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FINITE ELEMENTS METHOD (FEM) SIMULATION BASED PREDICTION OF DEFORMATION AND TEMPERATURE AT ROLLING OF TUBES ON A PILGRIM MILL

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3D - FEM simulation was used as an efficient tool for description of stress-deformation thermal field at rolling of tubes on a pilgrim mill. The monitored objectives comprised also behaviour of working tools at this rolling. This paper assumes rolling of already pierced thick-walled blank, which passes through the pilgrim stand at simultaneous reduction of thickness of inside and outside diameters at the expense of elongation of initial length. Main attention is focused on the mentioned parameters with respect to various conditions of rolling, such as different heat transfer, different friction or different distance of insertion of the rolled product into the gauge. The input data used at simulation were derived from real conditions of tubemaking.

Key words: FEM, temperature, tube rolling, pilgrim mill

Predviđanje deformacije i temperature metodom konačnih elemenata (MKE) tijekom valjanja cijevi na pilger – stanu. Za prikaz termičkog polja naprezanje – deformacija tijekom valjanja cijevi na pilger - stanu učinkovito je rabljena trodimenzijska metoda konačnih elemenata (3D – MKE). U radu je razmatrano i ponašanje alata tijekom izrade cijevi valjanjem. Pretpostavljeno je valjanje šuplje debelostjene cijevnice na pilger stanu uz istovremeno smanjenje vanjskog i unutrašnjeg promjera na uštrb produljenja početne duljine. Rad se fokusira na navedene parametre obzirom na promjenjive režime valjanja poput različitog prijenosa topline, različitog trenja ili različite udaljenosti uvođenja valjanog proizvoda u uređaj. Ulazni podaci rabljeni u simulaciji odgovaraju onima iz realnog procesa valjanja cijevi.

Ključne riječi: metoda konačnih elemenata, valjanje cijevi, pilger, stan

INTRODUCTION

Several authors described experiments aimed particularly at determination of demandingness of piercing processes, namely with respect to piercing mandrels or their stress load, similarly as e.g. at technology of piercing of extremely high blanks Skripalenko et al. [1] or piercing of continuously cast ingots from alloyed steel [2]. Komori [3] dealt with mathematical simulation of piercing according to Mannesmann and of other piercing technologies [4]. Some studies investigated also technology of tube rolling between three overhung rolls Zhang et al. [5] when authors concentrated on prediction of temperature characteristics of rolling of copper blanks. This paper is focused mainly on mapping of influence of the rolling technology on the pilgrim mill itself with respect to service life of tools, especially pilgrim mandrels at rolling of thick-walled blanks, influenced primarily by thermal and stress load. FEM based computer simulation proved to be an efficient tool for these purposes and results of these simulations were confronted with findings obtained from practice.

EXPERIMENTAL

Computer simulation of rolling of tubes from thick-walled blanks on a pilgrim mill was carried on. Simulation itself was realized with use of the software Forge 2007, which enables both 2D and 3D simulations. Spittel relation was used for calculation of resistance to deformation at plastic deformation for the given steel (1).

$$\sigma_f = A \cdot e^{m_1 T} \cdot T^{m_6} \varepsilon^{m_2} e^{m_4/\varepsilon} (1+\varepsilon)^{m_5 T} e^{m_7 \varepsilon} \dot{\varepsilon}^{m_3} \dot{\varepsilon}^{m_8 T} \quad (1)$$

where A, m_1, m_2, m_3, m_4, m_5, m_6, m_7, m_8 are regression coefficients, $\dot{\varepsilon}$ is strain rate, ε is magnitude of deformation, T is temperature.

The Tresca friction law (2) was used for ensuring of friction conditions. It can be written in following form:

$$\tau = -\overline{m} \frac{\sigma_0}{\sqrt{3}} \frac{\Delta V}{\Delta v}$$

or also

$$\tau = -\overline{m} K(T, \overline{\varepsilon}, \dots) \frac{\Delta V}{\Delta v} \quad (2)$$

This friction coefficient is equivalent to the description of the visco-plastic friction when the material sensitivity to the strain rate $\overline{m}$ and the interface sensitivity to the sliding velocity v_p are close to zero. ΔV, Δv are differences in velocities, σ_0 is stress.

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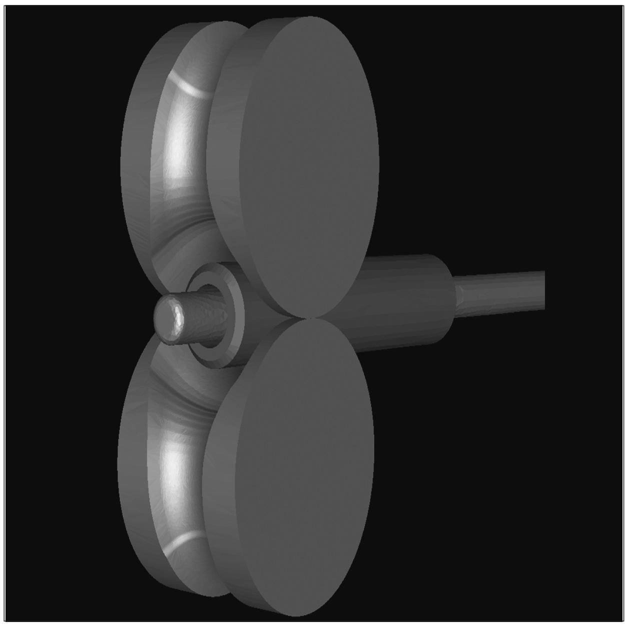

Figure 1. Initial assembly for rolling on the Pilgrim mill

The following data were used as inputs:

- blank made of steel 14NiCrMo13,
- initial temperature at the start of rolling 1100 °C,
- initial temperature of pilgrim rolls 200 °C,
- mandrel temperature 150 °C,
- mandrel diameter 120 mm,
- outer diameter of the blank 250 mm,
- inside diameter of the blank 150 mm.

The blank was placed before its first pass through the pilgrim stand in such a manner that its end exceeded the imaginary vertical edge passing through the rotation axes of pilgrim rolls by 19,8 mm. Thanks to geometry of the pilgrim rolls based on real values, the pass was made in a way to achieve the maximum possible squeezing on the protruding end, while taking into account the transitional area of the gauge - see Figure1.

The next step after the passing of the blank through the rolls was its clockwise turning by 90°; the blank was shifted back by the given length in order to bead flash at the end of the tube.

The whole simulation was focused primarily on determination of the thermal field, stress and deformation characteristics of the rolled tube. The monitored factors comprised also thermal and deformation load of the mandrel.

The Figure 2 shows thermal field of the blank at the 1^{st} pass. The diagram contains 3 curves. The first one is related to the part, which directly contacts the mandrel, i.e. this is the tube internal surface. The second one is related to the part in the middle of the wall thickness and the third one is related to the part that is on the tube external surface, i.e. in direct contact with the work roll. About the situation of thermal field in individual sections after first pass informs Figure 3.

It is evident that during initial stages of rolling the biggest drop of temperature was registered in the parts on the external surface of the tube. This can be explained by quicker heat removal thanks to the contact with much colder surface of the rolls; at this moment the rolled blank is not yet in contact with the mandrel, which due to its smaller diameter cannot remove the heat as rapidly as the rolls. Nevertheless, after approx. 1 s of rolling it is visible that the coefficient of the curve of temperature reduction at this part of the tube has changed and rate of cooling has increased at the places in central parts of the tube (internal surface of the tube), which is in comparison with other parts of the tube the quickest one. Internal surface of the tube cools down at the quickest rate during the whole rest of the pass, which is caused by the fact that internal surface of the tube is already in contact with much colder mandrel, which causes such a heat removal. The course of the other two curves manifests a close similarity, which is given by smaller contact of the deformed metal with the mandrel and (as it is also demonstrated in the Figure 4) by generation of deformation

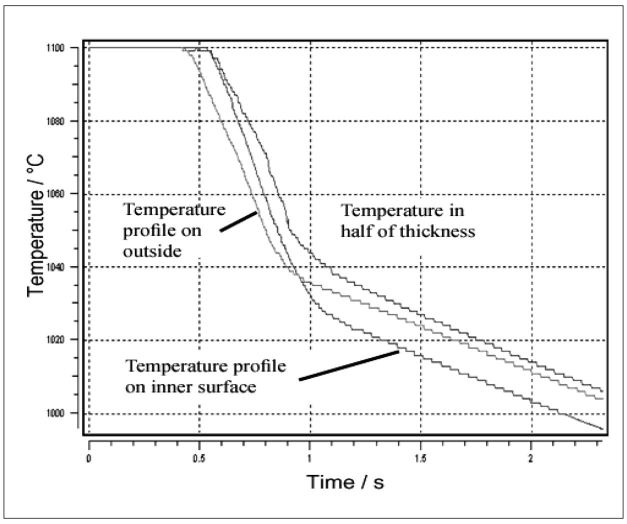

Figure 2. Graphical dependence of temperature on time from the start of rolling at the monitored parts

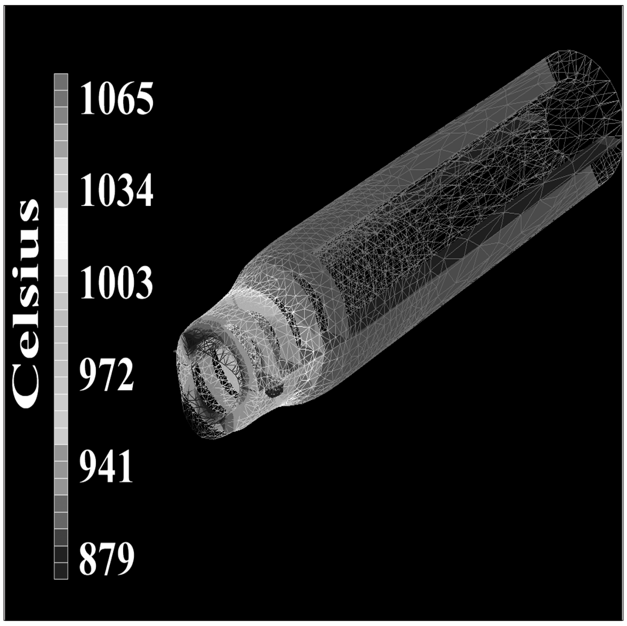

Figure 3. Temperature range of tube in individual sections after the first pass

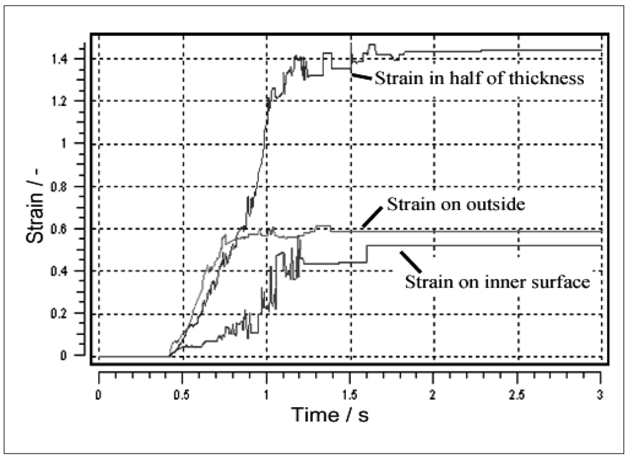

Figure 4. Profiles of strain intensity at rolling of tubes at monitored parts

heat caused by increase in strain intensity at these places, which partly eliminates thus formed heat losses. It must be added that this time of rolling corresponds to the place of the shallowest depth of the notch in the gauge, i.e. to the final diameter of the tube after the rolling.

Strain intensity in central parts is more than double. Other parts of the tube, i.e. internal surface of the tube and centre of the tube thickness behave similarly, i.e. that slope of the curves decline is almost identical.

During rolling of the blank, i.e. at reduction of the wall thickness and external and internal diameters at the expense of tube elongation the influence of side walls of the gauge manifested itself and as it created also cavities between the mandrel and the rolled blank. The Figure 5 confirms creation of cavities between the mandrel and the rolled tube. The biggest strain and stress intensity is seen at the places diverted from the vertical plane. It is evident from the view of lateral sides of the blank that at these stages the material has not yet filled fully the gauge and it therefore can flow in direction of the rolling plane. This is the cause of formation of already mentioned cavities between the mandrel and the rolled tube.

Situation during the final stage of the pass is somewhat different. The maximum stress intensity is evident at the places corresponding to the vertical plane of the gauge and the cavities between the rolled tube and the mandrel have disappeared during subsequent rolling thanks to flow of metal, which was limited by side-walls of the gauge.

As it was already mentioned above, one objective of this experiment was also mapping of the load of tools, particularly the mandrel, which is not cooled during the rolling and which is therefore exposed to considerable temperature load, if we take into consideration that rolled tubes are after the last pass stripped and the mandrel goes to the cooling bath, where it is cooled down to the temperature of approx. 150 °C and then it is used again for rolling of the next tube. It was assumed at simulation of the mandrel load that similarly as in case of the rolled blanks the results obtained after the pass will be used as input data for the pass, which is necessary for beading of the formed flash, i.e. after turning of the blank. Temperature load of the mandrel during rolling is shown in the Figure 6, in which two monitored parts are marked. The first one was situated at the very proximity of the mandrel surface and the second one was situated into its central part.

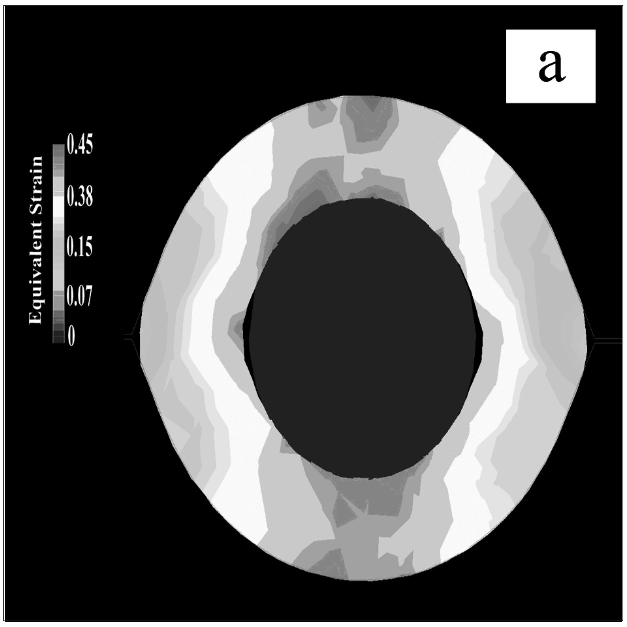

Figure 5. Strain intensity in rolling process

The fact that the mandrel is heated during rolling quite considerably is demonstrated in the Figure 6, which confirms already mentioned proper heat removal or drop of the blank temperature. In this case the value of alpha was chosen as 1×10^4 W/($m^2\cdot K$). For completeness of image the graphical dependence of temperature in monitored points of the mandrel is included. For im-

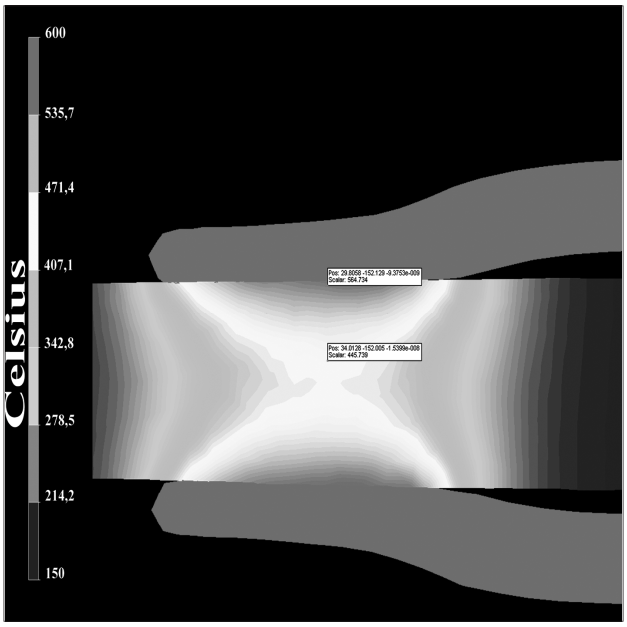

Figure 6. Marking of the parts monitored in a 2D cross-section of the mandrel and temperature field of the mandrel

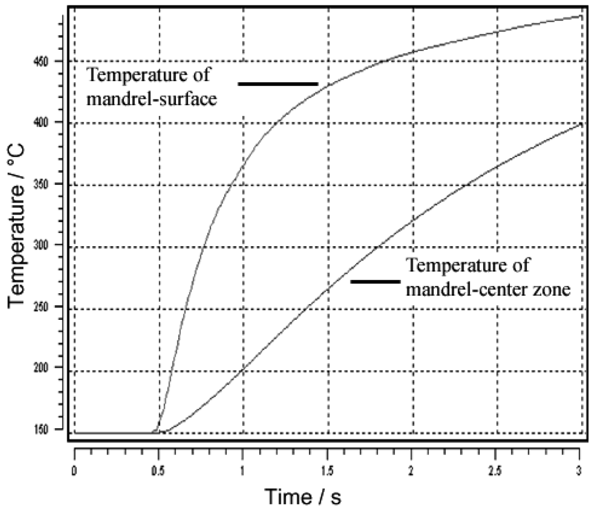

Figure 7. Temperature profile of the mandrel at the parts monitored during the first pass

age fullness the graphical dependence of temperature in monitored parts of mandrel is included see Figure 7.

To make the picture complete this simulation evaluated also an influence of the different coefficient α from the viewpoint of temperature behaviour of the mandrel in the case when heart removal will be limited either by coatings or by other factors. The alpha value was chosen as 2×10^3 W/(m$^2\cdot$K). The Figure 8 demonstrates very distinct influence of reduction of the heat transfer coefficient, as the diagram shows almost half temperature to which the mandrel is heated during the first pass.

After completion of the first pass the blank was shifted back to its initial position and turned clockwise by 90°. The aim of this, in compliance with the findings learned from practice, was to "bead the fins" that were formed by the shape of the gauge or by metal flow at several places of the blank. The data obtained after the first pass were used as input data for the rolled blank.

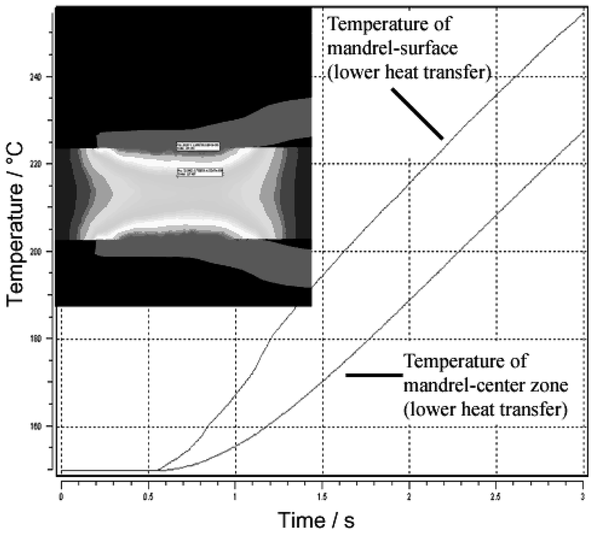

Figure 8. Temperature field of the mandrel after the first pass

DISCUSSION

The obtained results document the fact that considerable heat transfer occurs between the rolled blank and the mandrel. The tendency of the influence of coatings or surface treatment towards lower cooling of the blank even by 100 % in comparison with the mandrel pre-heated to 150 °C and without any other treatment is evident from graphical dependencies. This leads consequently to more rapid reduction of temperature of the blank, which naturally shortens the possible length of forming due to the reduced plasticity. Besides, the local cooling of the rolled metal influences also the unformed yet metal closely situated to the already formed metal. These effects are related also to the service life of the used mandrels or formers, which wear away sooner due to the increased thermal load, whether it concerns dimensional changes, surface quality or other characteristic degradation of material, which requires their replacement with appropriate economic consequences.

It can be stated at evaluation of stress-strain parameters that strain heat was developed during rolling, which partly eliminated temperature losses caused by heat transfer into the environment, or into the work rolls or the mandrel. Graphical dependence confirms that the highest strain intensity was obtained in central parts of the wall of the rolled tube; it was double in comparison with other monitored places. If we moreover take into consideration that the course of strain at this place begins to differentiate at the moment of "approach" of the final transient part of the gauge to the rolled bulk of the metal, it indicates that flow of metals in central areas is in comparison with areas almost double, which is also confirmed by the ends of the rolled tube. Temperature field of the blank only confirms the fact that more rapid heat removal is through the mandrel rather than through the rolls. This can be caused by their higher temperature of pre-heating, but also by the contact surface and duration of contact with the rolled tube.

CONCLUSIONS

Computer simulation showed rather considerable influence of preparation of the mandrel surface prior to the rolling on its temperature load i.e. its service life, which equals to the economic demandingness of manufacture of seamless tubes by rolling on the pilgrim mill. In the next step we succeeded in determination of strain-stress parameters of rolling both for the rolled blank and tools. Variation of friction conditions enabled determination of this influence, which participates in the whole efficiency by different thermal exchange among mandrel, tube and rolls. It can be seen from experiment conclusions that suitable lubricant utilization causes except others factors also more economical tube production. Results of these simulations were confronted with practice, which proved their validity. Investigation should continue on the basis of these results. It should be focused on use of the pilgrim rolling for specific types of steels used for nuclear energetics, which requires tuning of some rolling parameters in order to ensure a trouble-free production.

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Note: The responsible translator for English language is J. Drnek, Czech Republic.