MODELLING OF THREE DIMENSIONAL ROLLING PROCESS TO DETERMINE SPREAD WITH BULGE

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Abstract

The present investigation is concerned with determination of spread with bulge profile for flat rolling of mild steel using FEM modeling. The bulge profile is compared with the solutions of three dimensional upper bound method based on dual stream function method. It is observed that the bulge profile obtained in FEM modeling is qualitatively similar to that of the upper bound method.

INTRODUCTION

When a billet of comparable width in height ratio undergoes compression in the roll, it not only flows in the direction of roll rotation but also along a direction parallel to the roll axis. This flow of material at right angles to the direction of compression is termed as lateral flow or spread. The degree of spread depends on many factors such as friction condition along the roll/billet interface, roll diameter and stock height to width ratio. The spread is made use of to achieve the required shape as in section rolling. Tselikov had estimated spread profile under controlled laboratory conditions[1] and developed some mathematical modeling as an earliest attempt. A number of empirical equations were presented for estimation of spread in hot rolling by other investigators[2],[3]. However, above analysis lack generality and apply only to specific rolling conditions.

The theoretical studies for estimation of spread involves complex three-dimensional deformation. The first endeavor in this direction was by Oh and Kobayashi[4] who sought to the solution of the problem using Hill's general method[5]. Kobayashi et al.[6] determined spread using rigid-plastic finite element analysis. However, both methods are only marginally better than that of three dimensional modeling by upper bound method, though those involve considerable computation time. Kennedy[7] has proposed an upper bound solution for estimation of spread with bulge in hot-rolling. But , the kinematically admissible velocity field in his analysis is based on guess work, rather than from a generalized approach.

In the present investigation, three dimensional deformation in flat rolling has been carried out using an upper bound approach. The spread with bulge has been considered. The kinematically admissible velocity field for the purpose is derived from the dual stream function method proposed by Yih[8] and extended to metal deformation problems by Altan and Nagpal[9]. Torque and thrust has been estimated for different friction conditions and for different billet and roll geometries assuming three different spread profiles. The spread determined from the present theory agrees well with the available experimental results. The bulge is the variation of spread in the vertical direction. The shape of the bulge determined from the modeling is concave in nature for all reduction with maximum spread at the roll billet interface and minimum at the center. FEM modeling has been carried out to compare with upper bound solution. The methodology used here is general in nature. The compatibility of the theory with experiment is more compared to other theory[7] specially at high reductions.

DUAL STREAM FUNCTION

In a three dimensional flow field, a stream line is spatial in nature and such it is described as the intersection of two surfaces. These surfaces are termed as the stream surfaces and the functions specifying these surfaces are called stream functions. Since two stream functions are necessary to specify a spatial streamline, these two are called dual stream function. If $\psi_1(x,y,z)$ and $\psi_2(x,y,z)$ are the two stream functions describing a three dimensional flow field field, the three velocity components are given by

$$V_x = \frac{\partial \psi_2}{\partial y} \cdot \frac{\partial \psi_1}{\partial z} - \frac{\partial \psi_1}{\partial y} \cdot \frac{\partial \psi_2}{\partial z} \tag{1a}$$

$$V_y = \frac{\partial \psi_2}{\partial z} \cdot \frac{\partial \psi_1}{\partial x} - \frac{\partial \psi_1}{\partial z} \cdot \frac{\partial \psi_2}{\partial x} \tag{1b}$$

$$V_z = \frac{\partial \psi_2}{\partial x} \cdot \frac{\partial \psi_1}{\partial y} - \frac{\partial \psi_1}{\partial x} \cdot \frac{\partial \psi_2}{\partial y} \tag{1c}$$

It is easily seen that the velocity components derived through equations (1) above satisfy the volume constancy condition identically. The boundary conditions on the velocity field can be easily imposed on the velocity field can be easily imposed on the chosen stream function making use of the properties of streamline and stream surfaces. For example, the material velocity along the normal to the roll surface (also along the normal to the planes of symmetry) m kust be zero. This boumdary condition can be satisfied by choosing the stream function in such a manner that one or both of the stream function have a constant value along the roll surface (or at the plane of symmetry). Therefore, the velocity field determined through dual stream function is kinematically admissible.

The upper bound theorem

The upper bound theorm states that among all the kinemetically admissible velocity fields, the actual one minizes the expression

$$J = \frac{2}{\sqrt{3}}\sigma_0 \int_{\gamma} (\tfrac{1}{2}\varepsilon_{ij}\varepsilon_{ij})^{\frac{1}{2}} dV + \frac{\sigma_0}{\sqrt{3}} \int_{s_1} |\Delta v|_1 \, ds_1 + \frac{m\sigma_0}{\sqrt{3}} \int_{s_2} |\Delta v|_2 \, ds_2 \tag{2}$$

Here $|\Delta v|_1$ and $|\Delta v|_2$ are the velocity discontinuities on the planes of velocity discontinuity s_1 and the friction surface s_2 (roll surface) respectively. The first term on the right hand side of the equation 2) is the power of internal deformation. The second term represent the shear power at the planes of velocity discontinuity (entry and exit planes) and the third term represent the power dissipation due to friction at the roll/work piece interface.

Spread function with bulge profile

$$\phi(x,z) = w_0 + \left\{ a_1\left(\frac{H_0}{W_0}\right)x + a_2\left(\frac{H_0}{W_0}\right)\frac{x^2}{L} + a_3\left(\frac{H_0}{W_0}\right)\frac{x^3}{L^2} \right\} \times \left\{ b_1\left(\frac{h}{z}\right)^2 + b_2\left(\frac{h}{z}\right)^4 + b_3\left(\frac{h}{z}\right)^6 \right\} \tag{3}$$

The spread increases from entry plane to exit plane. The bulge is symmetric about the central axis.

FEM SIMULATION

FEM simulation of the hot rolling process of mild steel has been carried out to determine spread with bulge using DEFORM software. The width and height of billet is taken as 10mm and 5mm respectively. The constant friction factor has been assumed at the die billet interface with m=0.75. The tetrahedral element has been considered for modeling. 25000 elements have been taken for modeling. The billet velocity is 1mm/min. The initial position of roll and billet is shown in Fig.1. Final position of product and roll is shown in Fig.2. The diameter of roll is 10mm. RPM of roll is 4. The velocity of the product at the exit plane is 2.2mm/sec.

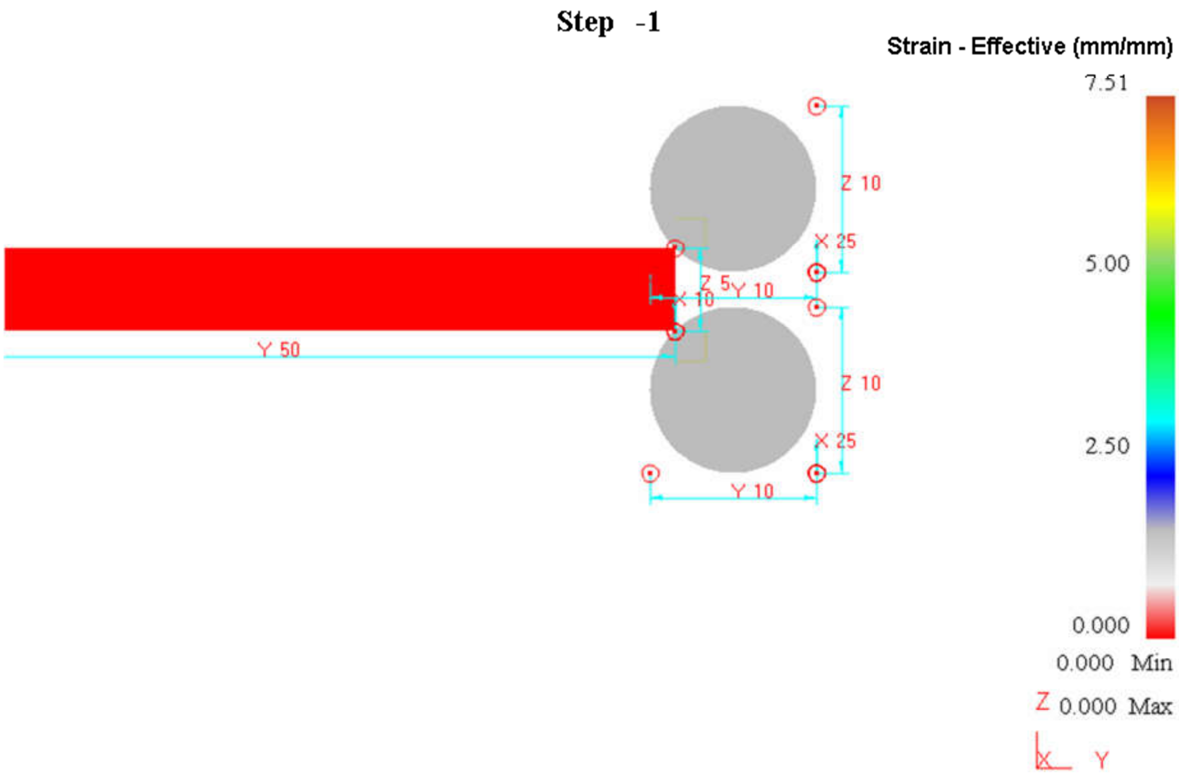

Fig. 1 Initial position of roll and billet

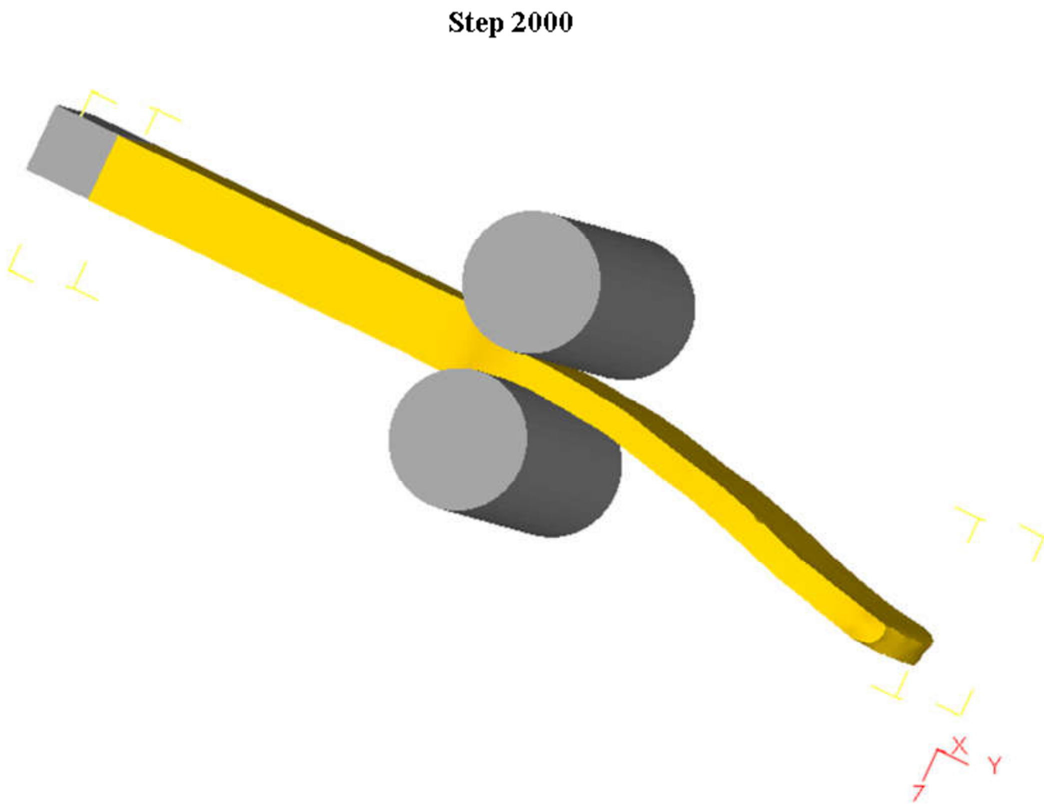

Fig. 2 Roll and billet after deformation

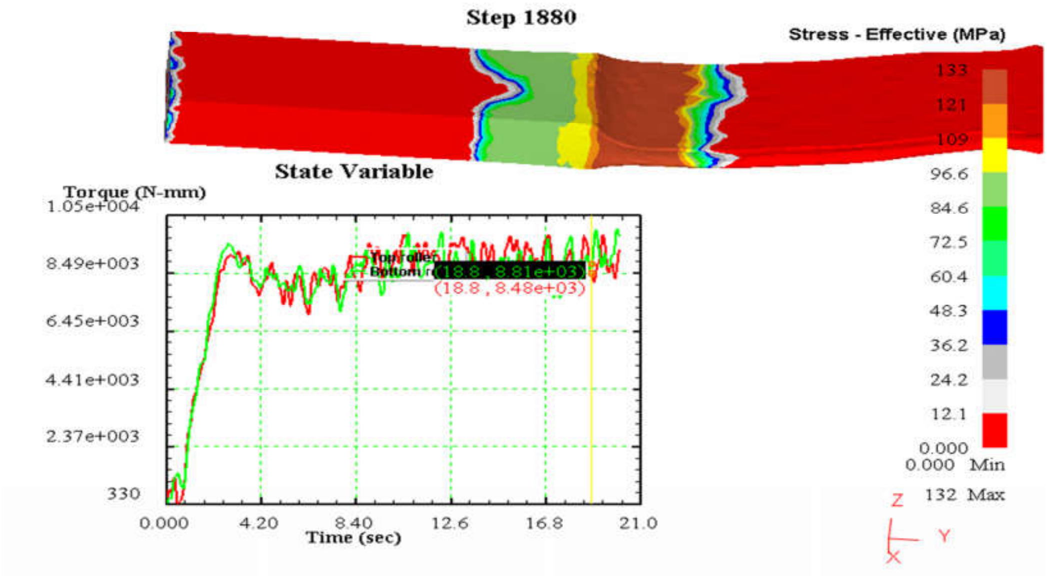

Fig. 3 Variation of roll torque with respect to time

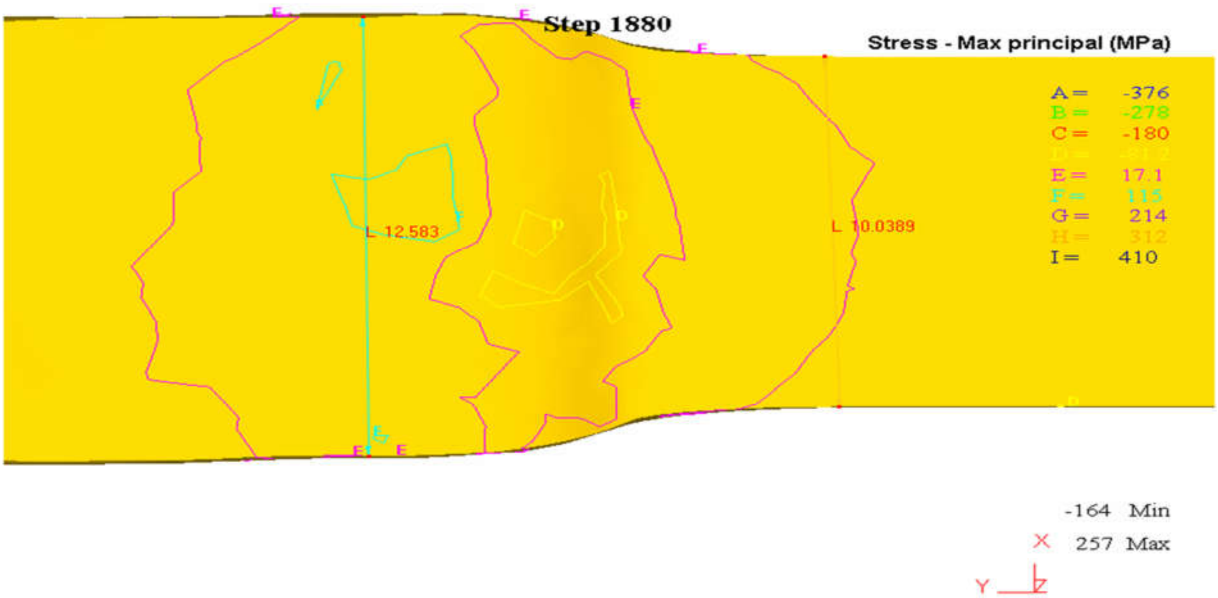

Fig. 4 Spread in rolled product

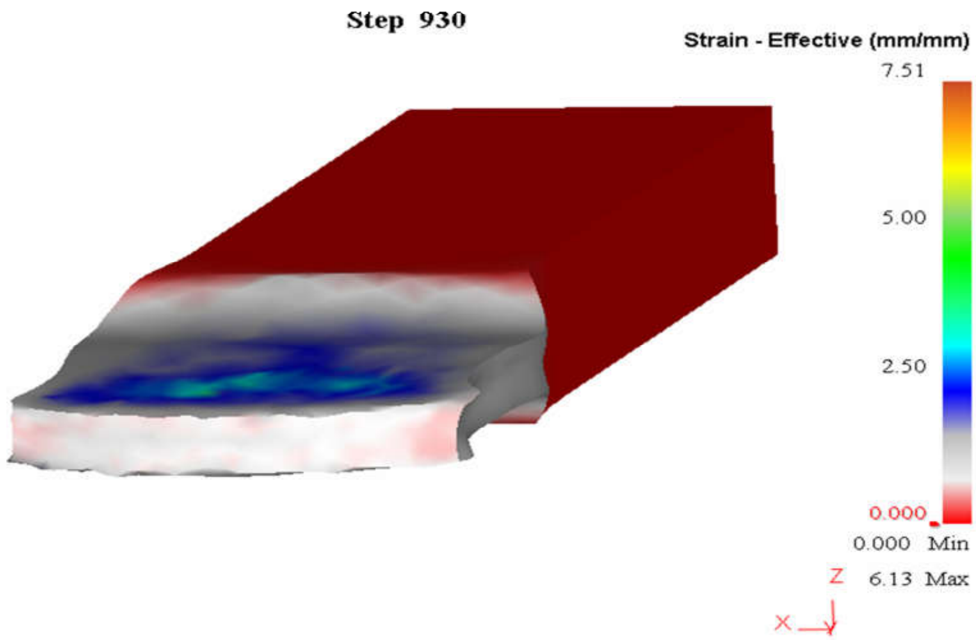

Fig. 5 Bulge profile in rolled product

RESULTS AND DISCUSSION

The variation of roll torque with respect to time is shown in Fig3. It is observed that 8490Nmm is the roll-torque. The spread in rolled product is shown in Fig.4. The width of rolled product increases to 12mm from 10mm at 66% of reduction. The bulge profile of the rolled product is concave in nature as shown in Fig.5. The bulge profile obtained from the upper bound method is also concave in nature. It is observed that the qualitative nature of the bulge profile for both the methods is similar. The quantitative verification is to be done considering identical condition in each case.

REFERENCES

1. Tselikov A. I. –'Stress and strain in metal rolling', Mir Publishers Moscow.
2. Larke E. C. E.-'Rolling of strips, sheets and plates' Chapman and hall, London, 1957.
3. Roll Pass Design, Percy lund, Humpries Company Limited, London and Radford, 1960.
4. Oh S. I. and Kobayashi S – An approximate method for a three dimensional analysis of rolling', Int.. ech. Sci., V33, 1975, pp293.

5. Hill. R ‘A General method of analysis of metalworking process’ ournal of Mechanics and Physic of solids, Vii, 1963, pp305.
6. Li G. J. and Kobayashi S, ‘Spread analysis in rolling by the rigid plastic finite element method’ Numerical methods in Industrial Forming rocesses, Pineridge ress td, wansea, U. K., 1982, pp777.
7. Kennedy K. F. ‘ A method for analyzing spread, elongation and bulge in flat rolling, V109, 1987, pp248.
8. Yih C. S. ‘tream functions in three-dimensional flow’ a Haulle Blanche, V12, 1957, pp445.
9. Nagpal V and Altan T- ‘Analysis of the three-dimensional metal flow in extrusion of shapes with the use of stream functions’, Pro. Of the 30th North American Metal Working Reseaech Conference, arnegie-Mellon University, Pittsburgh, ay 1975.