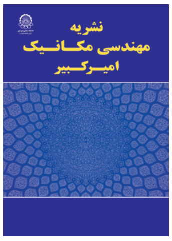

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A New Deformation Model for Bimetal Tubes Extrusion Process

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ABSTRACT: In this paper, bimetal tubes extrusion process through conical dies has been analyzed by upper bound method using stream functions. The bimetal tube is in un-bonded conditions initially and the proposed deformation model, investigates the bonding at the interface of two metals in the deformation zone. For this propose, the deformation region has been divided into three deformation zones where the position of the start point of bonding at the interface of two metals is determined. For each deformation zone, an admissible velocity field has been proposed and the internal power, shear and frictional powers and the total power have been calculated. The total power, which is expressed by deformation zone boundaries and the position of the start point of bonding, is optimized and the extrusion force has been calculated. Analytical results are compared with the results given by experimental data of other researchers and also by finite element method that show a good agreement. Finally the effect of various extrusion conditions such as reduction in area and semi die angle upon the extrusion force and the position of the bonding start point at the interface have been investigated.

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1- Introduction

Demands for using bimetal materials are growing quickly in everyday life. Bimetallic composites, in which two different metals or alloys are joined together, are important materials because of their special properties and functions not found in individual metals or alloys. The proper selection of components allows obtaining products with valuable properties [1].

In this paper the bimetal tube is in un-bonded conditions initially and the proposed plastic deformation model is used to investigate bonding at the interface of two metals in the deformation zone.

2- Upper Bound Method

The deformation region has been divided into three zones denoted by zones I, II and III.

2- 1- Velocity field

The flow pattern of the plastic deformation in each zone is assumed to be represented by a single stream function denoted by ϕ_1, ϕ_2 and ϕ_3 respectively, as

$$\phi_1 = Q_1\left[\frac{r^2 - r_2^2}{r_1^2 - r_2^2} + A_1\left(r^2 - r_1^2\right)\left(r^2 - r_2^2\right)\right] \tag{1}$$

$$\phi_2 = Q_2\left[\frac{r^2 - R_m^2}{r_2^2 - R_m^2} + A_2\left(r^2 - R_m^2\right)\left(r^2 - r_2^2\right)\right] \tag{2}$$

$$\phi_3 = Q_3\left[\frac{r^2 - r_2^2}{r_1^2 - r_2^2} + A_3\left(r^2 - r_1^2\right)\left(r^2 - r_2^2\right)\right] \tag{3}$$

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$$r_1 = r_1(z) = R_{1f} + \frac{R_{1o} - R_{1f}}{Z_5} z \tag{4}$$

$$r_2 = r_2(z) = R_{2f} + \frac{R_{2o} - R_{2f}}{Z_4 - Z_1}\left(z - Z_1\right) \tag{5}$$

where Q_1, Q_2 and Q_3 denote the volume flow rates at any cross section in zones I, II and III, respectively. A_1 and A_2 denoting the gradient of the horizontal velocity distribution in zones I and II, are assumed to be a quadratic function of z as

$$A_1 = b_1 z^2 + c_1 z + d_1 \tag{6}$$

$$A_2 = b_2 z^2 + c_2 \tag{7}$$

A_3, denoting the gradient of the horizontal velocity distribution in zone III must be determined by the boundary condition along S_8.

The horizontal and radial velocities in the core and the sleeve layers can be derived directly from the stream functions as

$$V_r = -\frac{1}{2\pi r}\frac{\partial \phi}{\partial z} \tag{8}$$

$$V_z = \frac{1}{2\pi r}\frac{\partial \phi}{\partial r} \tag{9}$$

Due to the continuity of stream line at the entrance and exit of the die, boundary functions at the entrance and exit, S_1, S_2, S_3 and S_4, can be determined.

2- 2- Condition of incompressibility

From the velocity-strain rate relations, the normal strain rates in each direction are obtained as

$$\dot{\varepsilon}_{rr} = \frac{\partial V_r}{\partial r} = \frac{1}{2\pi r^2}\frac{\partial \phi}{\partial z} - \frac{1}{2\pi r}\frac{\partial^2 \phi}{\partial z\,\partial r} \tag{10}$$

$$\dot{\varepsilon}_{zz} = \frac{\partial V_z}{\partial z} = \frac{1}{2\pi r}\frac{\partial^2 \phi}{\partial z\,\partial r} \tag{11}$$

$$\dot{\varepsilon}_{\theta\theta} = \frac{V_r}{r} = -\frac{1}{2\pi r^2}\frac{\partial \phi}{\partial z} \tag{12}$$

Clearly, an arbitrary stream function can automatically satisfy the condition of incompressibility.

2- 3- Boundary conditions

Because the interface between zones II and III is assumed to have no relative sliding, A_3 can be obtained as

$$A_3(z) = \frac{1}{\left(r_1^2 - r_2^2\right)^2} - \frac{Q_2\left(1 + A_2(z)\left(r_2^2 - R_m^2\right)^2\right)}{Q_3\left(r_2^2 - R_m^2\right)\left(r_1^2 - r_2^2\right)} \tag{13}$$

The horizontal and radial velocities along the interface of zones I and III, which is assumed to be a vertical straight line, must be equal to each other on both sides. So from the geometry boundary conditions the constants in Eq. (6, 7) can be obtained.

2- 4- Internal power of deformation

The internal power of deformation is given by

$$\dot{W}_i = \sigma_m \int_V \dot{\bar{\varepsilon}}\, dV\,, \quad \sigma_m = \frac{\int_0^{\bar{\varepsilon}_m} \sigma_c\, d\varepsilon}{\bar{\varepsilon}_m}\dot{\varepsilon}_{rr}\,, \tag{14}$$

$$\dot{\bar{\varepsilon}} = \sqrt{\frac{2}{3}\left(\dot{\varepsilon}_{rr}^2 + \dot{\varepsilon}_{zz}^2 + \dot{\varepsilon}_{\theta\theta}^2 + 2\dot{\varepsilon}_{rz}^2\right)}$$

where σ_m denotes the mean flow stress of the material and dV is a differential volume in the deformation zones.

2- 5- Shear power dissipation

The general equation for the power losses along a shear surface of velocity discontinuity in an upper bound model is

$$\dot{W}_s = \frac{\sigma_m}{\sqrt{3}} \int_S |\Delta v|\, dS \tag{15}$$

2- 6- Frictional power dissipation

The general equation for the frictional power losses along a surface with a constant friction factor m is

$$\dot{W}_f = \frac{m\,\sigma_m}{\sqrt{3}} \int_S |\Delta v|\, dS \tag{16}$$

3- Finite Element Simulation

To make a comparison with the developed model, a bimetal tube composed of aluminum and copper is used. The configuration of the sleeve and core layers is shown in Fig. 1. The flow stresses for copper and aluminum and the friction factors are obtained by Ref [1]. The extrusion process is simulated using the finite element code, ABAQUS.

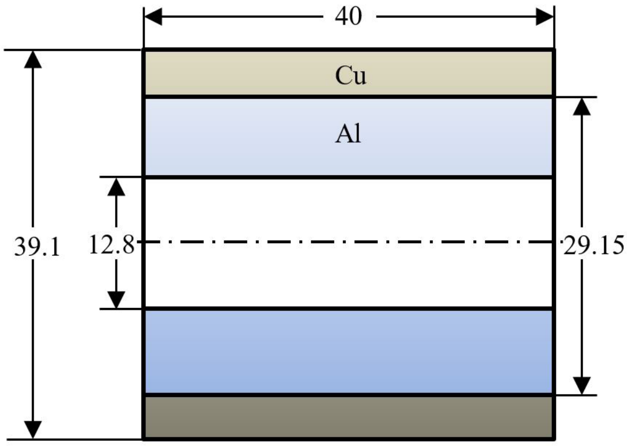

Figure 1. Configuration of the bimetal tube before extrusion (dimension are in mm)

4- Results and Discussion

In this part effect of various extrusion conditions such as reduction in area and semi die angle upon the extrusion force and position of bonding point at the interface have been investigated.

In Fig. 2 the extrusion force variation during the whole extrusion process obtained from the upper bound solution and the FEM simulation are compared with the experimental results for conical die, obtained from Ref [1] and the upper bound solution from Ref [2]. The results show a good agreement among the analysis, the FEM and the experimental data.

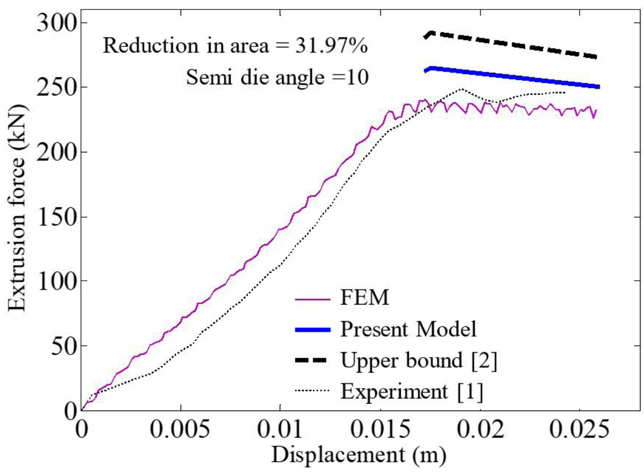

Figure 2. Comparison of analytical model, FEM, experimental and the upper bound solution [2] force-displacement curves

The effect of semi die angle on the bonding length at the interface between layers is shown in Fig. 3. As it is expected, for a given value of reduction in area, there is an optimum semi die angle in which the relative bonding length is maximized.

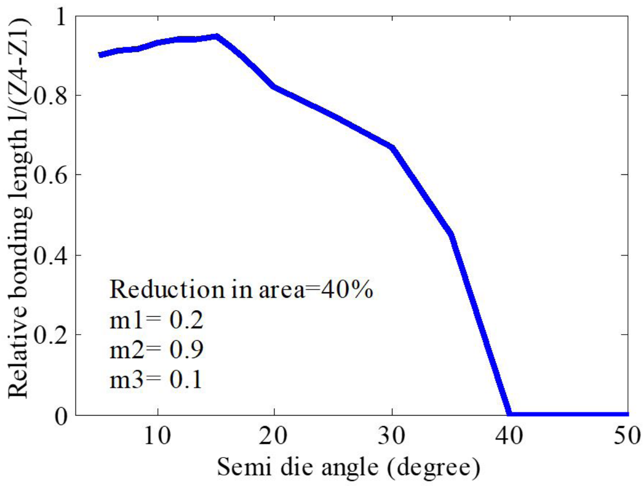

Figure 3. Effect of semi die angle upon the bonding length at the interface between layers

5- Conclusions

In this paper, bimetal tube extrusion process through conical dies has been analyzed by upper bound method. Bimetal tube is in un-bonded conditions initially and the proposed plastic deformation model, investigated bonding at the interface of two metals in the deformation zone. Analytical results are compared with the results given by experiments of other researchers and also by finite element method that show a good agreement.

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