NOVAS TECNOLOGIAS EM STAVES DE COBRE*

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Resumo

Staves Coolers de cobre proporcionaram uma excelente proteção da carcaça do alto-forno em áreas de alta temperatura. Isso resultou para que os operadores de alto-forno alcançassem alto desempenho em termos de produtividade e taxa de combustível, além de campanhas de mais de 15 anos. No entanto, nos últimos anos, alguns altos-fornos experimentaram um desgaste prematuro nos staves de cobre. Algumas dessas empresas se alinharam com Paul Wurth para investigar a causa fundamental desse fenômeno com base em todos os fatores de influência e, em seguida, propor ações corretivas. Estes resultados são discutidos e apresentados a seguir no trabalho técnico.

Palavras-chave: Alto-forno; Stave de cobre, Trocador de calor stave; stave.

THE NEW CUSTOMIZED COPPER STAVES TECHNOLOGY

Abstract

Copper staves have provided excellent protection of the shell in high heat areas on many blast furnaces. This has resulted in the blast furnace operators achieving high performance in terms of productivity and fuel rate as well as campaigns of more than 15 years. However in recent years, some blast furnaces have experienced severe premature wear of copper staves. Some of these concerned companies have aligned with Paul Wurth to investigate the root cause of this phenomenon based upon all the influencing factors and then propose corrective actions. According to the numerous observations, studies, simulations and analyses performed by Paul Wurth, the root cause of the observed premature failure of copper staves is mechanical abrasion from the descending burden. The design factors as well as the operating conditions have been investigated and new features have been developed in order to cope with this abrasion issue. These new copper stave developments are a large part of the solution which prevents premature wear during detrimental operational periods. The new stave design features have been tested in-situ in some blast furnaces and under accelerated conditions in a scaled down shaft model which has shown promising results. Today this new stave technology is installed successfully in several blast furnaces with close monitoring of the stave conditions. New stave exchange methodologies which make it possible for the copper staves to be exchanged quickly and without having to enter the furnace have been investigated and validated on site. High performance operation together with long campaign lifetimes are thus made possible.

Keywords: Blast Furnace; Copper Staves, Stave Exchange.

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1 INTRODUCTION

The copper stave technology was introduced already a number of decades ago to the iron making process and it has spread on a wide front in the world wide iron making process in the 1990s. The reasons are obvious and numerous, and include important features such as increased blast furnace volume, better protection of the blast furnace shell against heat load, reduced investment cost and higher blast furnace productivity. In the most recent decade the return of experience from the operators showed many very successful furnaces and while some furnaces showed premature wear of the cooling elements.

A thorough overview of the stave technology including an analysis of the performance has been given in a numerous papers at different international congresses. Paul Wurth as the leading supplier of this technology has participated in this analysis together with many clients and put all the information together in order to get a more definitive picture of the behaviour of these cooling elements in the blast furnace.

A lot of improvements have been developed which needed to be evaluated in order to propose a new generation of copper stave technology to the market. This evaluation was done together with ArcelorMittal at a common test stand in France. Furthermore, many of these improvement features have been installed for several years in different furnaces together with the latest high performance instrumentation enabling to closely follow the behaviour of the new stave concepts in the blast furnaces. Today we know that the stave technology cannot be uniformly applied to all areas of the furnace and that each operation and blast furnace profile requires its own customized cooling element arrangement. This paper gives a short introduction to these new stave features developed by Paul Wurth, and an overview of the test rig on which some of these they are tested.

Finally, today's trend is towards campaign extension of the blast furnaces before making a complete revamp. This requirement is born from the most recent difficult economic conditions and the related effort to maximize the existing investment by campaign extension. Besides the hearth refractory, the cooling elements become critical since they are exposed to the harsh operating conditions. Therefore modern stave exchange tools and procedures have been developed and successfully applied allowing the quick exchange of complete rows of staves in small intermediate repairs.

2. Modern copper stave design

2.1 Basic principle of the copper staves technology

The idea to use copper staves in the blast furnace, was to combine the advantages of stave cooling technology with the advantages offered by the copper material. The main benefits of copper staves for the high heat load areas, compared to cast-iron staves, can be explained as follows:

- Copper has around 10 times higher thermal conductivity of compared to cast-iron
- Direct contact between a drilled stave or cast-in channels with the cooling water (no thermal resistance due to coating/steel pipes or air gap/porosity)

Thus, the basic principle of copper staves is the use of high heat flux removal capacity which ideally protects against heat load peaks. The changes in the blast furnace operation process can lead to a sudden increase of the copper stave body temperature as described in [1] up to temperatures higher than 150°C. These stave body peak temperatures are still rather low, if compared to the admissible maximum temperature for copper and to temperatures recorded in cast iron staves [2].

There are recent cases, which have shown premature abrasive wear failure of copper staves. This has brought many of the concerned companies, together with Paul Wurth as a partner, to investigate the root cause of this phenomenon based upon evaluation of all the influencing factors.

According to the many observations, studies, simulations and analyses performed by Paul Wurth, the root cause of this observed premature failure of copper staves has been identified as mechanical abrasion from the burden. The effect of temperature and chemical attacks on this wear phenomenon are very limited.

As a consequence, the choice of the copper staves should not only be only based on thermal considerations. In order to meet the harsh conditions, the following parameters must also be considered [3]:

- Hardness of the burden material at the level of the copper staves (linked to an insufficient reduction of the burden material);
- Burden decent speed on the face of the copper staves (i.e. blast furnace profile; stave and grooves shape)
- Material pressure at the wall (i.e. blast furnace profile);
- Hardness of the copper stave hot face;

These parameters have led to a new design of copper stave. The use of these new features will increase their lifetime and make them totally resistant to process variations.

2.2 Stave design

On blast furnaces which have a good profile, the bosh and belly are equipped with staggered arrangement of steel blades and protruding steel inserts to promote and stabilize a protective layer which is created by the stone box effect;

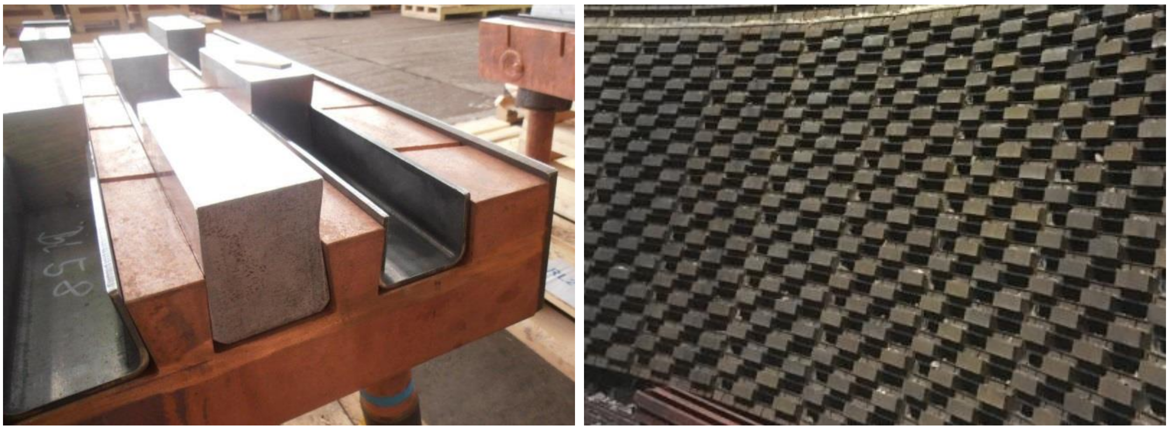

Figure 2.1 *Staves with patented steel blades and steel inserts at workshop and during erection*

On blast furnaces with a steep profile, the bosh and belly are equipped with a continuous arrangement of cooled copper ledges to promote and stabilize a protective layer by stagnant zone effect . In order to protect the tip of these ledges, the ledges are machined and covered with exchangeable elements which are fit tight to the stave body. These elements are exchangeable from the outside of the furnace without requiring a blowdown, thus providing the same advantage as cooling boxes, but their design provides a continuous covering of the ledge. As a side advantage, this burden buffer will also induce a thermal protection (and thereby a reduction in the coke rate).

Figure 2.2 *Staves with cooled ledges at workshop and ledge with patented exchangeable elements*

For the stack area, the hot face protection of staves is based on steel blades fixed to the upper edge and inside the grooves, still allowing for the staves to cope with high heat loads.

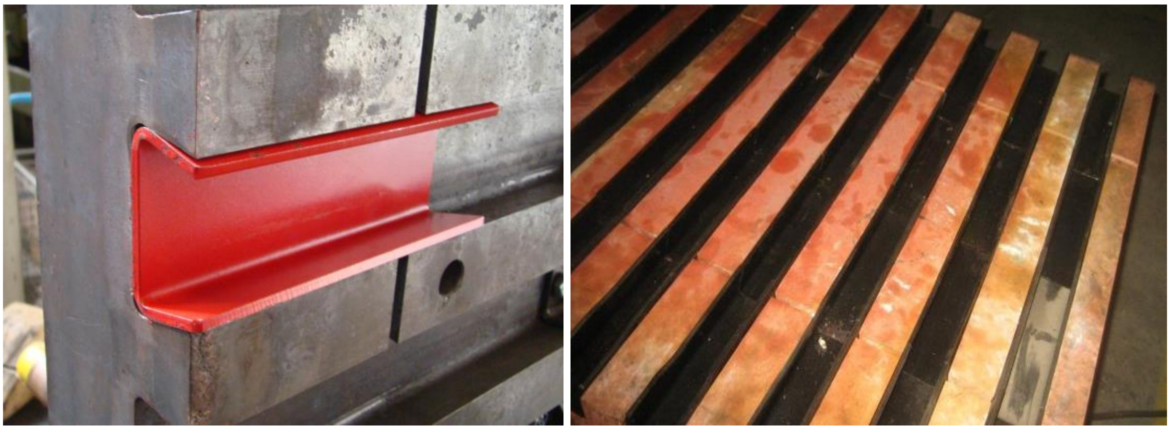

Figure 2.3 *Staves with patented steel blades*

Besides of the specific stave arrangement, all the staves are now curved according to the radius of the shell to avoid the typical ‘balconies’ created at the step from one stave row to the next. Without curving of the staves, there is a high potential for wear at the upper midpoint of the copper stave. Staves are also equipped with steel blades which are located vertically in-between the staves and at their top and bottom surfaces. This patented solution prevents the descending burden from entering the gap between staves and thus trench the top of the stave below.

Figure 2.4 ***Damaged staves with the 2 typical wear patterns at the middle top and according to radius***

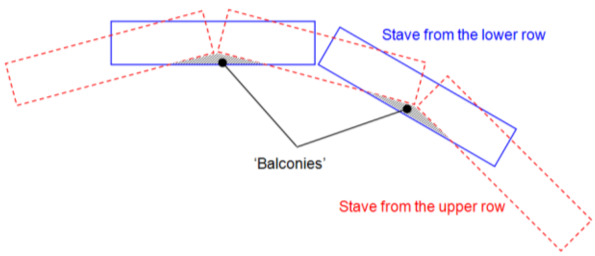

Figure 2.5 ***Scheme of the balconies and Curved stave at workshop***

Figure 2.6 ***Curved stave with in-between blades during erection***

In addition to these patented solutions, the following further enhancements have been implemented:

- Increasing rib thickness and modifying the rib orientation. The ribs and grooves arrangement is an important feature of the staves, not only to increase the exchange surface in case of high heat loads, but also to create a rolling effect of the burden close to the wall and to stabilize accretion layers as well as to trap material inside the grooves which insulates and protects the stave;

- Increasing the hot face's hardness (through coating / hardfacing) and modifications in the base material such as copper alloy.

- Improved monitoring of the process through Paul Wurth's level 2 system BFXpert®;

- In situ detection of wear through thickness measurement probes and improvements in the instrumentation;

- Auditing the stave wear pattern of the furnace with specially developed probes.

and finally Paul Wurth is proposing new stave exchange methods which are presented in the chapter 4.

3. Copper stave test rig facility

In addition to many developments and investigations performed internally, and with different partners, Paul Wurth together with ArcelorMittal, decided to develop and erect a representative test rig facility in order to analyse the abrasive wear phenomena on copper staves and to validate the wear resistance of the new features (section 2).

This test rig is a great asset to evaluate the quality of the developments, parallel to in-situ references in the blast furnace. This test rig also offers the opportunity to follow the wear on a regular basis on the whole surface of the stave, which is almost impossible on a real furnace.

Figure 3.1 ***Cu-stave test rig; material recirculation principle (left) and picture (right)***

The purpose of the stave test rig is to simulate the abrasive wear conditions at the blast furnace walls as realistically as possible in a reasonable manner and, as a result, to compare different stave wear protection designs. The wear process is performed by recirculating material inside a hopper equipped with 20 staves. The burden material is screened sinter used in the blast furnace. This burden is descending vertically across the staves, uniformly over the circumference.

In order to have a realistic approach and to test the influence of the stave angle, the profile of the stave hopper has been based on an existing ArcelorMittal blast furnace. The staves are divided in two rows, the top row has the inclination of belly; the lower row is at an angle corresponding to the bosh angle. The stave height and width have been reduced for economic reasons. However the dimensions of the protective features on the hot face of the staves and the material grain size are at a 1:1 scale. The material flow in the test rig simulates 4 years of operation in around 4 months by increasing accordingly the burden descent speed.

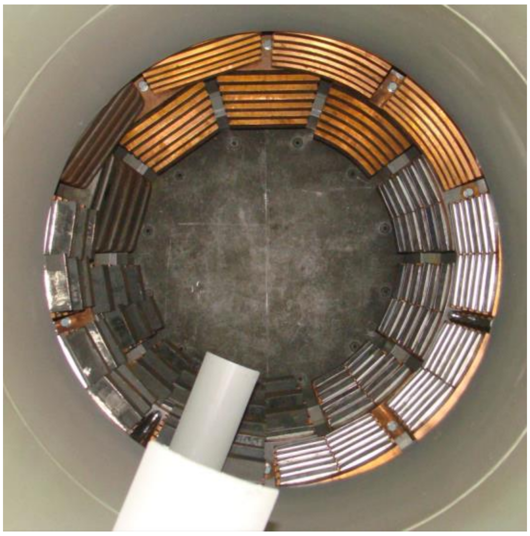

Figure 3.2 ***Staves hopper before the start of the first campaign***

In order to avoid the risk of preferential flow and for all the staves to see the same material flow, the stave hopper is set on a rotation system and it is turned daily by a few degrees.

In order to simulate the weight of the burden column located above the staves, a piston has been added on top of the material layer. This piston is compressing the material so that the staves endure the same forces created in a blast furnace. The material is extracted from the stave hopper using a rotary table with a homogeneous flow at the wall and shifting the material into a bucket conveyor. The stave hopper is regularly extracted from the test rig in order to record the wear on the staves. The observation of the wear of the staves is done using a 3D-laser and in addition, the staves have been painted, showing the areas where the burden material is stagnant.

Figure 3.3 ***Bosh/belly stave design with blades - stone box effect***

The wear measurements conform to the observations in real blast furnaces. The wear is more pronounced in the centre and on top of the bosh stave than on the bottom. The comparison between the staves with protection and the staves without protection validate the efficiency of the protection devices (blades, inserts as described above).

4. Copper stave exchange methodologies

Paul Wurth has developed special procedures and tools for stave replacement which can extend a blast furnace campaign. The development was done jointly with several customers and has been industrially proven. This hot repair method is based on the 2 following constraints:

- Safety first, which means no worker present inside the blast furnace.
  The intervention in a blast furnace including the handling of heavy equipment is a dangerous task, especially there isn't any salamander tapping which is the case for such a short outage. People entering the blast furnace for installation work will be confronted with difficult conditions such as heat, gas and high dust loads.

- Reduce the outage duration as much as possible:
  - Stoppage not exceeding 120 hours between wind off and wind on
  - No salamander tapping
  - Up to 60 staves shall be changed in 1 outage.

To reach these objectives, a special foldable handling tool that could be in operation few hours after wind off was designed and tested. Paul Wurth and the customers also took advantage of pre installation work during scheduled down days in order to reduce the outage time for the stave replacement. Tools have been developed which offer multiple work fronts to help achieve the schedule objective. Paul Wurth has engineered 2 tools for this task, depending on the local surrounding constraints. Up to 8 simultaneous intervention points can be proposed.

Beside these mechanical aspects, a dedicated erection team has to be trained on a test stand in order to gain sufficient experience to perform the job fast and to face unexpected problems. This avoids accidents and contributes in reducing the time schedule risk for the outage.

The arrangement model and picture of the stave handling tools erected through a cast iron stave row, in the blast furnace shaft through special access doors are presented in figure 4.1.

The arrangement model and picture of the stave handling tools erected through the top cone are shown in figure 4.2.

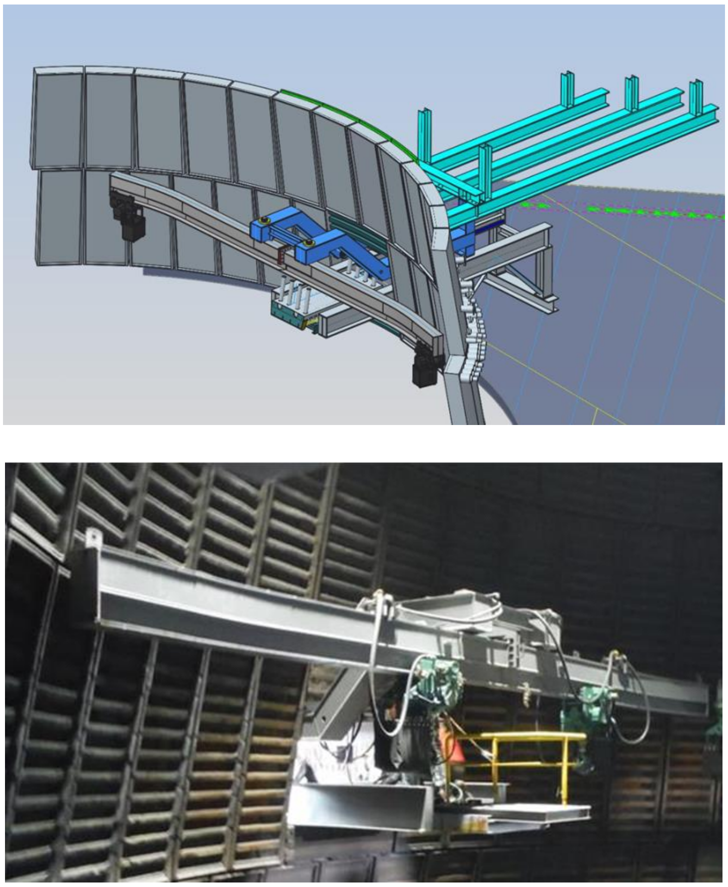

Figure 4.1 ***Paul Wurth stave handling tool introduced through BF shell openings***

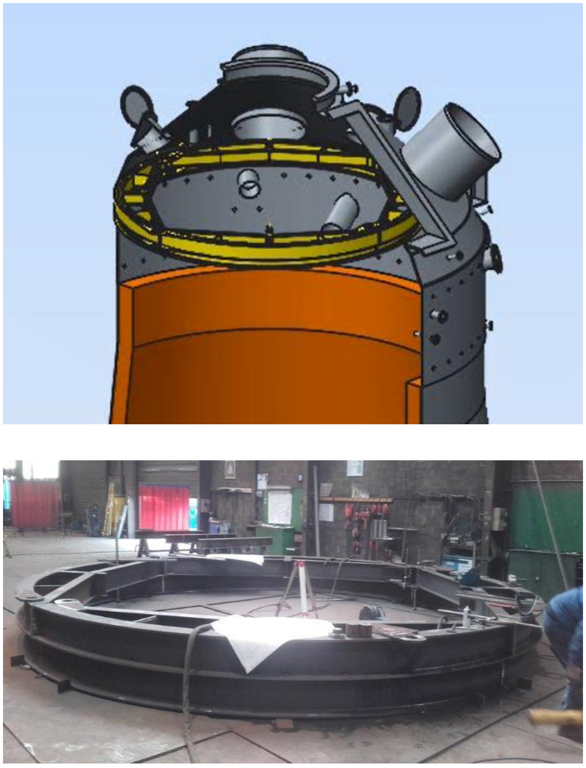

Figure 4.2 ***Patented Paul Wurth stave handling tool introduced through top cone***

5. CONCLUSION

Copper staves have, over the previous few decades, shown their ability to resist harsh conditions such as high heat loads and the contact with primary liquids inside the blast furnace at high injection rates and high productivities. They effectively protect the shell by insulating it against high temperatures and the carburization process. The long lifetime of the stave is made possible by basic working principles, such as the built up of a protective layer or a hot face resistant against wear.

To achieve this principle, Paul Wurth has developed wear resistant stave designs for all blast furnace profiles and all areas for the blast furnace, namely the bosh, belly and stack, with excellent results.

The optimal choice of these features depends on the position in the blast furnace and the profile of the blast furnace.

Parallel to the in situ references in the blast furnace, a test rig has been built in collaboration with ArcelorMittal to evaluate the wear resistance of these new features and to further increase the knowledge regarding copper stave wear by following the wear on a regular basis.

In order to install these new copper staves quickly and without entering the furnace, new stave exchange methodologies have been investigated and validated on site. The stave exchange is now possible by utilization of dedicated Paul Wurth tools which result in a very short intervention at a high safety level.

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