Finite element analysis of a Mannesmann rollpiercing process

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1. Introduction

There are two kinds of commercial pipes, i.e., welded pipes and seamless pipes. Welded pipes are fabricated by welding of bent or rolled sheets or plates by roll forming process while large seamless pipes are mostly pierced by rollpiercing process. Welded pipes are relatively cheap and thus are vastly used for common commercial purpose. However, they have weak product reliability and low structural rigidity. For this reason, seamless pipes have been mostly employed for the applications requiring high reliability and long service life under high pressure or repeated loads.

It is general that the sequence of fabricating seamless pipes are composed of three processes including rollpiercing or pierce rolling, elongation rolling and reduction rolling. Rollpiercing is to manufacture thick pipes from raw materials of circular rods at the elevated temperature, elongation rolling is to manufacture thinner pipes from the thick pipes and reduction rolling is to manufacture final product with allowable tolerance of thickness and radius at the room temperature.

Rollpiercing technologies can be classified into three categories [1], i.e., press roll piercing [2], barrel-type rotary piercing [3-6] and corn-type rotary piercing [1,7,8]. Barrel-type rotary piercing has been well known as Mannesmann rollpiercing in which the workroll is of barrel shape.

Mannesmann rollpiercing takes advantage of Mannesmann effect[9], that is, tensile stress at the front edge of mandrel that causes crack or hole due to concentraive damage. Mannesmann rollpiercing process is characterized by its number of rolls employed and type of supporting material [5].

To meet the need from the industry, many researchers have tried to apply various finite element methods to analyze various rollpiercing processes [1-8,10]. Urbanski and Kazanecki [10] applied two-dimensional finite element approach to a rollpiercing process and their approaches, however, could not be fully developed to obtain the valuable information for process design due to the geometrical complexity of rollpiercing process. Mori et al. [3] employed a generalized plane strain modeling technique to simplify the complex three-dimensional finite element method. In their approach, a rollpiercing process was approximated to a roll forging process and elongation at the cross-section was assumed uniform in the axial direction. They showed that the predictions are close to the experiments of plasticine.

Mannesmann rollpiercing process using a three-dimensional rigid-plastic finite element method and obtained the predictions that are in good agreement of the experiments of plasticine.

Pater et al. [5] carried out non-isothermal analysis of a Mannesmann rollpiercing process with Diescher-type supporting equipment. Their results showed distinctive shape defects of final product which are supposed to have caused from limitation of brick elements employed for the sake of remeshing. Note that many remeshings in simulating a rollpiercing process are inevitable during being pierced. And that intelligent remeshing is of great importance.

In this paper, a rigid-thermoviscoelastic finite element method with intelligent remeshing capability of tetrahedral elements is applied to simulating the rollpiercing process that was firstly studied by Pater et al. [5] and the validity of the approach is discussed.

2. Finite Element Analysis of a Diecher type Mannesmann rollpiercing process

As shown in Fig. 1, a Diecher type Mannesmann rollpiercing process is composed of two barrel-type work rolls, two disk-type supporting rolls and a piercing mandrel. In the analysis model, the initial material should be short for precision and efficient simulation but its oscillatory motion should be avoided. In this paper, we adopted a cup type artificial die for the purpose. Of course, the artificial die can guide the initial material to be sufficiently contacted with the work rolls by pushing it.

Pater et al. [5] employed a simple flat die just for pushing the material, instead of our cup-type die for both pushing the material and preventing it from oscillating. Speed of the pushing die was set to be lower than the almost steady-state speed of the material such that it separates from the material when the normal contact between the material and the work rolls takes place and thus tensile nodal forces are exerted on the pushing die.

Mannesmann rollpiercing simulation should be preceded by its proper mathematical modeling because it is so complicated that the full model itself cannot be dealt with by a finite element method. In particular, it is not easy to make proper and accurate modeling of contact condition at the interface between material and dies including work rolls, mandrel and supporting rolls or guide shoes. In most previous researches, the interface was modeled by law of constant shear friction with friction factor of 1.0, implying that the interface has been treated as sticking boundary.

In this paper, it was also assumed that no-slip boundary condition can be applicable on the interface between material and work rolls. The interface between material and guide rolls was modeled by law of Coulomb friction with frictional coefficient of 0.4 fixed. The interface between material and mandrel was assumed frictionless because twisting moment exerted on the mandrel should vanish and the contact area becomes relatively small when the process reaches its steady-state.

The process conditions and geometries that are the same as those of Pater et al. [5] are summarized as below:

- Material type: SUJ2(100Cr6)
- Radius of initial material : φ 60 mm
- Angular speed of work roll : 60.0 rpm
- Angular speed of guide roll : 6.8 rpm
• Initial temperature of material : 1180°C
• Initial temperature of mandrel : 300°C
• Initial temperature of guide roll and work roll: 100°C

AFDEX 3D [11] was used to simulate the process above. Number of tetrahedral elements was controlled about 50000 during automatic remeshing. An intelligent remeshing capability was assisted to make the finite element model with finer mesh density near the plastic region, as shown in Fig. 2.

The predictions are shown in Figs. 2-5. Fig. 2 shows history of deformation with mesh system. Fig. 2(a) shows an external shape while Fig. 2(b) shows internal shape. It can be seen that the radius of the workpiece reduces in gradual until it reaches the roll gap while it increases in gradual until it reaches the end of mandrel. Note that the numerical volume loss was 0.09%, indicating that the predictions are quite reliable.

Fig. 3 shows cross-sections at the important positions. Nearly the same phenomenon of deformation characteristics as

![Fig. 2 History of deformation](image)

Fig. 3 shows cross-sections at the important positions. Nearly the same phenomenon of deformation characteristics as

![Fig. 3 Deformed cross-sections with strain](image)

![Fig. 4 Distribution of effective strain](image)

Fig. 4 shows cross-sections at the important positions. Nearly the same phenomenon of deformation characteristics as

![Fig. 5 Distribution of temperature](image)

Fig. 5 can be observed from Fig. 3. It is interesting to note that the circular shape maintains internally while the external shape of the cross-section deviates much from circular shape before the material passes through the end of the flug of mandrel. Of course, the concentricity of the cross-section of the material increases even after the material passes the end of the flug of mandrel until it passes the end of the work rolls.

The ellipticity of external shape predicted in the middle of the flug of mandrel is 1.057, which is the maximum value. Note that the maximum ellipticity of the Pater et al.’s predictions is 1.054, which is next to the current prediction of 1.057. On the contrary, the smoothed corners were observed in the predictions of Pater et al.’s while no smoothed corners were observed in the present approach. The smoothed surface is supposed to have caused from remeshing problems when hexahedral elements were employed. Note that the shape of leading edge in the Pater et al.’s predictions is convex while that in the present approach is opposite. Fig. 4 shows the effective strains from external and internal viewpoints and Fig. 5 shows the temperature.

3. Conclusions

In this paper a Mannesmann rollpiercing process with Diecher type guide rolls was simulated by a rigid-thermoviscoplastic finite element method with intelligent remeshing technique of tetrahedral elements. A detailed finite analysis model was presented. The predictions obtained by the approach were compared with those of Pater et al. who employed the hexahedral elements, showing that the shapes of material at the selected cross-sections are nearly the same but that the corners of material and geometry of the front end of material are considerably different from each other. It is believed that there must have been some numerical smoothing in the Pater et al.’s predictions. Consequently, the present approach is competitive in simulating Mannesmann rollpiercing processes.

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Reference

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