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Numerical investigation of effects on blanks for press hardening process during longitudinal flux heating

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Numerical investigation of effects on blanks for press hardening process during longitudinal flux heating

André Dietrich and Bernard Nacke

Institute of Electrotechnology, Leibniz Universität Hannover, Wilhelm-Busch-Str. 4, 30167 Hannover, Germany

E-mail: dietrich@etp.uni-hannover.de, nacke@etp.uni-hannover.de

Abstract. With the induction heating technology, it is possible to heat up blanks for the press hardening process in 20 s or less. Furthermore, the dimension of an induction system is small and easy to control in comparison to conventional heating systems. To bring the induction heating technology to warm forming industry it is necessary to analyze the process under the view of induction. This paper investigates the edge- and end-effects of a batch heated blank. The results facilitate the later design of induction heating systems for the batch process.

1. Introduction

In the last years different induction heating concepts for blanks were tested. The article [1] analyzes the potential of continuous heating with longitudinal and transversal flux concepts. With those heating concepts it is possible to heat blanks up to the Curie temperature. The potential to heat blanks above the Curie temperature was described in [2] using a single side induction coil and in [3] using the concept of a single side induction heater too and examine the influence of a longitudinal flux heating coil on the temperature distribution. The influence of longitudinal flux heating on holes and block-outs was investigated in [4] and [5]. This paper analyzes an induction heating system which allows temperatures up to 950 °C. The advantage of single stage induction heating is that conventional heating systems like a gas furnace aren't necessary if a homogeneous final temperature distribution of the blank can be reached only by induction heating. In the hot sheet metal forming process blanks are heated up to a temperature of 930 °C to 950 °C for uncoated material and AlSi coated resp. 890 °C to 920 °C for Zn coated material in order to reach the austenitisation temperature and compensate the thermal losses, which occur during the transport from the heating system to the press.

2. Numerical model

For the numerical modelling and calculation, the commercial software package ANSYS 16.2 was used, which bases on the finite-element-method (FEM). The calculation algorithm which is used in the study is divided in two sub-steps. In each iteration step a harmonic electromagnetic and a transient thermal calculation are performed. To solve the Maxwell Equation's for the harmonic electromagnetic field the magnetic vector potential is used. The result of this solution is the heat source distribution in the work piece. In the second sub-step the heat transfer equation is solved for a time interval Δt taking into account thermal losses due to radiation and convection. The solution of the electromagnetic calculation is the input value for the heat transfer equation.

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The output value is the temperature distribution. In the next iteration step the temperature distribution is the input value for a new harmonic electromagnetic calculation with adjusted material properties like specific electrical conductivity, relative permeability, specific thermal conductivity and the specific heat capacity. For the calculation of the following results a verified 3-dimensional model is used [6]. Due to the symmetry only the half of the system is modelled in order to reduce the calculation time. The induction coil has a rectangular cross section (Figure 1). For an exact calculation it is important to mesh the edges of the blank very fine. The calculations are based on the material properties of 22MnB5 steel [7]. The reference thickness of the blank is 1.5 mm, because in many industrial application blanks with a thickness in this range are used. In most cases the width and the length of the blank is 500 mm. The coil has a number of 8 windings. The width of one winding is 60 mm and the distance between the windings is 5 mm. The frequency of the inductor current is 400 kHz. The air-gap in vertical direction is 40 mm and in horizontal direction 50 mm on each side.

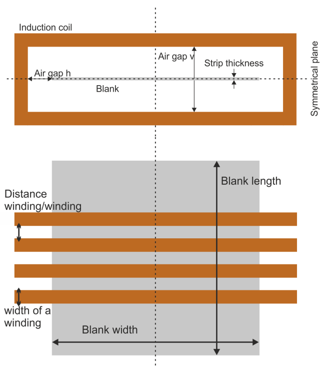

Figure 1. Sketch of the numerical model

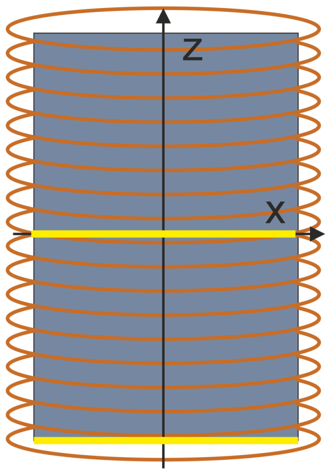

Figure 2. Evaluation path in x-direction

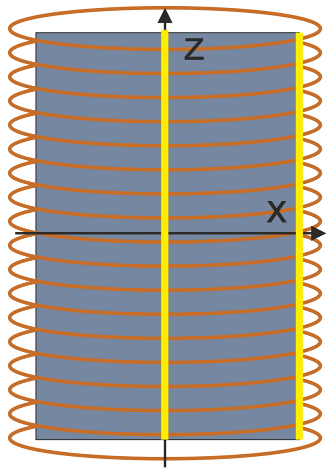

Figure 3. Evaluation path in z-direction

3. Numerical investigation

3.1. Influence of the horizontal air gap on the temperature distribution

The air gap is an important geometrical value in the induction heating process. It acts on the temperature distribution and the electrical efficiency. First the modification of the air gap in horizontal direction is analyzed. This is the distance between the edge of the blank and the normal part of the induction coil. The temperature is evaluated in two directions and each on two paths (Figure 2 and 3). In figure 4 and figure 5 the temperature profiles parallel to the windings are shown. Between 0.05 m and 0.45 m the temperature is nearly homogeneous.

Close to the edge the blank is overheated. The margin of the overheating depends of the size of the horizontal air gap. The overheating at the edge falls with increasing the horizontal air gap. At the end of the blank (Figure 5) the temperature profile is qualitatively the same but around 2 percent lower because the magnetic field spreads at the end of the induction coil.

In figure 6 and figure 7 the temperature profile normal to the windings (Figure 3) is illustrated. The temperature profile in figure 6 is evaluated at the position $x = 0$ m. For the four air gaps the temperature has qualitatively the same trend. But in figure 7 the temperature along the edge is different for the air gaps. If the horizontal air gap is small the magnetic field which is generated from the normal part of the induction coil has more influence on the

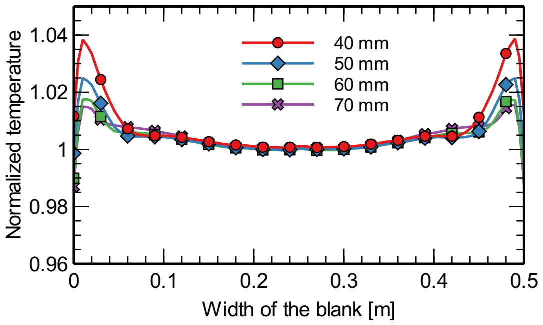

Figure 4. Temperature in x-direction in the centre

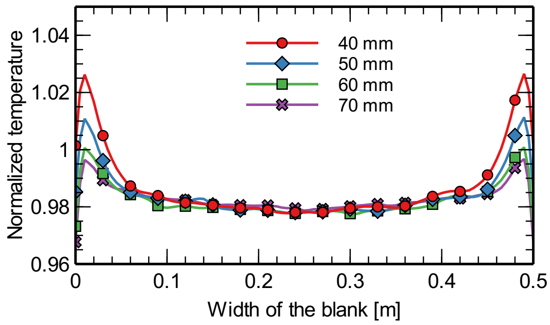

Figure 5. Temperature in x-direction at the end

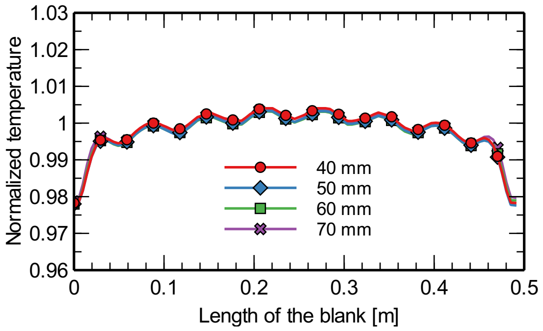

Figure 6. Temperature in z-direction in the centre

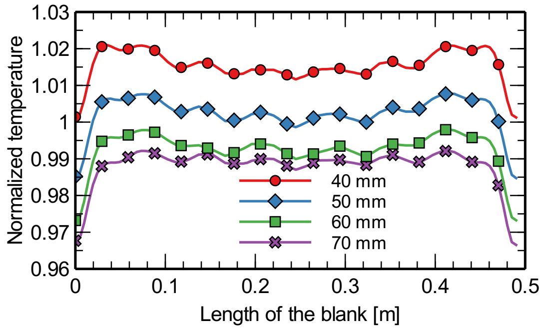

Figure 7. Temperature in z-direction at the edge

temperature of the edge and causes a higher value (Figure 7). The ripples in figure 6 and figure 7 are produced by the distance between the windings. A part of the magnetic field doesn't close over the whole coil rather over a single winding. That means the magnetic field between the windings is lower than under a winding and therefore the temperature too.

3.2. Influence of the vertical air gap on the temperature distribution

The next analyzed parameter is the vertical air gap. The temperature profile at position $z = 0$ mm is influenced by the vertical air gap (Figure 8). With increasing the air gap the homogeneous zone gets smaller and the shape of the curve is smoother. Due to the increased distance between the blank and the horizontal part of the induction coil the coupling becomes weaker. The influence of the normal part of the induction coil increases and, therefore, the magnetic field is greater in the edge area. The temperature at the end of the blank is shown in figure 9. The increasing of the vertical air gap results in a lower temperature at the end of the blank because of a weaker magnetic field in this area but the difference from minimum to maximum is the same for each curve.

In figure 10 and figure 11 the temperature along the z-axis is illustrated. With a greater air gap the temperature at the end of the blank decreases. Furthermore, the ripples of the graphs are reduced because the influence of the magnetic field around a single winding decreases with a greater air gap and therefore, the magnetic field is more homogeneous.

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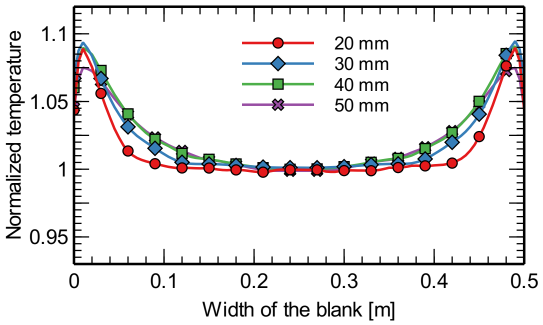

Figure 8. Temperature in x-direction in the centre

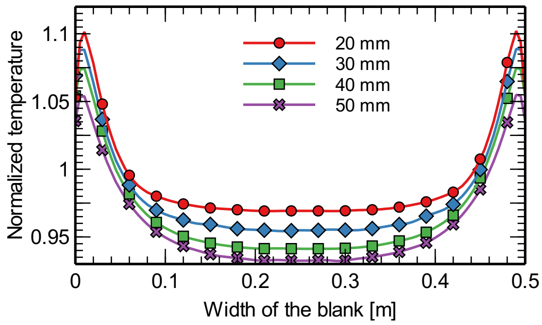

Figure 9. Temperature in x-direction at the end

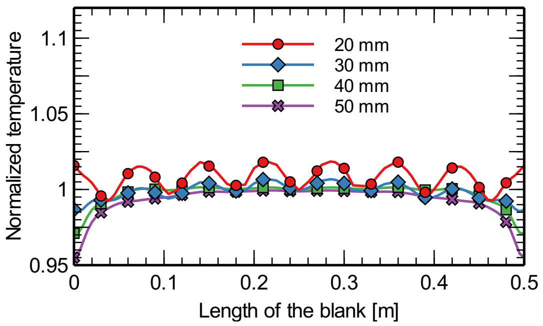

Figure 10. Temperature in z-direction in the centre

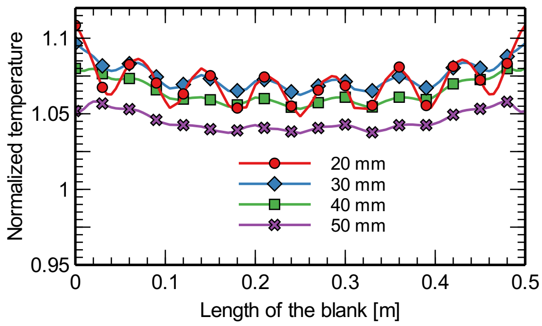

Figure 11. Temperature in z-direction at the edge

3.3. Influence of the length of the blank on the temperature distribution

The next parameter in this investigation is the length of the blank. Blanks in the press hardening process are different in length. So it is important to know in with range the length of a blank can be varying for a nearly homogeneous heating. The modification of the length has no influence on the temperature in x-direction at position $z = 0$ m (Figure 12). But at the end of the blank there is a dependence of the length on the temperature profile (Figure 13). If the blank is longer than 480 mm the temperature difference between the position $z = 0$ m and the end of the blank is more than 1 percent. If the blank is shorter than 480 mm the temperature profile is no longer influenced that means the temperature is nearly the same as at position $z = 0$ m.

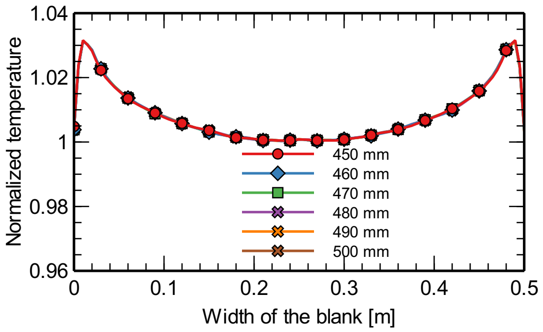

Figure 12. Temperature in x-direction in the centre

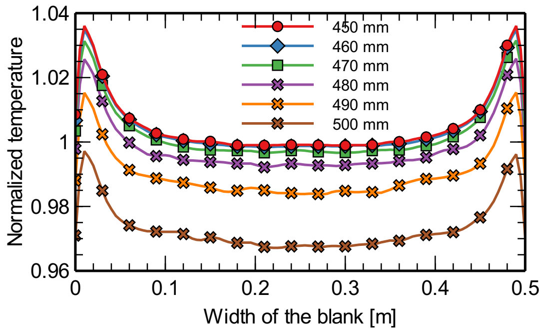

Figure 13. Temperature in x-direction at the end

The temperature profile in z-direction for position $x = 0$ m and at the edge of blank is shown in figure 14 and figure 15. At position $x = 0$ m (Figure 14) the temperature is very homogeneous for a length of 480 mm or shorter. The temperature directly at the edge is around 1 percent higher than in the centre of the blank (Figure 15). For a longer blank the temperature drops because of a spread magnetic field at the end of the coil. The temperature profiles of the curves are qualitatively the same and the difference between minimum and maximum for each curve are 2.9 percent.

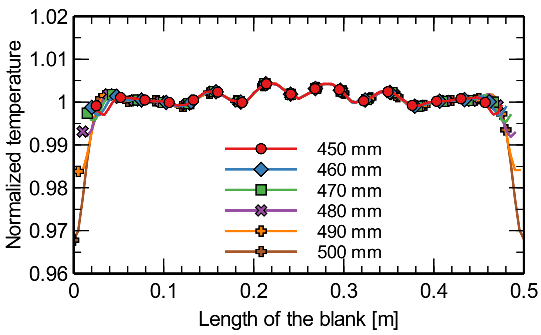

Figure 14. Temperature in z-direction in the centre

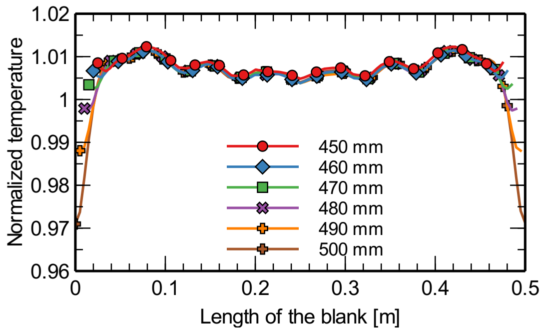

Figure 15. Temperature in z-direction at the edge

3.4. Influence of the thickness of the blank on the temperature distribution

The thickness of the blanks which are used in the press hardening process varies in a range of 1 mm to 3 mm. Between 0.06 m and 0.44 m the difference in the temperature profile (Figure 16 and Figure 17) isn't big but near the edge of the blank the temperature increases with the thickness of the blank. With a thicker blank more Joule Heat is generated in the vertical part at the edge because the way for the electrical current gets longer. This Joule Heat superposes with the Joule Heat of the surface and results in higher temperatures at the edge.

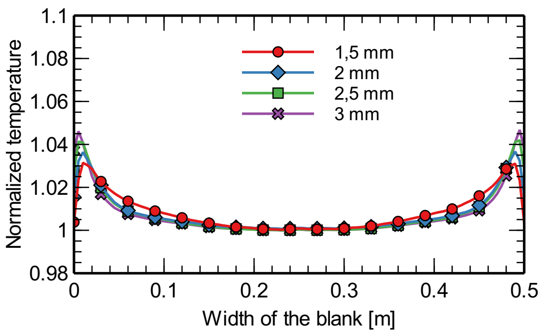

Figure 16. Temperature in x-direction in the centre

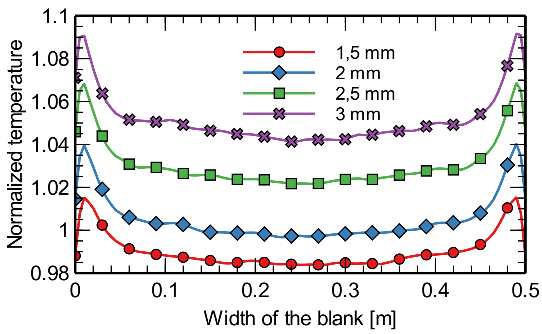

Figure 17. Temperature in x-direction at the end

Figure 18 and figure 19 show the temperature profiles in z-direction. The temperature profiles in the centre (Figure 18) have nearly the same trend for the different blank thicknesses. Only at the end of the blank the temperature rises with thicker blanks.

At the edge of the blank (Fig. 19) the temperature is higher than in the centre. Furthermore, the temperature of thicker blanks is higher than for smaller ones at the edge of the blank.

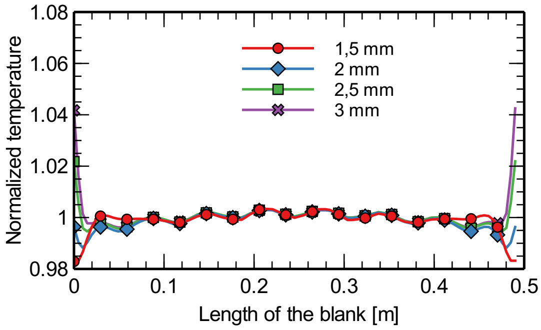

Figure 18. Temperature in z-direction in the centre

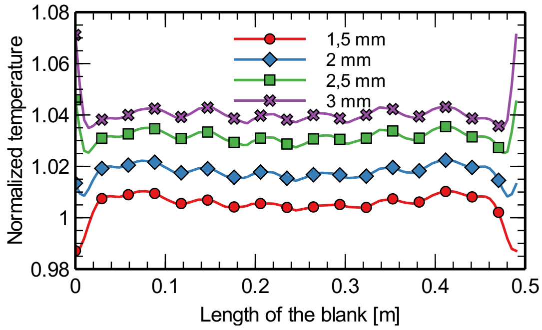

Figure 19. Temperature in z-direction at the edge

4. Conclusion

With a 3D numerical model, the batch heating process for thin blanks in longitudinal flux field was investigated. With increasing the horizontal air gap the overheating at the edge and at the end of the blank could be reduced. The vertical air gap has only a small influence on the temperature in the centre of the blank but at the end the temperature drops around 5 percent for a large air gap. The length of a blank influences only the temperature at the ends. For the investigated length the temperature drops 3 percent. The last analyzed parameter was the thickness of the blank. With increasing the thickness, the temperature at the edge and end increases. The influence of the thickness on the temperature distribution at the end of the blank has to be investigated in more detail. In the future an experimental setup is planed for heating a b-pillar.

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