DEVELOPING THE BLAST FURNACE COPPER STAVE FOR IMPROVED PERFORMANCE*

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Abstract

The copper stave was a development of the Blast Furnace cooling system intended to utilise the high heat transfer properties of copper within a fully covered shell cooling solution. They were originally conceived as being able to provide a permanent cooling lining for use primarily in the higher heat zones of the Blast Furnace. Despite a large number of campaign successes around the world the everlasting concept has not proven universal, with some plants having suffered issues in two particular areas: stave bending (leading to water leaks at back of the stave) and stave wear (erosion on the hot face). Primetals Technologies have in the past been approached to provide assistance to a number of Blast Furnace operators who were experiencing operational issues with the copper stave furnace cooling systems of others. Through knowledge gained resolving these issues, and with the positive experiences of their own copper stave designs, Primetals Technologies have worked towards developing a new concept in copper stave design capable of providing a more robust solution to cope with the greater productivities of modern ironmaking. This paper will provide an outline to the concepts that have driven the design of this new technology.

Keywords: Blast Furnace Cooling; Copper Staves; New Hexagonal Stave; Development.

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1 INTRODUCTION

Throughout the development of Blast Furnace ironmaking the cooling system has been critical to meeting the ever increasing demands for greater production. As furnace size has increased and campaign life extended the furnace shell cooling system has evolved in a search for the optimum design. In the 1990's the copper stave was introduced in an attempt to marry the advantages of the high heat transfer advantages of the copper plate coolers with the full cooling coverage of the cast iron stave solution. It was considered that the use of the copper stave solution in the high heat flux zones of the Blast Furnace could lead to extended campaign life well beyond the 8-12 years of cast iron staves, and potentially provide a permanently protected shell.

Despite the many successful campaigns with copper stave technology there have also been multiple reported instances of premature failure where campaigns have either been cut short for repairs or have suffered from significant additional maintenance activities. Primetals Technologies have carried out a number of investigations for Blast Furnace operators aimed at overcoming on-going furnace cooling issues through definition of the root causes of failures and then engineering the individual solutions for implementation. With Primetals Technologies' own design experience with copper stave cooling systems being overwhelmingly positive these additional failure investigations have enabled a complete picture of copper stave operations to be developed which in turn allowed the next stage of optimization of the cooling element to be conceived.

2 COPPER STAVE DESIGN ISSUES

2.1 Experience

The original concept of copper staves was to utilize the superior heat transfer capabilities of copper to rapidly freeze a protective layer of burden materials on the stave front surface. If this material layer was robust enough then the surface of the copper stave would be permanently protected from wear as a result of the movement of burden material. In addition a layer of solid material fixed to the front of the stave would provide some further insulation from the internal process temperatures thus reducing heat losses to the cooling system. Any loss of the accretion layer should naturally see the heat flux increase and then rapidly refreeze a new material layer.

Monitoring these heat flux variations have enabled some Blast Furnace operators to establish stable long term operational control however for others the actual experience has not delivered the same performance. Many reports from around the world plus the failure investigations that Primetals Technologies have carried out for Steelmakers have highlighted a number of recurring issues. In some cases the copper staves have simply suffered from manufacturing faults which can be overcome by improvements to the supplier selection process and by a more rigorous manufacturing inspection regime. The two critical areas covered in this paper, which drove the development of new copper stave technology, are:

1. Failure of the cooling pipe connections at the cold face of the staves
2. Wear of the hot face of the staves

2.1 Copper Stave Bending

Copper stave bending has been reported more frequently in terms of stave failures although this may be because it is easily detectable from external inspection of the cooling pipes. In many cases it can also be repaired within the constraints of a normal planned maintenance stop.

It can be detected early by looking for excessive movement of the cooling water pipes relative to the compensators and shrouds, but if left to deteriorate then ultimately the cooling water connection to the stave can fail through fatigue leading to ingress of water into the furnace.

The copper stave in operation experiences a stable cold face temperature which is set by the temperature of the cooling water but has a varying hot face temperature that is subject to the internal process conditions and any changes to the accretion layer thickness on the front face. These stave conditions therefore lead to differential thermal conditions within the stave that must be considered in the overall stave design – insufficient control measures to cope with the variable internal stresses can lead to bending. Rapid changes of temperature due to variations in furnace conditions or the loss of the protective layer cause the stave temperatures to cycle and deflection occurs at the points where it is least restrained. In some instances bending of the staves has occurred along the length which can lead to localized wear of prominent parts but in other instances the stave deflection has been observed at the corners. This allows material to get behind the stave and also for dust to penetrate the compensator locking free movement. As any thermal cycling continues further bending occurs allowing more material behind the stave and this cycling results in failure of the weld connection of the water pipe to stave body and ultimately cooling water leakage into the furnace. It is therefore very important that copper stave designs include provision to handle these movements in such a way that the areas of the cooling pipes and joints are not compromised.

In general measures to help control bending have focused on improving the details of ribs and grooves and ensuring fixing of the stave where required.

2.2 Copper Stave Wear

Premature wear at the hot face of the copper stave may sometimes be associated purely with the early onset of stave bending exposing sections of the stave to burden movement disturbance. However there are many factors that contribute to the initiation of wear and to its ultimate extent. The internal blast furnace profile is one factor that if incorrectly specified is very difficult to adjust after start up and is therefore a critical consideration in all Primetals Technologies' cooling system designs. As some of the failure investigations have shown, this critical consideration is not the focus of all designers and Primetals Technologies have in the past had to improve solutions that have previously focused on increasing volume without consideration for good furnace operation.

An incorrect furnace profile can create conditions of poor furnace operation allowing abrasive wear from unreduced burden material. This wear occurs as the descending burden pressure forces are directed normally on to the front face of the stave.

Instabilities in the burden descent may also lead to excessive local gas temperatures further affecting the stave protection.

However poor furnace operation is not just a design function and can also be caused by many factors outside the designers control such as raw material quality, incorrect burden distribution modelling, rapid process changes and furnace slippage. Any development of copper staves needs to consider all the potential process upsets in order to optimise the cooling system.

Where monitoring is carried out regularly the onset of wear can be noted early and operational adjustments made to reduce the effects. The rate of wear has been seen to increase rapidly under certain conditions and then to be reduced by process adjustments showing that there is an operational input that is critical. If allowed to continue then excessive wear can ultimately lead to water leaks into the furnace through exposure of the cooling water channels and then, once water passages are isolated, the complete loss of the stave and shell damage. Leakage can be arrested temporarily with the insertion of flexible pipes or by the use of nitrogen injection but finally replacement of the stave is required.

Therefore it can be identified that in order to avoid wear problems, along with ensuring a correct furnace profile, it is important to try to promote the build-up of an accretion on the stave front face and to ensure it either has a permanent presence or is replaced rapidly when lost.

3 DEVELOPING THE NEXT GENERATION STAVE

After observing the negative experiences of some Blast Furnace operators Primetals Technologies therefore investigated methods for improving the reliability of stave installations. With the Primetals Technologies furnace profile design concept already being well proven any future development needed to focus on the two highlighted failure mechanisms that could be influenced by the stave design.

Any future stave needed to maintain the full coverage cooling of the furnace shell and therefore still retains many elements of the Primetals Technologies standard stave of today. In terms of the basic stave design the constraints associated with size and thickness and the retention of internal water cooling passages means that the hot / cold face thermal differences are still evident and therefore engineering solutions must continue to be included to cater for bending phenomena. Therefore the original Primetals Technologies' anti-bending solution is incorporated into the new stave. This solution, as indicated in the Figure below (Figure 1), allows the cooling pipes to move during thermal expansion but prevents any bending of the stave corners inwards. It has successfully been installed on a number of furnaces and prevents the fatigue failures associated with other designs.

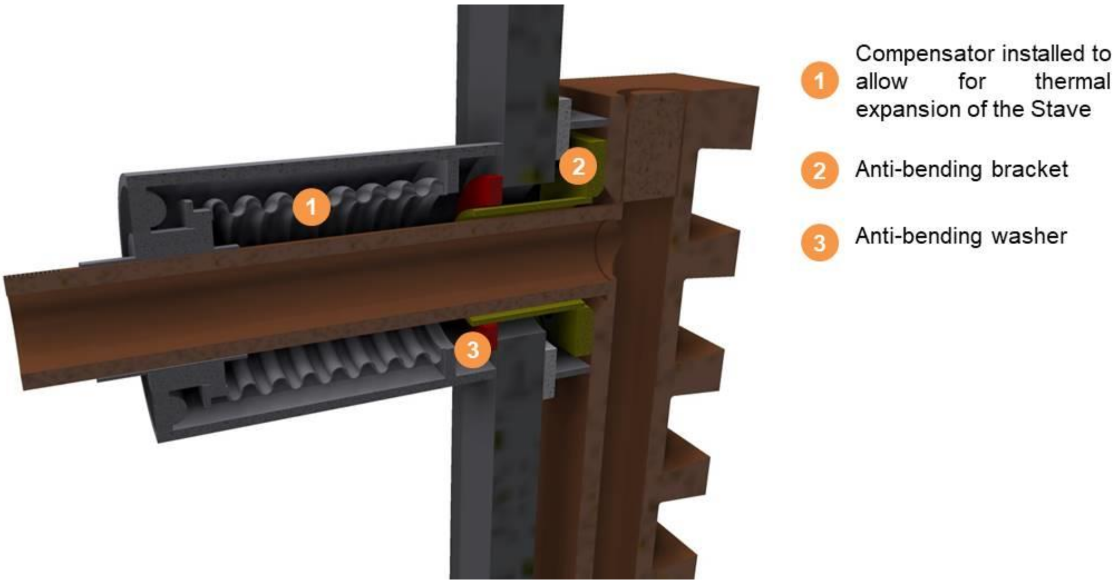


Figure 1. Primetals Technologies Anti-Bending Solution

The original concept of this Patented bracket has operated successfully for over 15 years without any failures and later generations are incorporated within other furnaces with the latest version included as part of the current standard Primetals stave. The continuing success of this bracket design means it was therefore retained as a standard part of the new stave concept. The incorporation of the anti-bending solution along with other proven critical design parameters regarding the correct positioning of the fixed and moving pins ensures that the future Primetals staves will continue to be protected from uncontrolled bending.

Confident in the anti-bending solution the new stave development therefore had to focus on how to improve the wear solution. The simplest development would be to engineer a solution that increased the ease of formation of the protective accretion layer and improved its robustness to survive variations in process conditions. A more robust layer would also reduce the overall heat lost from the process.

To be a practical solution however it would still need to retain some of the constraints from existing installations and therefore the external cooling system requirements were maintained as the same as the current Primetals Technologies standard stave. These conditions have been shown to allow for rapid formation of the accretion layer once a bare face is exposed and therefore the responsible product design engineers concentrated on how to make the layer more robust. Investigating different rib designs it was considered that channeling burden material movement to create a locking point would greatly improve the hold of any accretion and with a firm base it would then build up to a stable thickness. The channeling of the burden material was shown to be improved by testing of various rib designs with the honeycomb arrangement proving to be the most successful. The basic arrangement of such a stave design, with and without inserts, is shown in the Figure below (Figure 2).

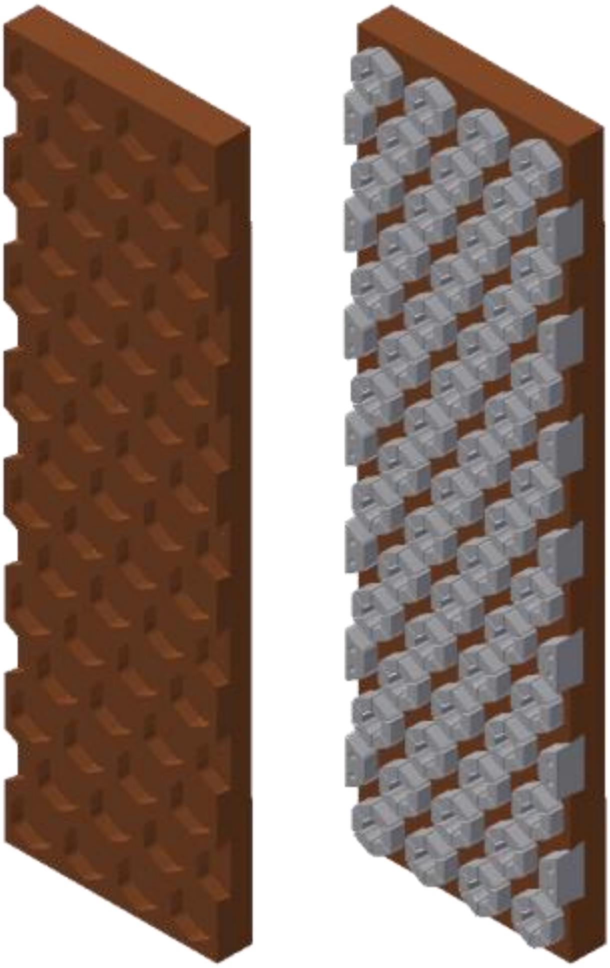


Figure 2. Honeycomb Stave Solution

The original stave designs were restricted by the practical manufacturing solutions available at the time but making use of modern machining techniques now allows for much more complex patterns to be formed on the stave hot face. After considering the many different arrangements investigated it was the honeycomb pattern which stood out as the most advantageous. As indicated above the bare stave has a machined honeycomb pattern which forms discrete pockets for adherence of an accretion material. However the design of the pockets was engineered so as to allow retention of hexagonal inserts of a metallic or ceramic wear resistant material. The pattern of the hexagonal inserts acts in a similar way to existing staves providing either a stone-box effect with unreduced burden material or utilising the excellent cooling of the copper face to freeze on a protective accretion layer. The honeycomb arrangement however promotes the capture of the material between the inserts by guiding it to converge to a position where it is more securely held by three points. This 3-point hold is indicated in the Figure below (Figure 3).

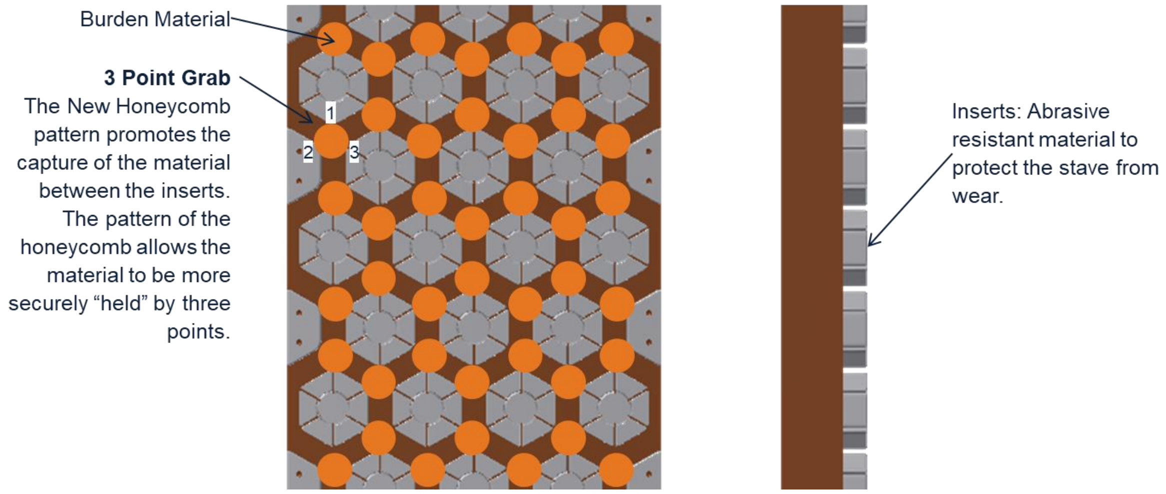
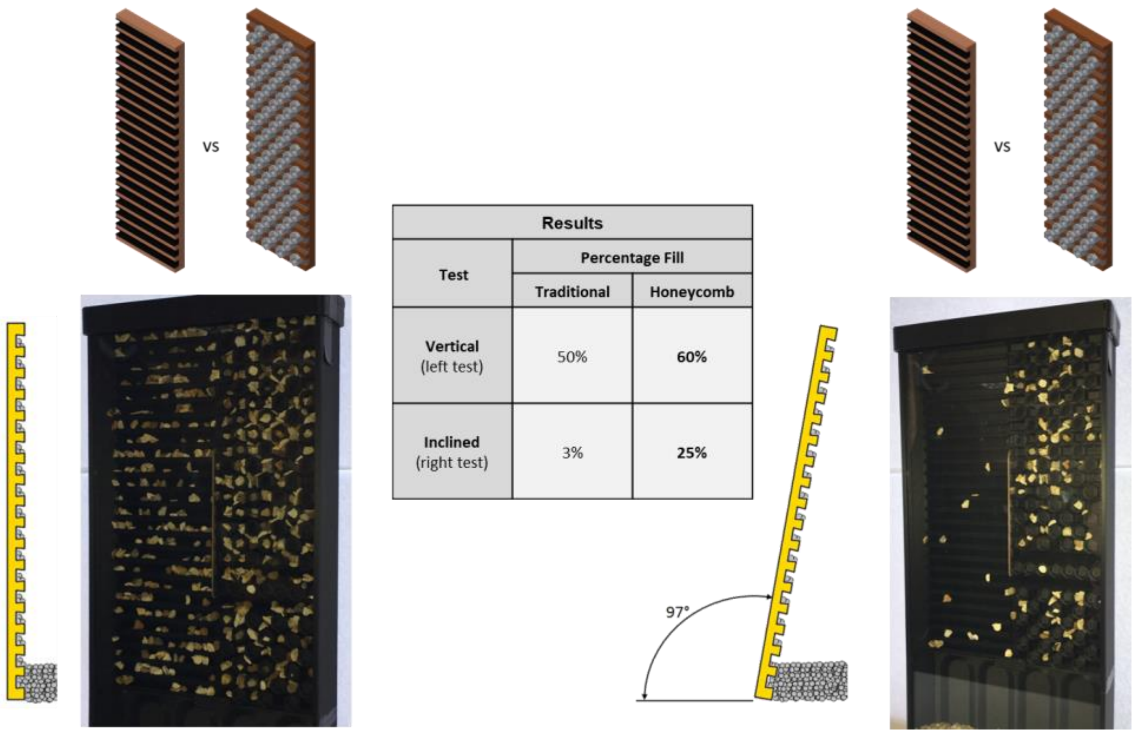


Figure 3. Superior Material Retention

It was considered that this 3-point hold mechanism would provide better support for any protective layer developed on the copper staves thus improving the robustness and durability of the stave overall. Therefore scale models were produced in order to demonstrate the design concept. As can be seen in the Figure below (Figure 4) when testing a current stave design against the new arrangement the initial hold is similar but once tilted to an angle the inclined plane shows the material is much better held by the honeycomb pattern. In a real situation where the material is likely a mix of gases, liquids and solids this will produce a far more robust protective layer.



Results		
Test	Percentage Fill	
	Traditional	Honeycomb
Vertical (left test)	50%	**60%**
Inclined (right test)	3%	**25%**

Figure 4. Superior Material Retention

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Having established the concept further investigations were carried out to ensure that the thermal behaviour of the new stave would be suitable for operation within the furnace. The Figure below (Figure 5) shows the thermal profile of the new hexagonal stave showing typical temperatures of the copper stave and inserts, in this case of cast iron.

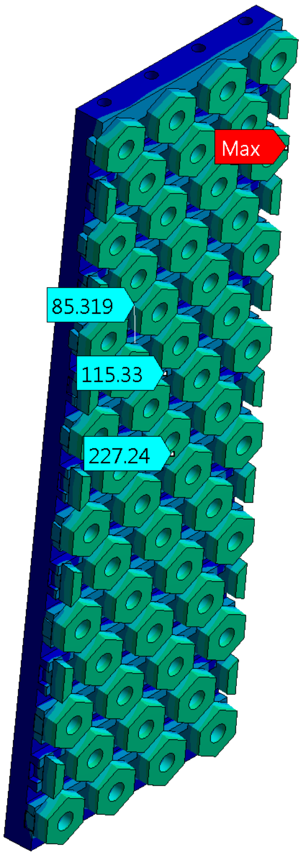

Figure 5. Stave Thermal Analysis

With the first installation of the new honeycomb stave design taking place in 2019 demonstration of the improved performance can be confirmed. The Figure below (Figure 6) shows a full sized honeycomb stave prior to, and after, the mounting of the inserts.

Figure 6. Honeycomb Stave Manufacture

4 INCREMENTAL CHANGE

As an alternative to the completely new stave design Primetals Technologies also considered an incremental change to the existing stave design in order to get some of the new benefits without changing the base stave. This takes an existing Primetals Technologies' standard stave and incorporates sliding single piece inserts and spacers to produce a similar honeycomb arrangement, as indicated in the Figure below (Figure 7).

Figure 7. Sliding Insert Honeycomb Stave

5 CONCLUSION

As a leading supplier of copper stave designs Primetals Technologies continues to develop blast furnace cooling solutions in order to meet the expectations of our Customers for long consistent campaigns. Although standard features are important it is our historical recognition that optimum furnace cooling design starts with understanding the furnace profile and process conditions. The new stave developments will allow this understanding to be applied flexibly through different materials, shapes and arrangements to provide a more stable operation.

REFERENCES

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