

Advanced Design for Continuous Roller Furnace for Hot Forming Line

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Abstract. Use of press hardened parts in BIW (Body in White) structures has evolved in recent years to encompass wide range of part complexity, size and mechanical properties. In addition, the number of components per vehicle has also increased pushing demand for more capital investments. Suppliers of press hardened parts need to accommodate these changes while staying competitive. Advanced design of heat treatment furnace has to offer a unique furnace design that provides flexibility to handle future part sizes minimizes down time to increase line utilization and offers a unique solution to produce tailor tempered parts for crash performance. This paper presents advanced innovative design of continuous roller furnace. These types of furnaces are generally used in hot forming lines. Design is focused on optimal heating layout, modern drives of rollers, new design and other items respecting the optimal technological and technical aspects. Also the technological functions like the dew point temperature regulation, oxygen rate regulation. Based on the long-time experiences with manufacturing and development of the machinery for the automotive industry, new roller furnaces were designed using modern methods including the FEM analyses for numerical simulations of heating processes and heating power distribution. The numerical solution of many mathematical problems involves the combination of external and internal conditions and different technological processes.

1. Furnace design characteristics

An important parameter of the furnace design is its modularity, which allows an OEM to build the furnace according to user requirements (Figure 1). The design allows for comfortable access to the furnace for maintenance, safety features that meet updated international safety standards, and technological requirements such as the dew point regulation system and oxygen rate control.



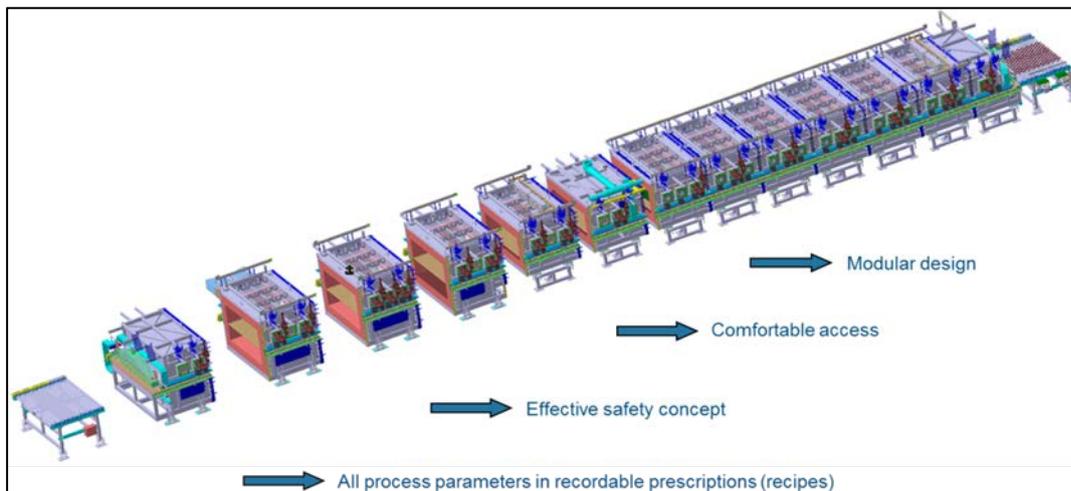


Figure 1. Furnace modular concept.

There are many design considerations used for designing and manufacturing roller furnaces for hot forming applications. Due to new varieties of blanks (coated and uncoated) the hot forming furnace needs to be adaptive for future requirements. Therefore the following key design characteristics are essential: Heating system and dew point regulation.

1.1. Blanks transmission inside the furnace

Rollers are driven by an external bevel gear drive which is isolated from furnace heat. No cooling system is required which reduces the complexity of the system and reduces required maintenance. But, the main advantage of this system is that each roller can be accessed and replaced individually from outside the furnace. Quick disconnect design separates the roller from the gear drive. Damaged rollers can be replaced in less than 5 minutes without the need to stop production or purge the blanks from the furnace. The gear drive also allows rotating the rollers in oscillation mode, i.e. rotating back and forth, during line stoppages. This feature maintains the flatness of the hot blanks in the furnace and prevents creep deflection of the rollers.

These features reduce down time of the furnace when maintenance or roller replacement is required. They also eliminate the need to purge and scrape blank from the furnace when short time stoppage is required and contribute to overall availability of the furnace for production.



Figure 2. Blank transmission system through roller drivers.

2. Heating concepts

2.1. Heating transfer

The heat flux in the furnace and the homogeneous temperature distribution inside the furnace atmosphere are key factors to reach the required quality of the original equipment manufacturer (OEM). FEM analysis of heat transfer was used as the main tool for the design of advanced heating system. This calculation takes into account all mechanisms of heat transfer i.e. conduction, convection and radiation as shown in the chart down below [1].

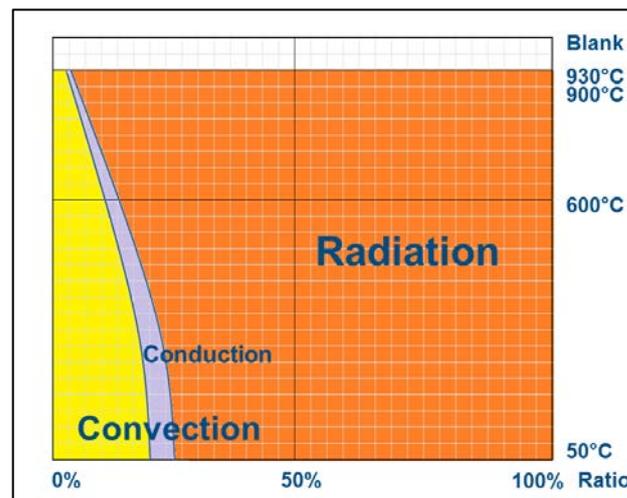


Figure 3. Heating mechanism inside the hot forming furnace. (Source: BENTELER internal paper)

Heating concepts include basic models like the recuperative gas burners with the radiant tubes or electric resistance heaters [2].

The advanced system is based on efficient recuperative burners using the flameless oxidation (FLOX) technology equipped with the silicon reinforced silicon carbide radiant tubes produced by WS GmbH Company⁴. The main advantages of these burners are the higher efficiency calculated by using equation (1) and reduction of NO_x-emissions. The efficiency is up 10% - 15% higher compared to common burners. Design also brings other benefits such as homogenous temperature distribution, reduction of the thermal stress in the burner, noise reduction and lower restrictions on fuels.

$$\eta = 1 - \frac{\text{exhaust gas losses}}{\text{fuel input}} \quad (1)$$

2.2. Formatting author affiliations

FEM analysis of heat transfer was used as the main tool for the design of heating system. This calculation takes into account all mechanisms of heat transfer, i.e. conduction, convection and radiation. Table 1 shows an overview of different regimes of heat transfer for different temperature difference between the blank and the furnace. Radiation is the dominant heat transfer mechanism.

Table 1. Heat transfer inside the furnace.

Temperature of furnace [°C]	Temperature of blank [°C]	Emissivity	Convection coefficient h [W/m ² K]	Heat flux radiation [kW/m ²]	Heat flux convection [kW/m ²]	Ratio between
870	25	0.38	9.0	36.6	7.6	4.8
900	600	0.12	9.0	8.9	2.7	13.3
920	900	0.54	9.0	4.1	0.18	22.8
930	920	0.70	9.0	2.7	0.09	29.4

2.2.1. *Radiation heat transfer.* It is possible to calculate radiation energy flux from so called “black” body eb (W/m²) using the famous Stefan-Boltzmann law as

$$e_b(T) = \sigma T^4 \quad (2)$$

Where $\sigma = 5.6707 \times 10^{-8}$ (W/m²K⁴) is Stefan-Boltzmann constant and T (K) is thermodynamic temperature. It is known, that non-black bodies absorb and emit less energy than black bodies, which are perfect emitters. It is possible to characterize the emissive power on a non-black body (or gray body) using a surface property called emittance (e). The equation (2) for non-black bodies should be written in the following form:

$$e(T) = \varepsilon \sigma T^4 \quad (3)$$

The emittance is a property of a surface, which depends on temperature and considered wavelength. For simplification, the concept of non-black body is established and supposes that emittance only depends on temperature.

When radiation is exchanged between bodies (1) and (2) that are non-black, the total net heat flux is calculated as:

$$Q_{net} = A_1 F_{1-2} \sigma (T_1^4 - T_2^4) \quad (4)$$

The transfer factor F_{1-2} depends on the emittances and geometrical view between bodies (1) and (2). That is also called the view factor. Transfer factor or view factor must be determined to calculate the radiative heat transfer. Generally, view factor can be calculated according to the equation:

$$F_{1-2} = \frac{1}{A_1} \int_{A_1} \int_{A_2} \frac{\cos \beta_1 \cos \beta_2}{\pi s^2} dA_2 dA_1 \quad (5)$$

Where β_1 and β_2 are angles between surface dA_1 and dA_2 normal lines and a ray between dA_1 and dA_2 , and s is distance between dA_1 and dA_2 . Nevertheless this calculation is impossible for complicated geometries. By FEM numerical simulations, the computational domain division into individual finite elements is advantageously used. The view factor is then numerically determined between each two elements in the system. Even here, the direct integration according the equation (5) would be very difficult. So it is necessary to use some appropriate statistical methods. Details about the radiation heat transfer could be found in [3].

3. Tailored Tempering

To improve energy absorption during crash or roll over, some BIW components like B-Pillar, A-Pillar and transmission tunnels are designed with lower strength areas within a high strength matrix. Several concepts are currently adopted at different OEMs. Earlier designs involved spot welding a conventionally stamped low strength component to a hot stamped main component. Others used tailor laser welded or tailor rolled part with thinner segments. Newer designs utilize a single blank with tailored mechanical properties. BENTELER tailor tempering furnace consists of several standard furnace modules of which, the last 8 meters of the furnace chamber is divided into two longitudinal chambers. One chamber is maintained at 930°C while the other is maintained at about 575°C. Blanks are fully heated to Austenite (930°C) before reaching the split zones. Then, as the blanks move through the split zones, the portion of the blank required being at lower mechanical properties passes through the lower temperature chamber while the high strength portion is maintained at 930°C in the high temperature chamber (Figure 4).

The portion of the blank that passes through the low temperature chamber is cooled down under controlled conditions (rate) using dried air or Nitrogen showers transforming the material from austenite to lower strength structures. The cooling rate is controlled and can be adjusted to influence final mechanical properties of the lower strength area. The blank is subsequently formed in a standard water cooled hot forming tool to get a press hardened part with lower strength at targeted area and high strength in the rest of the part (Figure 5). Both chambers of the split zones can be heated to 930°C to run product with uniform mechanical properties without the need to do any physical changes to the furnace.

This solution offers the following advantages:

- One furnace can be used to produce tailor tempered or uniform strength parts without the need for additional setup of physical changes to the furnace
- Use of one blank without the need for laser or spot welding.
- Lower blank cost (no assembly required)
- No investment required for assembly
- No performance issues related to laser or spot welding
- This process can be used with tailor rolled or patched blanks
- Standard hot form tools are used to form and quench the part. No need for heated tool details. Therefore, dimensional quality of the part is equivalent to similar parts with uniform mechanical properties and better than that produced with heated dies
- Overall heating time in the furnace is not impacted by the controlled cooling in the split zones. Therefore, standard cycle times can be achieved without penalties or any additional requirement on the tools or other equipment

This process can be used for both aluminized and uncoated steel. AlSi coating is fully diffused in the entire blank and therefore, there will be no weld or paint issues related to excessive Aluminium in the weld pool or paint tank.

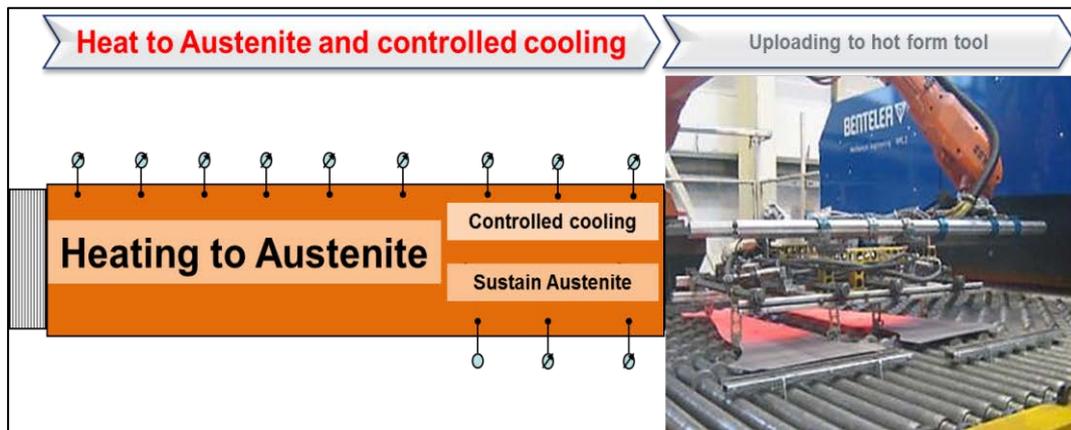


Figure 4. Tailored tempering process – Patented solution.

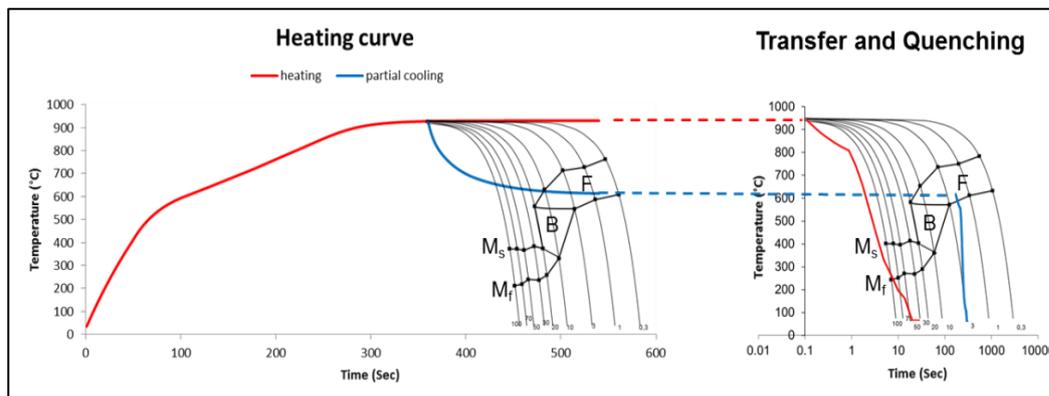


Figure 5. Tailored tempering heating curve. (Source: BENTELER internal report)

4. Dew point regulation system

With the knowledge of the problem called the hydrogen embrittlement, a system for the dew point regulation has been developed and was patented in year 2011 [5]. The dew point is the temperature at which the water vapor in a sample of air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates. Basically the dew point temperature is a function of the content of water vapor inside the furnace atmosphere.

Hydrogen embrittlement occurs when various metals, especially high-strength steel, become brittle and fracture following exposure to hydrogen. Hydrogen embrittlement is often the result of unintentional introduction of hydrogen into susceptible metals during heating, forming or finishing operations. The source of hydrogen is water inside the furnace. The chemical reaction during the embrittlement process is described by a basic equation:



This equation shows that it is quite important to control the mass of H₂O inside the furnace to prevent the risk of hydrogen embrittlement. The risk is high especially for coated blanks. Basic chemical reactions for Al – Si coated blanks are:



When the hydrogen (H) diffuses along the grain boundaries and combines with the carbon (C), which is alloyed with the iron inside the steel, it forms methane gas (CH₄). The methane is collected inside the small voids along the grain boundaries where it builds up enormous pressures that initiate crack.

This is quite important during the processing of Al-Si coated blanks; because the hydrogen can be easily collected and locked below the coating.

Possible sources of water (hydrogen) inside the furnace causing hydrogen embrittlement are:

- Endo – Exo gas protective atmosphere inside the furnace (H₂, CO, N₂, CO₂, H₂O)
- Nitrogen + natural gas mixture inside the furnace (CH₄, CO, N₂, CO₂, H₂O)
- Open flame inside the furnace (N₂, CO₂, H₂O, CO)
- Missing controlled atmosphere (N₂, CO₂, H₂O)

Nowadays, most OEMs only accept the parts produced under the controlled atmosphere with reduced dew point temperature to -10 °C and lower. The influence of hydrogen embrittlement can be decreased by using pure nitrogen (N₂) for uncoated blanks. This approach may reduce the dew point temperature and protect the surface against oxidation or using dried air (with dew point temperature -40°C) atmosphere (CO₂, N₂, O₂) for blanks with AlSi coating. This approach reduces the dew point temperature and supports the Al – Fe diffusion.

Cognizant of the problems that hydrogen embrittlement cause, a system for the dew point regulation was developed that saves energy and is based on the use of dried air or nitrogen [5]. The level of dew point is real time analysed and regulated to reach permanently the required value. Furnaces following the modern practices and latest trends used during the hot forming production are essential for an efficient press hardening process. Well-designed hot forming furnace contributes an improved OEE (overall equipment efficiency) of the hot forming line.

The mechanical design of the unloading area is based on similar configurations of the destacking area with different supplementary equipment and less complex design of the automation comparing to the destacking station. Nonetheless the cycle time in that area could be a challenging aspect when the availability of the space floor is limited and the required short cycle time of the customer has to be respected.

5. Conclusion

The latest trends and modern practices for manufacturing the hot forming parts has to be implemented by using process oriented equipment which enhances the productivity of the hot forming process to meet future evolution of press hardened parts at minimal capital investment. The hot forming furnace is also built to maximize line availability by minimizing down time, giving suppliers of press hardened parts higher throughput and more competitive costing. Many particular technologic drivers have been researched and developed in order to manufacture premium hot forming parts according to the OEMs required specifications and standards. Two main drivers contribute by respecting those required pressed hardened parts: The advanced utilized heating system based on the radiation heat transfer

mechanism which allows the uniform heating transfer distribution along the hot forming parts and the active measurement of the dew point temperature through the automated dew point regulation system of the furnace atmosphere. Besides the advanced thermodynamic furnace design the cycle time for the material handling effectiveness of the complete hot forming line beginning with the stacking station through the hot forming furnace to the uploading station has to be mono-synchronized entire the complete line in order to respect the necessary heating treatment of the press hardened parts to ensure the required quality parameters and to avoid unnecessary down times along the complete line.

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