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‘Effect of Initial Temperature and Cooling Practice on Thermo-Mechanical Stress of Ring Rolling

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ABSTRACT: Ring rolling is a metal forming process used to forge precise, seamless, circular, shaped parts. Due to the unique properties of the produced rings, the application in the advanced industries is high. The most important advantage of the process is the uniform flow of material in the ring after the process. Usually, the working temperature of the device is high during the rolling of super alloys. The high temperature could damage the work rolls. In spite of the cooling practice, the work roll temperature is raised. In general, this reduces the work roll strength. In this research, the effect of various temperature and cooling practice on thermo-mechanical stresses in work roll of ring rolling mill has been investigated. The results show that the amount of produced thermo-mechanical stresses on the work rolls is completely different. In the main roll, mechanical stress has a greater effect on thermo-mechanical stresses. However, in the mandrel, thermal stress determines the amount of thermo-mechanical stresses. Unlike the mandrel, the effect of cooling practice on thermo-mechanical stresses of the main roll is negligible. The results show that cooling practice increases the amplitude of equivalent stress and reduces the mean stress in the work rolls.

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1- Introduction

In this research, the effect of initial temperature of ring rolling work roll and cooling practice on the thermo-mechanical stresses are investigated. In order to estimate the thermo-mechanical stresses in the work rolls, it is necessary to pay attention to the transient conditions of the ring rolling process. Song et al. [1], by using of a finite-element software program, developed a coupled thermo-mechanical model for the hot ring rolling of IN718 and predicted the surface temperature of the ring and work rolls. Benasciutti et al. [2] used a 1 dimensional harmonic element which permits the analysis of plane axisymmetric structures subjected to non-axisymmetric loads and save the computational time. They investigated thermo-mechanical stress in work-roll of flat rolling. Koohbor [3] developed an integrated mathematical model to study the thermo-mechanical behavior of strips and work rolls during the warm rolling process of steels. The model was first employed to solve the thermo-mechanical response of the rolled strip under steady-state conditions and then used to apply proper boundary conditions for solving the thermo-mechanical response of the work roll.

2- Methodology

The comprehensive study of the articles in this area indicates that the evaluation of thermo-mechanical stress in work rolls with local cooling practice and partial boundary conditions has been rarely studied. It is due to complex modeling and a lot of computational time. Also, most of the analyses that have been done on rolling focus on the flat rolling. Their assumptions such as symmetry, the same contact length, work hardening, and etc. are not true for the ring rolling.

By the discretization and approximation of thermo-elastic equations with finite element method and using the Galerkin-weighted residual method, the thermo-elastic finite element equations are obtained [4]:

$$[M]\{\ddot{\delta}\}+[C]\{\dot{\delta}\}+[K]\{\delta\}=\{F\} \quad (1)$$

In Eq. (1) M, C, K, F and δ are the generalized mass, damping and stiffness matrices, external force vectors and local unknowns (displacement vectors and temperature differences), respectively. By using the initial and boundary conditions of the model, the problem is solved.

In the simulations, the magnitude of pressure is determined according to the simulated or experimental force. The contact surface length of the work rolls and the ring is estimated according to the definition of Forouzan et al. [5]. In order to investigate the thermo-mechanical stresses in the work rolls, scripting in the Abaqus environment is used. The algorithm and the method of applying the boundary conditions and collecting the results are according to previous work of Negahban et al. [6]. In order to verify prepared code, the simulation results were compared with the research of the Benascuitti et al. [2].

3- Results and Discussion

The work rolls dimensions and general simulation conditions were applied in the script code according to Table 1.

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Table 1. Work rolls dimensions and general simulation conditions

Main-roll radius (mm)	200
Mandrel radius (mm)	60
Work rolls height (mm)	200
The initial temperature of work rolls $(^{\circ}C)$	30-250-500
The initial temperature of the ring $(^{\circ}C)$	$1050-5.85t$
Angular velocity of main-roll (rad/s)	6.28
Angular velocity of the mandrel (rad/s)	13.95

The main-roll is affected by mechanical stresses [6]. The magnitude of the temperature and equivalent stress on the main-roll with the initial temperature of $250^{\circ}C$ is shown in Fig. 1.

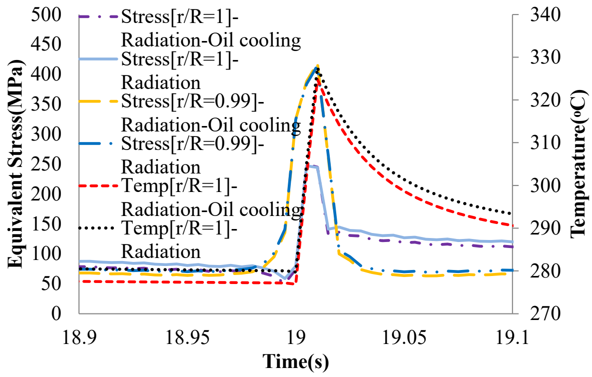


Fig. 1. The effect of cooling practice on temperature and thermo-mechanical stress in the main roll

This figure shows that the surface temperature of the main-roll with oil cooling is approximately 1.5% less than the main-roll without surface oil cooling. Also, the effect of cooling practice on the thermo-mechanical stresses of the main-roll is not significant. In general, it reduces the equivalent stress but does not affect the magnitude of maximum stress and its location. The history of the Von-Mises stress on the main-roll surface and below it (r/R=0.985) without cooling practice is shown in Fig. 2 with the initial temperature of 250 °C. This figure shows that the stress amplitude range is almost constant, but the mean stress increases during the process.

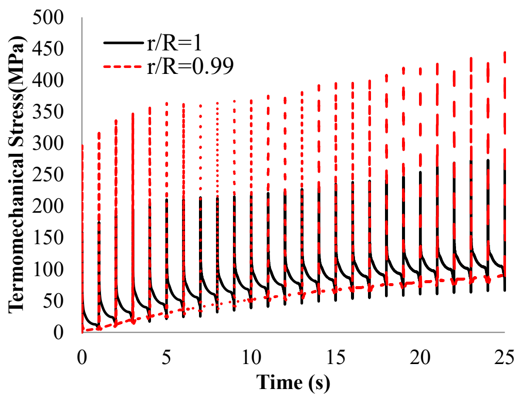


Fig. 2. History of equivalent thermo-mechanical stress in the main roll with an initial temperature of 250 $^{\circ}C$

The magnitude of the Von-Mises thermo-mechanical stress in the mandrel is shown in Fig. 3. In order to evaluate the effect of different loading condition on thermo-mechanical stress, the thermal, mechanical, or both are applied to the mandrel.

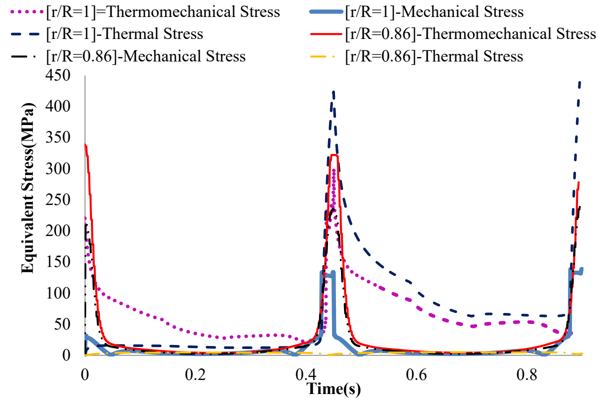
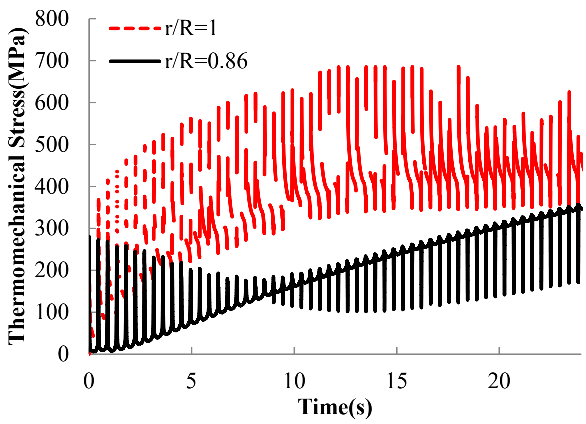


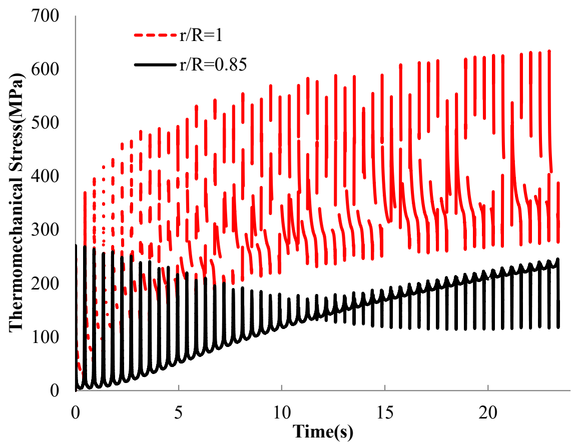
Fig. 3. History of Von-Mises stress in the mandrel with applying thermal, mechanical and mechanical-thermal loading

According to this figure, it is clear that by applying mechanical loads to the mandrel, the maximum equivalent stress occurs below the work roll surface. If the thermal loads are applied to the mandrel, the maximum equivalent stress occurs on the mandrel surface. If the thermal and mechanical loads are applied simultaneously on the mandrel, a different situation will occur compared with the main-roll. In the early stages of the process, when the surface temperature of the mandrel still has not increased, the maximum equivalent stress occurs below the mandrel surface. By increasing surface temperature, the maximum equivalent stress will occur on the mandrel surface. This situation is due to the higher heat penetration into the mandrel than the main-roll. So, large thermal stress will produce in the thermal boundary layer.

The estimation of thermo-mechanical stress in the mandrel at different temperatures with and without cooling has been investigated. The thermo-mechanical stress in the mandrel with the initial temperature of 250°C with and without cooling has been shown in Fig. 4. With respect to this figure, it is clear that at the beginning of the process, the thermo-mechanical stress is affected by mechanical loads. By rotating the mandrel and the higher heat penetration into the work roll, the temperature of points with dimensionless radial coordinates $r/R<1$ increase. So, higher thermal stress produces in these points. The cooling practice decreases the mean stress and increases the amplitude stress in the mandrel. The Cooling of the work roll surface also causes the time of equilibrium between thermal stress and mechanical stress postpone.



(a)



(b)

Fig. 4. History of equivalent thermo-mechanical stress in the mandrel with an initial temperature of 250 °C without cooling practice

4- Conclusion

The effect of cooling practice and the initial temperature was investigated by scripting. Work rolls of ring rolling mill have different thermo-mechanical stresses response. Thermal stresses are more effective on the work rolls surface. On the other hand, mechanical stress affects the inner surfaces of the work rolls. The effect of cooling practice on the thermo-mechanical stresses generated on the main-roll is negligible and only slightly different in the cooling zone. In the Mandrel, the effect of thermal stress on the amount of thermo-mechanical stress is considerable. In order to reduce the thermal stresses, it is necessary to maintain the temperature of the work roll in the initial temperature as far as possible with proper cooling. A proper cooling minimizes the amount of thermo-mechanical stresses and the heterogeneous temperature field in the work-roll.

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