Tailored Heating Of Billets For Hot Forming Using An Induction Heating Approach

Martin Ennen
Institute of Electrotechnology
Leibniz University Hanover
Hanover, Germany
ennen@etp.uni-hannover.de

Egbert Baake
Institute of Electrotechnology
Leibniz University Hanover
Hanover, Germany
baake@etp.uni-hannover.de

Igor Niedzwiecki
Institute of Electrotechnology
Leibniz University Hanover
Hanover, Germany
niedzwiecki.igor@googlemail.com

***Abstract*— This paper deals with an induction heating approach in order to realize a tailored heating of round billets for hot forming processes. In particular, this work examines the limits in which tailor-made temperature profiles can be achieved in the billet. In this way, a flow stress distribution based on the temperature field in the material can be set in a targeted manner, which is decisive for forming processes. The peculiarity of the tailored heating approach is that, in contrast to partial heating, where only partial areas are heated, the entire component is heated to the target.**

Keywords—induction heating, tailored temperature profiles, optimization, numerical simulation

I. Introduction

The massive forming can be divided into various forming processes. A classification of the methods can be made among other things according to the process temperature. Thus, a forming process in a temperature range up to 500 °C referred to "cold massive forming", above as a "warm forging" and finally in a temperature range between 1000 °C and 1300 °C as "hot massive forming" [1]. The latter is characterized by a low power and energy requirement during forming. Due to the high temperature of the workpiece, the flow stress is significantly reduced in the material and thus yields to a high formability. Usually, forging is used with a homogeneous temperature distribution in the billet. Inhomogeneities in the temperature distribution and the resulting different flow stresses usually lead to a lower or defective component quality (e.g. wrinkles). The main type of heating used in die forging parts is induction heating. However, small and medium-sized enterprises in particular also use conduction heating or heating by direct flame impingement with natural gas. Within a preliminary study, a first investigation of the influence of an inhomogeneous temperature distribution on deformation processes "flattening" and "upsetting" was investigated using FEM simulations. Therefore, cylindrical and rectangular blank sections were considered. In the FEM software FORGE3, a temperature profile was assigned to the billets and after a short compensation time the respective forming process was carried out (see Fig. 1).

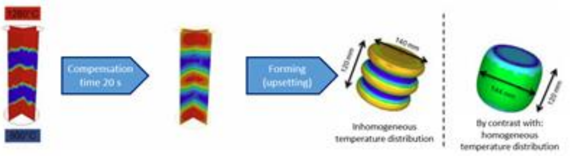

Fig. 1. Result of the preliminary study using inhomogeneous temperature distributions for forming (upsetting).

From this fact, the idea for the research project can be deduced: The targeted use of an inhomogeneous temperature distribution enables the possibility to produce suitable and complex preforms without special forming aggregates (e.g. cross wedge rolling) or to achieve a better forming behaviour in the billet due to the tailored flow stress. In this paper it will be shown how to design an induction coil using a numerical optimization method. The numerical optimized induction coil can be used to generate different hot zones in the workpiece respectively with through heating of each zone. Measurements on the real inductor and the comparison between simulation data and measured data, conclude this paper.

II. Temperature Profile To Be Achieved

As described in the previous chapter, there was a preliminary study investigating the forming behaviour of a cylindrical workpiece with different hot zones. In addition, within the research of [2], an inductor was designed that allows zone-wise heating with a through heated core in each zone.

In order to facilitate the comparability of the achieved temperature profiles, an axial target temperature profile is given, which has been deduced from the results of the above-mentioned research work. Fig. 2 shows the idealized target temperature distribution together with the geometrical dimensions. The tolerance range of the respective zone is highlighted and is 1250 °C ± 30 K for a "hot zone" and 950 °C ± 30 K for a "cold zone".

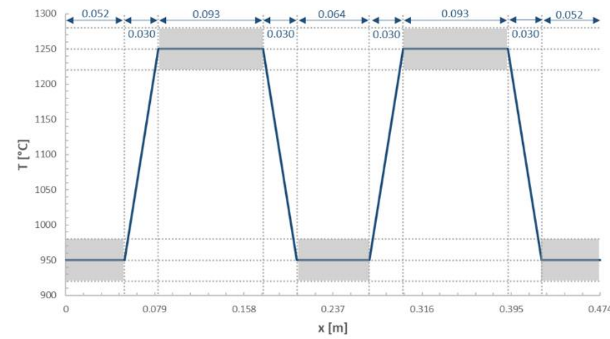

Fig. 2. Temperature profile with dimensions deduced from the investigation of [2] showing three coldzones and two hotzones.

Within the scope of the investigations, common geometries of forging billets (round and squared with different diameters) and different steels (1.4301 – stainless steel, 1.7225 – 42CrMo4 steel and 1.0503 – C45 steel) are examined.

III. FEM-Simulation and Optimization

For the investigation and design of the induction coil, suitable numerical FEM models and solution algorithms for the electromagnetic-thermal problem are developed using ANSYS® 19.0. In order to keep the calculation time as efficient as possible, symmetries of the geometry are used. The arrangement of the round billet can thus be reduced to a rotationally symmetrical 2D model. Fig. 3. below shows a quarter of the real arrangement after a symmetrical expansion (180 ° rotation around z-axis).

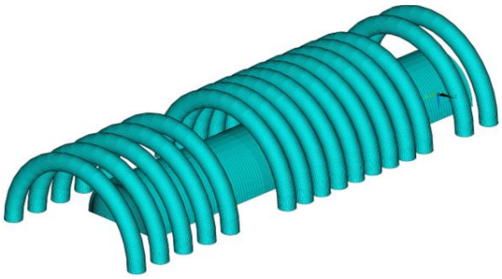

Fig. 3. FEM model of the round billet showing the quarter of the whole arrangement.

The arrangement for the rectangular billet is implemented as a 3D model and reduced to one eighth of the full model using suitable electromagnetic and thermal boundary conditions. Fig. 4. shows a quarter of the real arrangement after symmetrical expansion (Reflection about xy-plane).

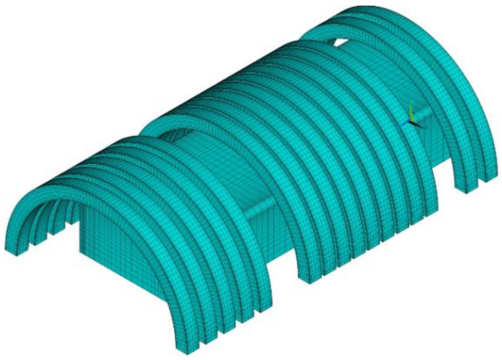

Fig. 4. FEM model of the squared billet showing the quarter of the whole arrangement.

The inductor in both models is represented by a series of individual short-circuit rings. A separate current flow can be fed to each turn. By specifying the same current in each turn, this corresponds to a stranded coil or a single inductor. Furthermore, all of the workpiece' s temperature dependent electromagnetic and thermal material properties which are relevant for the heating process are taken into account. Especially the field strength-dependent magnetic permeability is also taken into account for the ferromagnetic 1.0503 - C45 steel due to its significant influence on the heating behaviour.

To set the three dimensional temperature profile according to Fig. 2 for the respective geometries, the number of turns in each zone and their spacing from one another can be varied with the aim to achieve the sharpest possible separation or the highest possible temperature gradient between the respective through heated zones. Due to the complex problem in the generation of the temperature profile with regard to the dependence on geometric and electrical parameters and also the heating time, the simulation models are designed so that an interface to an optimization algorithm is given. This ensures an efficient way to get the best possible result as quickly as possible. The exact operation mode of the optimization algorithm is described in [3].

IV. Preliminary Results from Simulation and Measurement

An inductor geometry was designed and constructed for tailored heating of round billets with a diameter of 50 mm. Heating experiments have been carried out using the manufactured inductor prototype based on the simulation results. On the one hand, the inductor current and its frequency and on the other hand the surface temperature (using a thermographic camera) and five core temperatures (using a thermocouple) in different zones were measured. The measured electrical values were transferred to the simulation model and the temperature distribution was numerically calculated. Figure 5 below shows the comparison between measured temperature values and the simulated temperature distribution.

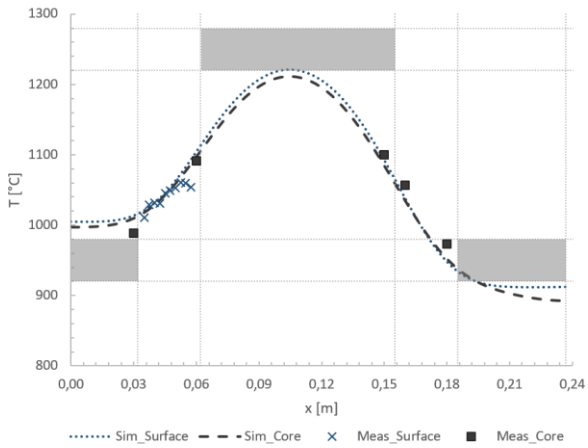

Fig. 5. Comparison between the simulated temperature profile of the round billet and the measured data.

The measured values show a very good coincidence with the simulated temperature profile. The model for ferromagnetic steels has thus been successfully validated.

In addition to the detailed description of the simulations and the validation measurements, the conference paper also describes the ongoing parameter studies with regard to the maximum adjustable temperature gradients for both applications.

Acknowledgment

The IGF-project 19511 N "Tailored Heating" of the AiF was supported by German Federation of Industrial Research Associations (AiF) in the frame of the Industrial Collective Research program (IGF) from Federal Ministry for Economic Affairs and Energy.

References

[1] F. Severin, Was ist Massivumformung.08/2014. S.1.

[2] M. Baldan, T. Steinberg, E. Baake, "Optimal design of inductor addressed to a tailored heating forging process", International Journal Microstructure and Material Properties, Vol. 13, Nos. 1/2, 2018

[3] M. Schulze and E. Baake, "Tailored heating of forging billets using induction and conduction heating approaches", COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, Vol. ahead-of-print No. ahead-of-print