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Equivalent Stress Analysis of Processing Tube Tension-Reducing of the New Steel 33Mn2V for Oil Well Tubes

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Finite element method (FEM) is used for simulation of two-pass processing tube tension-reducing of the new steel 33Mn2V for oil well tubes. The simulated results visualise dynamic evolution of equivalent stress, especially inside the work-piece. It is shown that the non-uniform distribution of equivalent stress on the longitudinal and transverse sections is a distinct characteristic of the processing tube tension-reducing, which can be used as basic data for improving tool and technics design, predicting and controlling the micro-structural evolution for manufacturing oil well tubes.

Keywords: oil well tubes, steel 33Mn2V, finite element methods, tube tension-reduction, equivalent stress

0 INTRODUCTION

In recent year, with the improvement of FEM (finite element method) and the development of computer technology, numerical simulation technology based on FEM is increasingly becoming a powerful tool to analyze the hot rolling and the hot forging process of steel and so on [1] to [5]. The processing tube tension-reducing is an important and complex deformation process in the producing seamless tubes, which is influenced by the materials properties, deformation temperature and rolling rate, stress, contact and friction condition, reducing size and others, which are a non-isothermal steady-state coupled with non-steady-state three-dimensional thermo-mechanical process. While numerically simulating the above process, it is necessary to conduct a coupled analysis, and give a consideration to the contact heat transfer by contact between the work-piece and the roll, convection and radiation between the work-piece and the environment, and the heat generation due to plastic work and friction force. This paper's aim is to get metal flow and distributions of equivalent stress on some special sections such as longitudinal and transverse sections under processing tube tension-reducing.

1 EXPERIMENTAL MATERIAL

The chemical composition of the experimental material 33Mn2V steel is shown in Table 1.

3-D thermo-mechanical coupled elasto-plastic FEM was used for simulation of two-pass processing tube tension-reducing of the new steel 33Mn2V for oil well tubes using MARC/AutoForge3.1 software. The material database of MARC/AutoForge3.1 software do not have the data of the flow stress of steel 33Mn2V, so its database should be set up. The experimental material was taken from the same part of a barren tube billet, and then manufactured into dozens of specimens with a diameter of 8mm and a length of 15mm. According to various process parameters based on practice production, the hot upsetting experiments was conducted on a thermal/dynamic simulation tester and then their flow stress curves were written down, and stored into the computer by MARC/AutoForge3.1 software's format. The whole flow

Table1. *Composition of experimental material in wt %*

C	Mn	Si	S	P	V	N	Ti	other one
0.32	1.70	0.29	0.006	0.013	proper	proper	proper	proper

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Table 2. *Thermo-physical property parameters of 33Mn2V steel*

Temperature [°C]	Young's modulus [G Pa]	Poisson's ratio	Conductivity [W/m K]	Specific heat capacity [J/kg K]	Thermal expanding coefficient [10^{-6}/K]
20	206	0.300	-	-	-
100	203	0.300	35.0	469	12.2
200	179	0.305	35.8	502	13.9
300	190	0.310	33.2	527	13.5
400	183	0.310	31.3	543	13.8
500	174	0.310	29.3	548	14.0

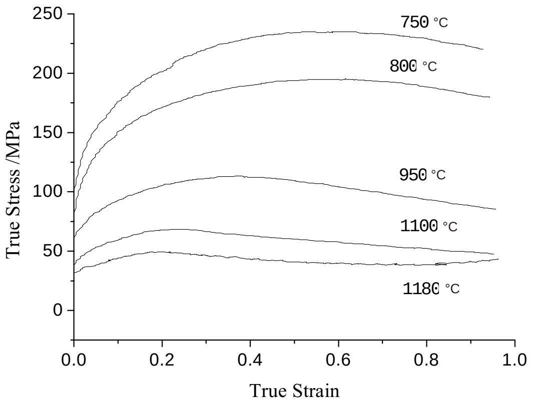

Fig.1. *Flow stress at a strain rate of 0.02/s at different temperatures*

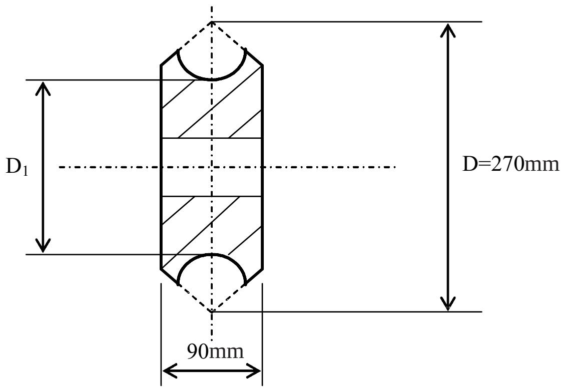

Fig. 2. *Schematic diagram of rolling roll*

stress curves are shown in Figure 1. The thermo-physical parameters including heat conductivity, specific heat capacity and thermal expanding coefficient at different temperature were directly input on the software windows, and the thermo-physical parameters at high temperature can be extrapolated based on Table 2 [6] and [7].

2 FINITE ELEMENT MODEL

Figure 2 shows a rolling roll of the three roll continuous hot rolling the machines of tube tension-reducing based on steel tube factory of wu-xi:

$$D_1 = D - \text{(each pass tube diameters)}$$

Making Φ60×5mm seamless tubes, every pass reducing size is about 3.4 %, the deformation temperature is 800°C to 860°C, the deformation rate is 0.02 s^{-1}.

Figure 3 shows a three-dimensional two-pass processing tube tension-reducing elasto-plastic FEM model according to Figure 2. The distance between No.1 and No.2 rolls along rolling direction (-Z direction) is just set as 260 mm. The work-piece is a barren tube billet whose initial diameter and length are 64.4 mm and 380 mm, respectively. The maximum rolling speed of the first pass is 0.7 m/s

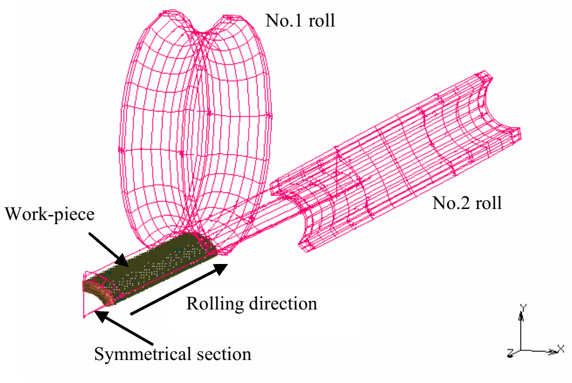

Fig. 3. *Three-dimensional elasto-plastic FEM model for two-pass processing tube tension-reducing*

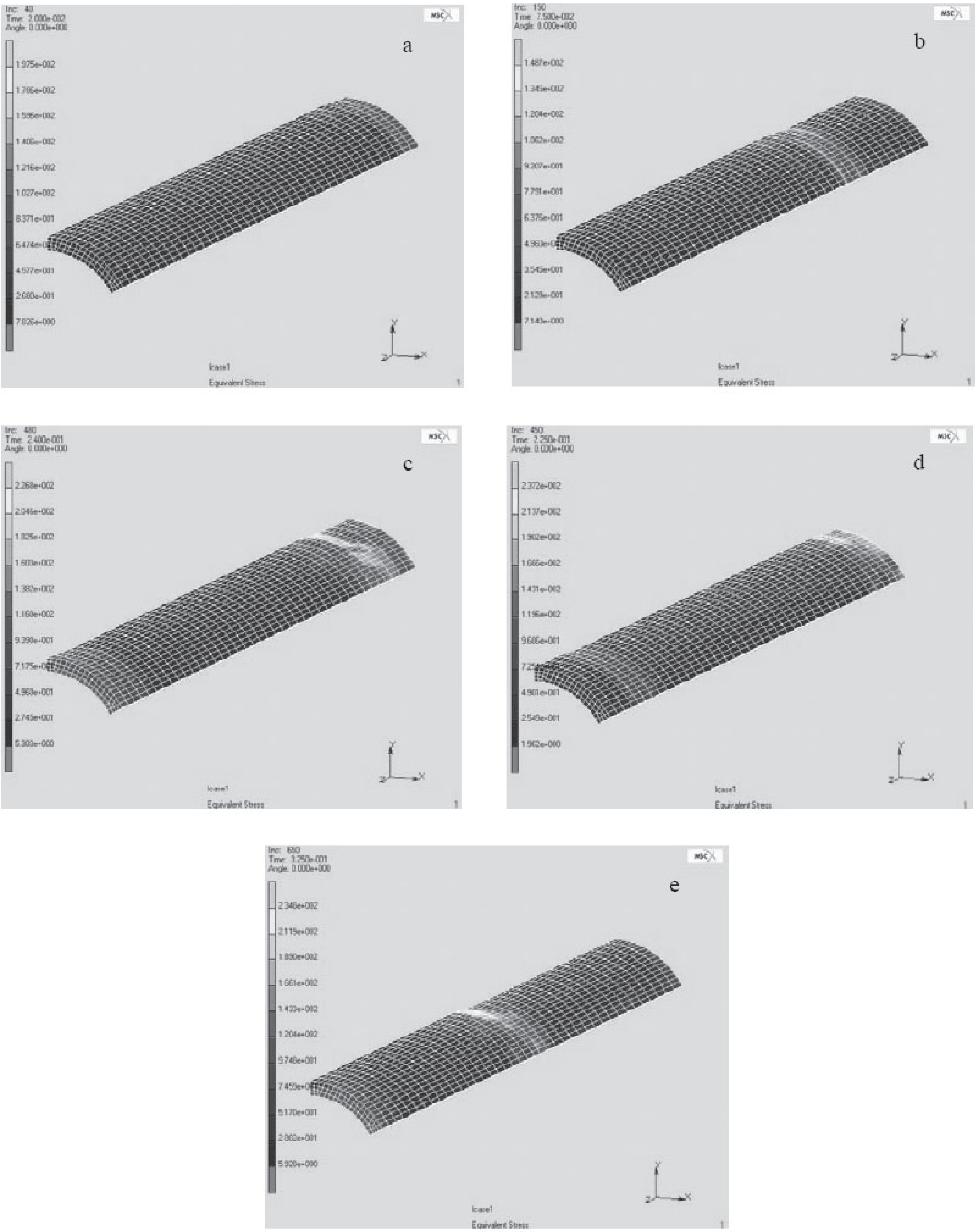

Fig. 4. *Metal flow and equivalent stress evolution on work-piece surface during two-pass processing tube tension-reducing. Initial deformation temperature: 860 °C; every pass reducing size = 3.4%; increment: (a) 40, (b) 150, (c) 450, (d) 480, (e) 650.*

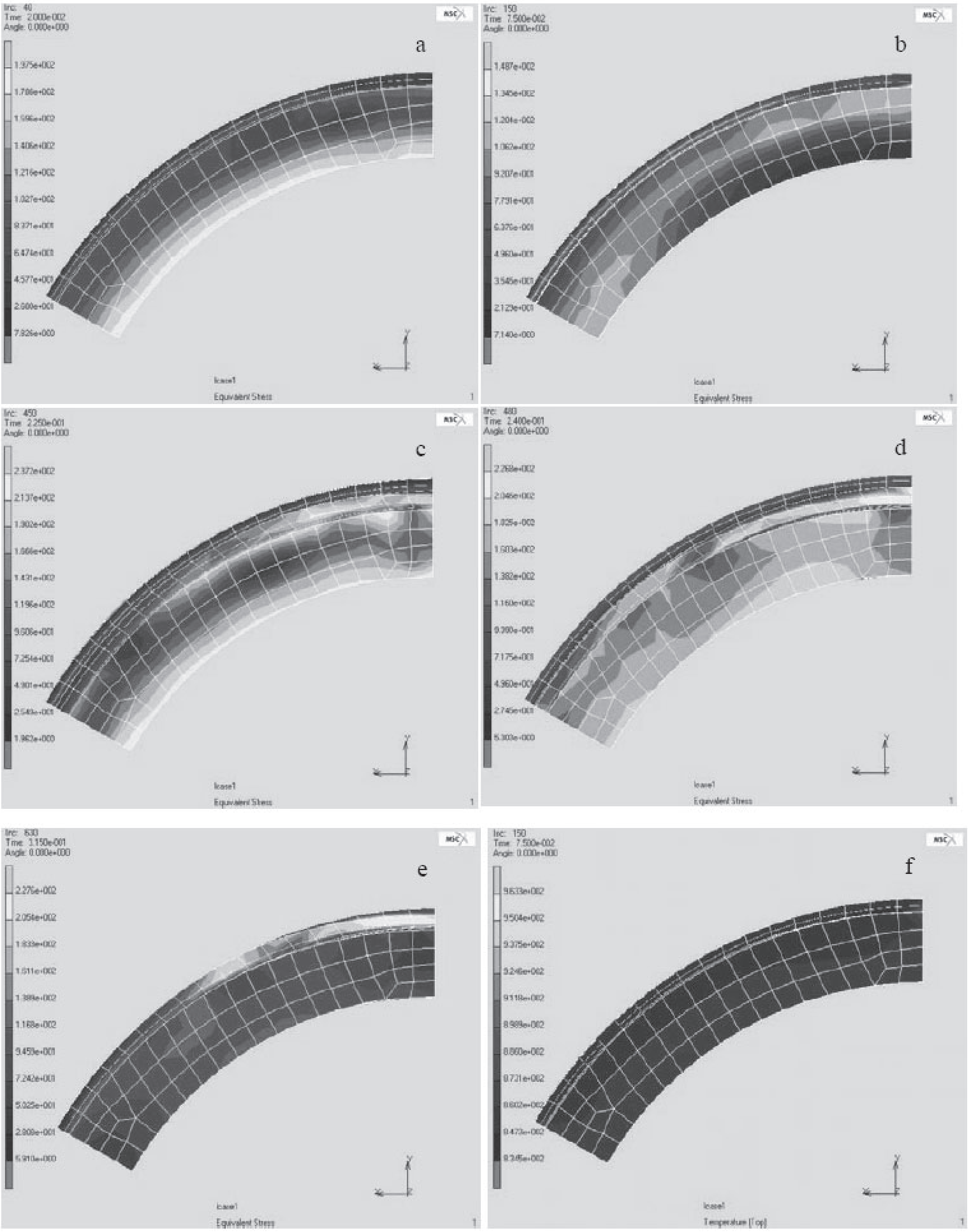

Fig. 5. *Distribution of equivalent stress and temperature on the cross section of the work-piece via the axis of No.1 roll. The initial deformation temperature: 860 °C; increment: (a) 40, (b) 150, (c) 450, (d) 480, (e) 650, (f) 150; reducing size = 3.4%. (a)~(e) equivalent stress, (f) temperature.*

and the second pass is 0.73 m/s. For its symmetry, just one sixth of the work-piece is taken as simulation object to further shorten computation time.

Eight-node hexahedral element type is taken, at the same time 2280 elements and 3239 nodes are obtained for the work-piece. The work-piece is assumed to be elasto-plastic and described by updated Lagrange method, i.e., it obeys the Mises yield criterion and Prandtl-Reuss flow rule, and its deformation is simulated in a step-by-step manner, updating the coordinates of material points and the property after each step. The rolls are assumed to be rigid and with heat-transfer, and they were analytically described.

The displacement of all nodes on symmetrical planes perpendicular to their corresponding symmetrical plane is zero. The friction between the work-piece and the roll contact surface keeps to shear law, and their friction coefficient is set as 0.7. The equivalent heat-transfer coefficient between the free surface of the work-piece and the ambience is set as 0.17 kW/(m^2 K). The contact heat-transfer coefficient between the work-piece and the roll is set as 23 kW/(m^2K). The initial temperature of the work-piece, the ambient temperature and roll temperature is set as 860 °C, 20 °C and 200 °C, respectively. The conversion factor from plastic work to heat was set as 0.9 [8] and [9].

3 SIMULATION RESULTS AND DISCUSSION

3.1 Equivalent Stress Evolution on Work-Piece Surface

Figure 4 are charts of the new steel 33Mn2V for oil well tubes by MARC/AutoForge3.1 software. They show the equivalent stress evolution on the work-piece surface during two-pass processing tube tension-reducing. At increment 40, No.1 roll has already bitted the work-piece, and the rolling was still in a non-steady state; at increment 150, No.1 roll have already rolled the work-piece steadily; at increment 450, the rolling for No.1 roll was still in a steady state, and No.2 roll began to bite the work-piece and the rolling was still in a non-steady state; at increment 480, No.1 roll approached the end of the work-piece, which was non-steady-state rolling, but the rolling for No.2 roll has already been in a steady state; at increment 650, No.1 roll has completed the rolling, and the No.2 roll has been in steady state. Its maximum equivalent stress is about 211.9MPa near YZ plane after the rolling for No.2 roll is steady at increment step 650 and its minimum equivalent stress is about 102.7MPa after No.1 roll has already bitted the work-piece at increment step 40.

3.2 Distribution of Equivalent Stress and Temperature on Typical Cross Sections

We give an example to describe the distributions of equivalent stress and the temperature on typical cross sections. Fig.5 shows equivalent stress distribution and temperature distribution on the cross section of the work-piece via the axis of No.1 roll at different increment step. It can be seen from Fig.5 that they are very non-uniform, and their ranges are 26.8 to 205.4 MPa and 847 to 899 °C, respectively. Their non-uniform distributions attribute to equivalent strain, equivalent stress and temperature interaction. On the one hand, the distribution of strain or strain rate on the cross section is non-uniform of itself, therefore, the result in non-uniform stress distribution, and non-uniform temperature distribution appear as a result of plastic work and heat-transfer; on the other hand, non-uniform stress and temperature distributions have effect on the distribution of the strain and the strain rate.

4 CONCLUSIONS

We conclude this paper by physical simulation experiments and FEM simulation are performed to analyze the processing tube tension-reducing of the new steel 33Mn2V for oil well tubes. FEM simulation coupled with physical simulation vividly visualizes the metal flow and dynamic evolution of stress and temperature during processing tube tension-reducing of the new steel 33Mn2V for oil well tubes. Simulated results show that the non-uniform distribution of stress and temperature on the longitudinal and transverse sections and inside the work-piece is a distinct characteristic of processing tube tension-reducing. The prediction of the metal flow, the evolution of stress and temperature and their distributions on some special sections during processing tube tension-reducing can be used as basic data for improving tool and technics design, predicting and controlling the micro-structural evolution of processing tube tension-reducing of the new steel 33Mn2V for oil well tubes.

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