行政院國家科學委員會專題研究計畫成果報告

計畫名稱：行星式輥軋機輥軋成形之有限元素分析研究（2/2）

The finite element deformation analysis on planetary rolling process

計畫編號：NSC-89-2212-E-009-089

執行期限：89 年 8 月 1 日至 90 年 7 月 31 日

主持人　　　：洪景華　教授　國立交通大學機械工程學系

計畫參與人員：施智綱　研究生 國立交通大學機械工程學系

　　　　　　：孫世傑　研究生 國立交通大學機械工程學系

　　　　　　：林孟哲　研究生 國立交通大學機械工程學系

一、中文摘要

本研究計畫首先對照既有的實驗數據，以塑性黏土為材料，針對已建立好的有限元素分析模組進行驗證。再採用有限元素模擬的方法，探討生產無縫管時採用行星式輥軋機輥軋成型的過程，以期瞭解工件輥軋成型的變化情形。同時，藉由流線方程式運用上界限法求出使塑性變形所消耗總功率為最小的動可容許速度場，從中求得管件在成型過程中各點的速度以及加工的能量，並與有限元素分析所求得的結果進行比較。

關鍵詞：行星式輥軋，有限元素法，流線方程式，上界限法。

Abstract

In this study, the PSW rolling with plasticine was first simulated and the results were compared with the experimental data to testify the numerical model. Then the finite element method and the dual-stream-functions upper bound method are selected to analyze the tube rolling process with planetary rolling mill. Three-dimensional elastic-plastic finite element simulations with special emphasis on the determination of roller profile and realistic contact conditions between rollers, workpiece and mandrel, is used to reveal the deformation characteristics of seamless tube during rolling process. In addition, the kinematically admissible velocity field of deforming tube is described in terms of two stream functions so that the velocity components of the deforming tube can be obtained through the upper-bound analysis. The results from both methods with different variables are observed and compared.

Keyword： Planetary rolling process; Finite element; Upper bound; Dual-Stream functions

二、緣由與目的

Planetary rolling mill（Planetenshrägwalzwerk，PSW)[1], has been successfully operated on roughing rolling process. The advantages of PSW include flexibility of workpiece size, low rolling load, low lateral spread of material [2][3] and low temperature drop between leading and tail ends of the rolled workpiece [4]. Because of its high reduction and continuity, the PSW is also able to manufacture seamless tubes from pierced billets. A set of PSW, which is used as a elongation mill, combined with a sizing or stretch-reducing mill in the tube production forms one continuously operating unit (Fig.1) [5] and permits the omission of the cooling and reheating operations that are usually required after elongation for conventional elongation mill. And noise level is lowered because of no cold tubes clashing against the mandrel. Further, the PSW provides close wall thickness tolerances through transverse rolling at elongation stage [6] and increased yield.

Most papers about PSW were focused on the rod rolling process, only a few on the seamless tube rolling process. For rod rolling process, Aoyagi [7] observed the flow of the material and pressure distribution on rollers during rolling process. In analytical research, Hwang [8] had used the dual-stream functions for investigating the plastic deformation behavior of the rod during planetary rolling process. On numerical analysis, Shih and Hung [9] employed the three-dimensional finite element analysis and optimum method to obtained the rolling deformation and resulting stress and strains. For tube rolling process, Siebke [10] had used the elementary mechanics to analyze the force acting on rollers and mandrel. However, few works have been done on studying the tube rolling process with the three-dimensional finite element deformation analysis or with upper-bound solution through the dual-stream functions. The purpose of this study is thus to use the finite element method to further analyzes the planetary rolling process with a systematic study on the effects of rolling parameters and also compares the results to those derived from the dual-stream functions.

三、研究方法

3.1. Comparison with experiment results

Plasticine was used as working material in most experimental work. Therefore, in the beginning of analysis, the plasticine PPW 1/3 1.5 was simulated. Fig.2 shows the stress-strain relationship of this plasticine [9].

3.2. Finite element model

With the procedures mentioned in the last year project, three rollers with 120 degrees separation together with a hollow workpiece and a cylindrical mandrel had been built and then the corresponding mesh system was generated as shown in Fig. 3.

3.3. Dual-Stream Function

An admissible velocity field for an incompressible body in a three-dimensional space can be represented in terms of two stream functions was first proposed by Nagpal [11]. The velocity components in cylindrical coordinate can be written as the cross product of the gradients of two stream functions,

$$\boldsymbol{V} = \boldsymbol{V}(V_r, V_\theta, V_z) = \nabla\phi \times \nabla\psi \qquad (1)$$

where ϕ and ψ are the stream functions and (V_r, V_θ, V_z) are the velocity components.

In this study, the rollers are considered rigid and the material property of hollow tube is rigid-plastic and isotropic. Thus the flow pattern of the deforming material in r-z plan can be written as [12] (Fig. 4):

$$\psi = v_0 \frac{R_w^2 - R_i^2}{2} \frac{r^2 - R_i^2}{R(z)^2 - R_i^2} \qquad (2)$$

where $R(z)$ represents the workpiece profile in the roll gap. In the $\theta - r$ plane, the flow pattern is assumed that the circumferential velocity along the radius direction is linearly distributed [8] and can be written as:

$$\phi = \frac{z}{l} - \frac{\theta}{2\pi} \qquad (3)$$

l is the moving distance along the z-axis as the hollow tube makes a complete rotation.

Among all kinematically admissible velocity fields, the actual one minimizes the expression [13]

$$J^* = \frac{2}{\sqrt{3}}\sigma_0 \int_V \left(\frac{1}{2}\dot{\varepsilon}_{ij}\dot{\varepsilon}_{ij}\right)^{\frac{1}{2}} dV + \int_{S_V} \tau|\Delta v| dS - \int_{S_t} T_i v_i dS \qquad (4)$$

四、結果與討論

4.1. Comparison with Experiment Results

PSW rolling with plasticine was first simulated and the results were compared with the experiment data [7] to testify the correctness of numerical procedures. The rolling load related to the reduction in diameters is shown in Fig. 5. The loads with simulation are a little higher than those of experiments but the tendency is very close. In addition, the effect of offset angles on exiting velocity of rod is shows in Fig. 6. The simulation results are close to those of experiments. The difference between simulation and experiment should be mainly on the property of plasticine

4.2. Results of Finite Element Analysis

The vertical cross-section of a deforming tube is shown in Fig. 7. The workpiece was twisted by the interaction of the rollers and the mandrel and thus has spiral marks on the tube surface. Due to the rotation and feed movement brought by rollers, the material flow was not uniform between the internal and external part of the tube.

Figure 8 is the contour of effective stress of the workpiece during the rolling process. It can be seen that the maximum von Mises stress occurs at the parts contacting with the rollers.

Figure 9 shows that the exit velocity increased with the magnitude of offset angle and decreased with respect to the wall thickness of deformed tube. In addition, the rolling load increased with the offset angle and also increased with the tube thickness as shown in Fig. 10.

4.3. Dual-Stream Function

Velocity components obtained from dual-stream functions are shown in Fig. 11(a) while Fig. 11(b) shows the velocity components on the tube surface from the finite element analysis. The velocity distribution from the dual-stream functions clearly indicates the rotation movement of the workpiece. Similar results are found in the FE calculation. However, the amount of advancing movement of the deforming tube is not as obvious as that obtained from FEM. The energy rates calculated from the dual-stream functions are displayed in Fig. 12 and are compared with the results from FEM. The tendencies from both analyses are very similar.

The differences between two methods of analysis mainly come from the over simplified assumptions of the dual stream functions. The circumferential velocity along the radius direction shall not be treated as linear distribution, especially in the deforming zone. In addition, the lack for the velocity discontinuities along the interface between deforming surface and free surface in the roll gap also leads to the deviations from the FE simulation.

五、計畫結果自評

This research tried to provide the solutions of the problem on the planetary rolling process for tube production by using both the finite element method and dual-stream functions. The conclusions follow.

1. The offset angle of the roller influences the exit velocity of the workpiece, the rolling load and the dissipated energy in deformation.
2. Combining the dual-stream functions and upper bound approach provides a feasible way to analyze the three-dimensional metal forming problems analytically. The results show similar tendencies with those from the finite element method about energy rate, but with some discrepancies in the magnitude.
3. The model of the dual-stream function from which velocity field is derived can be further modified to approach the real material behaviors during deformation.

六、參考文獻

[1] H. Marten, New Approaches in plant technology to increase quality and productivity, Mpt Metallurgical Plant and Technology 9 (5) (1986) 39-55.

[2] W. J. Ammerling, H. Brauer, Application of 3-roll technology for rolling specialty rod and bar products, Iron and steel Engineer 65 (9) (1988) 22-27.

[3] W. J. Ammerling, Kocks 3-roll technology for high precision specialty rod and bar product, MPT Metallurgical Plant and technology 12 (6) (1989) 14-19.

[4] C. Recalcati, C. Ventura and W. Rensch, HRM high-reduction rolling machine, Wire Industry 57 (673) (1990) 31-34.

[5] E. Bretschneider, "New process for the production of seamless tubes-PSW now also in the tube sector", Mpt Metallurgical Plant and Technology 6 (6) (1983) 44-49.

[6] E. Bretschneider, "Novel tube-rolling process using the 3-roll planetary mill (PSW)", Iron and Steel Engineer 58 (10) (1981) 51-54.

[7] K. Aoyagi and K. Ohta, Material Deformation, Rolling Load and Torque in 3-Roll Planetary Mill, J. JSTP 24 (273) (1983) 1039-1047.

[8] Y. M. Hwang, H. H. Hsu, and G. Y. Tzou, A study of PSW rolling process using stream functions, J. Mater. Proc. Technol. 80-81 (1998) 341-344.

[9] C. K. Shih and Chinghua Hung, "The finite element analysis on planetary rolling process", The 23rd National conference of theoretical and applied mechanics, Taiwan, R.O.C., 1999.

[10] T. Siebke and H. Gartner, "Development of and trials with a seamless tube rolling process employing a 3-roll planetary mill(PSW)", Mpt Metallurgical Plant and Technology 13 (2) (1990) 72-80.

[11] V. Nagpal, "On the Solution of Three-Dimensional Metal-Forming Process", ASME J. Eng. Ind. 99 (1977) 624-629.

[12] K. T. Chang, and J. C. Choi, , "Upper-Bound Solutions to Tube Extrusion Problems Through Curved Dies", ASME J. Eng. Ind. 94 (1972) 1108-1111.

[13] Betzalel Avitzur, Metal Forming, Marcel Dekker. INC., 1980.

七、圖表

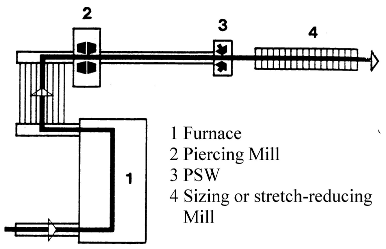


Fig.1 Layout of a tube production plant with PSW

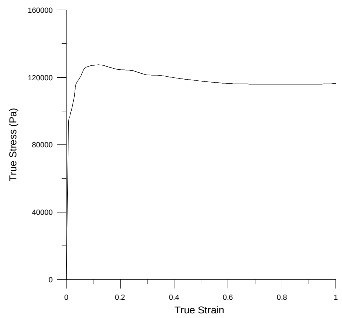


Fig. 2 True stress-True strain curve of Plasticine

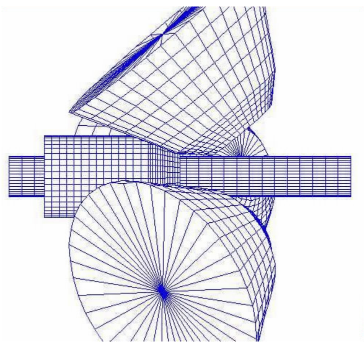


Fig. 3 Mesh system of PSW

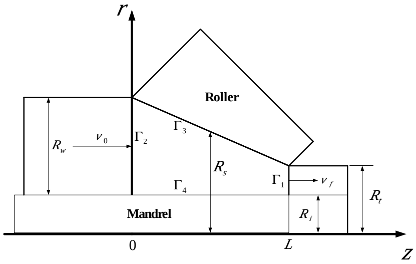


Fig. 4 Tube through Roller

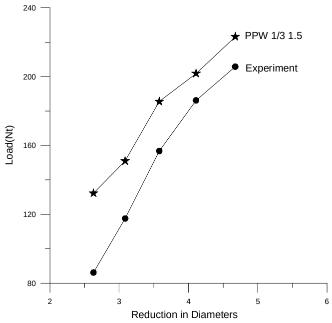


Fig. 5 Comparisons of Rolling Loads

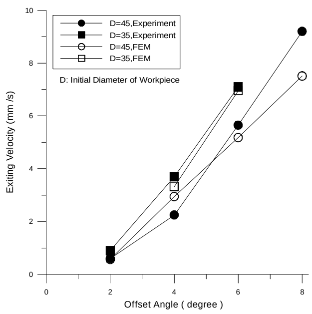


Fig. 6 Comparisons of Exiting Velocity

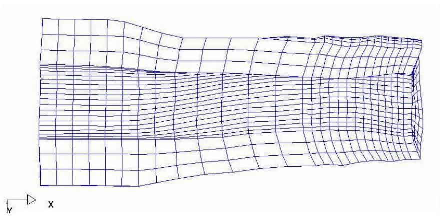


Fig. 7 Cross section of deforming tube

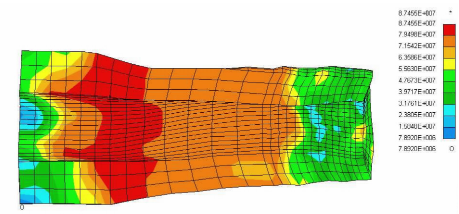


Fig. 8 Distribution of von Mises stress on deforming tube (Unit : Pa)

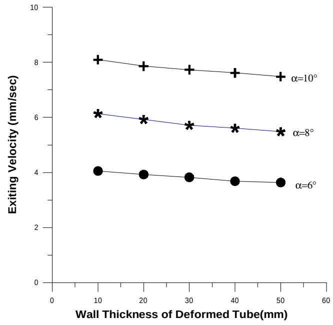


Fig. 9 Relation between offset angle and exit velocity of workpiece

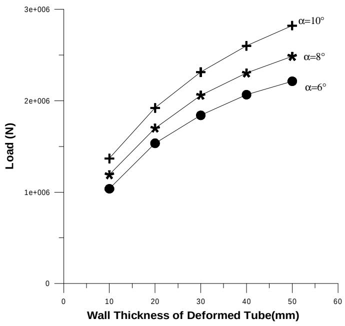
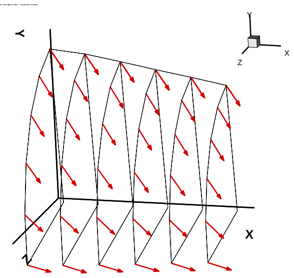
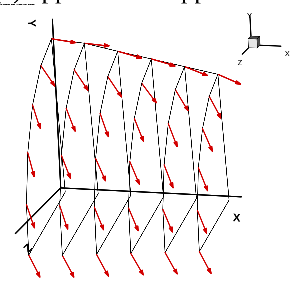


Fig. 10 Relation between offset angle and rolling load



(a)Upper bound approach



(b)Finite element analysis

Fig.11 Velocity field of roll gap

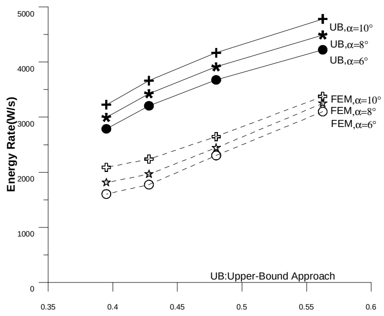


Fig. 12 Energy rate