STAVE REPLACEMENT PROJECT – TERNIUM BF 2[1]

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Abstract

Following some premature damage to staves on the blast furnace number 2 at Ternium Siderar San Nicolás works an investigation of the cause of the problem was carried out. This analysis included for discussions with a number of blast furnace operators around the world. Ternium operational experience in dealing with worn staves proved to be valuable in terms of follow up, damage correction and prevention of damage experienced. This experience was also important in designing the new staves. These concepts are discussed in the paper. The output of the analysis was a decision to replace all rows of copper staves on the Ternium blast furnace. The replacement project was scheduled to be carried out in 2012 during a stoppage of the blast furnace. This paper will review the issues with the original stave performance related to the operation of the blast furnace and the design of the new staves. The paper will also describe the shutdown associated with the stave repair and techniques used to remove and replace the staves. When presented, the paper will discuss the latest performance of the staves on the blast furnace.

Key words: Blast furnace; Stave; Refractory; Wear.

[1] *Technical contribution to the 43rd Ironmaking and Raw Materials Seminar, 12h Brazilian Symposium on Iron Ore and 1st Brazilian Symposium on Agglomeration of Iron Ore, September 1st to 4th, 2013, Belo Horizonte, MG, Brazil.*

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1 INTRODUCTION

Ternium Siderar Blast Furnace No. 2 (TX) ended its third campaign in October, 2006, after 11 years of operation and having produced 22 million tonnes of pig iron.[(1)]
Due to TX productive requirements, the need to increase BF 2 working volume arose. One of the possible alternatives was to replace the internal cooling system that consisted of graphite bricks and copper plates with cooling by means of staves. The refurbishment also included an increase in the throat diameter to gain volume in the upper stack. This modification would create an increase of 9 % in the useful volume.
The stave arrangement consisted of:

- rows of copper staves which were installed with a protective lining for the blow-in,
- rows of cast iron staves up to the BF throat.

Table 1 and Figure 1 show the comparison of the BF 2 dimensions and cross-section in the third and fourth campaigns.

Table 1. TX BF2 Main Parameters

	Third campaign	Fourth campaign
	September, 1995 - October, 2006	February, 2007
Working Volume (m3)	2134	2340
Inner Volume	2421	2610
Hearth Diameter	10.4	10.4
Top Diameter	8.0	9.4
Tuyere Number	27	27

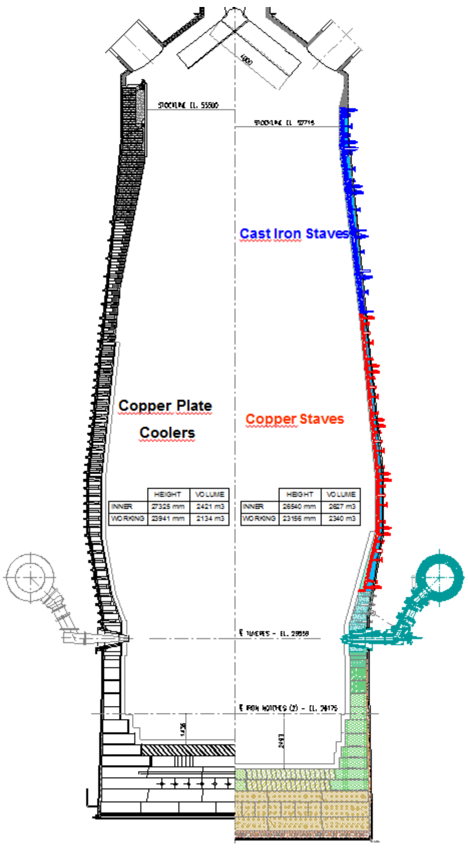

Figure 1.

2 EXPERIENCE WITH THE NEW COOLING SYSTEM

In February, 2006, the fourth BF 2 campaign began, from the beginning the main objective was to learn the control of the gas flow to avoid thermal stress and deformation of the staves. A control and measurement plan was established for that purpose.(2)

After 3 years of operation, during the period of highest productivity achieved, in May 2010 the first water leakage appeared in the stave channels; on a copper stave located in the bosh. Upon the identification of this first leak the decision was made to reduce the production level of BF 2. Additionally a stave thickness measurement plan was executed. The results of this proved there was significant stave wear, mainly affecting the bosh and the belly. The damaged channels were by-passed and finally grouted, maintaining an internal independent cooling through each channel.

As a preventive measure, inspection tasks were initiated during shutdowns carrying out channel endoscopies, which defined 3 different damage states in the channels, as it is shown in Figure 2. As the channels of the red phase of deformation were found, the by-pass was executed to prevent water ingress to the BF and its shutdown.

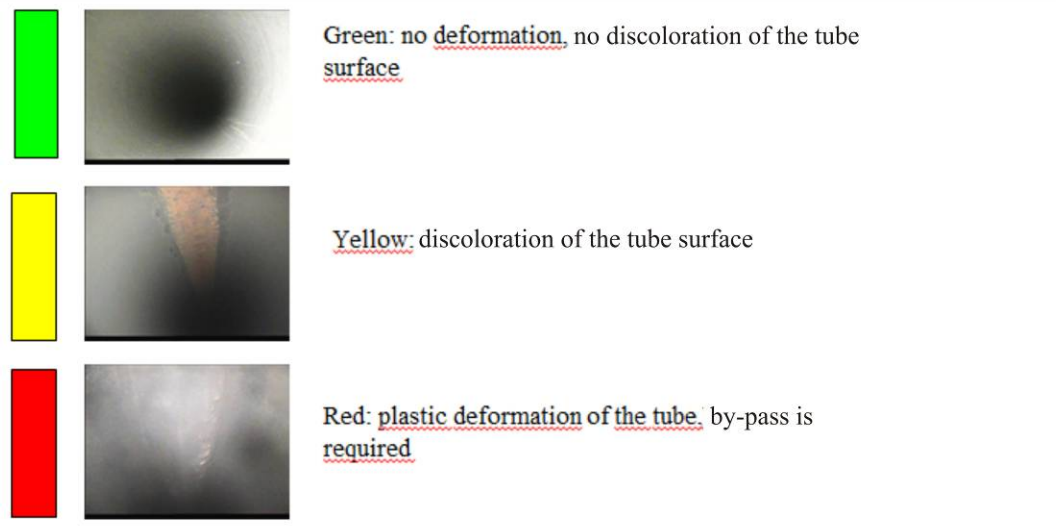

Figure 2. References for diagnosis of stave tubes.

At the same time and in order to protect the shell, it was established that when two consecutive channels were damaged then that area had to be protected by a casing to externally cool the shell and then monitor its temperature so as to prevent shell deformations. Figure 3 shows the casing protecting the shell.

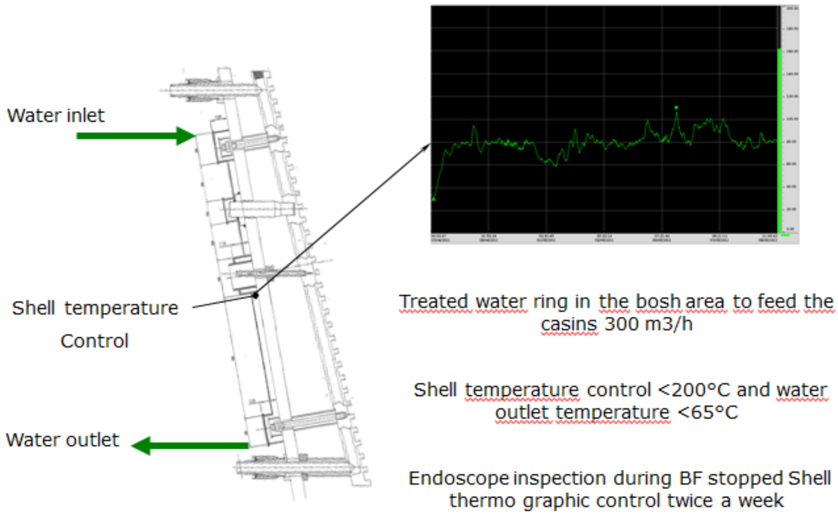

Figure 3. Shell protection (casing).

At the beginning of 2012, the process by which damaged channels appeared in the bosh started to speed up. The cooling plates located in the transition area between bosh staves and tuyeres started to become damaged, too (Figure 4).

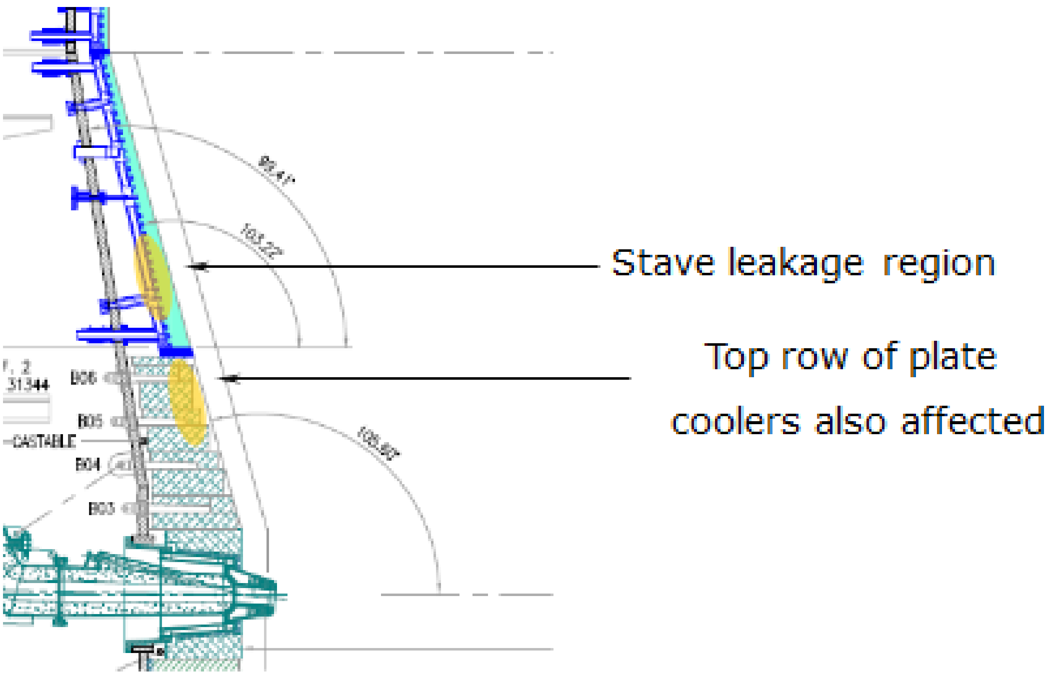

Figure 4. Area of burnt plates and staves.

Between June 2010 to June 2012 30 unscheduled shutdowns were carried out because of leakage in cooling circuits; 17 of them were due to the staves; 9 due to the plates and 4 due to the tuyeres. 84 by-passes were performed to stave channels. 43 channels were grouted and 12 cooling casings were mounted.

The development of damaged tubes in the staves is shown in Figure 5.

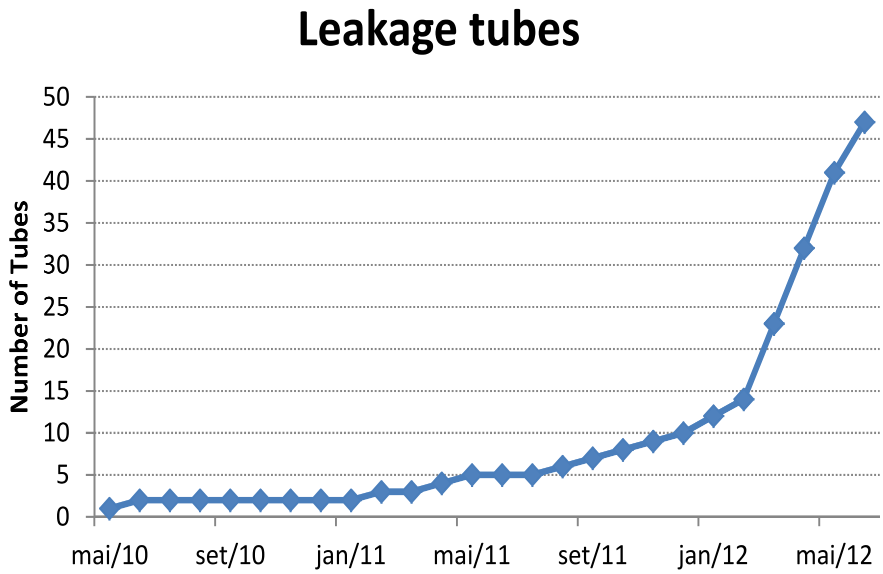

Figure 5.

An auxiliary cooling ring and collecting pans were mounted, which were essential to feed the auxiliary systems. As regards the possible causes of premature wear of the copper staves, there are still no definitive conclusions. In July 2012 the blow-down was carried out to change the 5 rows of copper staves. Figure 6 shows their conditions. There was massive copper stave wear, covering the 5 levels and the erosive process of the load on the staves is clearly visible.

Figure 6. Stave condition after the blow-down.

3 NEW STAVE DESIGN

As noted above the repair project comprised the replacement of five rows of copper staves BO1, BE2, S3-S5 all with an improved design. With this philosophy, the existing furnace lines were maintained such that the overall concept provided the following:

- improved copper staves in rows BO1, BE2, S3 – S5;
- modified installation of bosh staves to move the staves away from the hot face to further promote scull formation and reduce wear;
- silicon carbide/graphite sandwich construction in front of all replacement copper staves to reduce mechanical wear;
- body/rib stave thermocouple installation modifications to allow more accurate copper hot face monitoring.

The replacement staves were dimensionally similar to those originally employed. However several design improvements were still made. A copper stave with a castellated and slotted hot face, along with SiC refractory inserts combined with graphite to provide a composite lining in front was utilised.

The silicon carbide/graphite arrangement followed the concept previously used with the original plate cooled furnace at TX. In this arrangement the silicon carbide brick size is reduced to reduce internal stresses by temperature gradients and graphite is used to maximise the cooling from the copper cooler. The consideration to make the decision to install this lining is to balance the benefit of the wear protection that the SiC provides against the additional cost involved.

Attention was also given to the method of attachment of the staves to the shell. The existing staves had been designed with the known problems of copper stave distortion under certain conditions in mind. This problem was approached differently with a new design following some FE analysis.

The five rows of copper staves replaced in the furnace, covered the Bosh, Belly and Lower Stack. As well as replacing the existing staves with staves of a similar dimension, the same number of cooling pipes per stave, i.e. forty (40 off) staves per row with four (4 off) cooling pipes per stave was repeated. This negated the need for major changes to the shell and stitch piping and the cooling system. The replacement staves for BO1, BE2, S3, S4 and S5 were manufactured from hot rolled copper with drilled cooling channels and grooves at the hot face for the refractory material described.

The cooling pipe connections are fitted with expansion bellows so that the staves are free to expand without overstressing the welded connection between the cooling pipes and stave.

As is common with modern copper staves, they also incorporate “slots” in the castellation; these alleviate the stresses induced by thermal expansion and contraction and thereby reduce the ‘banana’ effect associated with early generation copper staves.

The staves are bolted to the furnace shell with four bolts per stave, located toward the corner of each stave. The purpose of the bolts and their arrangement is to set the position of the stave during installation and to ensure the optimum ramming gaps between each stave. The stave is also located relative to the shell with two pins; one fixed pin and one sliding pin. The purpose of the pins is to ensure that any thermally induced expansions and contractions of the stave are guided in a controlled manner such that the movements imparted to the stave expansion joints are acceptable. In the case of the TX project it was necessary to maximise the re-use of the existing hole pattern in the shell. Therefore during the detailed design stage of the contract, attention was paid to matching, as far as possible, the stave bolts with the existing shell holes.

In the bosh area to create the correct angle to suit the furnace lines requirement Sialon bonded Silicon-Carbide was also used with a ramming material between the bricks and the stave. The profile of this refractory material is considered to be the true furnace lines of the furnace. Existing plates in the bosh were retained. TX and Siemens believe that the additional support and cooling from these plates enhances the lifetime of the bosh refractory material. This will then lead to a longer life combined with smoother profile and operation.

Simple copper rods are employed to be able to monitor the wear. Although these are simple rods, a form of on-line measurement is permitted by use of the rods and external sensors. Data from this analysis is regular checked to ensure that the performance of the staves is within specification and such that any necessary proactive actions can be taken promptly to ensure that the furnace operation is correctly adjusted to suit the needs of the staves when appropriate.

Table 2. TX BF2 Cooling System Main Parameters

	Copper Staves	**All Staves**
Water Requirement	2038 m3/h	2038 m3/h
Temperature Rise	8.67 oC	10.0 °C
Heat Load	20.56 MW	23.59 MW
Hearth Diameter	10.4	10.4
Top Diameter	8.0	9.4
Tuyere Number	27	27

NB: The copper staves are a direct replacement of the existing staves so the original water cooling system was not changed and is still a once through system. The total water flow was maintained at 2038 m^3/hr with a by-pass on the top 3 rows (again an already existing feature). A pressure drop calculation was carried out to confirm pump capacity for the new system arrangement although it was never expected to be a problem.

Table 3. TX BF2 Stave Instrumentation

STAVE TYPE	**LOCATION**	**No. OFF Temperature**	**No. OFF Copper Wear Rods**
Copper	Middle Stack	20	8
Copper	Lower Stack	40	8
Copper	Lower Stack	40	8
Copper	Belly	40	8
Copper	Bosh	20	8
TOTALS		160	40

4 SHUTDOWN

A pre-planned, extended outage was planned to fully change out the agreed rows of staves. The procedure proposed was similar to that adopted around the world by other operators with some particular reference to experience gained in the USA. The shutdown proper was executed by TX with the planning, management and supervisory guidance of Siemens.

In summary, furnace was blown down, the salamander tapped and the burden plus “deadman” raked out to a level approximately 300mm below the tuyere level. The remaining burden was then capped off to create an acceptable working environment.

To enable the work to proceed inside the furnace, all loose material attached to the staves in the furnace was first removed. In addition, the uptakes were closed to prevent material from falling down into the furnace. With gas monitoring and forced ventilation through several tuyere openings a safe working environment was successfully maintained.

Before personnel entry to the furnace was permitted, it was necessary to remove scabs and other debris adhering to the inside face of the stack walls. This was achieved with the insertion of a specialist wrecking machine. A retractable arm with hydraulically actuated hammer was remotely controlled to pick off the debris.

The old staves were jacked into the furnace from the outside and fell down onto the capped burden. After a number of staves had been removed they were hoisted out through the top cone. This process was repeated until all of the old staves are removed. Access to the furnace for the removal of old staves and the introduction of the new staves was through the BLT chute removal door. Following removal of the damaged staves, the inside of the furnace shell was also cleaned off to ensure a good fit up of the new replacement staves. From experience this can be a cumbersome and time consuming activity.

The new staves were lowered in the furnace with a special hoisting tool that was fitted on the rotating chute of the furnace top. This ensured that the stave was positioned as close as possible to its final position. The staves were fitted by pulling them into their final position from the outside. Access to the work area inside the furnace was made through a pipe scaffold that was erected inside the furnace. For each new row of staves the scaffold / platform was extended upwards. By using this method, the bosh refractory and the ramming between the staves were able to be installed in parallel with the erection of the staves (by working at opposite sides of the furnace).

When the installation work was completed the cap was broken/removed to facilitate use of proprietary equipment for the quick and efficient recovery of the furnace.

To seal the space between the staves, the principle of using backing flats, which facilitate the filling the gaps between the staves with carbon ramming without filling the space between the staves and shell was followed. This material has good thermal conductivity but still has some compressibility allowing the staves to grow.

The space between the stave and shell was filled with a low iron ‘self-flow’ castable material, filled by pouring from inside the furnace after each row is complete. The last row of staves was filled from the outside of the furnace. Low iron materials are required for resistance to CO attack in the event of gas tracking.

To protect the staves during blow-in a 1.600°C grade low iron castable was incorporated on the front face of the stave. This blow in lining was retained by a network of anchors and/or a steel mesh.

5 BLAST FURNACE 2 BLOW-IN

The Blast Furnace 2 blow-in was carried out in February, 2013, and due to the short period of operation of the new staves protected with refractories at the front, it is not possible to assess their performance.

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