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Procedia Engineering 81 (2014) 197 – 202

Procedia Engineering

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11th International Conference on Technology of Plasticity, ICTP 2014, 19-24 October 2014, Nagoya Congress Center, Nagoya, Japan

Quantitative study on Mannesmann effect in roll piercing of hollow shaft

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Abstract

Mannesmann effect is studied using a hollow cylinder model, which is devised to analyze a hole expansion phenomenon in artificial roll piercing of a hollow cylindrical material by two barrel-type rolls without any mandrel and guiding tools. A rigid-thermoviscoplastic finite element method is employed with a special mesh generation scheme which can control the mesh density especially on the small hole surface. No damage model is used to soften the material and the hole expansion simulation is conducted without any additional assumptions about material and process. Artificial roll piercing processes for a wide range of hole diameters with outer diameter fixed are simulated with emphasis on hole expansion. It has been shown that the relative hole expansion ratio of the maximum hole diameter to the initial hole diameter increases as the initial hole diameter decreases, indicating that the hole expansion phenomenon is next to the Mannesmann effect occurring in actual roll piercing. It has been also shown that the hole expansion is related to the cavity formation occurring just after the material passes the mandrel nipple, which leads to the decrease in the pushing force exerted on the mandrel in an actual roll piercing process.

Keywords: Mannesmann effect; Roll piercing; Hollow cylindrical material; Hole expansion

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doi:10.1016/j.proeng.2014.09.150

1. Introduction

In roll piercing, the bars are pierced under the action of tensile stress developing at the centre due to the so-called Mannesmann effect. Elongating and reduction rolling ordinarily follows afterwards to make the pipes thin, longer with their diameter getting smaller as required. The effect is a kind of useful defect phenomenon occurring in the workpiece under the tensile plastic stress state, whereas it guides to create the cavity for a hole and refine the uniform microstructure, leading to a well-known enhancement of quality in the final seamless product.

In manufacturing seamless pipes, therefore, the roll piercing process, exerting a tremendous effect on the following procedures, bears one of the significant industrial interests. Widely known as Mannesmann piecing, the barrel-type roll piercing is the most representative with its roll a barrel shape (Mori et al., 1998). Several researches have been directed toward Mannesmann effect especially at the central region of workpiece under tension, still constituting the main and active research issue.

Urbanski and Kazanecki (1994) analyzed the strain distribution in the piercing process by the 2-D finite element method, and Capoferri et al. (2002) studied the phenomenon of Mannesmann effect using the theory of maximum principal stress with 2-D finite element models as well, while Ceretti et al. (2004) extended the analysis to the 3-D cases. On the other hand, many researchers tried to visualize the softening phenomenon at the central cavity area based on the damage model. Mori et al. (1998) performed a simplified 3-D simulation of the roll piercing via the generalized plane deformation model, together with damage model based on the mean stress and effective stress schemes. Using the 3-D rigid-plastic finite element method, Komori (2005) further simulated the process of roll piercing in its steady state, which in fact did not touch the issue of Mannesmann effect itself, whereas he assumed the cavity creation in front of the mandrel. Meanwhile, Pater et al. (2006) hired thermo-mechanical finite element method to the analysis of non-steady state of roll piercing process with regrettably no consideration of Mannesmann effect, while Chiluveru (2007) used the damage model of porous materials to study the Mannesmann effect. Ghiotti et al. (2009) modified the Lemaitre damage model (Lemaitre et al., 2005) and performed a numerical and experimental analysis upon the Mannesmann effect. They reflected the fact that the central portion of material structure appears to be relatively vulnerable to fracture, endowing the workpiece with an artificial initial damage proportional to an early stage cavity. Their results reveal the analysis is severely dependent on the initial values. Shim et al. (2012) most recently simulated the roll piercing process by an intelligent remeshing scheme with no further consideration about the Mannesmann effect.

The analyses of Mannesmann effect by the damage model, as the various researches up to now indicates, requires an extensive dependence on several assumptions made and there seemingly exist no universal or prevailing research results. In the present paper Mannesmann effect is quantified to elaborately trace the geometric change of inner diameters in a hollow workpiece, which replaces the controversial damage model with a small initial hole along the axial direction in the workpiece. The apparatus of an artificial hole is supposed to properly describe the macroscopic behavior of Mannesmann effect.

2. Simulation of Mannesmann effect

Fig. 1 shows a typical example of roll piercing process where two barrel-type rolls and a mandrel with two other guiding shoes engaged (for the details see Shim et al., 2011).

To introduce a central microscopic failure, Ghiotti et al. (2009), one of the typical outcomes based on damage model, assumed the high initial damage value near the central line to predict the Mannesmann effect. An analysis based on Ghiotti’s previous scheme, performed by the authors using a general package for thermoviscoplastic finite element analysis (Joun et al., 2011) is presented in Fig. 2, where a Mannesmann hole is generated along the axial line of the workpiece. As the figure depicts, an initial damage assumed a priori, of course, is the key feature of the Ghiotti’s method. It is regrettably not an easy task to single out the mechanical part from the analysis in which both metallurgical and mechanical features are mixed together.

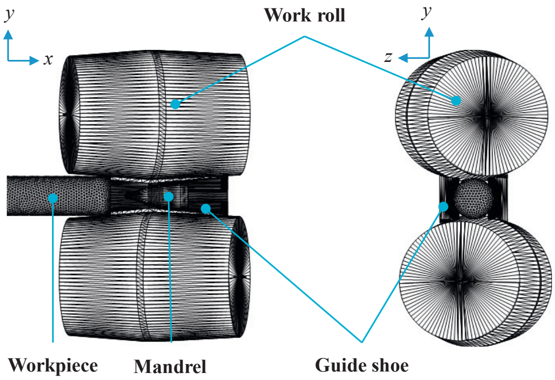


Fig. 1. Analysis model of Mannesmann roll piercing process.

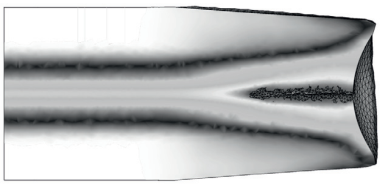


Fig. 2. Predictions of crack and hole generations due to Mannesmann effect by Ghiotti's damage model.

To circumvent the difficulties in singling out mechanical features in the damage model, the current analysis model is replaced by an initial workpiece hollowness as to resultingly behave like a thick tube. And the current study carries out an analysis of a roll piercing with no mandrel engaged, in which the changes of inner radii are traced laboriously, leading to the close visualization and quantification of the Mannesmann effect. The same analysis conditions of the process including geometric and process information employed in the study of Pater et al. (2006) and Cho et al. (2011) are used.

An intelligent tetrahedral element system (Lee et al., 2007) is hired for the analysis with total number elements in the range of 50,000 to 80,000. The internal region of the hollow workpiece is densely discretized with finite elements for a better representation of plastic deformation inside the hole.

Fig. 4 shows an analysis result for the change of an inner radius along the center line of the workpiece especially when r = 2.0 mm. The farmost right-hand side of the hollow workpiece, called a trough, deforms conspicuously in a concave manner, which stems from the edge effect. Looking closely at the change of inner radius, one may find that it slowly starts to change from the entry cross section of A_0 to the section A_1 where the roll gap becomes minimum. And then it experiences a sharp and drastic change to have the maximum value r_{max} at the section A_{max}, proceeding to the trough area. It is noteworthy that the whole change profile along the center line of the process soon gets to the steady-state deformation and the final inner radius of the hollow workpiece in the exit have the value a little smaller than r_{max} . Comparing the result obtained with that in Fig. 2, one may easily recognize that they are nearly the same pattern of deformation and trend.

Fig. 5 depicts predictions with emphasis on inner diameter expansion when initial values of inner radii r vary from 2.0 mm to 10.0 mm. In every case, all the inner radii are observed to have larger values. Meanwhile the expanded regions are near to the exit side of the process as the initial radius is relatively small, whereas the cases of bigger radii show a rather flattened tendency over the axial direction.

Regarding the expansion level of the hollow workpiece due to Mannesmann effect per each initial inner radius, the relative expansion ratio of the maximum radius r_{max} to an initial value r_0 is investigated. Note that the maximum radius was measured just after the workpiece attained the steady-state deformation region. The graph for the relative expansion ratio is depicted in Fig. 6, which vividly reveals the fact that it is remarkable as the initial inner radius gets smaller, while it rapidly becomes negligible as the radius gets much larger.

In an actual roll piercing the existence of mandrel is essential for the final seamless pipe product, while the mandrel is purposely excluded in the current analysis. With a typical mandrel engaged, an intriguing result like that presented in Fig. 8 can be obtained. It can be seen from the figure that only the tip of mandrel nipple touches the material and that there is a distinct non-contacting region at an end of mandrel nipple where coolant holes exist in usual course. It is quite notable that the creation of cavity between the mandrel and workpiece, arising from the chosen geometric shape in a mandrel and the characteristic expansion of the inner radius described above, ultimately play a role in lessening decisively the force exerted on the material-die contact surface. Both features from the mandrel and expansion of the hollow workpiece, of course, constitute the whole story of Mannesmann effect.

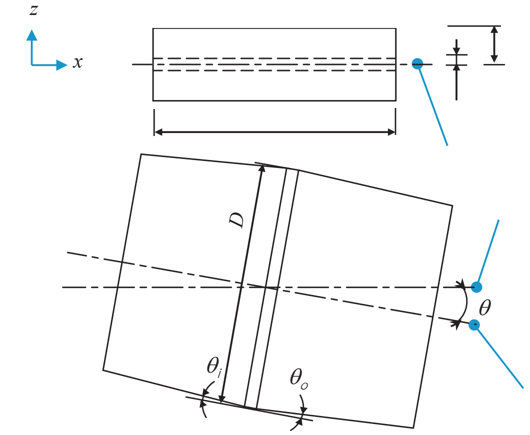


Fig. 3. Configuration of roll and workpiece.

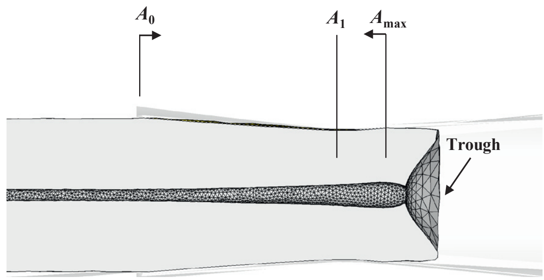


Fig. 4. Profile of inner radius when $r = 1.5$ mm.

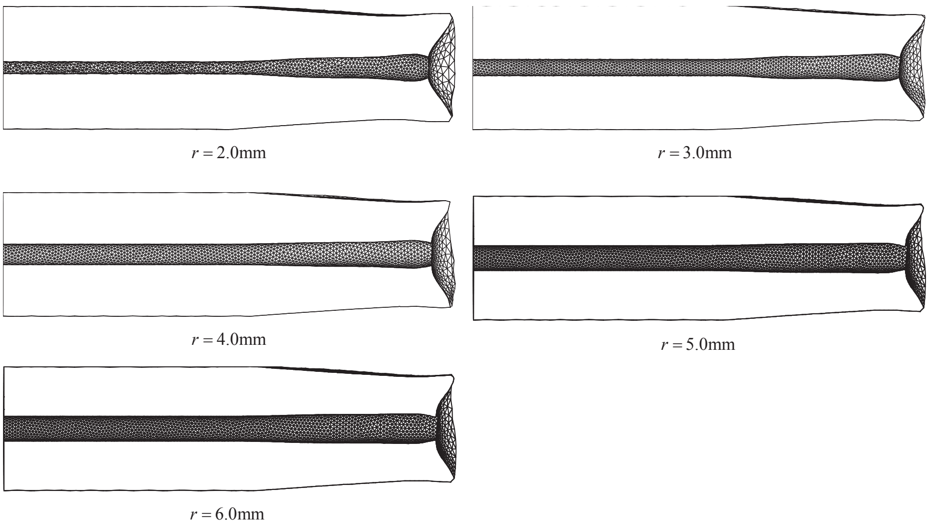


Fig. 5. Variation of inner diameters with stroke for each initial inner diameter.

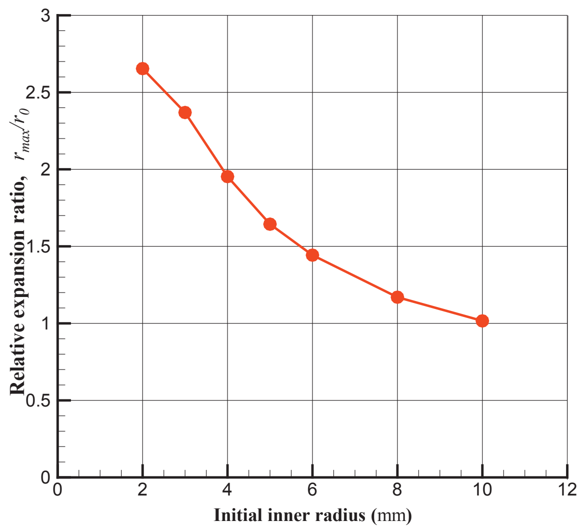
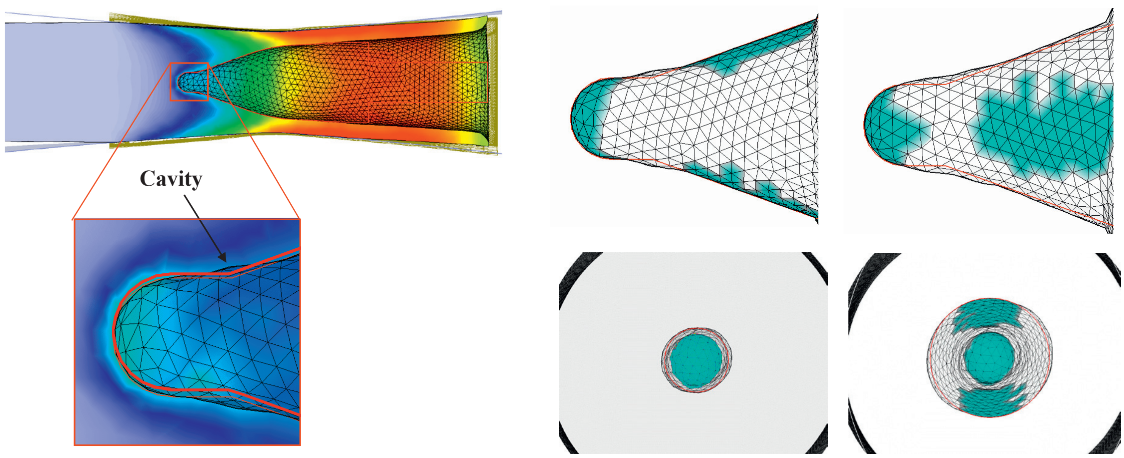


Fig. 6. Effect of initial hole size on Mannesmann piercing process.



(a) Global view

(b) Local view (Shaded area means the die-material interface)

Fig. 7. Material-die contact in roll-piercing.

3. Conclusions

For the purose of describing and quantifying the Mannesmann effect, the current study from the pure mechanical viewpoint predicts and analysizes the inner radius expansion in the roll piercing process, replacing the damage model by an artificial hollow workpiece with the mandrel not in play, called as an artificial hollow cylinder model. Any other mechanical assumptions were not made for the analysis model and no damage model was hired. It should be noted that the predictions of Mannesmann effect are too much affected by the specific damage model used.

The finite element predictions for various hole sizes with outer workpiece diameter fixed revealed that the artificial hollow cylinder model can provide meaningful information about Mannesmann roll piercing processes more easily and clearly compared to the exsiting damage model. Outcomes also show that the inner radius gradually starts to change from the entry cross section to the section of minimal roll gap and then experiences a sharp expansion near the exit region proceeding then to a steady-state deformation.

Meanwhile it is noteworthy that the expansion ratio is remarkable as the initial inner radius gets smaller, which is supposed to provide a clue to understand the Mannesmann effect. It has been also shown that the hole expansion is related to the cavity formation occurring just after the material passes the mandrel nipple, which leads to the decrease in the pushing force exerted on the mandrel in an actual roll piercing process.

Acknowledgement

The research was financially supported by National Research Foundation of Korea and Korea Research Foundation (Ministry of Education, Science and Technology) under grant No. 2011-0003889.

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