Simulation of co-extrusion of Mg/Cu clad bi-metals using Fine Element Method

M. N. Kyalo, J. M. Mutua Z. Y. Liu, and W. Z. Chen

Abstract—In this paper finite element simulation of co-extrusion of Magnesium/Copper clad composite was carried out using DEFORM-2D software. In the simulation, a comparison between two models; a cup-shaped sleeve and a pipe-shaped sleeve was done to analyze flow behavior especially with regard to sleeve thickness (t_s). The variation of load between the two set ups and the effect of core shortening for the pipe shaped sleeve were analyzed. A cup-shaped sleeve resulted to a thinner sleeve diameter in comparison to a pipe-shaped sleeve and failure occurred for thin sleeves. In general a cup promotes concurrent flow of both core and sleeve but this is accompanied with material wastage. Concurrent flow of material can be promoted in a pipe sleeve set up by shortening the core. The results in the paper will contribute positively in the optimization of geometry in extrusion of bi-metals for applications in electrical and automobile industries.

Keywords—Co-extrusion, core shortening, cup sleeve, Pipe sleeve

I. INTRODUCTION

CO-extrusion is a process of concurrently extruding two or more materials from a single composite billet [1]. The major advantage of co-extrusion is the completion of the process in a single step with development of interfacial bond in a short time. In metal co-extrusion, a combination of geometric and process parameters have the greatest effect compared to the inherent properties of the materials making up the composite billet [2]. Extrusion causes high compressive state of stress with shear which can improve workability of materials and achieve high reductions [3]. Bi-metallic materials can be obtained through co-extrusion, they exhibit specific physical and mechanical properties as a result of combined properties of the constituent metals , these properties can hardly be obtained for monometallic materials [4]. Sound flow of the core is favored by small core-to- billet diameter ratio and the tendency to core fracture will increase with increasing volume fraction [5].

In this paper, composite billets made of magnesium cores clad by a copper sleeves were modelled. Magnesium possesses high strength to weight ratio, whereas copper has a higher corrosion resistance. Simulations were carried out to compare the effects of cup-sleeve and pipe-sleeve cladding set ups, find the optimum ratio of sleeve thickness to core diameter ($R_s : R_c$) sufficient to promote concurrent flow and analyzed the effect of core shortening. DEFORM 2D$^{\text{TM}}$ software version 8.1 was used in the simulation. The software is a process simulation system designed to analyze two-dimensional flow of complex metal forming processes using an axi-symmetric or plane strain assumption. A comparison between simulation and experimental results was done.

II. EXPERIMENTAL PROCEDURE

Composite billets made of magnesium cores and copper sleeves were modeled as elastic materials. Two types of billets, were modeled; one with pipe-shaped sleeve and another one with cup-shaped sleeve as shown in Fig.1 (a) and (b) respectively. The die was modeled as a rigid body, elastic deformation was neglected without loss of accuracy due to small magnitude of deformation compared with that of the billet materials. The die cavity had a diameter, ø52 mm and an orifice of ø18 mm (extrusion ratios of 8.3), the die semi angle was $45°$. Because of geometrical symmetry of the specimens,

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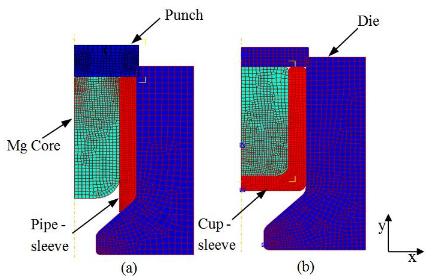

Fig. 1. Geometrical set up for simulation with composite billet and tooling (a) billet with cup sleeve (b) billet with pipe -sleeve.

half symmetric FEM models were deemed to be sufficient. A shear friction factor of 0.15 between the following interfaces: sleeve-core, bottom die-sleeve, and punch-sleeve. A shear factor of 0.36 was set for the die-core and punch-core interfaces, all based on the nature of materials. Friction was assumed to be constant during simulation. There was no inter-object relationship between the punch and the die, thus it was possible to create a negative clearance characterized by a large punch and penetrating a smaller bottom die. The sleeve and core were modeled with relatively higher mesh density compared to the dies. Heat transfer coefficient for deformation process was assigned a value of 11 $N/sec/mm/C$. The boundary conditions set were: Environment temperature of $20°C$, velocity of elements along the centerline was set as zero along the X-axis. The punch was set to move along the Y-axis at 20 m/s. Material properties are illustrated in Table 1, flow curves for pure copper and pure magnesium were adopted for the simulation.

Table 1: Properties of the materials used in the simulation

Property	Pure Cu	Pure Mg	AA 6061 H-13 Steel
Density (Kg/m3)	8960	1728	7760
Young Modulus (kPa)	130	45	210
Poisson ratio	0.3	0.35	0.3
Thermal conductivity (W/m-K)	384	150	50
Heat Capacity	3.5302	1.827	3.822
Emissivity	0.5	0.5	0.7

Load prediction curves were plotted against time. The punch and billet were at room temperature at the start of extrusion. Variation in temperature depicted in the graphs refers to the temperature variations of the bottom die.

The first experiment was done to compare the two types of billets' geometry and find the optimum $R_s : R_c$ ratio. The billets were modeled with an overall diameter of 52 mm and a length of 58 mm. Sleeve thickness was varied from: 1, 3, 5, 7, 9 to 11 (mm), with $(R_s : R_c)$ as 2.0% 6.5% 11.9% 18.4% 26.5% 36.7%, for example for the sleeve of 1 mm the core had a diameter of 50 mm and $R_s : R_c$ of 2.0%. To investigate the effects of temperature of the die on load, simulations were done at different temperatures as follows: $20°C$, $100°$, $150°C$, $200°C$ and $300°C$, for sample billets. Finally, simulations on the effect of core shortening on material flow for a pipe sleeve with a sleeve thickness of, $t_s = 7\ mm$; (optimum sleeve thickness) were performed.

III. Results and Discussion

A. Sleeve thickness

Generally, sleeves with small $R_s : R_c$ ratio were not sufficient to clad the magnesium core. The sleeve breaks and the core extrudes at high velocity without sufficient cladding. Higher $R_s : R_c$ ratios seem to favor extrusion. Higher sleeve thickness can withstand stress thus eradicating sleeve fracture [6].

In the case of a pipe sleeve set up when $R_s : R_c$ was 2% , the sleeve was stuck in the die orifice thereby hindering the flow. When the $R_s : R_c$ was increased to 6.5% the sleeve flows applying compression to the core but was incapable of accommodating shear stress thus breaking. As the $R_s : R_c$ was increased to about 12%, sleeve's propensity to flow increases but it still lags. When $R_s : R_c$ ratio was 18%, the sleeve and the core were moving at comparable speed This was found to be the optimum thickness to minimize sleeve fracture and promote concurrent flow. $R_s : R_c$ ratio above 18% resulted to reduction of compressive forces on the interface and velocity contours were more discontinuous. The sleeve flows without fracture but the core material flow with higher velocity. The high thickness of copper leads to shift of the interface near the axis of symmetry where compressive stresses are relatively low, thus the bonding between the two metals is relatively weaker.

In the case of a cup-sleeve set up, the velocity of core was relatively low compared to that in pipe-sleeve setup, because the cup controls flow of the core. It was observed that the cup sleeve produced a concurrent and a more uniform flow compared to the pipe sleeve. Fig.2 (a) and (b) shows simulation results $t_s = 7\ mm$, at a temperature of $200°C$, average sleeve thickness of 2.0 mm and 2.5 mm was obtained for the cup sleeve and pipe sleeve respectively.

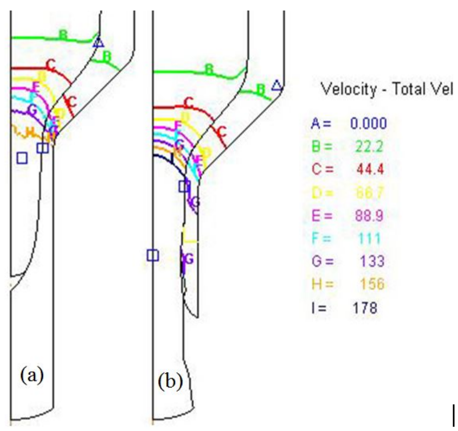

Fig. 2. Variation of sleeve thickness 7 mm thick sleeve, die temperature 200C (a) cup-shaped sleeve, (b) pipe-shaped sleeve.

In the pipe-shaped sleeve set up, the core extrudes at a high speed and balloons in the leading side while the sleeve lags. Since the cup controls the core, more stresses are transmitted to the sleeve leading to more plastic deformation.

B. Core shortening

It was possible to improve flow behaviour for the pipe-sleeve by shortening the core, this is shown in Fig.3. Shortening the core by a length equal to 1.2% of sleeve thickness (t_s) produced flow behavior similar to that of cup-sleeve. The extended edge of the sleeve (h) curves inwards thus controlling the speed and hindering ballooning of the core. Other parameters like the radius (R_f) had an influence on the flow behaviour, radius of 3 mm at the edge favored uniform flow of the sleeve of 7 mm thick .

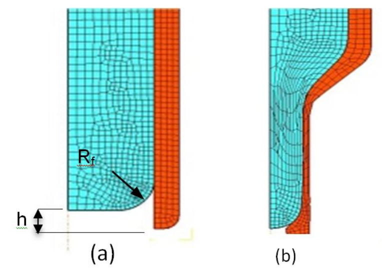

Fig. 3. Core shortening; (a) Set up, (b) Flow behavior

C. Load prediction

Load prediction is important in analysis since the reduction in load translates into reduction in cost. Fig.4 (a) and (b) shows the effect of temperature on load. In both cases of pipe sleeve and the cup sleeve, load increases as the billet fills the extrusion chamber and decreases after breakthrough attaining a relatively level curve. The peak observed in the cup sleeve is produced by upsetting the core before breakthrough. At $20°C$ the load is slightly higher than at $150°C$ and $200°C$. As the bottom die temperature is increased the temperature gradient between the billet and die increases.

Fig.4 (c) shows the effect of the variation of cup-sleeve thickness to the load at a constant die temperature of $200°C$. As the sleeve thickness is increased, the load decreases significantly. The flow stress of copper is lower than that of magnesium at low temperatures. Increasing the sleeve thickness leads to a smaller core, thus magnesium content which is difficult to deform at low temperature is reduced.

D. Comparison between simulation and experiments

Fig.5 (a) shows extrusion simulation result of a pipe-sleeve ($t_s = 7mm$)extruded at die temperature of $200°C$, and Fig.5 (b) shows actual extruded

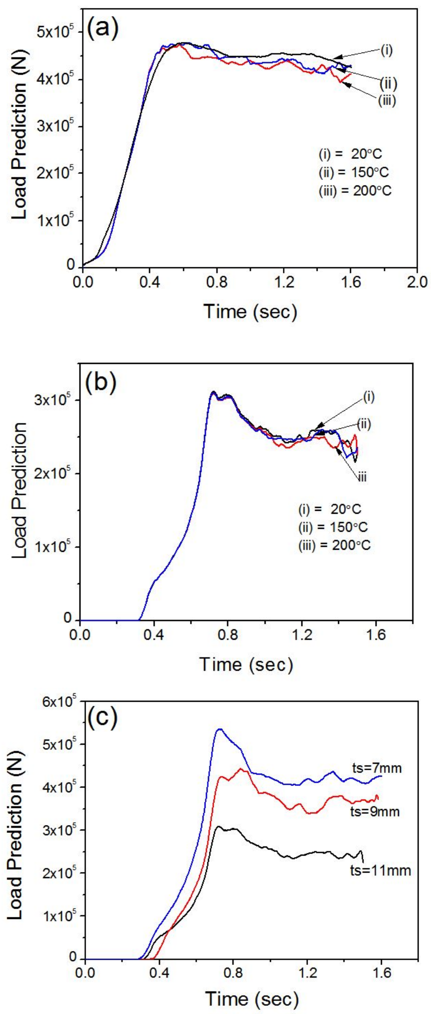

Fig. 4. Fig. 3-5 Load predictions for 7 mm sleeve:(a) Pipe sleeve at different temperatures, (b) Cup sleeves at different temperatures.(c) Cup sleeve constant temperature of 200C - varied sleeve thicknesses .

sample under similar conditions. The results show a good relationship of flow behavior between simulated and the experimental results. It can be observed that after extrusion, the core material was longer than the sleeve material in both cases. There existed some discrepancies between FEM and actual results; in simulation, the assumption that the friction was equal on die surfaces was to simplify the

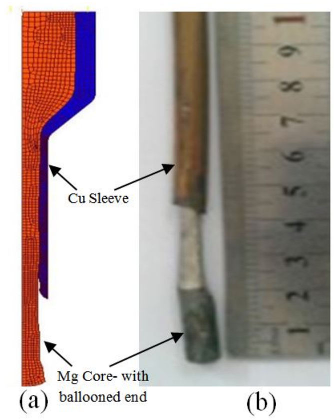

Fig. 5. Core shortening; (a) Set up, (b) Flow behavior similar to cup sleeve

simulation. The friction factor between the sleeve and core interface was set to 0.36, this was an assumption since the friction coefficient is difficulty to determine in reality. The actual flow stress curves are not exactly the same as those adopted for the simulation.

E. Conclusion

1) In the simulation, an increase in sleeve thickness favored co-extrusion of Mg/Cu clad composites, and the optimum $R_s : R_c$ ratio was 18%.
2) Core shortening favoured concurrent flow of core and sleeve for the pipe-shaped sleeve billets
3) The cup-sleeve promoted a concurrent and a more uniform flow compared to the pipe-sleeve set up.
4) Extruding the pipe-shaped sleeve billet requires higher load than cup-shaped sleeve. Increasing sleeve thickness reduced load requirement for the composite billets.

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