Wear-Resistant Copper Staves — An Update



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Since the installation of the first wear-resistant staves in February 2013, Primetals Technologies continues to develop and monitor its wear prevention solutions for copper staves. There are currently three sites globally featuring installation of the latest wear resistance designs. Operational data demonstrates that the inserts remain in place with no apparent wear developing. Reduced heat losses from the blast furnace to the cooling system have also been observed, delivering an additional, potential fuel-saving benefit. This paper will describe the new stave features and how the innovative, class-leading design has been developed to overcome commonly experienced stave issues.

Copper staves offer one of the highest heat removal capabilities for a blast furnace cooling system. This is one of the main reasons that they have become the predominant method of cooling blast furnaces. But operators are coming under increasing pressure to extend blast furnace campaign life and use more cost-effective raw materials while maintaining high-productivity operation. This has highlighted two common failure modes of copper staves.

Copper stave bending was the first widely recognized failure mechanism linked to thermal expansion of an incorrectly restrained stave. In this case, a failure of the water pipe connection to the back of the stave will occur, leading to loss of stave cooling and water entering the blast furnace process. It is possible to repair such failures without replacing the stave; however, these repairs are often difficult and time-consuming. It is possible to avoid these problems with the correct design.

Wear of copper staves is a more recent failure mechanism. This is potentially disastrous with only replacement of affected staves available as a mitigation.

This paper will focus on the issues copper staves have faced through stave wear, why the problem occurs and the best technology available to prevent it happening altogether for a long campaign life. Furthermore, operating feedback from the first three sites to adopt material retaining wear-resistant inserts will be displayed and discussed.

Discussion

What Is Stave Wear? Copper staves survive the arduous process conditions in the blast furnace by freezing a protective accretion layer on their hot face. This then shields the stave from the abrasive wear of burden material descending the blast furnace. However, the thickness of these accretion layers has been proven to vary in even the most stable of blast furnace operation. This leads to the possibility of the soft copper stave being worn.

The stability of the accretion layer therefore has a big impact on the possible campaign life of copper staves. Because of this, the profile of the furnace can also influence stave wear rates.

Burden material quality can also play a part in stave wear rate with harder material more able to damage the soft copper. This kind of failure is often seen at, but not limited to, the interface between the cast iron and copper staves in a blast furnace. It is this location which may not operate at sufficient temperature to melt burden material and form protective accretion layers.

Furthermore, with variation in blast furnace operation and cohesive zone heights, the gas temperatures at the highest row of copper staves may vary.

Although wear measurement can be included in the stave design, these are generally at a limited number of fixed points within the network of staves. This can lead to the thickness measurements being of little value if stave wear is occurring in areas not covered by the measurement points. In the worst case, it can lead to stave wear going undetected until it causes multiple cooling channel failures and significant water ingress to the blast furnace.

Causes of Stave Wear — Copper stave wear has been observed to be caused by any one, or a combination, of the following factors:

- Incorrect furnace profile/lines.
- High rates of reductant injection.
- Furnace process and position of cohesive zone.
- Low burden permeability due to furnace charging patterns.
- Poor burden quality.

The above are all believed to affect the ability of the copper staves to form a stable accretion layer which then protects the stave from abrasive wear. Although designers should be able to provide blast furnaces with a suitable profile, some have ignored this important aspect even when engineering a new stave-cooled blast furnace.

Development of Wear-Resistant Inserts — A hexagonal arrangement of inserts was conceived to capture the burden material as it descends the blast furnace. This immobilized material then shields the copper stave from the moving burden. As gaps will still be present between the material, any molten liquids can still reach the copper surface and freeze to form an accretion.

To prove this concept, a $^1/_{10}$ physical-scale model was built to demonstrate the relative increase in material capture between a bare ribbed stave, competitors' designs and this hexagonal pattern. This allowed the performance of the different designs to be rapidly compared. The results showed that material retention increased slightly in the vertical belly section of the blast furnace when a hexagonal pattern was present on the stave hot face. However, the retention increased by approximately 25% when considering an inclined, hexagonal patterned stave in the lower stack.

More recently, the scale model was replicated by an independent end user with discrete element modeling (DEM). This software simulates a flow of material and the effect on a fixed surface. By using a simplified arrangement of staves from an operating blast furnace, the effect of insert spacing on material retention could be determined. The model confirmed what was seen from the physical model — the hexagonal arrangement is able to capture burden material and form a protective layer. Due to the flexibility of the model, four different insert spacings were investigated to see which had the greatest capture of the simulated burden with a mean particle size of 52 mm and a range from 42 to 58 mm.

Operational Feedback — The very first installation of wear-resistant staves was equipped with additional instrumentation to measure the differences between this revolutionary design

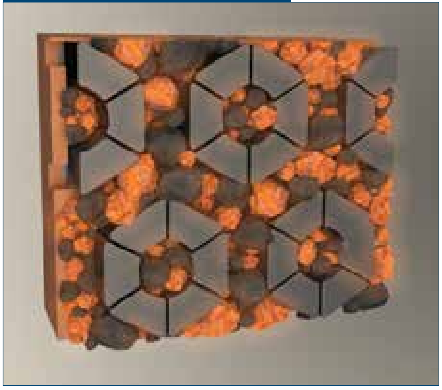
Figure 1

Illustrative example of a potential stave wear cause.

Figure 2

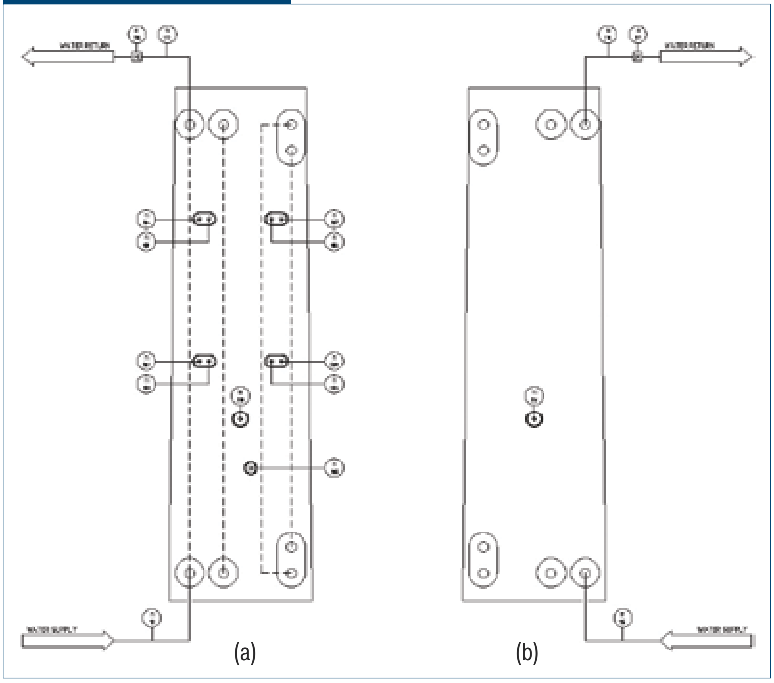
Photograph of 3D-printed physical-scale model.

Figure 3



3D render of hexagonal inserts with captured burden material.

Figure 4



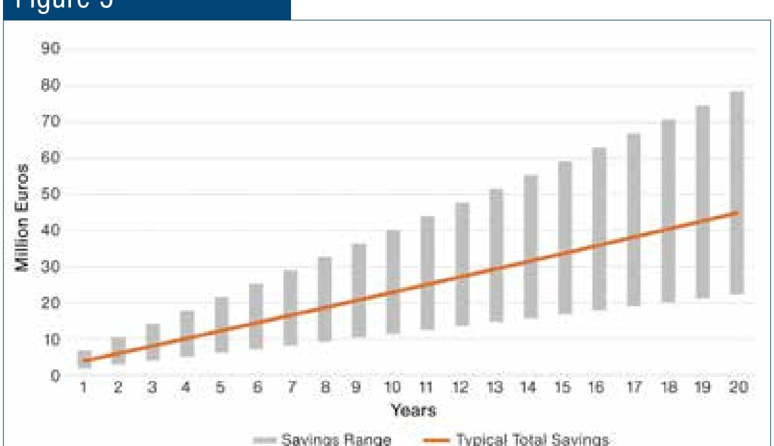
Instrument locations in wear resistant (a) and comparison stave (b).

Table 1

Heat Removal From Hexagonal and Comparison Staves Over Two Years of Operation

Period	Duration (days)	Hexagonal stave (GJ)	Comparison stave (GJ)	Difference in heat load	Coke saving (kg/tHM)
Stable operation	513	945	1,026	-9%	1-2
Unstable operation	110	715	1,094	-53%	4-7
Average	623	1,660	2,120	-28%	2-4

Figure 5



Estimated savings from adopting wear-resistant inserts.

and traditional designs also installed in the same blast furnace. Measurements show consistently lower temperatures for the wear-resistant design, which show a more stable accretion/protection layer is formed.

The heat flux was also measured and compared for the two designs of stave. Again, the results show that the wear-resistant stave removes less heat from the process than the traditional stave design. This is understood to be further proof that the hexagonal pattern captures material and forms a more stable accretion/protection layer. However, by removing less heat, the wear-resistant staves also offer an advantage to the thermal efficiency of the process. By reducing the heat lost from the process to the cooling system, the total fuel rate is reduced. To analyze this, three separate operating regimes were identified: stable operation, unstable operation and the long-term average. The heat removal from both hexagonal and traditional stave designs are included in Table 1 with the percentage difference and estimated coke saving if all the copper staves were to be equipped with wear-resistant inserts. It should be noted that these are provisional figures which will depend on coke quality and furnace productivity, among other factors, individual to the specific furnace and raw materials.

By saving coke, there is an obvious reduction in operating costs for a blast furnace equipped with wear-resistant inserts. However, there is also a reduction in CO_2 generated by the blast furnace. With the introduction of penalties for emitting CO_2 to the atmosphere being introduced in steel-producing regions, there is a further potential saving for blast furnace operators. By assuming a European carbon tax price of EUR80/metric ton of CO_2 and a coke price of EUR250/metric ton, the combined savings over the stave campaign life can be estimated. This is shown in Fig. 5.

In addition to this site, two further installations came into operation toward the end of 2020. The first of these were inserts-only installed onto a set of existing copper staves during a planned furnace reline. The site identified their wear issues only during the reline and therefore did not have the time or budget to replace full rows of copper staves. Instead, the Primetals Technologies retrofit anti-wear inserts were manufactured and installed on a tight schedule to ensure the copper staves would survive until the next major furnace repair. Large volumes of data have been provided on the blast furnace operation and performance of the inserts in the bosh and belly region of the blast furnace which is under regular review by process specialists. After over a year of operation, the anti-wear protection is still in place, protecting the staves.

An alternative patented design of insert has also been developed to sit between the ribs of a traditional copper stave. This solution was also installed and brought into operation late in 2020 and, as with the retrofit design mentioned above, the anti-wear protection is still in place protecting the staves. The data confirms that staves with inserts are better insulated than staves without inserts, and that the life of the copper staves is extended. Operating data from this set of inserts, located in the belly – lower stack region, also provides further insight into the benefits to adopting wear-resistant inserts.

Conclusions

The widespread implementation of copper staves for blast furnace cooling has often resulted in problem-free campaign lives, especially when the designer has taken care with the furnace profile and stave design. However, some blast furnaces have suffered from premature copper stave wear, leading to shortened operating lives. This wear can expose and puncture the internal cooling channels and result in water leaks into the furnace. When there is no flexibility to improve furnace profiles, a wear-resistant lining should be installed to maximize the life of copper staves. Operating feedback from the world's first hexagonal copper stave has shown that:

- The hexagonal insert pattern develops a stable self-protecting layer and the insert pieces have not worn since coming into operation almost three years ago.
- This means a prolonged life of the copper staves behind the inserts which will not suffer from wear with the inserts installed.
- The duration and magnitude of heat load peaks to the cooling system are reduced.
- The lower heat losses to the cooling circuit leads to a reduction in fuel rate and a reduction of CO_2 emissions.

Primetals Technologies now has patents pending around the world for a number of variants of this design. By offering these technologies to customers, it can be said that copper stave life can be prolonged even when the furnace profile encourages stave wear by descending burden material, and fuel rates reduced at the same time. ✦

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