MODELING OF FRICTION IN COLD STRIP ROLLING UNDER HYDRODYNAMIC LUBRICATION

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Abstract

A friction model with the help of ANSYS software is made for cold strip rolling under hydrodynamic lubrication. The finite element model is developed from a flow problem of non-Newtonian incompressible fluid. The result of solution is nodal velocities over the arc of contact and the friction (shear stress) model is determined using the formula developed by Saxena et.al. The friction model as a result of applying ANSYS software shows the same trend as the existing developed model.
Keywords *: friction, cold strip rolling, hydrodynamic lubrication, simulation*

1. Introduction

The physical phenomena constituting a massive forming process such as rolling is difficult to express by quantitative relationships. The metal flow, the friction at the tool-material interface, heat generation and transfer during plastic flow and the relation between the micro structural properties and process condition are difficult to predict and analyze.

The complexity of the rolling process leads to the necessity of creating suitable simulation model. Bearing in mind that rolling process can actually be carried out due to friction, an adequate modeling of the friction at the interface between the roll and the workpiece is of great importance.

2. Problem formulation

2.1 Finite element analysis

In rolling process, the mechanical behaviour of a material is governed by the continuity and momentum equations. For a steady state process:[1]

$$\frac{\partial v_i}{\partial x_i} = 0 \quad (1)$$

$$\rho v_j \frac{\partial v_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial S_{ij}}{x_j} \quad (2)$$

where v_i , v_j are components of velocity vectors; x_i , x_j are Cartesian coordinates; ρ and p is density and pressure respectively; S_{ij} is the deviatoric part of stress tensor.

The equation (1) and (2) is similar to that of a flow problem of a non-Newtonian incompressible fluid.

For the steady state process, the finite element model of the above equations is given by: [2]

$$\left([A_e^{advection}] + [A_e^{diffusion}] \right) \{ \phi_e \} = \{ S_e^{\phi} \} \tag{3}$$

where $[A_e^{advection}]$ and $[A_e^{diffusion}]$ are the global coefficient matrix, $\{\phi_e\}$ is the velocity vectors, $\{S_e^{\phi}\}$ is the source term or force vectors.

2.2 Deformation zone

The geometry and the coordinate system of the problem are shown in Fig.1. The shear stress t_s equation is given by: [1]

$$t_s = \frac{\eta}{l} [\, 3(v_R + U_1) l_1 / l - 2(v_R + 2v_s)] \tag{4}$$

$$\text{where} \quad l = l_1 \left[1 - \frac{r\, U_1}{[(1-r)\, v_R + U_1] L_s^2} (2\, \xi\, L_s - \xi^2) \right] \tag{5}$$

$$l_1 = \frac{3\eta_0\, \delta\, (v_R + U_1)}{\tan \theta} \tag{6}$$

η is viscocity, η_0 viscocity at atmospheric pressure, l lubricant film thickness, l_1 film thickness at the inlet zone, U_1 inlet velocity, v_R roll velocity, v_s tangential velocity, r reduction ratio, L_s length of the arc of contact , δ lubricant constant, θ angle of bite.

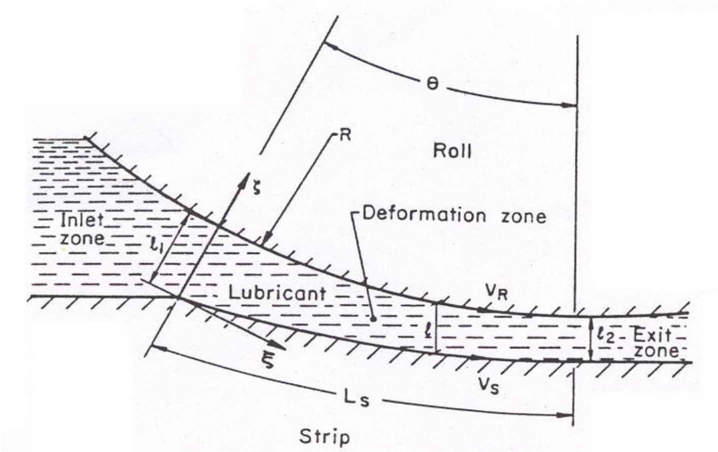

Fig. 1 The geometry and coordinate system of the deformation

3. Numerical Simulation and Analysis

The domain or the control volume along with the coordinate system and the boundary conditions are shown in Fig.2.[1]

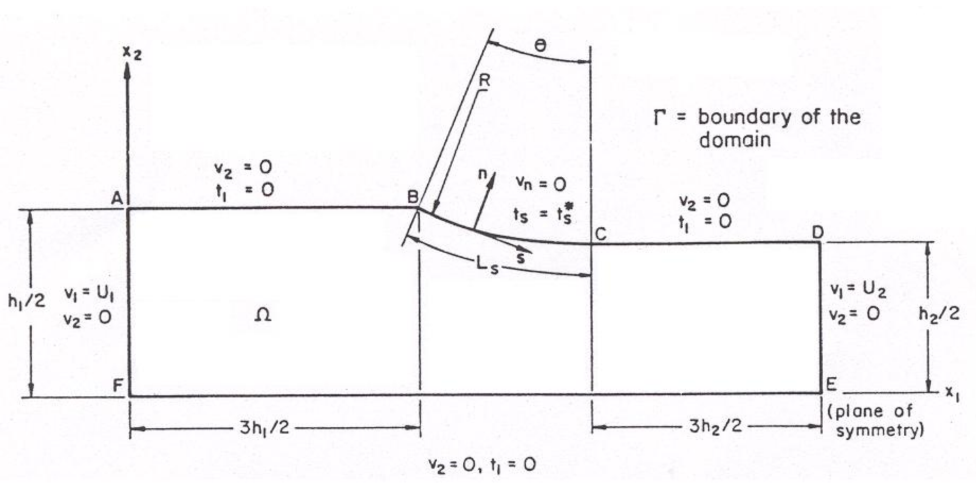

Fig. 2 The domain and the boundary

The condition on the boundaries AF and DE are

$v_1 = U_1 \quad , \quad v_2 = 0 \quad$ on AF

$v_1 = U_1 \quad , \quad v_2 = 0 \quad$ on DE

Here U_1 and U_2 are inlet and exit velocities respectively, related by:

$$U_2 = U_1 (h_1/h_2) = U_1 /(1\text{-}r)$$

where h_1 and h_2 are the inlet and exit thickness of the strip respectively; r is the reduction ratio.

The inlet velocity U_1 is obtained by the relationship [3]

$$U_1 = v_R (h_n/h_1)$$

where v_R is the roll velocity and h_n is the strip thickness at the neutral point being calculated using Avitzur's analytical equation [3].

Along the boundaries ABCD and FE are the wall in which the fluid flows, therefore on that boundaries, the velocities are zero.

The initial condition for pressure on boundary DE where the fluid flows out is zero.

Using the ANSYS software then a model is created based the given data above and the finite element mesh is shown in Fig.3.

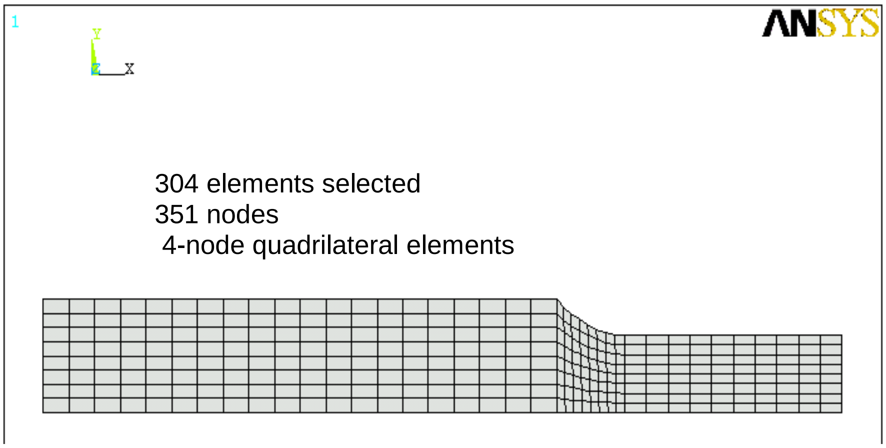

Fig. 3 Finite Element mesh

The nodal velocities are obtained by solving Eq.(3) in an iterative fashion. The friction (shear stress) model over the arc of contactis determined using the Eq.(4) and the graph is depicted in Fig.4. The graph as a result of ANSYS modeling shows the same trend as Saxena et.al's model using 9-noded rectangular elements with a bi-quadratic approximation for the velocity components.

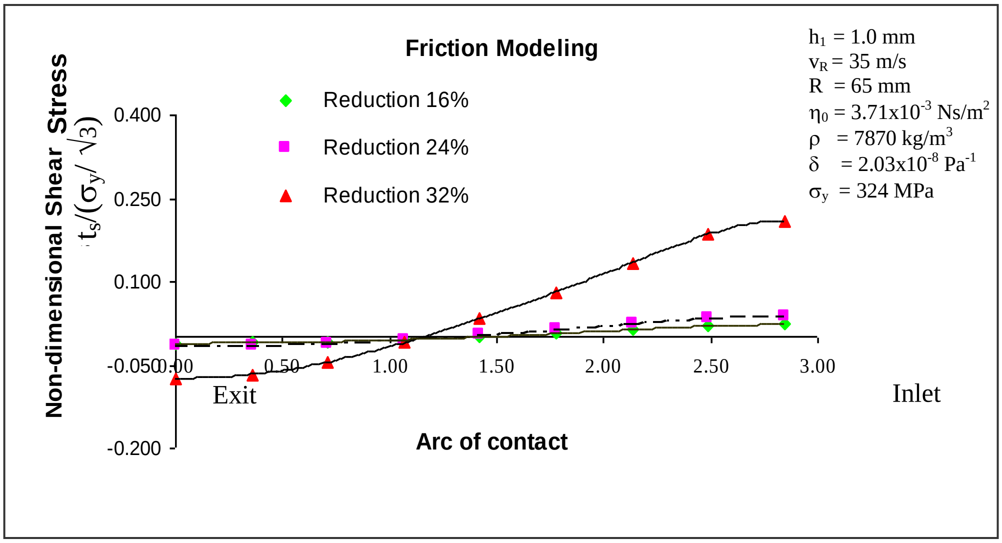

Fig. 4 Non-dimensional Shear Stress vs Arc

4. Conclusion

With the object of modeling the friction (shear stress) over the arc of contact using the ANSYS software, the followings can be drawn:

1. Comparing the present model with the existing one, a similar trend is obtained and therefore it is judged that the calculations are valid enough for the analysis of the friction.
2. The discrepancy between the result of present model and the available one is due to the different shape functions used for two compared models. In ANSYS, the shape function available is for 2-D 4-node quadrilateral elements while in the existing model, it uses 9-noded rectangular element with bi-quadratic approximation for the velocity components.

Reference

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