Modelling and simulation of three-roll bending process of bimetal Circular Billet

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Abstract. Bending process is an important metal forming technique which is used on industrial scale. An asymmetric three-roll bending is sub-type bending process and has a simple configuration. The present study has focused on the investigation of the bonded bimetal billet. The two material consist of copper alloy rod inside an aluminium alloy (AA 6061-T6) tube with one common dimension between the rod and the tube which is the radius of rod and the inner radius of tube. The effect of varying the radius has considered on this study. The results shown that the increasing of copper alloy radius increased the reaction load and the mass of the bimetal billet with exponential increment.

1. Introduction

Alloys consist of two or more different parent materials. Because of the characteristic advantage in term of thermal, mechanical, physical, corrosion resistant and other properties, the composite material has been used in different industrial applications [1–4]. Fabrication of alloys can be attained through several existing processing methods including casting [5,6], diffusion bonding [7–9], roll bonding [10–15] and explosive welding [16–18]. The selection of fabrication technology and materials composition have influenced the mechanical properties of manufactured alloys [19].

Complex metal products for manufacturing, like large plastic forming, bending and hemming, the formability and flow behaviour of alloys are not the same with special characteristics relative to homogeneous material [20]. Verguts and Sowerby [21] have investigated the bending of bimetal laminated sheets. Majlessi et al. [22] have studied the bending behaviour of a linear stress-strain model for the bi- and tri-metal plates. Yoshida et al. [23] found that the bendability and residual stress of bimetal plates have influenced the relative position of the weak and the strong steel layers. Ryutaro et al [24] have testified that the thickness ratio and relative position of component layers were influenced by the bimetal spring-back in draw-bending operation. Xiao et al. [25] and Yilamu et al. [26] have applied the finite element (FE) modelling to study the behaviour and response of stainless steel cladded with aluminium bimetal sheets on bending and flexural. Advanced bending theory and Ludwik hardening law have utilized to investigate the bending of bimetal plates as explained elsewhere [20, 27]. The authors have compared their results of the bending characteristics with FE model under different material conditions. Other researchers were use a hybrid method of deformation and investigate it either experimentally or through finite element methods [28].

Most of researchers have investigated the total performance of bimetal laminate sheets / plates / rods under roller bending, such as bending angle, bending moment, thinning, and bimetal billet fabrication processes. The main objective of this paper is to study the effect of variables of combination of two
different metals called bimetal, including the ratios of component, relative positions and bending characteristics of bimetallic materials. Numerical simulation using finite element modelling were also used to investigate the bending deformation process.

2. Methods and Materials

2.1. Geometric Modeling
A schematic of the asymmetric roll bending process is shown in Fig.1 where a billet is being processed by three identical rolls in the three-roll bending machine. The process would start when bottom roll goes up in the vertical direction without rotation. In the same time, the plate to be bent is passed between the rollers. In this manner, the plate is pressed against the top rolls. This is followed by the rotation of top rolls in the clockwise sense. Further, the center of the bottom roll describes the diameter of the bending.

![Figure 1. Schematic of asymmetrical three-roll bending process.](image)

2.2. Material Modeling
In the present model, bimetal contains two type of material in which all of them are elasto-plastic material. Here, aluminium alloy (AA 6061-T6) tube and copper solid rod were used in the material model. The mechanical propertied fed in to the FE model is illustrated in Table 1. The Von-Mises yield criterion with isotropic hardening was used for matrix yield surface. The simulation was carried out at room temperature, hence all properties were provided at room temperature only.

| Property                | Copper   | Aluminium (AA 6061-T6) |
|-------------------------|----------|-------------------------|
| Density kg/m³           | 8300     | 2770                    |
| Young's Modulus GPa     | 110      | 71                      |
| Poisson's Ratio         | 0.34     | 0.33                    |
| Yield Strength MPa      | 280      | 280                     |
| Tensile Ultimate Strength MPa | 430 | 310                     |

The circular billet was made from two materials as shown in Fig 2. The rod of cupper material with radius was varied from 25 to 45 mm. In addition, the second material is a tube of AA 6061-T6 aluminium alloy in which the inner radius was same as the copper rod radius and the outer radius was kept constant value of 50 mm.
3. Finite Element Modelling

The model mesh of bimetal billet consists of 60415 nodes and 48408 elements of quad/tringle combination for AA 6061T6 alloy and copper rod respectively which is shown in Fig. 3. The adaptive mesh was used to overcome an elemental distortion during the FE running. The three rollers were treated as a rigid body.

![Figure 3. 3D Mesh of the biomaterial circular billet](image)

**Figure 2.** Billet with two materials (Cooper alloy and Aluminium Alloy).

**Figure 4.** Bending processes showing the circular bimetal billet and the three roller with arrow indicate the type and direction of its motion.
Figure 4 shows the three roller bending operation with the feeding of bimetal circular billet. The circular billet was modeled as a half circle taking into consideration of the symmetry and to reduce the tone of running. The analysis step was done by two steps. The two rollers on the right side were kept idle on the first step then rotated clockwise with 180°. However, the roller on the right side was translated on the negative side of x-axis with 20 mm on the first step and 40 mm at the second step. Moreover, the same roller was kept idle of rotation on the first step and rotate with 180° at the second step.

4. Results and Discussion
The following definition and assumptions were applied in order to get acceptable results and to minimize the computational cost. Billet material was assumed isotropic. The elastic-plastic behavior of the material was defined by bilinear elastic-plastic which is having constant value of elastic modulus, yield strength and tangent modulus. The values are illustrated in Table I

![Figure 5](image1.jpg)  
**Figure 5.** Total deformation of the billet at the end of lading (a) and equivalent elastic strain of billet (b).

![Figure 6](image2.jpg)  
**Figure 6.** Normal stress in directions x, y and z through the centre of circular billet from (A to B) with r = 30 mm.
Table 2. Structural Steel NL and Aluminium Alloy NL mechanical proper.

| #  | r (mm) | Total mass (kg) | Reaction Force (kN) |
|----|--------|-----------------|---------------------|
| 1  | 25     | 11.41           | 926.33              |
| 2  | 30     | 13.09           | 1232.98             |
| 3  | 35     | 15.06           | 1644.34             |
| 4  | 40     | 17.34           | 2186.91             |
| 5  | 45     | 19.93           | 2903.35             |

Figure 7. Displacement in y direction vs. reaction force. (Elastic and Plastic Portions).

5. Conclusion
The finite element analyses were carried out to study bimetal billet bended process of an asymmetrical three-roll with different material of circular cross section geometry successfully. The bilinear elastic/plastic material model was selected for the billet corresponding to force and tensile tests. The inner material is copper with higher density and strength while the aluminium is in the outer side of the billet. Results of the simulation has shown that the reaction force and the mass increased exponentially with the increase of inner radius. The exponential power constant is higher for the reaction force as about twice of the mass.

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