



New opportunities—exhaustive monitored copper coolers for submerged arc furnaces

by M. Hopf* and E. Rossouw†

Synopsis

The use of water-cooled copper components as sidewall elements of submerged arc furnaces and other pyrometallurgical applications has become increasingly common. The high cooling efficiency of copper has made it possible to increase the service life of furnace refractories when compared to conventional refractory linings. However, even the self-healing effect of 'freezing' worn areas of the lining does not necessarily protect the copper coolers against wear or corrosion completely. In order to avoid furnace explosions, various methods have been used to monitor the wear of coolers. Unfortunately, these have not been able consistently to identify localized wear.

Thos Begbie (South African) and SAVEWAY (German) jointly developed technology to embed a line sensor into the copper cooler during the casting process. This system allows an exhaustive monitoring of the copper cooler. A SAVELINE sensor is placed inside the copper-cooling panel between the water-cooling passage and the hot face of the panel. The sensor follows the meandering shape of the cooling water channels.

In the first instance, the sensor provides analogue information as the thickness of the copper reduces. Secondly, this wear signal will be confirmed by a signal of interruption if the sensor is washed away. Because of the structure of the sensor, a self-diagnosis is possible and indications can be confirmed (double proofed).

Subsequent to the manufacture of some test pieces, coolers for a large submerged arc furnace were manufactured. The sensorized coolers have been installed at the intermittent surface (slag line) where the largest amount of corrosion has been encountered. The system has been operating since December 2005 in what is considered one of the largest submerged arc furnaces in South Africa.

Keywords: Pyrometallurgy, furnace, copper coolers, freeze lining, monitoring, Saveway

Introduction

The use of water-cooled copper components as sidewall elements of submerged arc furnaces and other pyrometallurgical applications has become increasingly common.

The high cooling efficiency of copper has made it possible to increase the service life of furnace refractories when compared to conventional refractory linings. However, even the self-healing effect of 'freezing' worn areas of the lining does not necessarily protect the copper coolers against wear or corrosion completely.

In some furnace applications the presence of elements such as sulphur or halogens will cause erosion of the copper components.

Because the cooling of the components is based on a closed-mesh water channel system inside the copper panels, a catastrophic situation generally occurs if the erosion of the component results in a breach of the water passage.

Furnace explosions result in significant financial losses, not only losses in production and damage to the plant, but also injuries to personnel, sometimes tragically involving the loss of human life.

In spite of various methods of monitoring the coolers, furnace explosions have not been avoided. The various methods, including the measurement of energy losses or cooling water temperatures, the measurement of the temperatures by thermocouples, ultrasonic waves, or visual inspections, have not been able to consistently identify localized wear. This is partially due to the fact that the methods are discontinuous and that the application is limited to specific areas only.

In order to address these constraints, a system has been developed that allows an exhaustive monitoring of the copper cooler. A SAVELINE sensor is placed inside the copper-cooling panel between the water-cooling passage and the hot face of the panel. The sensor follows the meandering shape of the cooling water channels.

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During the development, identical water-cooled test pieces were produced, one of which contained a SAVELINE sensor, and another (control) test piece without the sensor. These test pieces were simultaneously subjected to thermal performance testing where the thermal imaging technique was carried out. While there were very small deviations between the two pieces, their performance was to all purposes identical.

Other tests were also carried out where the temperatures were recorded using independent measuring equipment to confirm the temperatures recorded by the SAVELINE sensors; no differences were recorded.

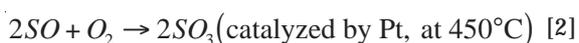
Subsequent to the manufacture of some test pieces, coolers for a large submerged arc furnace were manufactured. The sensorized coolers have been installed at the intermittent surface (slag line) where the largest amount of corrosion has been encountered.

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Corrosion on copper coolers and risk potential

It is generally considered that the closed-mesh water channel system and the high thermal conductivity of copper will freeze molten slag on the surface of the copper cooler.

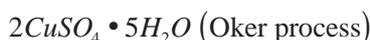
From this point of view, corrosion of the surface of the copper cooler should never occur, as the melting process of the raw material takes place in a frozen refractory layer of the same composition. However, sulphur and other chemical substances are found in the composition of the raw material. Sulphur melts at 120°C and vaporizes at 445°C. Sulphur reacts with oxygen to form:



The vaporized sulphur or the oxides within the raw material are anxious to reach a location of lower vapour pressure and move, therefore, to a cooler place.

In other words, all chemical substances with a low melting and vaporization temperature, including H₂O, are driven by the high temperature of the arc to concentrate straight in front of the copper coolers.

Thermal shocks also create cracks in the frozen skull, and sometimes the frozen lining collapses. In addition, the frozen lining maintains a level of porosity. The following reactions occur, with the resultant erosion of the copper.



Halogens, in particular, react with copper causing significant erosion of the copper cooler.



The halogens are also contained in the raw materials as minerals (e.g. CaF₂, Ca₅(PO₄)₃F, Na₃AlF₆ or KMgCl₃, KCIMg(SO₄)). The corrosion rate on the surface of the copper is sometimes as high as 20 to 30 mm within half a year.

If the copper is eaten away up to the position of the channels of the cooling water system, physically we encounter the following problem.

Expansion of water in standard condition of vaporization

Molar volume of a gas under standard condition:

22.414 l/mol (condition of a system at standard pressure of 101.3 kPa and a temperature of 273 K)

$$18.015 \text{ g H}_2\text{O} \rightarrow 22.414 \text{ l steam}$$

$$1 \text{ l H}_2\text{O} \rightarrow 1244 \text{ l steam}$$

Additional expansion of volume (V) by increase of temperature (T) at an isobaric change of state (pressure P = constant)

$$V_1 \times T_2 = V_2 \times T_1$$

$$V_{1500^\circ\text{C}} = V_{\text{standard}} \times 1773 \text{ K} / 273 \text{ K}$$

$$V_{1500^\circ\text{C}} = V_{\text{standard}} \times 6.49$$

1 l water will be transformed to 8047 l steam at a constant pressure of 101.3 kPa and an increase of temperature by 1500 K.

In reality, one finds the expansion of a litre of water to be between 1244 and 8047 times. In other words, a steam explosion occurs. Production shutdowns, with resultant financial losses, are incurred.



Figure 1—Panel after 5 months' use

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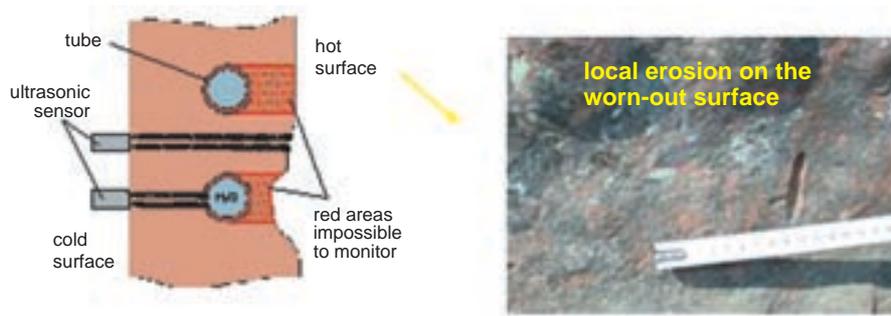


Figure 2—Limitation of ultrasonic measurements

What is available?

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| <p>Measurement of energy losses, or cooling water temperature</p> <ul style="list-style-type: none"> Local erosion cannot be detected It is only an integral measurement of the whole cooling water circuit Local erosion and unusual erosion can occur if the chemistry of the slag is changing and/or there are casting defects in the copper panel There is always a high remaining risk. <p>Measurement by thermocouples inside the copper panel</p> <ul style="list-style-type: none"> Only local limited measurements (one thermocouple measures only one point) Because of mechanical restrictions, the thermocouples cannot be placed in front of the cooling water pipes (only orthogonal drillings from the back side of the copper panel). <p>Measurement by ultrasonic waves</p> <ul style="list-style-type: none"> Not a continuous, exhaustive closed-mesh measuring method Because of cooling water channels, the copper between the cooling water pipes and the hot surface cannot be observed! (Measurements take place only from the back side of the copper panel.) <p>Thermal imaging</p> <ul style="list-style-type: none"> Infrared based measurements from the outside are senseless because of the water-cooled structure of the copper blocks. <p>Measurement by individual visual inspection</p> <ul style="list-style-type: none"> Not a continuous measuring method By Murphy's Law, the burn-through will happen at an unusual time between two inspections |
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Current monitoring methods are unable to avoid such happenings.

Working principle of saveline sensor

The SAVELINE sensor makes it possible to detect hot spots over its entire length. It is unlike a thermocouple that measures the temperature only on one point on its tip.

Figure 3 shows the construction of the sensor. Two conductors are embedded in a special ceramic contained in a 3 to 6 mm diameter external shell. This ceramic has the same property as shown in Figure 4, and is selected in accordance with the required temperature range.

The measurement is based on the strongly negative temperature gradients of the electrical resistance of the applied ceramic materials. Figure 4 shows the relationship $\rho_{el} = f(\vartheta)$.

While for quartz and corundum, a 1000 K change in temperature causes a five times power of ten drop in the specific electrical resistance, other ceramic materials have an even steeper characteristic line. For example, with a PTZ ceramic ($PbTiO_3-PbZrO_3$) a temperature difference of only 200 K is enough for a 100 000 times reduction in the resistance.

If an increased temperature now occurs at an arbitrary point on the sensor, this reduces the specific electrical resistance of the ceramic at this point. This change in resistance between the two internal conductors is measured and converted into a temperature reading. This results in a sensor that enables measurements of the temperature over its complete length. The sensor can be bent to different shapes (15 mm minimum bending radius) and can, for example, be installed in a meandering shape on the inner side of the steel shell of a metallurgical vessel.

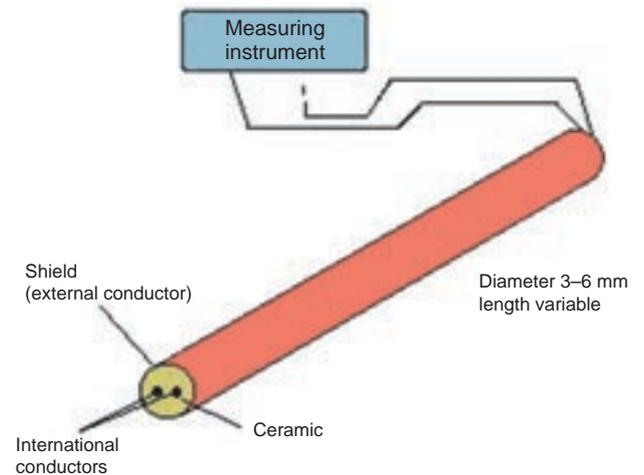


Figure 3—Construction of the SAVELINE sensor

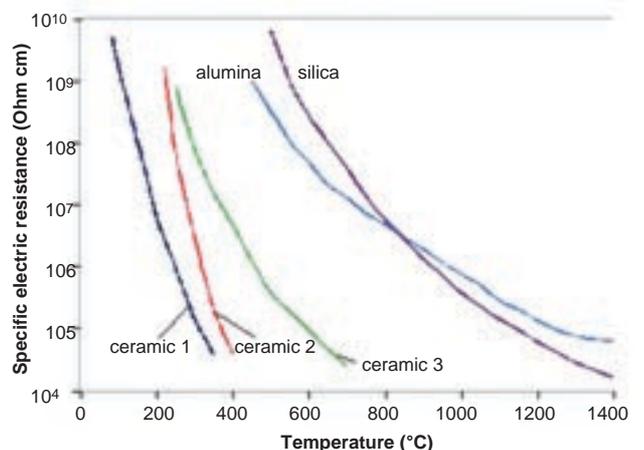


Figure 4—Relationship between temperature and the specific electrical resistance of various ceramic materials

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The active sensor length is variable, but for standard applications should not exceed 6 metres. The internal conductor is led through on both sides, thereby enabling the permanent checking of the operation of the sensor in the installed condition (self-diagnosis).

Such line sensors have been in practical operation since 1996. Practical experience has shown, and continues to show, that critical hot spots are safely detected.

The system is used in Imperial Smelter plants (Figure 5), in arc furnaces, on purge blocks, and in furnace floors of induction furnaces. The SAVELINE system ensures that metal run-throughs and plant damages are avoided in many cases. It is a dependable system and a well-proven measuring method for picking up critical temperature changes.

Technical solution, from testing pieces to production proven technology

What was more obvious than the idea to place such line sensors inside a copper cooler? New developments need ideas, but the practical realization of these ideas requires good technicians and engineers.

What are the major demands of condition monitoring of copper coolers used in a submerged arc furnace?

- ▶ Continuous monitoring during the furnace operation
- ▶ Exhaustive closed-mesh measurement
- ▶ Even local wear of smallest extension in front of cooling pipes must be picked up safely
- ▶ Ensure the use of the copper blocks as long as possible without any risk
- ▶ Get a safe and undisputable signal.

Figure 6 shows the principal arrangement of a cooling water system inside a copper cooler. The idea was to place a SAVELINE sensor straight in front of the cooling pipes inside the copper. The sensor follows the bended shape of the cooling pipes.

That position in front of the endangered location (contact of molten metal with cooling water) ensures accurate and effective monitoring. The distance of the sensor from the cooling pipe can be chosen and should ensure that even in the case of erosion of the copper up to the sensor location, there is enough time to schedule the shutdown of the melting operation.

Such a placement of a sensor is shown in principle in Figure 7. How to achieve that goal? The SAVELINE sensor is fixed by mounting clamps on the metal tubes, which form the cooling channels inside the copper block. The sand mould with the fabricated tube is shown in Figure 8. A rigid reinforcement of the sensor shell was required. From the foundry point of view, it is critical that the in-gate position of the casting and pouring technology has had to be developed.

Today we can say that, with careful application of knowledge, a proven technology is available to embed the sensor into the copper block. Thermal imaging, X-ray tests, ultrasonic investigations and numerous destructive tests of the test pieces showed that there is no negative influence on the heat transfer through the copper blocks and there is perfect contact between the SAVELINE sensor and the surrounding copper (Figure 9).

The sensor provides an analogue temperature signal that will increase as the hot surface of the copper block erodes. If the frozen lining collapses, a peak in the temperature will be logged. The high of these peaks will increase over time.

Figure 10 shows the results of a calculation of the temperature profile in case of erosion of the copper cooler. The original thickness of the copper between the cooling water system (abscissa value 0) and the hot surface is 70 mm. The SAVELINE sensor is located 7.5 mm in front of the cooling water pipes. As shown in Figure 10, the temperature on the sensor location (marked by an arrow) increases from



Figure 5—SAVELINE sensors applied in the condenser floor of an Imperial Smelter

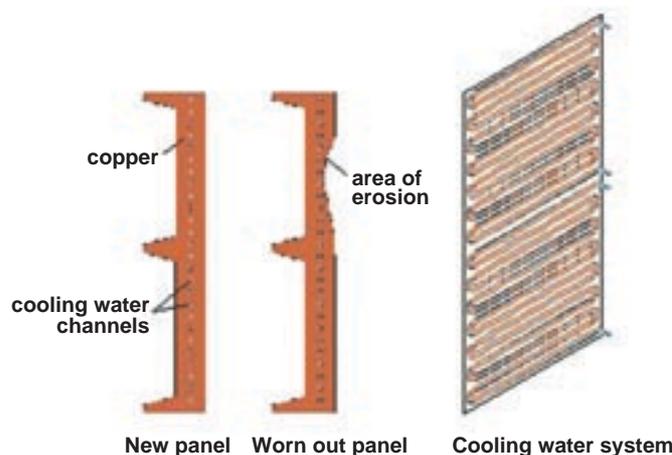


Figure 6—Wear profile and cooling water system of a panel

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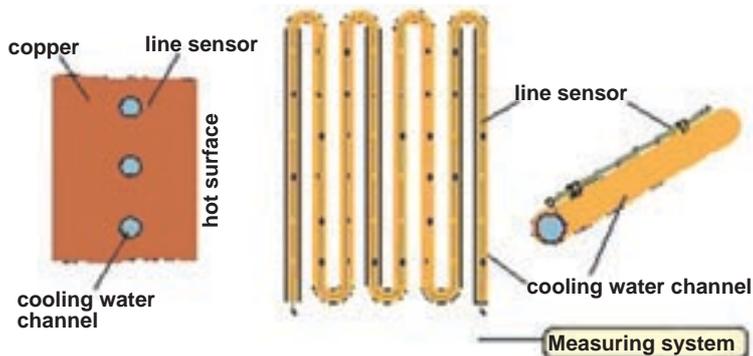


Figure 7—Placement of the SAVELINE sensor in the exhaustive sensorized panel



Figure 8—Prepared metal tube inside the sand mould



Figure 9—Perfect contact between the SAVELINE sensor and the surrounding copper

177°C (0% erosion) to 294°C (75% erosion). These calculations are true only for a collapsed frozen lining (heat transfer coefficient $\alpha = 10\,000\text{ W/m}^2\text{K}$). The dashed lines show the temperature profile for an existing frozen lining (30 mm slag).

As confirmation of the analogue wear signal, and as a definite signal that the copper block is worn up to the sensor location, a digital signal 'sensor break' will be given. The signal is generated by a conductivity test of the internal

conductors of the sensor. Both ends of the sensor exit the copper block. So both ends of the internal conductors are connected to the measuring unit, as shown in Figure 11. This ensures the opportunity of a self-check (self-diagnosis); the self-check is programmed to be carried out every 10 minutes.

Similar to other applications, the wear history on the control and visualization unit allows the recall of various readings such as the erosion speed, and thereby results in an improvement in the predictability of the service life of the sidewall blocks.

The sensor always records the highest temperature over its entire length. By placing more than one SAVELINE sensor per copper cooler it is possible to localize the most stressed area.

First results

Since 8 December 2005, four sensorized copper coolers have been in operation in one of Anglo Platinum's smelters. The sensorized copper coolers are placed in the intermediate phase (slag line) of the furnace sidewalls.

First measurements show that the measuring technique is working well. Over the first seven weeks of operation, there has been an increase of 25 K. At the current stage it is too early to give experienced statements. But, so far, everything is working as expected.

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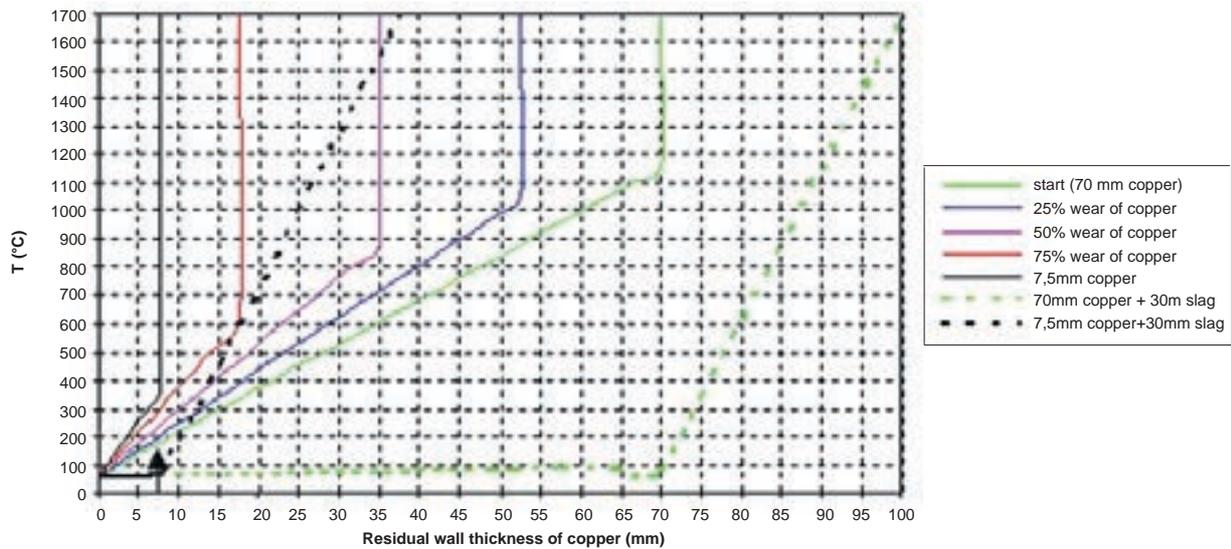


Figure 10—Temperature profile in case of wear of the copper cooler (heat transfer coefficient 'melt-copper' $\alpha = 10\,000\text{ W/m}^2\text{K}$)

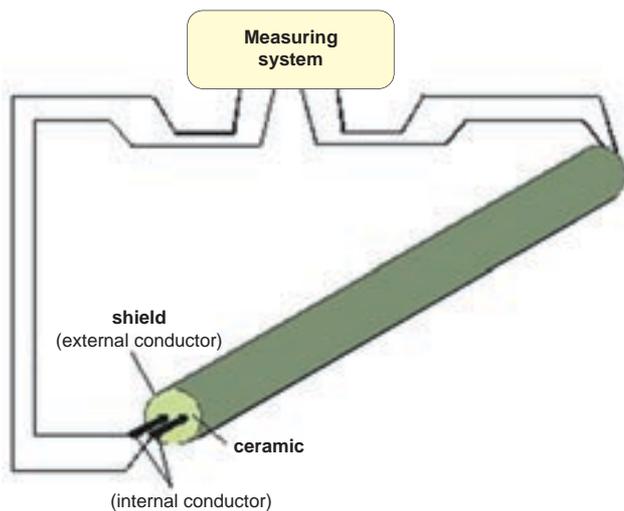


Figure 11—SAVELINE sensors offers self-diagnoses of internal conductors by continuity test



Figure 12—Steps of the manufacturing process

Conclusion

A technology has been developed that allows exhaustive closed-mesh safe monitoring of water-cooled copper blocks. A line sensor is placed in front of the cooling water channels. This ensures that the sensor recognizes the erosion of the copper, long before a break-through to the cooling water passage in the inside of the furnace can occur.

The measurements recorded always show the highest temperature of the monitoring area. The increase of temperature is related to the remaining lining thickness of copper in front of the sensor. The structure of the sensor allows a self-diagnosis, and ensures that a signal is given if the sensor is washed away.

The first practical application has been running on a submerged arc furnace since December 2005. The sensorized panel technology offers the opportunity to avoid furnace explosions and unforeseen shutdowns of production. This is expected to increase the safety of the operating staff and the plant equipment.

The first results of the first application are very promising. We are sure a very useful technology has been introduced to all smelter operators.

References

1. HOPF, M. Six years operational experiences of lining wear monitoring, AFS 102nd Casting Congress & Cast Expo, Atlanta, USA, May 1998, AFS Transactions 98-129, pp. 759-767.
2. HOPF, M. The refractory wear measurement system SAVEWAY—increase of process safety and service life of lining, *European Metallurgical Conference*, Friedrichshafen, Germany, 18-21 September 2001.
3. HOPF, M. Monitoring of lining wear in crucible and channel induction furnaces, *Casting Plant + Technology International*, 2/2002.
4. LINKE, P. Four years operational experience of lining condition monitoring on an Imperial Smelter, *European Metallurgical Conference*, Dresden, Germany, 18-21 September 2005.
5. Patent: DE 196 02 249 A1, German patent application No. 10 2005 013 924.8. ◆