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The Effect of Non-uniform Temperature Distribution over the Charge Length on the Variation of Longitudinal Stresses During the Continuous Rolling Process

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The paper present the results of theoretical studies on the effect on non-uniform temperature distribution over the chare length on the variation of longitudinal stresses in the rolling direction during the process of continuous rolling 70 mm-diameter bars. The studies were carried out based on the actual engineering data for 160x160 mm square cross-section charge of steel S355J0. Numerical modelling of the rolling process was performed using Forge2008®, a finite-element based computer program.

Keywords: CONTINUOUS ROLLING, NON-UNIFORM TEMPERATURE, FINITE ELEMENT METHOD

Introduction

The non-uniform distribution of temperature over the length of charge being rolled has the effect of changing the conditions of plastic metal flow in the roll gap during the continuous rolling process. The temperature variation across the rolled charge length influences the friction conditions and the plastic properties of the metal being rolled, and thereby on the advance and strip widening during the continuous bar rolling process. The change of these parameters in the case of the continuous rolling process causes a change in the values of longitudinal stresses in the band rolling directions between the adjacent rolling stands [1-4].

The main cause of the occurring non-uniform temperature distribution over the charge length is the process of heat the charge in a heating furnace [5]. Heating of charge prior to plastic working processes is accomplished in heat furnaces of different designs. In the case of continuous Shape Mills, either walking beam or pusher heat furnaces are widely used. The operation and charge heating regime of these furnaces allow the continuous operation of the Rolling Mill without having to introduce breaks for charge loading and unloading [6, 7].

The computer program Forge2008® [8] was employed in this study for numerical modelling of the rolling process, using which the flow of strip was modelled, while considering the non-uniform distribution of temperature over its length.

Conditions adopted for numerical computation

For the numerical studies, engineering data for the rolling of 70 mm-diameter round bars in the D370 continuous Shape Mill was used. In numerical modelling of the continuous rolling process, 160x160 mm cross-section and 2000 mm long charge of steel S355J0 was adopted, over the length of which a non-uniform temperature distribution was introduced, with a temperature difference of 90°C (**Figure 1**). For the friction coefficient, values from 0.35 for a temperature of 1200°C to 0.5 for 800°C were assumed, while for the friction factor values were taken based on the results provided in work [1], which ranged from 0.6 for 1200°C to 0.9 for 800°C. The temperature of the rolls was 60°C, while ambient temperature was taken as 20°C. The coefficient of heat exchange between the rolls and the band was α = 3000 W/m^{2}K; the coefficient of heat exchange between the band and the air, α_{air} = 100 W/m^{2}K; thermal conductivity, 35.5 W/(m·K); specific heat, 778 J/(kg·K); the density of steel, 7 850 kg/m^3; emissivity, 0.82.

Results of the studies and their analysis

From the theoretical studies carried out it was found that the non-uniform distribution of temperature over the length of the charge being rolled caused a change in longitudinal stresses in the band rolling direction. In order to precisely determine the effect of the change in band temperature during rolling of the higher and lower temperature regions of the band in

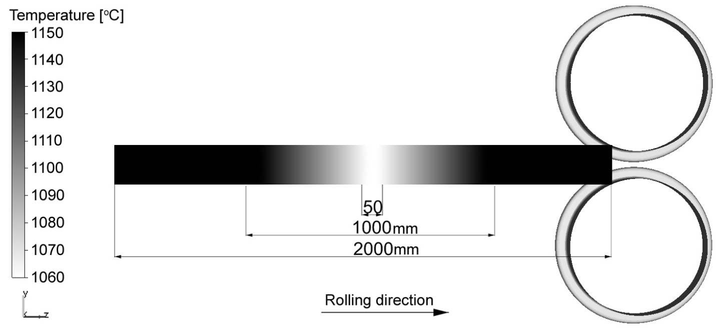

Figure 1. The initial distribution of temperature over the length of the charge used for numerical simulations of the process of rolling 70 mm-diameter round bars

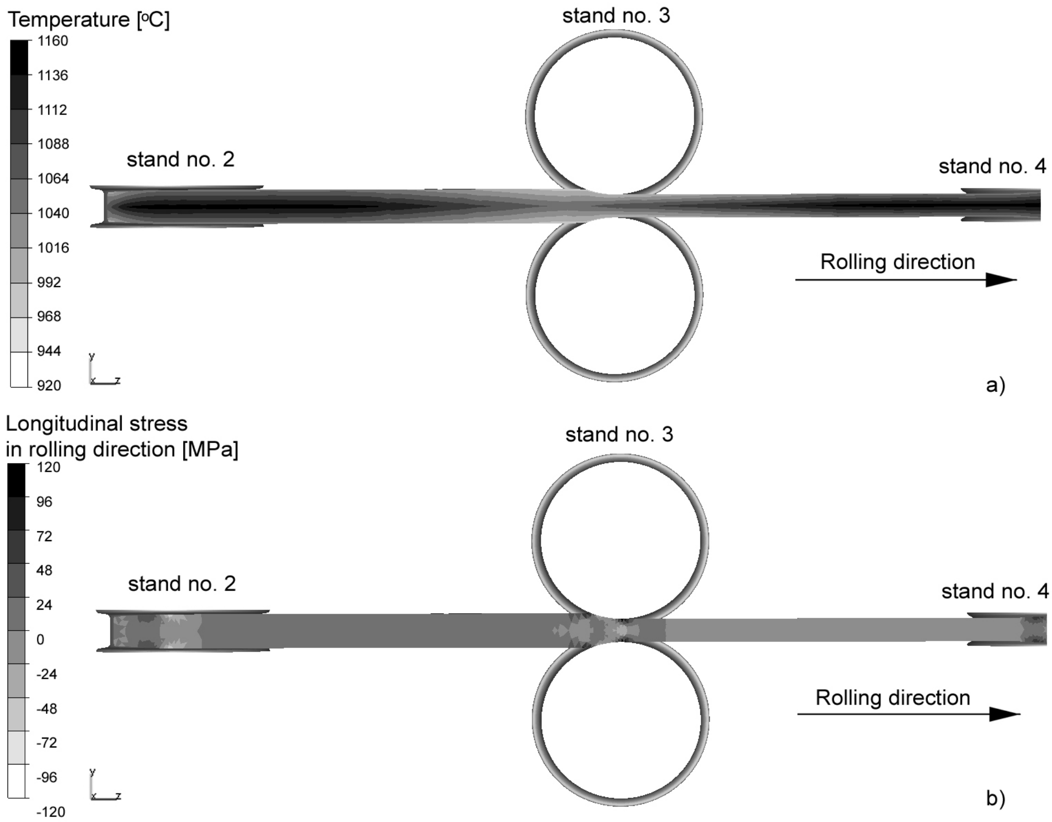

Figure 2. Distribution of temperature: *a* – and longitudinal stress in the rolling direction; *b* – during the process of continuous band rolling in rolling stands nos. 2÷4 from band with a non-uniform temperature distribution over its length

two adjacent rolling stands, the analysis of the obtained results of numerical modelling of longitudinal stress variation in the rolling direction during the continuous rolling process was made. **Figure 2** represents the numerical computation results for longitudinal stress distribution in the rolling direction during rolling of band in rolling stands nos. 2÷4 from charge with a non-uniform temperature distribution over its length.

By analyzing the obtained results of numerical computations of the band rolling process in rolling stands nos. 2÷4 (**Figure 2**) it was found that the occurring non-uniform temperature distribution over the band length significantly influences the distribution of longitudinal stress in the strip being deformed. During rolling of lower temperature band regions in rolling stand no. 3, an increase in band plastic flow velocity in the rolling direction follows upon band exit from rolling stand no. 3, which results in the occurrence of longitudinal stress within the rolled band in the rolling direction between particular stands. In the band length between rolling stands nos. 2 and 3, a region of longitudinal tensile stress in the rolling direction of a value of approx. 3 MPa forms, causing the band to be tensioned between these stands. In the band length between rolling stands nos. 3 and 4, on the other hand, a region of longitudinal compressive stress in the rolling direction of a value of approx. -1.5 MPa forms, causing supporting (piling up) of the band between these stands.

Figure 3 represents numerical simulation results for the process of rolling band with a non-uniform temperature distribution in rolling stands nos. 5÷8.

The data in **Figuere 3** shows that during the process of rolling band with a non-uniform temperature distribution over its length in rolling stands nos. 5÷8, tension of the band (longitudinal tensile stress in the rolling direction) arose between rolling stands no. 5÷7, whose highest magnitudes, amounting to approx. 2.7 MPa, occurred in the band regions between the rolling stands nos. 6 and 7. In contrast, in the band regions between rolling stands no. 7 and 8, piling up of the band (compressive stress in the rolling directions of a value of approx. -1.4 MPa) took place.

Figure 4 illustrates variations in the magnitude of band longitudinal stress in the rolling direction during the process of continuous rolling 70 mm-diameter round bars from charge with a non-uniform temperature distribution over its length.

It can be seen from the data in **Figure 4** that during continuous rolling of bars from charge with a non-uniform temperature distribution over its length, tension and piling up of the band arises between adjacent rolling stands. The greatest differences in magnitudes between the tension and the pile-up of the band occur in rolling stands from 3 to 6. Because of this, the magnitude of band longitudinal stress in the rolling direction may vary from 1.9 to 4.5 MPa. The large difference in the value of band tension and back tension between rolling stands nos. 3÷4 and 4÷5 is due to the fact of choosing too low a rolling speed in rolling stand no. 4 relative to the rolling speed in rolling stand no. 3, which in turn has caused a greater stress compressing the band in the rolling direction to occur between rolling stands nos. 4÷5.

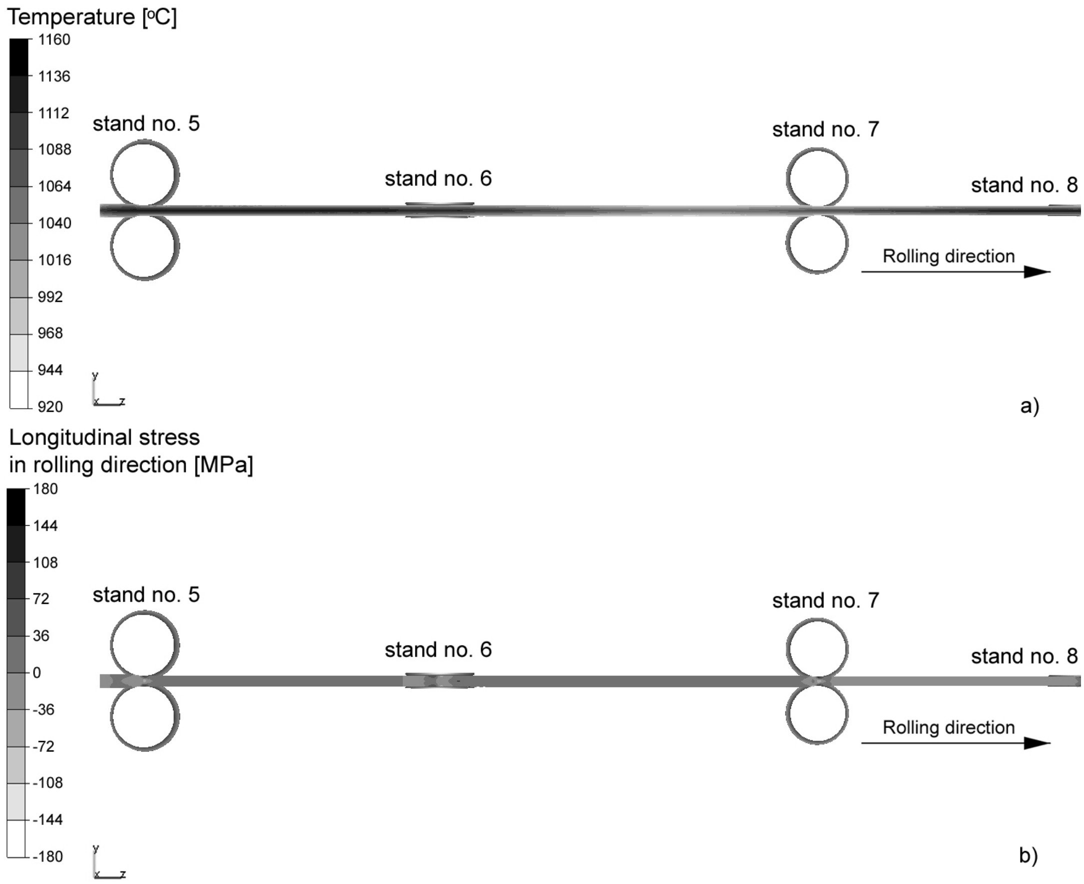

Figure 3. Distribution of temperature: *a* – and longitudinal stress in the rolling direction; *b* – during the process of continuous band rolling in rolling stands nos. 5÷8 from band with a non-uniform temperature distribution over its length

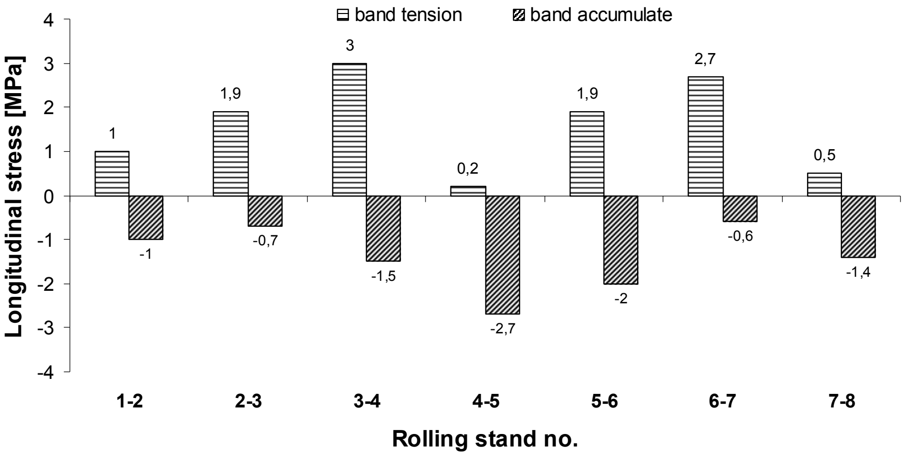

Figure 4. Variation in the magnitude of longitudinal stress in the rolling direction during the continuous 70 mm-diameter round bar rolling process

Conclusions

From the performed theoretical studies of the process of continuous rolling 70 mm-diameter round bars from charge with a non-uniform temperature distribution over its length it has been found that during rolling of higher and lower temperature regions of band in adjacent rolling stand, a longitudinal stress in the rolling direction occurs. The greatest differences in the magnitudes between the tension and the back tension occur after rolling stands nos. from 3 to 6. When performing numerical modelling of a continuous rolling process, the band should be rolled in two rolling stands at a minimum, since this assures that the tension and the back tension occurring in the band being rolled will be considered.

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Эффект неравномерности температуры по длине заготовки в зависимости от продольных напряжений при непрерывной прокатке

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В статье представлены результаты теоретических исследований неравномерности температуры по длине заготовки в зависимости от продольных напряжений в продольном направлении при непрерывной прокатке прутка диаметром 70 мм. Исследования были проведены на основании экспериментальных данных для квадратной заготовки 160x160 мм из стали S355J0. Численное моделирование процесса прокатки было проведено с использованием программы Forge2008®, основанной на методе конечных элементов.