Finite Element Simulation of Hot Continuous Rolling of 37Mn5 Tube Billet and Roll Pass Optimization

Huiping Hong， Yonglin Kang

School of Materials Science and Engineering, University of Science and Technology Beijing,
100083, Beijing/China

Abstract: In order to optimize the continuous rolling schedule for improving the quality of rolled tube billet, three dimensional thermal mechanical coupled finite element simulation is applied to analyse the multi-pass continuous rolling process of Φ100mm 37Mn5 steel tube billet from 200mm×200mm square cast bloom. Due to the larger plastic strain occurring at the corner area of the billet, the bias meshing method for the cross section of billet is used to fine the elements of surface and corner area. The stress, strain, temperature and rolling force of the hot continuous rolling process are simulated to analyse the cause of rolling defect, then the roll pass optimization is worked out based on the analysis of the rolling force variation. The simulated results are verified by the actual test.

Keywords: hot continuous rolling, roll pass optimization, FEM simulation

Introduction

The tube billet of 37Mn5 steel is commonly used for hot piercing of seamless tube for oil industry and there is a strict requirement for the surface crack of the rolled tube billet in order to avoid defect in the pierced tube. In the hot bar rolling process of alloy steel, 200mm×200mm square cast bloom is often used to be rolled into the alloy steel round bar which is less than Φ80mm in diameter[1～3]. If the cast bloom of the same size is used to be rolled into larger size round bar, the reasonable roll pass schedule needs to be determined. In this paper, the technology of thermal mechanical coupled finite element simulation by MSC.Marc is used to analyse the hot continuous rolling process of Φ100mm 37Mn5 steel round bar by 200mm×200mm square cast bloom, in which the bias meshing for cross section of billet is adopted for effective simulation of multi-pass continuous rolling. From the simulated results, the more reasonable roll pass schedule for the hot continuous rolling of

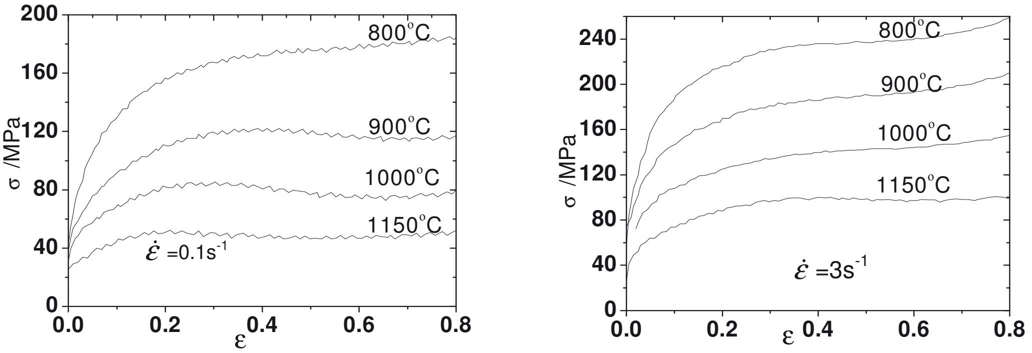
Φ100mm round bar of 37Mn5 steel can be worked out.

Initial rolling condition and roll pass schedule

Φ100mm 37Mn5 tube billet is designed to be rolled out by 200mm×200mm cast bloom through the six-pass continuous rolling mill with horizontal (H) - vertical (V) alternative arrangement. The roll diameter of the first pass (H1) and second pass (V2) is 700mm and the last four passes (H3,V4, H5,V6) have the roll diameter of 610 mm. The roll pass schedule (schedule I) is designed as box pass (H1), box pass (V2), box pass (H3), square pass (V4), oval pass (H5) , round pass(V6). The initial rolling temperature is 1080℃. The environment sink temperature is 30℃ and the temperature for the rolls is 300℃.

Material data and finite element model

The workpiece is assumed as elastoplastic deformable body and the rolls are defined as rigid contact body. The Coulomb friction model is used and the friction factor m is set as 0.3 for the initial three passes and 0.25 for the last three passes. The Poisson's ratio is 0.3, the mass density is 7.85×10^{-3}g/mm^3. Because there is no 37Mn5 steel in the material database of MSC.Marc, the hot upsetting tests were used to determine the flow stress of 37Mn5 steel which is shown in Figure1, where σ is flow stress (MPa), ε is true strain, $\dot{\varepsilon}$ is true strain rate (s^{-1}).



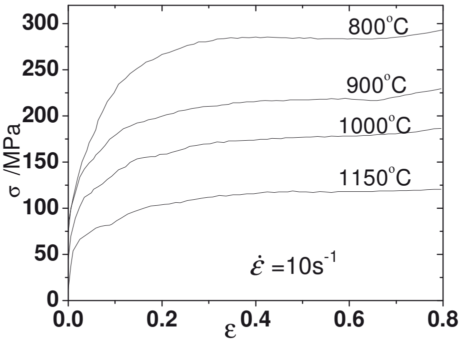


Figure 1: The measured flow stress of 37Mn5 steel

According to the designed roll pass schedule (schedule I), the thermal mechanically coupled elastoplastic finite element simulation of the continuous rolling process of Φ100mm 37Mn5 steel is done by application of MSC.Marc [4].

For describing the behavior of plastic flow, the yield criterion of von Mises and the flow law of Prandtl-Reuss are used. In order to more efficiently simulate the deformation of continuous rolling process, one quarter of symmetry is assumed and the bias meshing is adopted to mesh the cross section and the elements of corner are subdivided.

The initial length of workpiece is assumed as 2400 mm and evenly divided into 160 parts. The cross section of each divided part is meshed into 50 elements and the total workpiece has been meshed into 8000 elements and 10626 nodes. The eight-node hexahedral, isoparametric elements are used for the finite element simulation [5].

The heat transfer conditions include the heart transfer between the workpiece and rolls as well as the convection and radiation of the free surface of workpiece with the environment [6]. The heat transfer condition of the convection and radiation between the free surface of workpiece and ambience is

$$q = \alpha \left(t - t_{\infty}\right) \tag{1}$$

where q , α , t and t_{∞} are heat flux, film coefficient, unknown surface temperature and ambient temperature, respectively. Here α is assumed as 0.17 kW/ (m^2.°C) .

The contact heat transfer condition between the workpiece and the roll is

$$q = h_c (t - t_d) \tag{2}$$

where t and t_d are surface temperature of contact bodies. h_c is the contact heat transfer coefficient between the contact bodies. Here h_c is 6 kW/ (m^2.°C) based on the measuring of temperature change in the rolling process combined with the simulation.

The conversion factor of heat dissipated by plastic deformation work is set as 0.9 and the heat flow density of friction heat is hypothesized to flow into workpiece and roll half and half. The finite element model for the six-pass continuous rolling of Φ100mm 37Mn5 is shown in Figure 2.

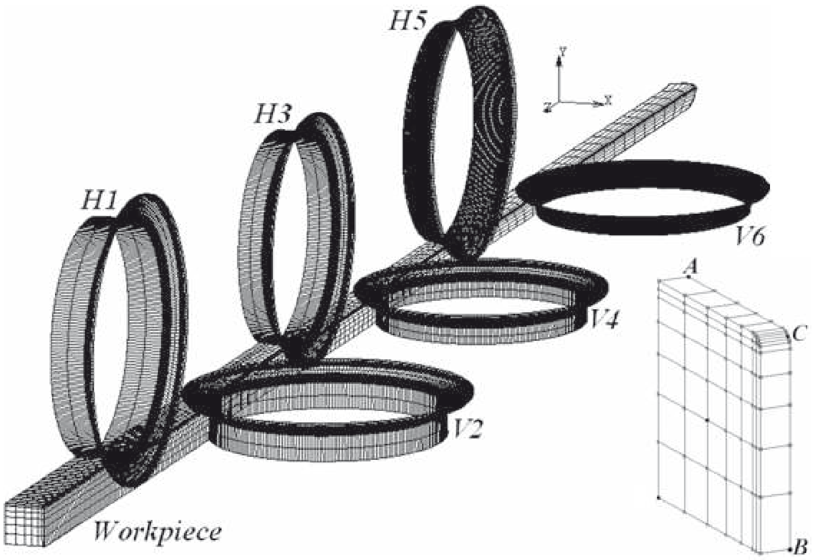


Figure 2: FEM model for six-pass continuous rolling of Φ100mm 37Mn5 round (for one quarter of cross section).

Simulated results analysis and roll pass optimization

The node A, node B and node C are chosen from the height, width and corner of the workpiece, respectively for specifically analysing the strain, temperature and stress variation during the continuous rolling process (in Figure3 ~ Figure 5).

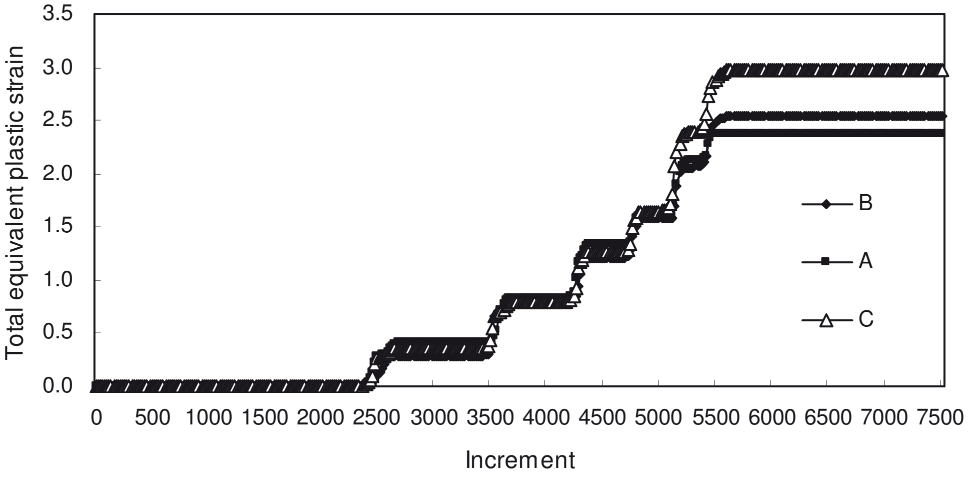


Figure 3: Total equivalent plastic strain in six-pass continuous rolling (schedule I)

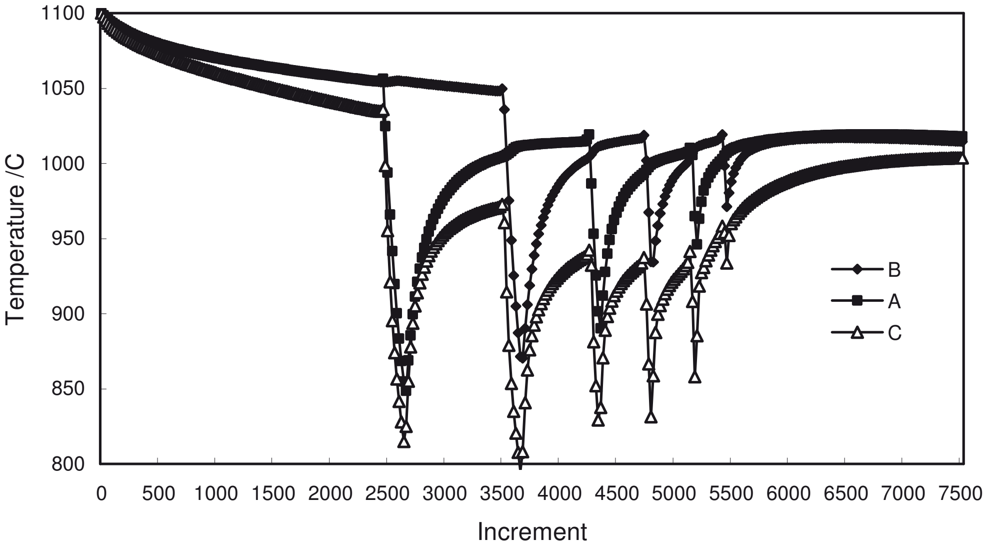


Figure 4: Temperature change in the six-pass continuous rolling (schedule I).

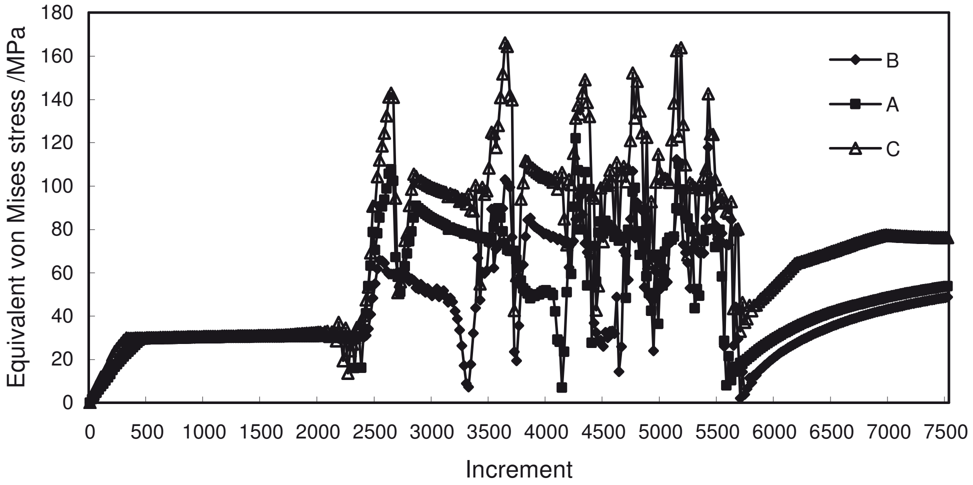


Figure 5: Equivalent von Mises stress in six-pass continuous rolling (schedule I).

Figure 3 illustrates that the total equivalent plastic strain for the corner node C is greater than that of the node A and node B after the continuous rolling process due to the fact that the corners undergo larger deformation, especially the deformation of corner increases when the square stock is rolled in the oval pass of H5.

Figure 4 shows the temperature drop for the node C at the corner is greater than that of node A and node B during the continuous rolling process because of greater contact heat transfer between the square corner of the workpiece and rolls.

Figure 5 exhibits that the maximum of equivalent von Mises stress for node C is greater than that of the node A and node B. The characteristics of stress, strain and temperature variation show that the region at the corner of rolled stock is more susceptible to rolling defects (such as cracking) in the hot rolling of alloy steel, which needs notice for the roll pass design.

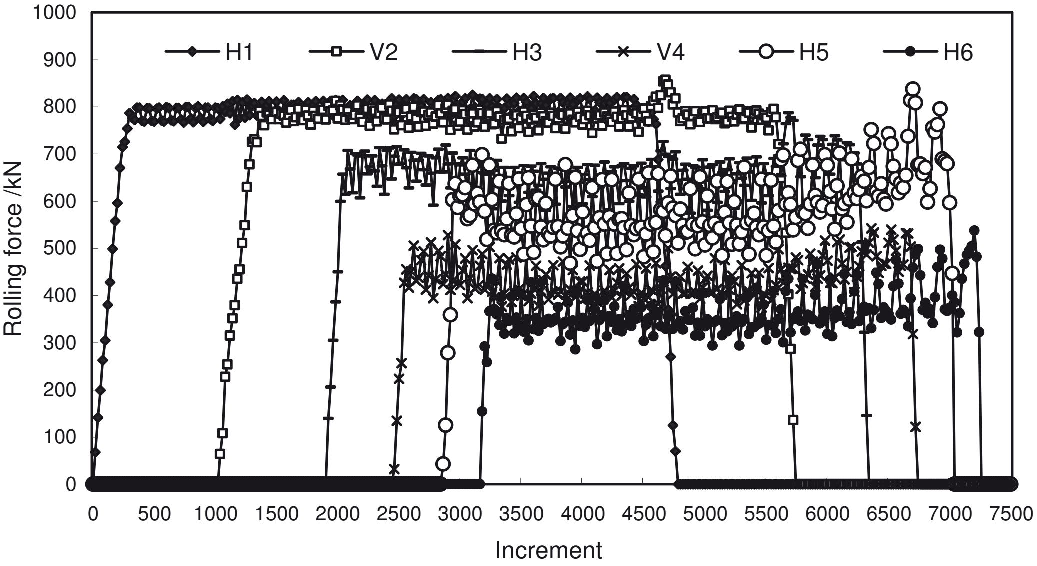


Figure 6: Rolling force in the six-pass continuous rolling of Φ100mm 37Mn steel (for one quarter of cross section, schedule I) .

Figure 6 shows the rolling force variation versus increment for Φ100mm 37Mn5 steel from 200mm×200mm cast bloom (for one quarter of cross section). It is demonstrated that the rolling force decreases along the rolling direction except the H5 pass. The reason for this is that a larger deformation occurred in the corner when square stock is rolled in the oval pass of H5, which can be seen from the total equivalent plastic strain of the corner node C in Figure 3.

It is noticed that the value of rolling force of H5 is almost amounted to that of H3 during the stable continuous rolling process, which is incompatible with the requirement of the hot continuous rolling process. The roll pass sequence from H1 to H4 is composed of box and square passes while the sequence of oval and round pass is only in H5 to H6, thus the larger inhomogeneous deformation resulted from square billet entry into oval pass has occurred in H5, while the average rolling temperature in H5 is lower than that of the previous passes (H1 ~ H3).

For decreasing the rolling force in H5, it is necessary to optimize the present roll pass sequence by moving the entry of square billet into oval pass from H5 to H3 and the roll pass sequence of H3 ~ H6 is modified as oval and round passes.

According to the modified roll pass schedule (II), the six-pass continuous rolling of Φ100mm 37Mn5 is simulated to analyze the rolling force in the six-pass continuous rolling (for one quarter greater than the last three passes, which is more reasonable than that in Figure 6.

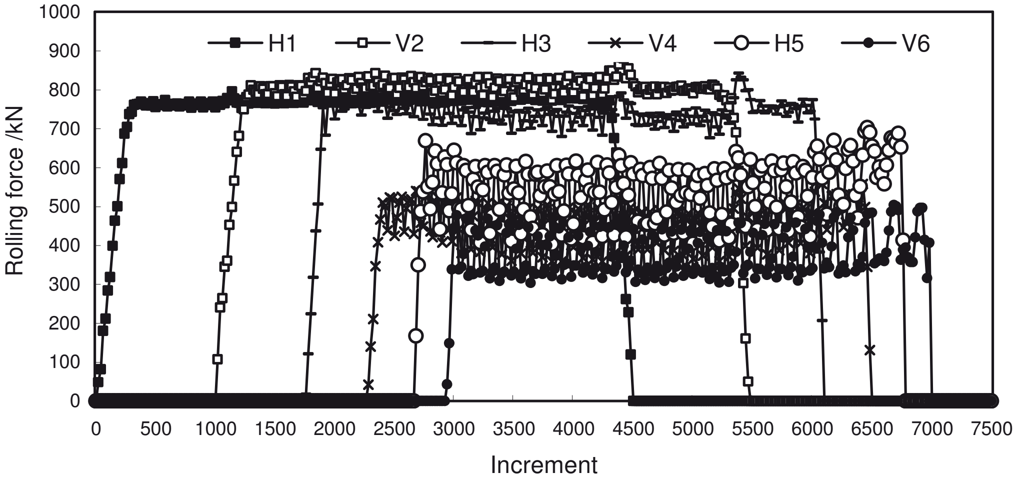


Figure 7: Rolling force in the six-pass continuous rolling of Φ100mm 37Mn steel (for one quarter of cross section, schedule II) .

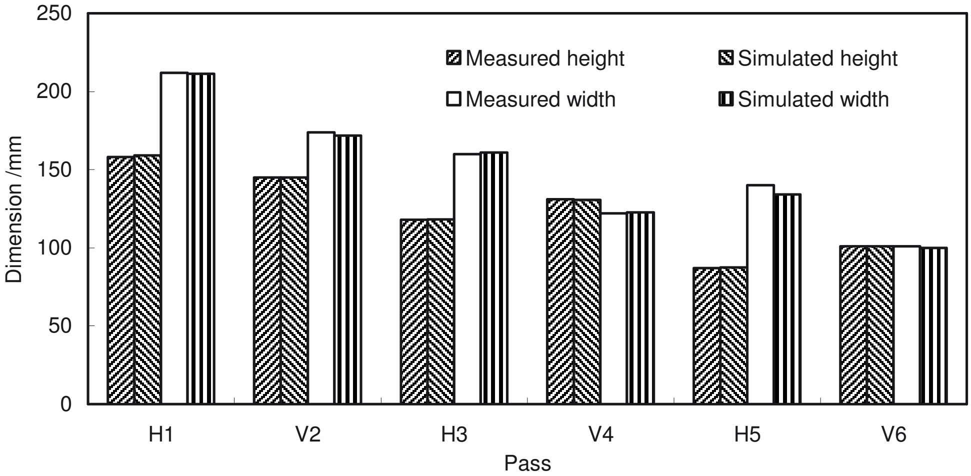


Figure 8: Comparison of simulated and measured sizes at exit of each pass (schedule II) .

Figure 8 gives the comparison of the simulated and factual measured dimensions (height and width) of the workpiece at the exit of each pass of the continuous rolling process (schedule II) . It shows that the simulated results are in good agreement with the measured values. The physical tests of the structure and mechanical properties of the rolled Φ100mm 37Mn5 meet the quality requirements.

Conclusion

The technology of three dimensional thermal mechanically coupled finite element simulation is used to study the stress, strain, temperature distribution as well as the rolling force variation, which can be used to inquire into the cause of rolling defect on the hot continuous rolling process of 37Mn5 tube billet. Based on the simulated results of rolling force variation, the roll pass schedule of the continuous rolling process is optimized in order to improve the rolling force variation for each pass and guarantee the quality of the rolled tube billet.

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