IMPACT OF WATER REMAINS ON A HOT ROLLED PLATE AFTER COOLING

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In situations when a sheet metal plate with large dimensions is rolled, the water remains from cooling can be observed on the top site of the plate. This paper is focused on the deformations of the hot rolled sheet metal plate which are caused by the water remains after cooling. A transient finite element simulation was used to describe a shape deformations of a metal sheet cross profile. The finite element model is fully parametric for easy simulation of multiple cases. The results from previous work were used for boundary conditions. The effect of gravitation was observed. The paper should provide an information if it is necessary to install blowing system in rolling process.

Keywords
water remains, FEA, simulation, hot plate, rolling, ANSYS

1. Introduction

The cooling is integral part of hot rolling process. Spraying water is used to cool down a rolled product in most cases. The water remains can be present on top site of the rolled plate after passing through the cooling section (Fig. 1) even when the roll is moving. These remains will evaporate eventually (after 60 second) but before that they significantly cool down the rolled plate. This additional unwanted cooling can deform a shape of plate. The problem is observed on a real case scenario from one international customer of Heat Transfer and Fluid Flow Laboratory. This paper is focused on numerical calculation (finite element analysis) of a rolled plate deformations and the main goal is to find the answer to question if water remains have significant influence on the shape of the rolled plate. The rolling process must be redesign and equipped with blowing system in situation when the influence is significant. That means additional investment and additional machinery to maintain.

The process chosen to analyse in this paper is hot rolling of plates with dimension 2000 × 4000 × 20 mm (length × width × thickness). The thickness of the water remains observed on the plate vary between 2 mm to 5 mm. Based on the water remains thickness, we can easily enumerate the time which is needed to evaporation of all water from plate surface. The thickness of 4 mm is used in a subsequent analysis to determine the evaporating time.

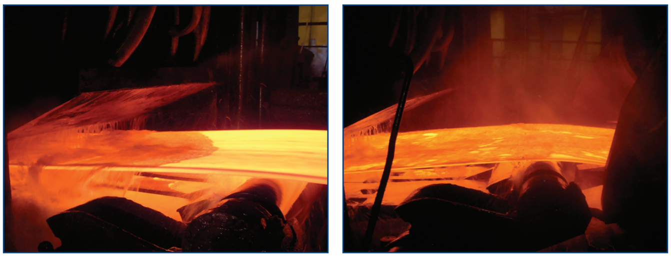

Figure 1. *The remains on the top side of rolled plate after passing through the cooling section*

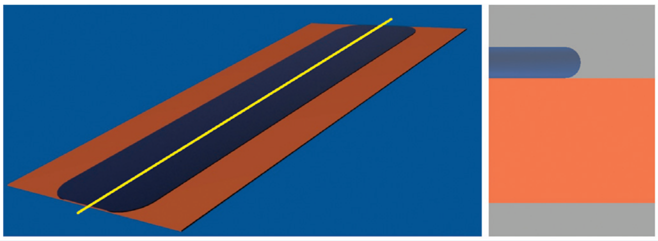

Figure 2. *The model of simulated problem, the yellow line symbolizes model symmetry plane (on the left side); the detail of water remains (on the right side)*

2. Finite Element Analysis

The simulation of the water remains influence is divided into two separated analysis – a transient thermal analysis and multiple static structural analysis. A temperature field over the time is calculated in the thermal analysis. This temperature field is used to calculate the structural deformation of the rolled plate caused by the non-uniform temperature distribution. The length of the thermal analysis is the evaporating time.

A finite element model uses symmetry of simulated plate with water. The model represents a section cut of a half of rolled plate (the yellow line at Fig. 2). There is no use of a support of the plate so it isn't part of the finite element model (FE model). The dimensions of FE model are 1000 × 1 × 20 mm (length × width × thickness).

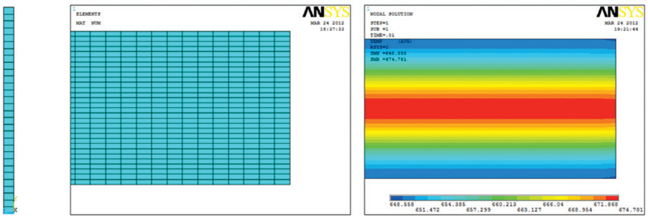

Figure 3. *The side view of FEM (on the left); the detail of FE mesh (in the middle) element type – SOLID90; the initial temperature distribution (on the right)*

The initial temperature field was recorded in a hot strip mill at the plate during a rolling process. It has a parabolic temperature distribution [Kotrbacek 2005] from a core temperature 675 °C to a surface temperature 650 °C (Fig. 3). Applied boundary conditions are values of a heat transfer coefficient (HTC) on external surfaces of the FEM in thermal analysis. The value of HTC is 400 $W \cdot m^{-2} \cdot K^{-1}$ for surface where is contact between the water and the plate. The value of HTC 55 $W \cdot m^{-2} \cdot K^{-1}$ is used for surface without the contact between the water and the plate. These values were obtained from previous work done in Heat Transfer and Fluid Flow Laboratory [Pohanka 2009], [Raudensky 2009]. A material model is temperature depended bilinear model. A temperature range of bilinear model is from 20 °C to 750 °C (Fig. 4).

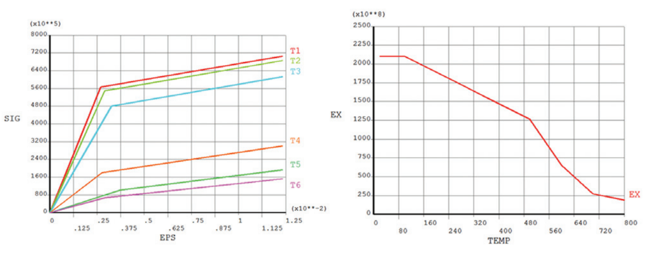

Figure 4. *The bilinear material model used for FEA (on the left side), T1 = 20 °C, T2 = 200 °C, T3 = 400 °C, T4 = 600 °C, T5 = 700 °C, T6 = 750 °C; The thermal depended Young's modulus used for FEA (on the right side)*

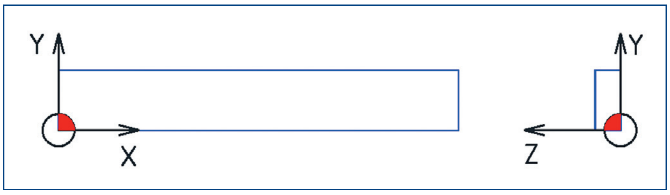

Figure 5. *The Axis system of FE model for better understanding constrains which were used in the structural simulation*

The boundary conditions applied in structural analysis are the temperature field, the gravitation and constrains which represents symmetry of the task. The plane strain or plane stress approach cannot be used because of these approaches does not represents the reality. The displacement in Z-axis of the nodes with Z = 0 was constrained and the displacement in Z-axis of nodes with Z ≠ 0 was coupled together. This approach leads to proper result. The nodes with Y = 0 were constrained because of FE model symmetry and the nodes with X = 0 and Y = 0 were constrained to prevent rigid body motion (Fig. 5).

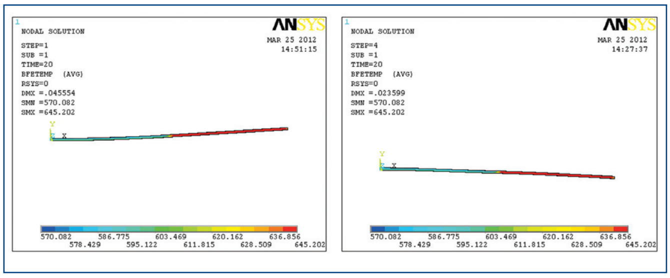

Figure 6. *Calculated displacement structure without/with gravitation on the left/right of the figure. Displacement scaling – 5:1*

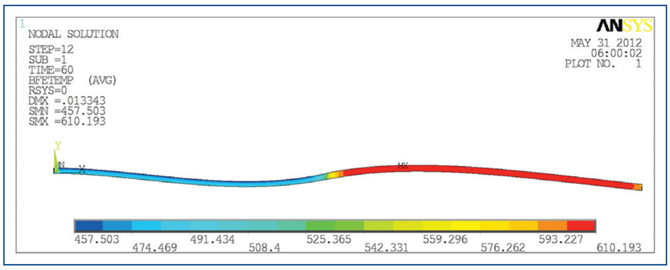

Figure 7. *The thermal field of rolled plate after the water remains evaporate; Displacement scaling – 100:1*

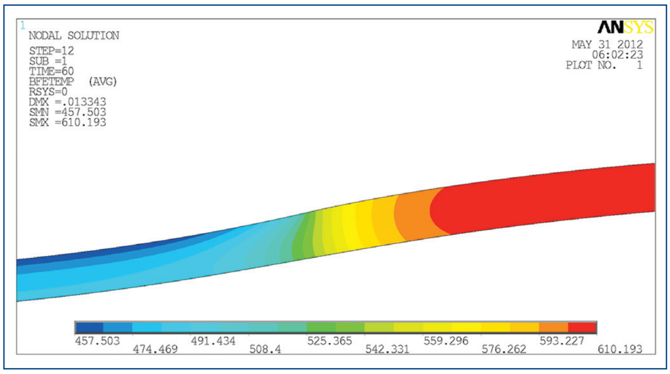

Figure 8. *The closer view of the centre of FEM; Displacement scaling – 100:1*

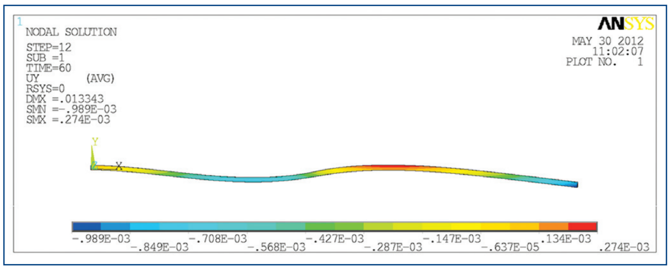

Figure 9. *Calculated displacement structure after the water remains evaporate; Displacement scaling – 100:1*

The structural damages were calculated in the specific points in time (5, 10, 15… 60 s). The maximal lift of roll edge was observed together with the highest difference between displacements in Y-axis.

3. Results

The difference between temperature leads to contraction because of different values of thermal expansion. The colder part of the roll contracts itself. This leads to bending and lifting of the roll edge. The maximal lift of the roll edge was detected in the time point 20 s. The thermal contraction isn't strong enough to bend the rolled plate as we can see on the right in Fig. 6. The gravitation force is almost two times higher than a bending moment produced by the contraction. The surface temperature beneath the water remains drops down to 458 °C. That is almost 200 °C decrease from a starting value (Fig. 8). The Fig. 7 shows displacement structure after the water remains evaporate (60 seconds). The range of deformation is +/–1 mm. Every negative displacement in Y-axis isn't possible in real case scenario because of plate support but we can see that size of plate deformation is small in comparisons with size of plate.

No plastic strain occurs during evaporation of water remains. The bilinear material model is sufficient for this task. The dilatation in Z-axis isn't an object of interest.

4. Conclusions

The cooling capacity of water remains is high enough to produce the non-uniform temperature field in thin rolled plate (Fig. 7). The water remains significantly cools down the rolled plate which will lead to a contraction. This contraction acts as a bending moment (Fig. 6 on the left). A rolled plate weight is sufficient to prevent considerable lifting of its edges (Fig. 6 on the right). The shape of plate is just slightly deformed. The maximal displacement doesn't exceed 1 mm and the influence of water remains is insignificant. The higher displacements are caused by manipulation or transportation with the plate to storage house.

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