COPPER STAVELETS – THE NEW, FLEXIBLE SOLUTION TO OPTIMIZE THE INVESTMENT COSTS FOR BLAST FURNACE WALL COOLING(1)

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INTRODUCTION:

Around 40 Blast Furnaces all over the world were equipped with copper staves in the last 10 years. The performance of the copper staves was excellent. Not a single failure has been reported so far. The current design in many ways still reflects the test staves investigated in the 80's. Only minor design and cost optimizations have been made so far. Based on the experience available today, the "conventional" copper stave will achieve a lifetime greater than that of the actual blast furnace plant, i.e., more than 40 or 50 years.

In spite of this extraordinary and ongoing success, the next generation of copper staves is now under way. The prime target here was not an extension of the already extremely long service life, but to accomplish the following:

- Process improvements: reduced cooling-water flowrate, increase in water heating rate, higher working volume of blast furnace
- Easier and faster installation.

- Modular design, leading to an easier adaptation to each blast furnace zone and much shorter delivery times

Key words: Blast Furnace, Shell cooling, Copper staves, Staveles, Design, Test results, Cost

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(1) Paper presented at the 1st International Meeting on Reduction – ABM – September, 2001 – Belo Horizonte / MG

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This paper reports on the status of this development.

Design development – It was decided that each element will have only one cooling channel. A combination of four cooling channels in a solid copper block thus no longer exists. This will reduce the installation weight of each element. Furthermore, the element will feature an oval cooling channel (Fig. 1) , which with identical surface has only half the cross section of a round cooling channel. For the same water velocity, the water flowrate (m^3/h) is reduced by 50%. With identical heat flux the temperature raise of the cooling water will double. The operating conditions of the cooling water pumps (power consumption) and the recooler will improve accordingly.

Another important feature are fins on both sides of the oval-shaped cooling channel. The element has a width which allows it to be used at stave-typical pipe spacings of 220 to 250 mm and also insures that adjacent stavelets overlap. Hence there are no vertical joints within a row of stavelets, the shell is protected completely (Fig. 2). Overlapping, however, has another advantage : the same stavelets that are used, for example, in the (cylindrical) belly, may be used unchanged in the (conical) bosh or stack. In the bosh, the overlap would then be slightly larger at the bottom and slightly smaller at the top. It is obvious that stavelets can also be angled without any problems, thereby allowing them to be adapted to the shell outline, for example at the bosh/belly transition.

The overlap of the stavelets in conjunction with the flat, oval cooling channel, results in the cooled wall to become yet thinner than in a "conventional" copper stave. While the latter's wall thickness is still 143 mm plus 50 mm of grout, the average wall thickness of stavelets is now reduced to 90 mm. This results in a substantial increase in the working volume of the Blast Furnace in the areas equipped with stavelets.

The stave front is connected to the rear by two automatically made parallel welds. This, together with the use of rolled material having a fine-grained, uniform and equiaxed structure which gives more resistance to cracking and crack propagation than coarser – grained coppers coming from sand – casting or continuous casting[1), allows a first-rate quality control. The component can be manufactured at any length required. Previous limitations in length to approx. 4 m, which were due to deep-hole drilling, no longer exist. The welds are moreover located on the protected, cold rear face of the stavelets.

Results of the design development - As compared to conventional copper staves, the new design results in :

- Lower cooling water flowrate at the same water velocity, higher water temperature raise, lower pump power consumption, smaller investment and operation cost for recoolers
- additional working volume of blast furnace through lower thickness of cooling element
- the possibility of prefabrication and adaptation of the length, leading to shorter delivery times in case of order
- easier and faster installation.
- substantially larger structural lengths than before, resulting in, among others, savings in the external piping

Testing at the test rig : four stavelets were fabricated, pressure-tested at 25 bar and then mounted to a holder plate (Fig. 3). In assembled condition, the dimensions of the four stavelets were 900 by 1,790 mm, similar to a previously tested conventional copper stave. The stavelets were furnished with a large number of thermocouples in three measuring planes, to be able to detect their temperature behavior and the amount of heat dissipated. The amount of heat dissipated was additionally checked on the water side, both integrally for all four stavelets together as well as individually for one stavelet (arranged at the front).

Tests took place at furnace temperatures between 750 and 1,100 °C. Hence they are directly comparable with previous tests made on a conventional copper stave. The same applies to water velocities, which varied between 0.8 and 3.0 m/sec. The evaluation of the various parameters always starts after steady-state conditions have been obtained. Results were obtained with both empty grooves on the hot face and with refractory materials of different thermal conductivity in the grooves.

The plotting of temperature curves over the thickness of the cooling element, which is common practice for nodular graphite iron and conventional copper staves, is rather difficult in the case of stavelets, due to their small thickness. However, comparing the temperature distribution calculated for a heat input of 100 kW/m² with the corresponding measured values (Fig. 4) is quite interesting. The degree of consistency is good. The calculation also allows the representation of heat fluxes (Fig. 5), which reveal a basic difference from the conventional copper staves. In the stavelets, the heat entering at the fin edges is deflected at a right angle in the direction of the cooling channel. The hottest spot is the outer edge or corner of the fin. In a conventional copper stave, a heat input of 100 kW/m² reveals a wavy temperature profile , heat fluxes are only relatively smoothly deflected in the direction of the cooling channels, with a larger amount entering the cooling channels from behind. The hottest spot is located on the hot face on the axis of symmetry between two cooling channels.

Selected test results – In one series of tests the 10 mm deep grooves at the front of the stavelets were filled with a refractory material with medium conductivity (Stave Ram LS, thermal conductivity at 1,000 °C: 1.18 W/mK). The front face of the copper fins was exposed to a heat flux of 100 kW/m². These results were compared with earlier measurements made on a conventional copper stave in which refractory bricks were glued into the dovetail grooves; the bricks projected around 50 mm into the furnace and therefore provided a sort of "shading" of the front face of the copper ribs.

Hot-face temperature as a function of heat flux density (Fig. 6) - With identical heat flux density and at the same water velocity of 1.5 m/sec., the maximum hot-face temperature of the stavelet is around 10 to 15 °C higher than the conventional copper stave. This is probably the result of the "shading" effect outlined above. If the water velocity in the stavelet is raised to 3.0 m/sec., i.e., the water flowrate in m³/(m² x h) is brought to roughly the same level as in the conventional copper stave at 1.5 m/sec., then the difference between the maximum hot-face temperatures of stavelets and conventional copper staves disappears almost entirely.

Heating rates as a function of furnace temperature (Fig. 7) - Owing to the deliberately chosen smaller cross section of the oval-shaped cooling channel of the stavelet, the same water velocity of 1.5 m/s and the same test rig furnace temperatures yield significantly higher water temperatures than in conventional copper staves. This effect is intended. Most of the closed-loop systems for blast furnace shell cooling are rated for a differential temperature of 5 to 10°C, but are operated at a differential temperature of 1 to 2 °C only [2)]. This causes an unnecessarily large amount of water to be recirculated, and also oversizes the heat exchangers. The benefit of stavelets in this respect cannot, however, be fully utilized until they are suitably incorporated in the overall circuit.

Influence of the ramming material on the hot-face temperature (Fig. 8) - The lower the thermal conductivity of the refractory material in the front – side grooves, the higher the thermal resistance of the partially coated stavelets will become. Hence, with rising thermal resistance, the differential temperature between the cooling water and the hot surface must increase at constant heat flux. With unchanged average cooling water temperature and unchanged heat flux, the surface or hot-face temperature of the stavelets rises when their thermal resistance is raised.

This theoretical relationship was confirmed by the tests. Fig. 8 also shows that the hot face temperatures of the partly protected stavelet are close to the hot face temperatures of the fully brick protected stave, in spite of the much lower specific water flow $m^3/(m^2 \times h)$ in the stavelets.

Dynamic temperature history after scab loss (Fig.9) - This effect cannot be simulated in the test stand. Therefore, a calculation method was applied which earlier has been used to better understand the thermal behavior of "conventional" copper staves with full (143 mm) and reduced (94 mm) thickness [2)]. Fig. 9 shows the temperature history of a full sized copper stave after scab loss with an assumed peak heat load during that period of 160 kW/m^2 and the same for a stavelet. The curves are related to 6 typical points each. The differences between the two types of staves are remarkably small. When – for instance – the temperature histories of their hottest point (1) are compared, it can be seen that the full stave heats up slightly slower than the stavelet, and also cools down somewhat slower, thus reflecting the inertia of the larger copper mass per unit surface area.

Both types reach their peak temperature after approx. 1,5 min, and return to their steady state temperature approx. 7 min after the scab loss. From this, it can be derived that the two types show analogous behavior when it comes to the re-formation of scabs.

These results clearly show that the new stavelets function similar to their parents, the conventional copper staves. They achieve the same or better results at a significantly lower expense.

Testing in a Blast Furnace : A practice-based test of the behavior of cooling elements at quickly changing temperatures cannot be made in a test rig at a reasonable expense and within reasonable time. For this reason testing of the stavelets in an operational blast furnace is required and also intended. The second series of test stavelets will incorporate certain optimizations which were derived from the test stand results. Testing will start by middle of 2001 in a German Blast Furnace and will, accompanied by measurements, last several months. At the end of the test period the stavelets will be removed from the blast furnace and inspected in detail, first by non-destructive test methods, then by destructive ones. A test period of 10 years, as in the case of the "original" copper staves, does not seem to be necessary though, given the experience available today. Testing in operation is merely an additional step that is designed to gain supplementary findings and to study the behavior of stavelets under as extreme conditions as possible.

Are those who are already using conventional copper staves supposed to remove them and replace them by stavelets? Definitely not! The conventional copper staves are a tried-and-tested, extremely reliable and long-lived product. But to those operators who do not yet use copper staves or who are looking to extend the area cooled by copper staves, stavelets should be a most interesting development.

REFERENCES

1) S.M. Purdy, „Evaluation of the Cu to be Used in Manufacturing Blast Furnace Bosh Cooling Staves", 2000 Ironmaking Conference Proceedings, Pages 149 - 154
2) R.G. Helenbrook, P.F. Roy, "Water Requirements for Blast Furnace Copper Staves", 2000 Ironmaking Conference Proceedings, Pages 461 – 470 (see in particular Table II on p. 465).

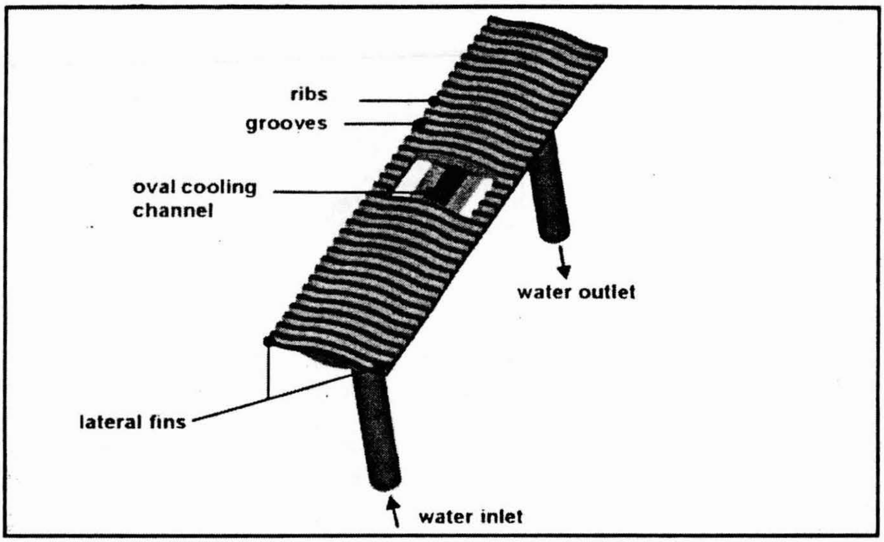


Figure 1. Stavelet with single oval cooling channel

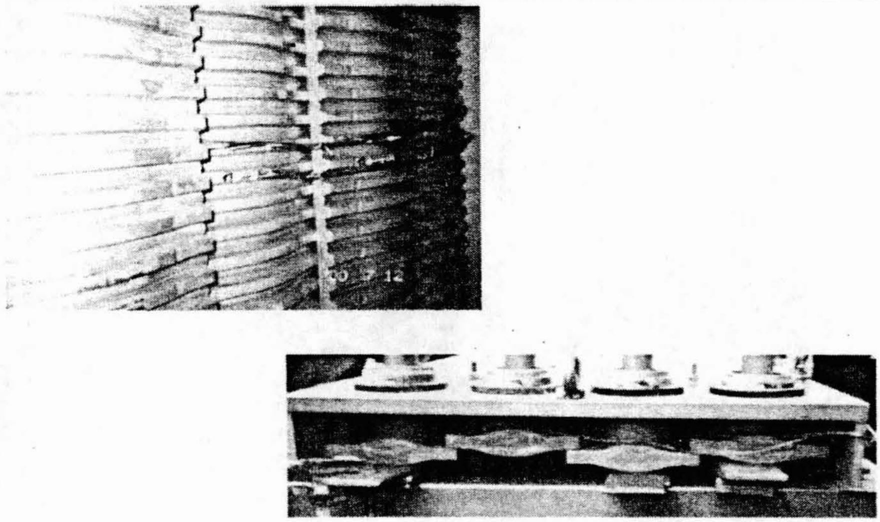


Figure 2. Hot face view with thermocouples and overlapping configuration of stavelets

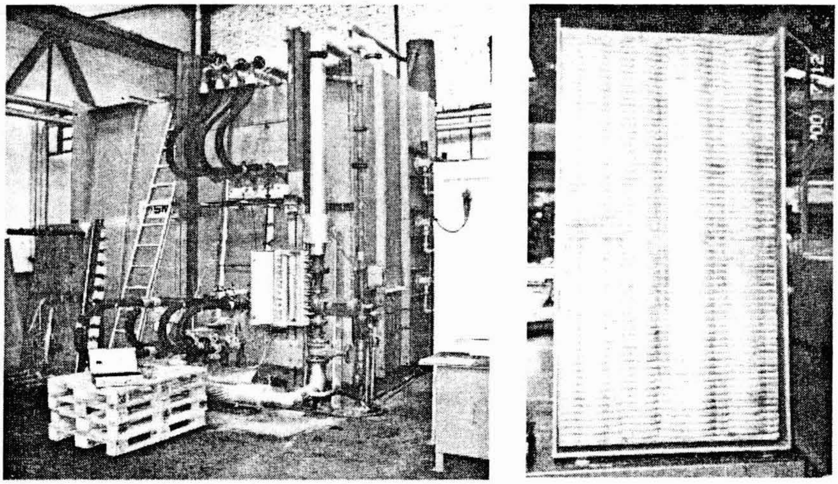


Figure 3. Test rig with 4 stavelets assembled

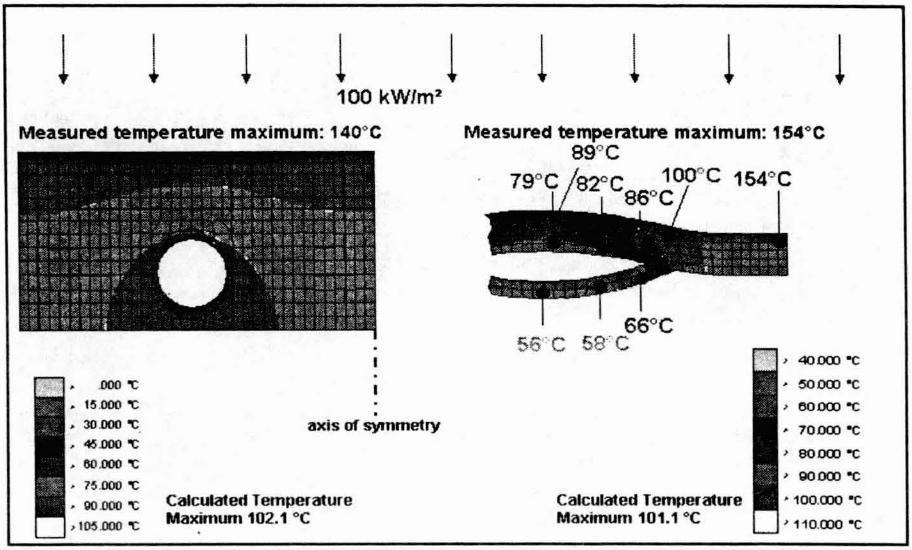


Figure 4. Temperature distribution in a „conventional“ copper stave and in a stavelet at 100 kW/m² heat flux density and 1,5 m/s water velocity

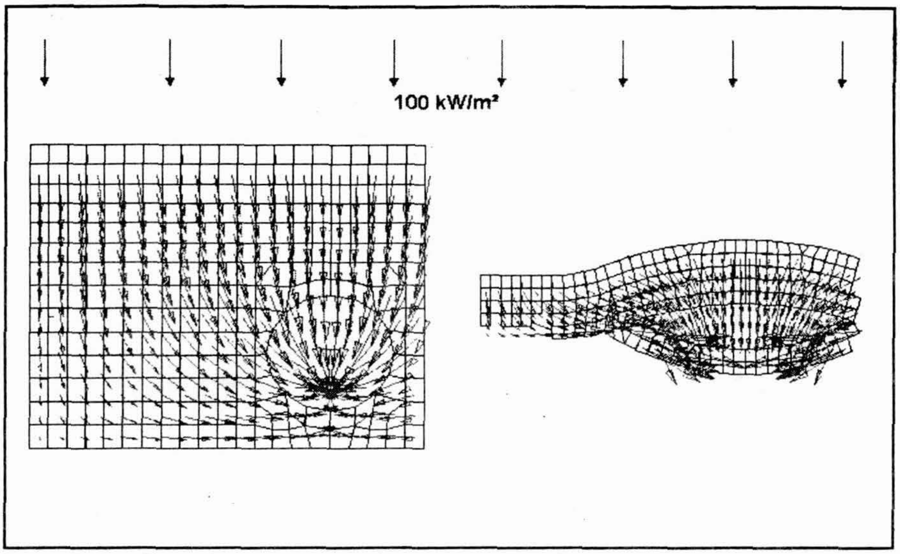


Figure 5. Heat fluxes in a „conventional" copper stave and in a stavelet at 100 kW/m² heat flux density

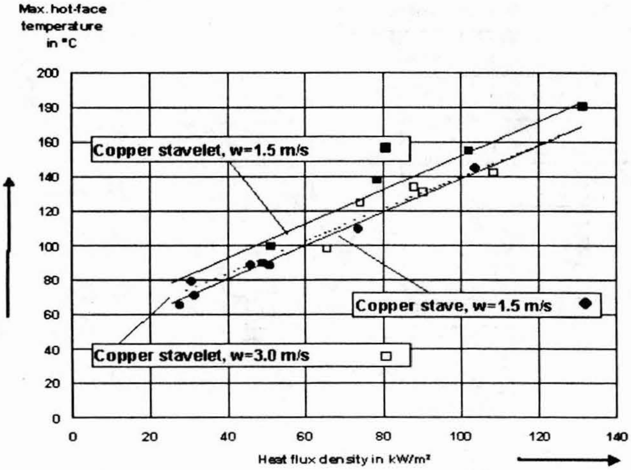


Figure 6. Maximum hot face temperature as a function of heat flux density

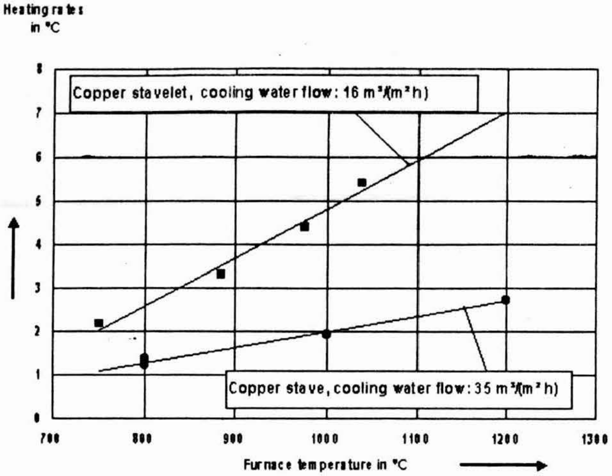


Figure 7. Cooling water heating rate at an unchanged flow velocity of 1.5 m/sec

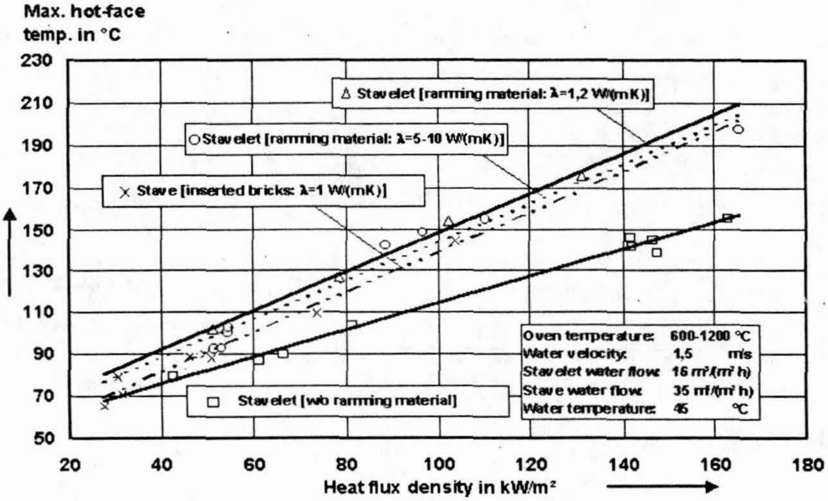


Figure 8. Influence of the ramming material on the maximum hot face temperature

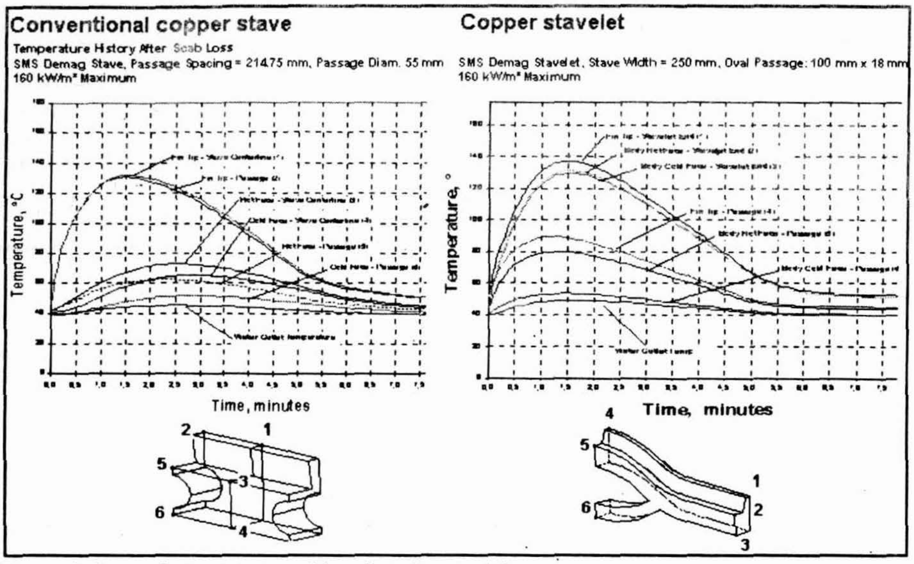
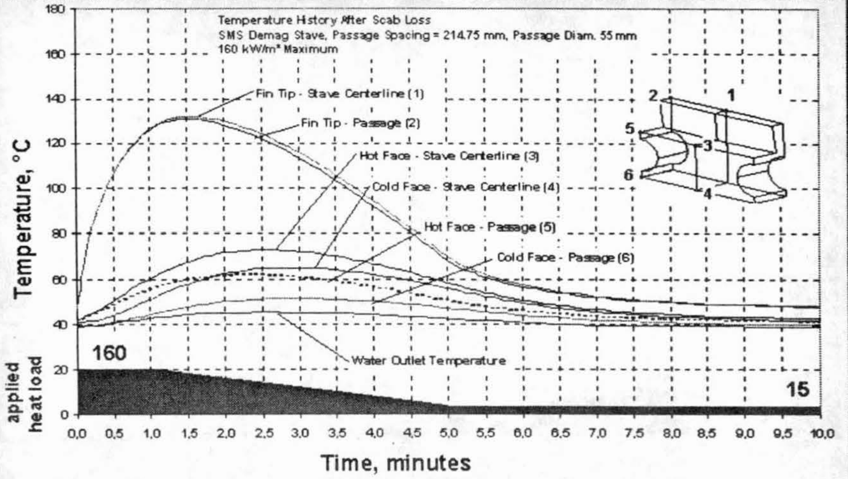
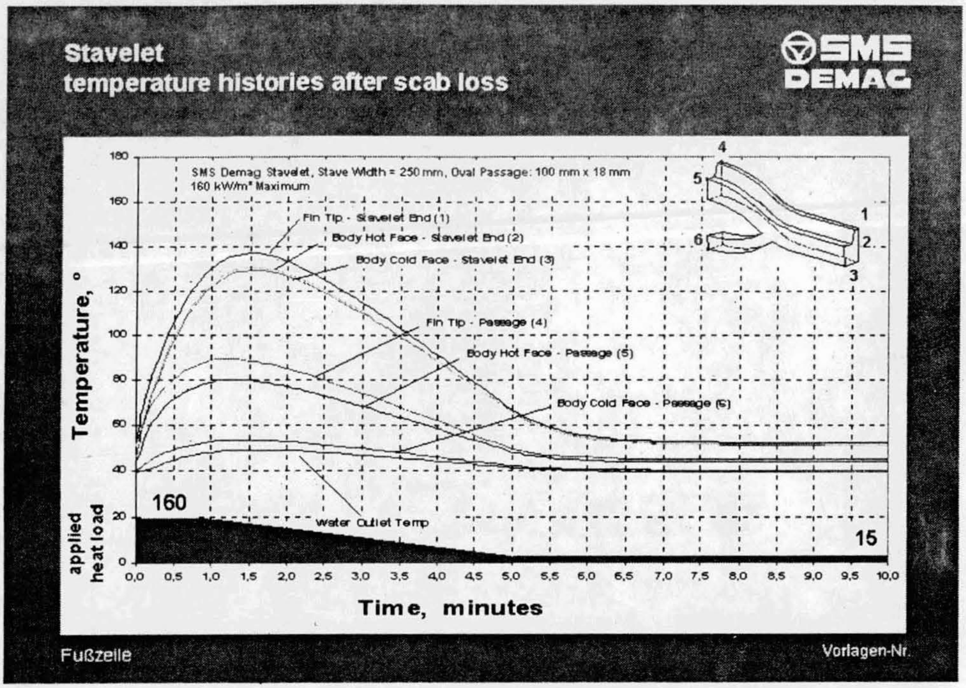


Figure 9. Dynamic temperature histories after scab loss

Full-sized Cu-stave
Temperature after scab loss





Stavelet
temperature histories after scab loss

Fußzeile

Vorlagen-Nr.