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INFLUENCE OF MANDREL ROLLING CONDITIONS ON LOAD OF MANDREL BAR

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Abstract

The mandrel bar, which is an inner tool for the mandrel rolling process, plays an important role in obtaining good inner surface quality and higher wall thickness accuracy in seamless pipes. During rolling, the mandrel bar is exposed to severe conditions, such as high temperature and rolling load. As a result, heat cracks are generated and fatigue cracks are also propagated on the bar surface. These cracks are a cause of scratch defects on the pipe inner surface and seizure between the bar and pipe.

The object of this research is to clarify the mechanism of bar damage in single stand rolling. An FE analysis and model experiment were conducted to study the stress distribution of the bar during rolling. It was found that large tensile stress occurred in the rolling direction at the flange areas and the caliber bottom just before and after roll bite of the bar. Especially, the rolling direction stress at the flange areas was distributed deeply and highly. It is considered that fatigue cracks on the bar surface are propagated by these stresses. In addition, the influence of rolling conditions on the stress in the rolling direction was also investigated by the changing the friction coefficient between the bar and the pipe inner surface, the deformation resistance of the material being rolled and the diameter and caliber shape of the grooved rolls. As a result, the influence of rolling conditions on the bar stress distribution, which causes bar damage, was evaluated quantitatively in this research.

Keywords: mandrel bar, seamless pipe, FE analysis, tool life

1. INTRODUCTION

The mandrel bar, which is an inner tool for the mandrel rolling process, plays an important role in obtaining good inner surface quality and higher wall thickness accuracy in seamless pipes. However, the mandrel bar surface is damaged by the severe use environment. Thermal stress causes initial cracks on the mandrel bar surface due to contact with the high temperature material and cooling after rolling [1], while the rolling load causes generation and propagation of fatigue cracks from the initial cracks and unstable breaking, which is the most dangerous form of damage due to fatigue crack development. Open cracks formed by fatigue and unstable crack propagation are a cause of scratch defects on the pipe inner surface and seizure between the mandrel bar and pipe.

To date, the stress distribution and deformation behavior of pipes during mandrel rolling has been reported [2], and the pressure distribution of grooved rolls has also been reported [3], but no reports have examined the mandrel bar load during mandrel rolling. The stress distribution of the mandrel bar during mandrel rolling is important for understanding the mechanism of crack occurrence. In addition, the influence of rolling conditions and the deformation resistance of the material being rolled are also important for evaluating tool damage. The object of this research is to clarify the mechanism of mandrel bar damage and the influence of rolling conditions.

2. MAIN TEXT

2.1. Method of research

An FE analysis and model experiment were conducted to study the stress distribution of the mandrel bar during mandrel rolling. **Table 1** shows the experimental conditions of model mandrel rolling. Lead was used as the experimental material. The mandrel bar material was S45C, and a strain gauge was bonded on the flange part of the mandrel bar surface. The rolling load, stress value of the mandrel bar and sectional shape of the lead pipe were measured during and after rolling. **Fig. 1** shows the FE analysis model of single stand mandrel rolling. ABAQUS/Explicit(6.13) commercial finite element software with an elastoplastic constitutive model was used to study the load of the mandrel bar and the deformation behavior of the lead pipe during mandrel rolling. The analysis conditions are shown **Table 2**. The coefficent of friction between the mandrel bar and the pipe inner surface was 0.08. The stress-strain curve of lead is shown **Fig. 2**. The mandrel bar was an elastic body with a Young's modulus of 205 GPa. After analysis, the rolling load, stress distribution of the mandrel bar and sectional shape of the lead pipe were compared with the experimental results. After matching the model experiment and FE analysis results, the mandrel FE analysis model was expanded to actual mill size. The tool and pipe shape of the actual mill size model are shown **Table 3** and **Fig. 3**. The influence of the friction coefficient, different materials, roll diameter and grooved roll shape on the stress distribution of the mandrel bar was investigated with the actual mill size model.

Table 1 Model experimental conditions

Pipe material	Lead (0.9 % Sb)
Pipe size	OD (outer diameter): 56.1 mm, t (thickness): 7.6 mm
Mandrel bar material	S45C
Mandrel bar diameter	33.5 mm
Rolling reduction	36.8%
Lubricant	Roll-Pipe: None, Pipe-Mandrel bar: Wax

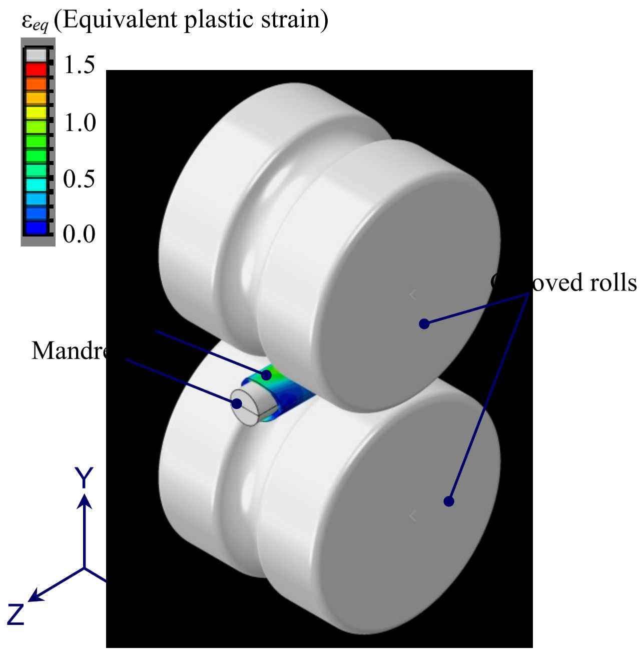

Fig. 1 FE analysis model of single stand mandrel rolling.

Table 2 FE analysis conditions for model size

	<Pipe>	<Mandrel bar>
S-S curve	Fig. 2	-
Young's modulus	24.5 GPa	205 GPa
Density	11300 kg/m^3	7740 kg/m^3
Poisson's ratio	0.3	0.3

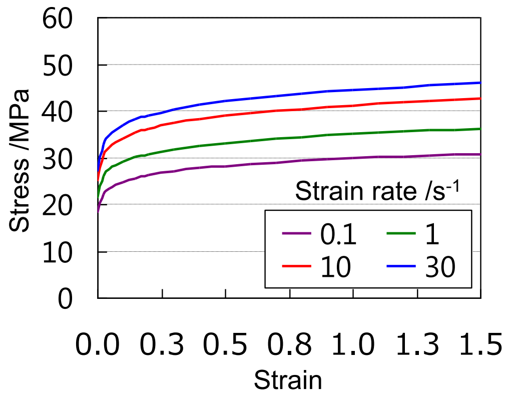

Fig. 2 Stress-strain curve of lead.

Table 3 FE analysis conditions of actual mill size model

Grooved roll diameter	400 mm
Grooved roll shape	Fig. 3 (R=90 mm)
Pipe size	OD: 162.0 mm, t: 9.0 mm
Mandrel bar diameter	122.0 mm
Rolling reduction	37.9 %

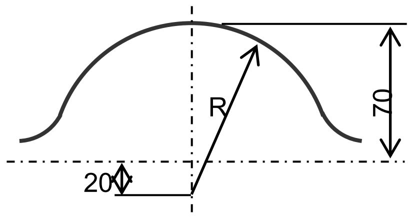

Fig. 3 Grooved roll shape.

2.2. Results and discussion

The FE analysis results agreed with the experiment results for the rolling load at model size (≦2.6%). **Fig. 4** shows the cross-sectional shape of the model size rolled lead pipe. The red solid line shows the FE analysis results, and the open black circles are the experimental results. The FE analysis results were in good agreement with the experiment results. **Fig. 5** shows the change in the stress values of the mandrel bar during mandrel rolling. The solid line is the FE analysis results, and the open circles are the experimental results. The calculated stress values of the rolling parallel direction and rolling vertical direction agreed with the measured values. From these results, it is considered possible to simulate the mandrel bar load by using the FE analysis model. **Fig. 6 (a)~(c)** shows the stress distribution of the mandrel bar in the actual mill size model. The contour shows the tensile stress of the rolling parallel direction. We focused on the tensile stress in the rolling parallel direction because it is thought that the tensile stress in the rolling direction causes propagation of circumferential direction cracks on the mandrel bar surface. Tensile stress in the rolling direction occurred in the flange areas and the caliber bottom just before (inlet side) and after (outlet side) roll bite of the mandrel bar, as shown in Fig. 6 (a). Fig. 6 (b) shows the cross-sectional tensile stress distribution of the maximum tensile stress of the flange areas, and Fig. 6 (c) shows the central part of the tensile stress distribution in a longitudinal section. As shown by Fig. 6 (b) and (c), the tensile stresses of the flange areas are deeper than those at the inlet and outlet sides. **Fig. 7** shows the results of quantitative measurements of the tensile stresses from the mandrel bar surface to the center part of the mandrel bar. The flange area stresses remain at high levels to the center of the mandrel bar. Therefore, it is considered that open cracks on the mandrel bar surface are primarily caused by the stresses at the flange areas.

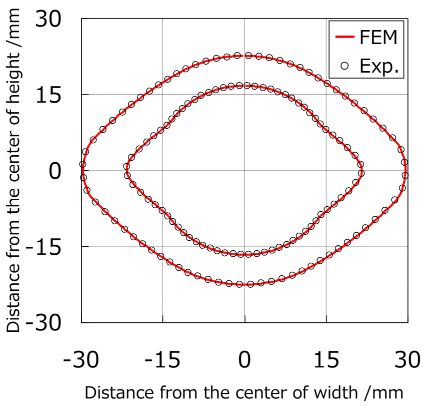

Fig. 4 Cross-sectional shape of rolled pipes.

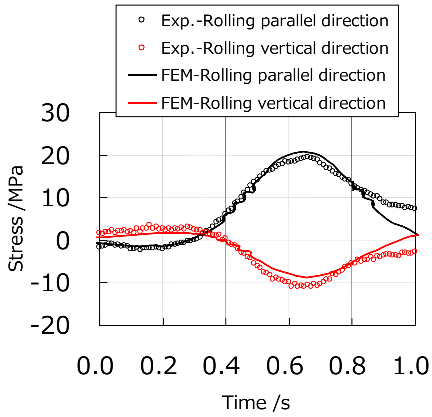

Fig. 5 Change in stress values during mandrel rolling.

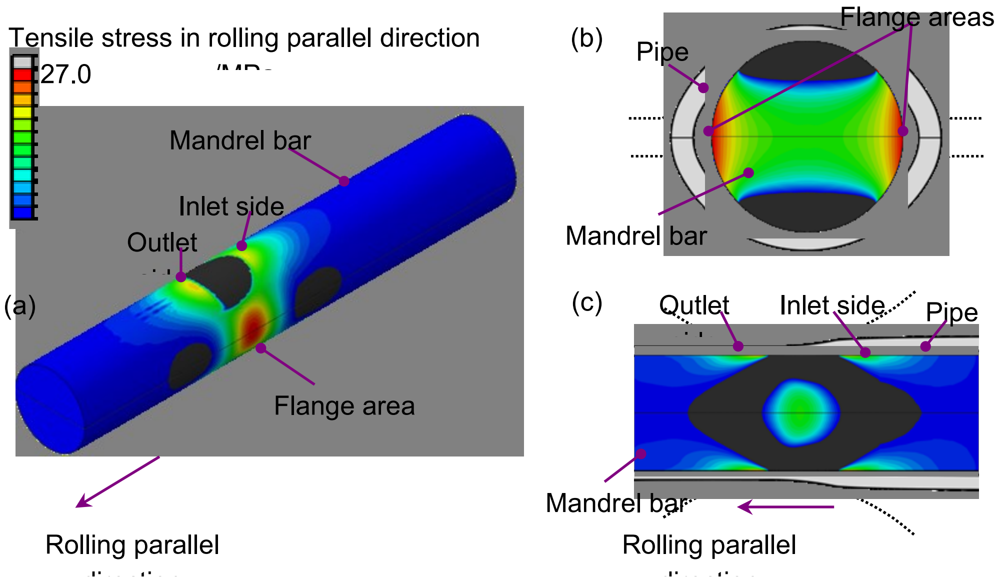

Fig. 6 Tensile stress distribution of mandrel bar during rolling: (a) Outward appearance, (b) Cross section of mandrel bar, (c) Center part of a longitudinal section of mandrel bar.

Fig. 8 shows the influence of the coefficient of friction and the deformation resistance of the material on the rolling load. To investigate the influence of deformation resistance, we used two types of material, lead, as shown in Fig. 2, and 9%Cr-1%Mo steel, as shown in **Fig. 9**. The coefficients of friction between the mandrel bar surface and the inner surface of the pipe were changed to 0.00, 0.04, 0.08, 0.12, 0.16 and 0.20. The rolling load increased as a result of higher coefficients of friction and deformation resistance. **Fig. 10** shows the influence of the rolling load on the inlet, outlet and flange area tensile stresses. The horizontal axis is the rolling load (shown on the vertical axis in Fig. 9), and the vertical axis is the rolling direction tensile stress at the mandrel bar surface. From these results, the tensile stress of the flange areas is proportionally dependent on rolling load changes due to changes in the coefficient of friction and the deformation resistance of the material. **Fig. 11** shows the influence of the diameter of the mandrel roll on the tensile stress in the rolling direction. The tensile stresses of the inlet, outlet and flange areas change proportionally depending on rolling load changes due to changes in the roll diameter. **Fig. 12** shows the influence of the grooved roll shape and the reduction rate on the rolling load. The radius R of the grooved roll, as shown Fig. 3, was changed to 80 and 100 mm, and the reduction rate r was changed to 28 and 48%. With all groove shapes, the rolling load changed proportionally depending on the reduction rate with different proportionality

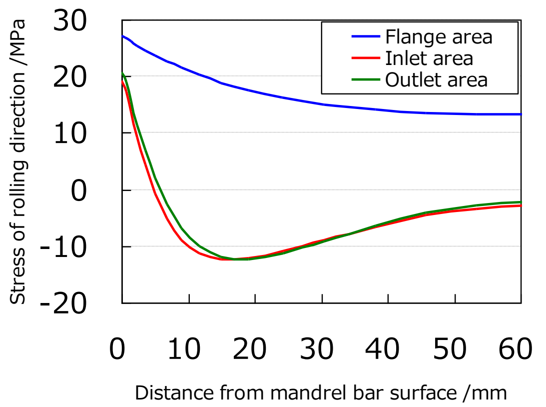

Fig. 7 Quantitative measurement of tensile stresses from mandrel bar surface to center part.

factors. The R: 80 mm roll shape had the highest rolling load and proportionality factor of all the grooved roll shapes. **Fig. 13** shows the influence of the tensile stress of the flange areas on the rolling load depending on the groove roll shape and reduction rate. The tensile stress of the flange areas changed proportionally depending on the rolling load, in spite of different proportionality factors between the rolling load and grooved roll shape. These results suggest that the tensile stresses of the flange areas are controlled by the contact area between the mandrel bar and the inner surface of the pipe.

The tensile stresses of flange areas, which cause open cracks on the mandrel bar surface, have a proportional relationship with the rolling load, which changes depending on the rolling conditions. This relationship may be used to suggest rolling conditions for forecasting and extending the tool life of the mandrel bar.

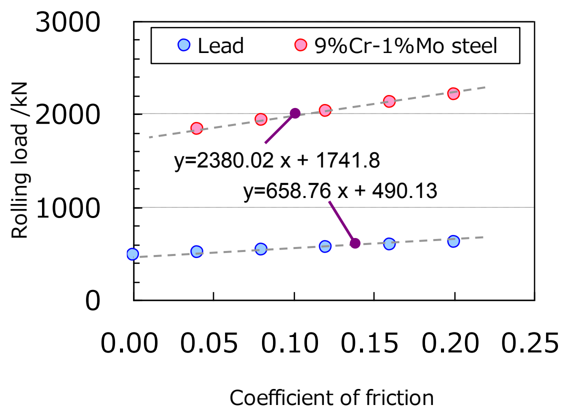

Fig. 8 Change in rolling load obtained with different coefficients of friction and materials.

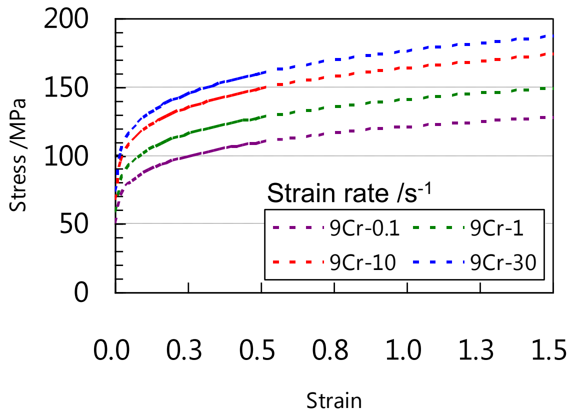

Fig. 9 Stress-strain curve of 9%Cr-1%Mo steel.

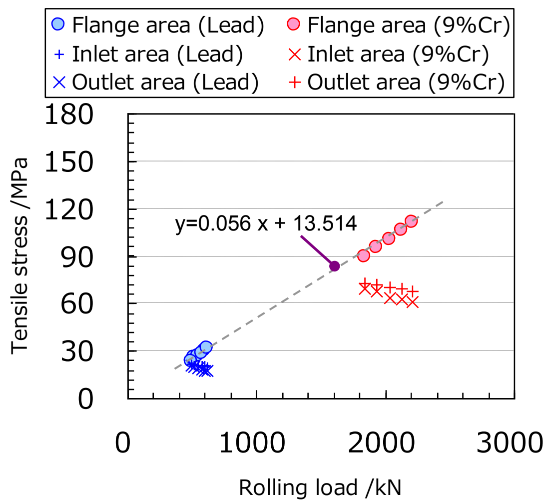

Fig. 10 Change in tensile stress obtained by FE analysis with different coefficients of friction and materials.

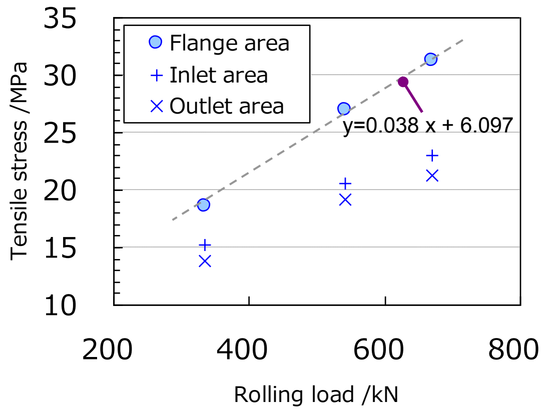

Fig. 11 Change in tensile stresses obtained by FE analysis with different roll diameters (rolling loads).

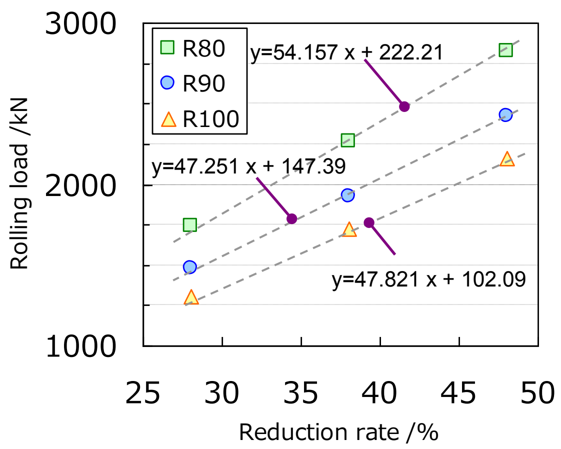

Fig. 12 Change in rolling load obtained by FE analysis with different grooved roll shapes and reduction rates.

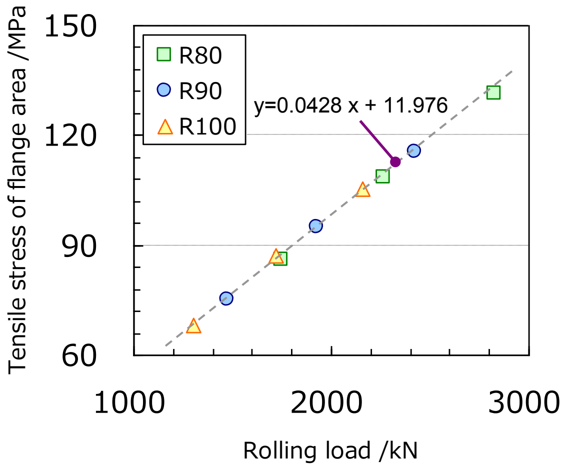

Fig. 13 Change in tensile stresses obtained by FE analysis with different grooved roll shapes and reduction rates.

CONCLUSION

The stress distribution of the mandrel bar during single stand mandrel rolling was calculated by FE analysis, and as the result, the caliber bottom just before and after roll bite and the flange areas of the mandrel bar displayed high tensile stress in the rolling direction. The tensile stress of the flange areas was higher and deeper than that in other areas, and was considered to cause crack propagation at the mandrel bar surface. The tensile stresses of flange areas change proportionally depending on changes in the rolling load due to rolling conditions, the deformation resistance of the material and the groove roll shape with different proportionality factors. From these results, the rolling conditions for forecasting and extending the tool life of the mandrel bar may be suggested by using the proportional relationship between the rolling load and rolling conditions.

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