WSP HExAR-Furnace

New possibilities for the Continuous Heat Treatment of Cu-Strips

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Floatation furnaces with floatation nozzle systems have been well proven for the heat treatment of Cu-strips and are now by far the most common design for continuous annealing. Back in the 80s, strip floatation furnaces finally gained the victory against the former prevailing technology of vertical furnaces or catenary furnaces.

Almost the entire spectrum of different alloys, strip widths and strip thicknesses can be heat-treated by strip floatation furnaces. Strips up to 3 mm strip thickness can be annealed at 750°C and strips up to 2 mm strip thickness at 850°C, process safe and scratch-free. Also thinner strips up to foils are annealed process safely and, for thinner material, the temperature range can be extended up to 900°C. Different furnace atmospheres are used for the various alloys, most common are forming gas (nitrogen with up to 5% hydrogen), pure nitrogen or air which is especially common for brass. The strip floatation furnace shows maximum flexibility, the atmosphere can be chosen freely with almost no change in productivity. The multi-zone principle with zonal flow system guarantees high heat transfers and an extremely high Nusselt number Nu (dimensionless parameter describing the convective heat transfer).

Special high-performance alloys (HP-alloys) require even higher temperatures than 900°C; in this case the temperature range of the furnace should be increased up to 1,000°C. It is not possible to serve this temperature with strip floatation furnaces. This is mainly due to the following reasons:

- The gas pressures needed for the floatation capacity would stress the components unnecessarily high under these high temperatures.
- Strips are extremely sensitive close to the melting temperature. Ideally, they are not burdened by floatation or stabilizing forces.
- The density of the furnace atmosphere continues to decline and the tensile strengths of the nickel-based materials of the installed hot gas impellers will get too low to reach sufficient floatation forces by reasonable effort, according to a needs-based design.

These two concepts are to be considered for this temperature range:

- Vertical Furnace: the strip hangs with its own weight on one roller, and
- Catenary Furnace: the strip hangs between two rollers

Both concepts were already investigated by WSP more than 10 years ago. At that time, the task was to design a special plant for temperatures up to 1,000 C°. As for the soft copper strips, among other things, also a low strip tension is of special importance, WSP chose a catenary furnace which has been successfully in operation since this time.

However, for this development the highest possible throughput was not in focus, which is why it cannot achieve comparable throughput to a strip floatation furnace.

The newly developed WSP HExAR-Furnace combines these requirements: high throughput, highest temperatures and low tensions.

The abbreviation HExAR stands for „Horizontal Extended Annealing Range“.

In developing the HExAR Furnace, special attention was given to the following points:

Combination of high temperature annealing and standard annealing in one plant

If the operating company's percentage of HP-alloys is rather low, then it is possibly not worth investing in special high temperature plant.

In contrast, the investment will be reasonable if (besides the HP-alloys) also copper and copper alloys can be annealed effectively by the same line at low temperatures, and the furnace is thus universally applicable.

The HExAR Furnace achieves this by extending the length of the plant by means of a supporting roller which is positioned in the cooling zone („Horizontal Extension“), see figure 1. Thus, a heating distance similar to a standard WSP Strip Floatation Furnace with 4 heating zones is achieved. This method allows comparable throughputs, see figure 2.

The term „Extended Annealing Range“ refers to the extension of the heating distance and the extension of the temperature range up to 1,000°C.

The HExAR-Furnace is constructed zonally. Each zone is equipped with speed controlled hot gas fans (by means of frequency converter) for an exact adjustment of the heat transfer. The zonally construction allows the adjustment of slightly different zone temperatures. This is advantageous for certain annealing techniques and it opens more possibilities than furnaces which are, due to their concept, limited to a single furnace temperature in the convective heating part.

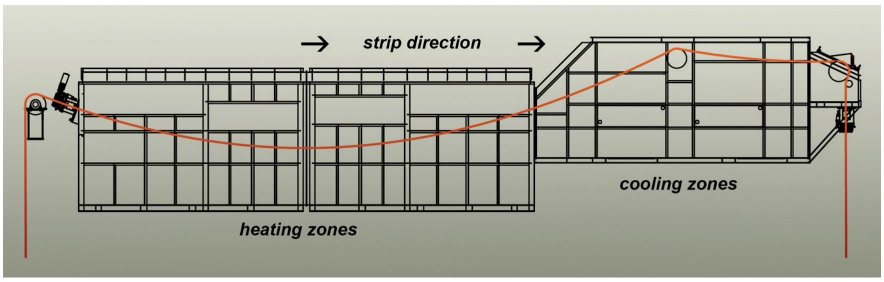

Fig. 1: HExAR-Furnace with pictured catenary line

Stable strip position and tension control after strip catenary

In catenary furnaces, the strip has a very stable position due to the curve predetermined by the catenary. Strip stabilizing measures (like the prevention of twisting in a vertical furnace) are not required. In

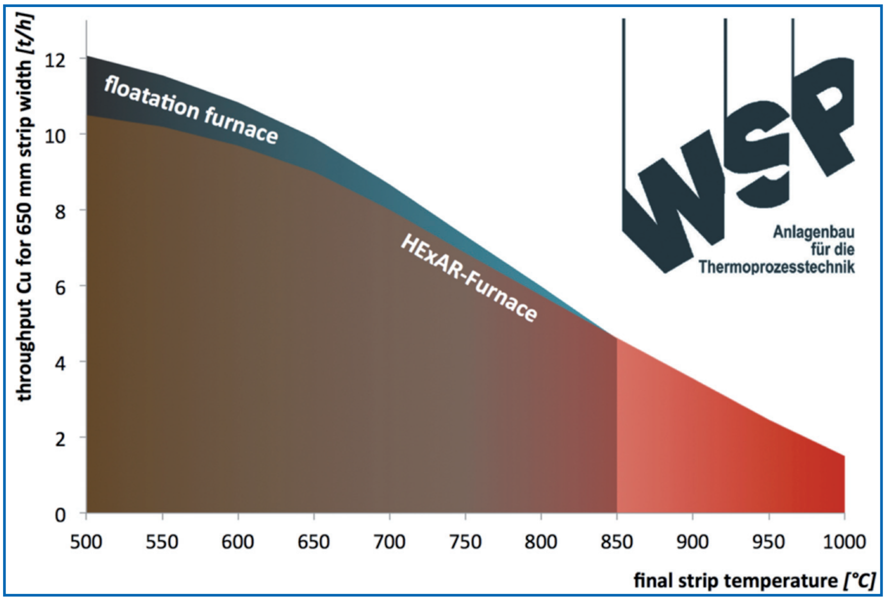

Fig. 2: Throughputs related to the final strip temperature

turn, the catenary depends only on the span length (roller distance) and the strip tension. Equal strip tensions lead, regardless of strip width and strip thickness, to the same catenary. The catenary is detected by a contactless sensor. Depending on the position, the speed of the preceding bridle/S-roll is controlled.

This allows forming a high convection nozzle system which is shaped according to the catenary.

Highest convective heat transfers in heating and cooling zones

In a high-temperature furnace with higher zone temperatures the heat amount put into the annealing material by radiation increases inevitably. The HExAR-Furnace is designed in such a way that when annealing bright strip made of copper alloys the convective heat input dominates over the whole temperature range and in all zones. This is shown in figure 3a and 3b for two different zone temperatures (also see figure 3c for further explanations). Further advantages of the convection are to be derived from the diagram.

- The convective heat transfer is constant for a given zone temperature. The same zone temperature (and a constant fan rotation speed) results in getting the same heat input. Resulting strip temperatures and annealing outcome can be excellently reproduced.
- On the other hand, heat transfer by radiation depends on many more factors (emissivity of components which radiate onto the strip, absorption factor of the bright Cu-strip). If the emissivity is changed due to deposits on the furnace internals or due to differences in the surface quality of the strip, also the heat transfer is changed. Even within a coil, minor changes of surface quality and thus a changed absorption factor cannot be excluded. For this reason, the heat input by radiation is much more difficult to control.
- For bright Cu-strip, the high convective heat treatment is significantly higher than the heat treatment by radiation.
- For furnaces zones which are only radiation-heated, much higher over temperatures are needed to achieve the same heat input into the strip. This over temperatures should be avoided because three negative effects will result: Firstly, the over temperatures enlarge the temperature differences within the strip material. This may lead to inhomogeneous annealing results. Secondly, over temperatures accelerate the creep of the metallic furnace internals; this will lead to increased wear. Thirdly, the risk of strip rupture increases in case of strip stop because the non-running strip is heated up to these higher over temperatures.

This last statement does not apply equally for the annealing material "stainless steel" (exemplary shown in Fig. 3 a and b) with about 10 times the absorption figures compared to bright copper. Stainless steel can be heated efficiently by radiation.

The high convective heat transfer rates in the heating zones of the HExAR Furnace are also facilitated by the tailored design of the hot gas fans. Hot gas fans developed and manufactured by WSP supply extremely high volume flows and pressure increases in proportion to the circumferential speed and therefore are ideally suited for high temperature furnaces.

Also in the cooling zone, the high heat transfer coefficient is profitable: in some cases the water sealing as a last cooling stage can be eliminated. The sealing function of the water would be replaced by a roller lock.

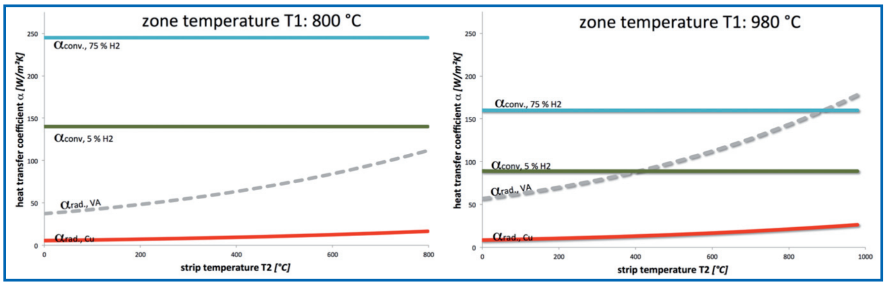

Fig. 3 a and b: Heat transfer factors radiation/convection at different zone temperatures

Explanations:

$\alpha_{conv., 5\% H2}$	convective heat transfer coefficient for forming gas with 5 % H2
$\alpha_{conv., 75\% H2}$	convective heat transfer coefficient for forming gas with 75 % H2
$\alpha_{rad., Cu}$	radiation heat transfer coefficient for a Cu strip
$\alpha_{rad., VA}$	radiation heat transfer coefficient for a stainless steel strip

calculation of the heat transfer coefficients for radiation for two parrallel plates by:

$$C_{12} = \frac{C_s}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\alpha_{str} = C_{12} \cdot \frac{\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4}{T_1 - T_2}$$

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C_s = Boltzmann constant

ε_1 = 0,80 (inner parts furnace) [1]

ε_2 = 0,06 (Cu strip) [2]

ε_2 = 0,40 (stainless steel strip) [1]

Fig. 3 c: Explanation of fig. 3 a and b

Use of an increased percentage of hydrogen in the protective gas is usually not necessary

The use of an increased percentage of hydrogen in the protective gas is an option at WSP. With this option, although the convective heat transfers increase but the high additional costs for the hydrogen and the investment costs for the required safety equipment must always be considered. Also the resulting expenses for maintenance and

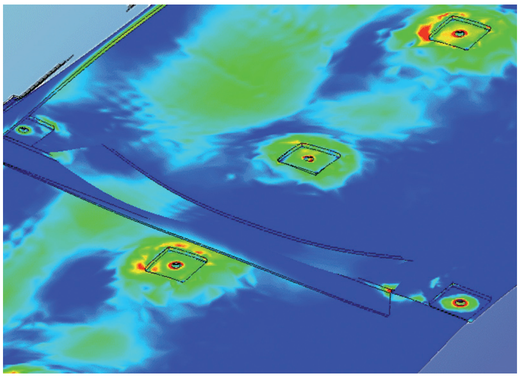

Fig. 4: Tension of a cladding shingle of the insulation

checks of the safety equipment as well as the costs due to downtimes for nitrogen emergency purging should not be ignored.
The flexibility which is advantageous for the plant operator can only be obtained if the design point of the plant does not refer to the non-hydrogen-containing atmosphere. Otherwise, for some annealing series, the operator must choose between optimum annealing atmosphere and the optimum throughput. Under protective gas atmosphere, brass or nickel silver evaporates significant amounts of zinc which settle in other locations. This pollution causes additional maintenance effort and quality problems which can be so substantial that operation at higher temperatures is no longer economically feasible. This is explained by a publication [3]. If these alloys, however, are annealed in an oxidizing or slightly oxidizing atmosphere, an oxide layer is generated which reduces the evaporation of zinc significantly. The plant operator has this option only if the design point was chosen correctly and if a pickling unit is available. The same applies to E-Cu alloys and high hydrogen contents. In this case, the cause is hydrogen embrittlement.
As the use of protective gas with higher hydrogen content does not result in any quality advantages and the HExAR-Furnace already reaches high flow rates without hydrogen, the use of an increased H_2-content will remain reserved for a few special applications.

Efficient maintenance

The maintenance and inspection of the HExAR-Furnace can be done as efficiently as for the strip floatation furnace because all zones are accessible from inside.
Compared to a vertical furnace, a reduced risk of strip rupture should be emphasized which can never be completely avoided with thin strips. The HExAR-Furnace has a considerable advantage due to its low over temperature, low strip tension and good accessibility.

Optimization of design strength by FEM

It is obvious that the components of the flow control, like the fan scrolls, the nozzle plenum and the nozzle system, require a solid construction. At high temperatures even subordinate parts, such as sheet metal parts used for covering the ceiling insulation, are challenging. For this reason, even for this parts a FEM analysis was carried out to reduce tension (see example in figure 4). Nevertheless, WSP improves the geometries especially because of practical experiences. This leads to a significant reduction of downtimes - in spite of increasing stress.

Flow optimization with CFD

Important aspects of the HExAR-Furnace were investigated and optimized by means of CFD concerning:

- Homogeneity of the nozzle system in longitudinal and transverse direction.
- Flow situation and circulation around the radiant tubes in order to reduce over temperatures of the metallic internals more.

A concrete example is shown in figure 5a. The stiffening mounted under the nozzle plate impairs the exit velocity and the exit angle of the open jets (especially visible at the right open jet). The reason is that the fluid which flows inside the nozzle box from the right to the left breaks off and now exits the hole type nozzle vice versa, from the left to the right. This is shown in figure 5b. For optimization, the distance between stabilizing plate and hole type nozzle was enlarged, see figure 5c. This has improved the exit angel and the exit velocity. The heat transfer coefficient at the strip was increased by almost 5%.
The results of the CFD calculations should be extensively checked and verified. In this concrete case, all results of simulations were verified with good conformities.

Heating and heat recovery

Further proven developments have been becoming state of the art for strip floatation furnaces during the recent years. These developments have been adopted for the HExAR-Furnace.
The indirect heat input is executed by means of long, straight radiant tubes with large diameter. This simple and rigid design of the radiant tubes prolongs their life time and was introduced by WSP already 15 years ago for strip floatation furnaces.
At high furnace temperatures burners with flameless oxidation are used, thereby the forming of a hot flame is avoided. Thus, the NOx-values are also at furnace temperatures of 850 to 1000°C significantly below the limits. The flameless oxidation operation also preserves the heating sys-

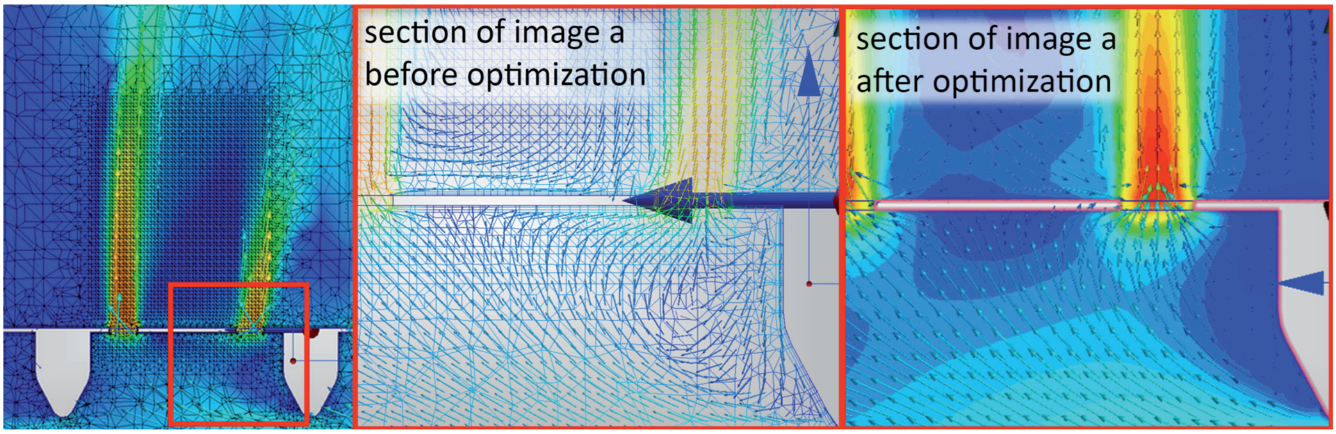

Figure 5 a: Inclination of the right open jet, b: Detail before optimization, c: Detail after optimization, stream exits vertical

tem because of the avoidance of temperature peaks.
Similar to the strip floatation furnaces, water can be heated by the waste heat of the cooling zone of the HExAR-Catenary-Furnace. This hot water can be used for the heating system of the surface treatment within the annealing line so that the heated tanks do not need an additional heating during strip run. Additionally, hot water can be supplied for a customer's heat circuit. WSP-customers use such systems for heating buildings or other production facilities.

Ordered HExAR-Furnace

Among other things, the mentioned advantages of the HExAR-Furnace convinced the customer Ningbo Powerway last year. They have been operating a WSP Strip Floatation Furnace since 2012. The customer is going to increase his annual tonnage by the new furnace significantly. If this increase in tonnage will be feasible mostly with standard alloys in the normal temperature range or with HP-alloys at high temperatures, only time will tell. The investment in the HExAR-Furnace will be profitable in both cases. The furnace will be delivered to the customer Ningbo Powerway in 2015.

Conclusion

The HExAR-Furnace up to 1.000 °C is the perfect complement or even alternative to strip floatation furnaces with temperatures up to approx. 850°C. Due to its high annealing power, it can also be effectively used for the annealing of standard alloys and has almost all the features of strip floatation furnaces. This is all achieved without the expensive use of an increased hydrogen content in the protective gas which is merely an option.

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