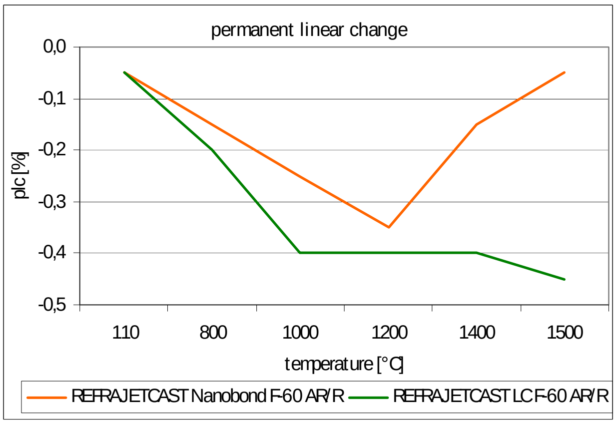

Figure 8. Jetcasting permanent linear change.

Laboratory results posted in (Figure 7), lead to conclude our both variants of Jetcasting material present excellent refractoriness combined with lowest creeping rates under load up to temperatures above 1.600°C, optimum values for crushing strength in unfired and fired state (Figure 6) and no permanent elongation or shrinkage during setting and after firing[(5)] (Figure 8). Additionally previous studies on Jetcasting material (Feliciano et al 2010),[(3)] demonstrated the materials high resistance against abrasion and low apparent porosity, in comparison to traditional dry-gunites.
The low amount of water required reverts into minimum porosity and improves heating-up characteristics. Another advantage of Jetcast material compared to conventional gunning mass is the significant lesser re-bound loss: approx. 15% at conventional gunning and only 2% at jetcasting. Due to minimal material loss during installation, that makes the estimation of refractory required (volume) easier.

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5 INDUSTRIAL EXPERIENCE RE-PROFILING BLAST FURNACE SHAFTS WITH JETCASTING

Despite of been a relatively new development, Refratechnik has performed over twenty blast furnace shaft re-lining projects with Jetcast® material world-wide since the first application in Salzgitter/Germany in April 2004. The list includes all of the three Salzgitter Flachstahl AG blast furnaces (Germany), Voestalpine in Linz/Austria, NISCO in China and numerous ArcelorMittal plants world-wide.

As previously mentioned Refratechnik offers both low cement Jetcasting materials with hydraulic bond and cement free Nanobond alternatives, these materials have been applied in diverse blast furnaces shaft exhibiting large durability. Jetcasting campaigns are illustrated in Figure 9, as shown most lifetimes excide 3 years operation, e.g. *Salzgitter BF B*, AM *Eisenhuettenstadt BF 5A*, *AM Bremen BF 3*, while others surpass 4 year of production, e.g. *Dillingen BF 5, NTMK BF 5, AM. Sicartsa BF 1, CHMZ BF 2, Zenica BF 4*. To the moment of writing this paper, 9 blast furnaces around the world continue reliable operation with Jetcasting lining and at *Salzgitter BF A* lifetime is higher than 5 year operation.

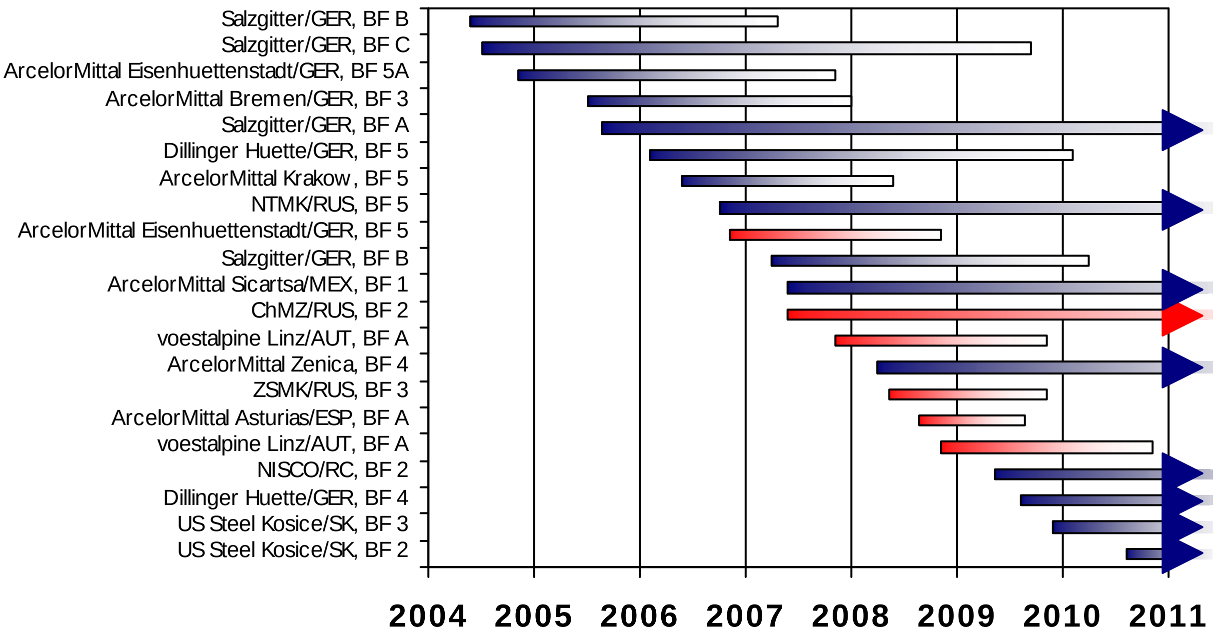

Figure 9. Lifetimes of Installations (blue = manual, red = robotic).

Hot repairs using a robotic shooter (depicted in red in Figure 9) have also proven to be durable options to extend the refractory lining in shafts, more than two years operations at *Voestalpine BF A, CHMZ BF 2, AM Eisenhuettenstadt BF 5.* This makes the Jetcasting Nanobond rapid and durable options to repair a blast furnace shaft, given the reduced installation time (Figure 4), and the attainable chemical (Figure 5) and mechanical properties (Figures 6, 7 and 8).

The combination of effective machinery, experienced installation team and highest lining quality fully meets the requirements of today's iron makers. In this respect the results prove Jetcasting to be a relevant alternative to brick lining, if time plays an important role to the construction schedule. Since the physical properties of jetcasting materials are almost equivalent to those of low cement castables, jetcasting mixes ensure highest installation quality.

Jetcasting enables a rapid refractory installation with a minimum of material loss.

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According to industrial experience, the rebound rate in case of a remote-controlled installation by means of an automatic shooter is less than 2%, in case of manually applied mixes on a working platform it is even less than 1%.
Refratechnik recommends standard jetcasting products in the blast furnace stack:

- low-cement - Refrajetcast LC F-60 AR/R
- cement-free (Nanobond) - Refrajetcast Nanobond F-60 AR/R

Regardless the planned type of installation: hot or cold repairs, manual or remote-controlled installations, warm or cold weather, with or without working platform, repair or relining - Refratechnik disposes of the required products, has the capacity and professional staff to perform reliable, long-lasting and quick blast furnace repairs worldwide.

6 CONCLUDING REMARKS

Jetcasting is a rapid and durable alternative to repair blast furnaces, as its installation drastically reduces downtime, and presents optimal properties equivalent to low cement castables, with minimum rebound (<2%).
In the present work, laboratory analyses have shown the resistance of the low cement and Nanobond Jetcasting materials against principal wearing mechanisms occurring in blast furnaces. High chemical resistance against alkali attack was observed, especially under reducing atmospheres. With respect to the mechanical properties, low cement Jetcasting materials exhibits remarkable characteristics at low temperatures due to its hydraulic bond, while the cold crushing strength and cold modulus of rupture of Nanobond Jetcasting material increases with the temperature, attaining high values at normal iron making temperatures (>1.200°C).
An analysis of the industrial experiences of Jetcasting over 21 blast furnaces worldwide leads to indicate that these superior characteristics of the jetcasting refractories does reverts into prolonged campaigns that can exceed three years of reliable operation.

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