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Frictional properties of AZ80 and ZE10 magnesium alloys under dry and lubricated contact conditions

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Abstract

The frictional properties of two types of magnesium alloys, i.e. AZ80 and ZE10 were investigated. A purpose-developed sheet metal forming simulator was used to conduct the experiments under constant plastic deformation. Both lubricated and dry sliding contact conditions were simulated and the effect of key process parameters such as contact pressure and sliding velocity on the frictional properties of these alloys were investigated. Due to the different sliding velocities, the contact pressure rose during each experiment which enables the measurement of the coefficient of friction for a wide range of contact pressures. The results showed an increase in the friction coefficients of both alloys with increasing contact pressure. Furthermore, a decrease of the friction coefficient was observed for higher sliding velocities.

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1. Introduction

In sheet metal forming, as the punch draws the sheet metal into the die, frictional forces at the die shoulder and over the punch face influence the workpiece deformation [1]. Since friction is important in determining and

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controlling workpiece deformation in forming processes, detailed knowledge of friction forces is needed for process design and control [2]. In addition, in sheet metal forming frictional forces are important boundary conditions and so must be known for accurate analytical and numerical modelling [3]. Accurate measurements of coefficient of friction can provide valuable information for process model development and validation [4].

In sheet metal forming, the workpiece experiences bulk plastic deformation, new surfaces are created and local surface deformation occurs on a plastically deforming substrate [5]. The importance and unique features of friction in sheet metal forming have led to the development of a sheet metal forming simulator apparatus which simulates the workpiece deformation in forming operations. The main concept of the apparatus is the measurement of coefficient of friction as a metal strip is pulled over the cylindrical surface of a steel pin [6].

In this paper, frictional properties of rolled sheets of two commercial magnesium alloys, AZ80 (8Al–0.5Zn–0.1Mn in wt.%) and ZE10 (1.3Zn–0.2Ce–0.1La in wt.%), with thickness of 0.8 mm were investigated with the sheet metal forming simulator. The effects of dry and lubricated contact conditions and test variables on the measured coefficient of friction are reported here. No research has been done before on the frictional behaviour of AZ80 and ZE10 alloys under plastic deformation and the results of this research can be used for understanding frictional conditions of magnesium alloys under forming operations at room temperature and improve the formability of these alloys.

2. Sheet Metal Forming Simulator

The principle of sheet metal forming simulator can be seen in Fig. 1. The metal strip is bent while sliding over a cylindrical pin. The bending of the strip as it moves over the cylindrical pin restrains workpiece flow and induce plastic deformation in the workpiece.

The displacements x_1 and x_2 are measured by the rotary sensor, while cylinder forces F_1 and F_2 are recorded by load cells. The coefficient of friction is calculated by using the following relations with the assumption of plane strain condition. In Fig. 2 the case of a moving metal strip in the direction of actuator 2 can be seen. During the movement in this direction, a friction force F_R arises between the die and the metal strip which is working against the movement [7], in this case in the direction of actuator 1. The actuator force F_2 is calculated as:

$$F_2 = F_1 + F_B + F_R \, , \tag{1}$$

where F_R is the friction force; F_B is the bending force; and F_1 and F_2 are actuator forces in left and right cylinders, respectively. In the sheet metal forming simulator apparatus, the most important values, which need to be measured or rather adjusted, are the displacements x_1 and x_2 as well as the cylinder forces F_1 and F_2 and the bending angle α. These five variables are the basis for the calculation of the friction coefficient μ.

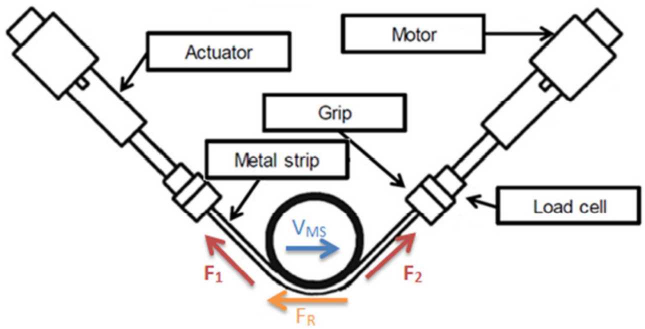

Fig. 1. Principal structure of the sheet metal forming simulator.

Two rotary displacement sensors are attached in the middle part of the apparatus under the strip. The entrance and exit displacements x_1 and x_2 and the sliding velocities at the entrance, v_1 and exit, v_2 of the specimen are measured or rather calculated by these rotary sensors. It is assumed that the contact pressure is uniformly distributed over the contact area and it is the average value p. Considering the general equilibrium condition, the resulting force P_1 which arises through the contact pressure between the die and the workpiece is:

$$(F_1 + F_2)\sin\left(\frac{\alpha}{2}\right) = P_1, \tag{2}$$

where α is the bending angle. Assuming that $F_2>F_1$, which implies a faster movement of cylinder 2 rather than cylinder 1, the friction tension τ_f defines the effective tangential tension resulting from the friction.

$$F_2 - F_1 = \tau_f \, x_{cr} \, w, \tag{3}$$

where x_{cr} is the real contact length, and w is the width of the specimen. The projected line between the die and the workpiece can be defined as:

$$x_c = 2\, r \,\sin\left(\frac{\alpha}{2}\right). \tag{4}$$

The uniformly distributed contact pressure p multiplied with the projected length x_c is equal to the resulting force P_1.

$$P_1 = 2\, p\, r\, w \,\sin\left(\frac{\alpha}{2}\right). \tag{5}$$

Combining Eqs. (2) and (5) the average value for the contact pressure can be obtained:

$$\frac{F_1 + F_2}{2\, r\, w} = p\,. \tag{6}$$

The definition of the coefficient of friction can be seen in the following equation:

$$\tau_f = \mu\, p. \tag{7}$$

The bending force is calculated as follow:

$$F_B = \frac{\sigma_y\, t_s^2\, w}{2r} \tan\left(\frac{\alpha}{2}\right), \tag{8}$$

where σ_y is the yield strength of the specimen; t_s is the thickness of the specimen; α is the bending angle and r is the pin radius. It can be inferred from Eq. (8) that the dimension and the yield strength of the specimen influence the bending force. Due to the substitution of the tension τ_f from Eq. (3) and the contact pressure p from Eq. (6), and taking the bending force into consideration, the coefficient of friction can be calculated by the following equation: (in case of $F_2>F_1$)

$$\mu = \sin\left(\frac{\alpha}{2}\right)\frac{(F_2 - F_1 - F_B)}{(F_1 + F_2)}. \tag{9}$$

3. Results and Discussions

Friction test were undertaken on specimens with bone shape according to EN ISO 6892-1:2009 standard with gauge length of 800mm and width of 10mm. Both dry and lubricated contact conditions were investigated in this study. Houghto-Draw 7060 lubricant was applied in the strip – pin interface for the lubricated contact condition. Brookfield viscosity test were conducted on the lubricant based on ISO 2555 standard under 2 rpm of spindle speed and the measured viscosity was 250 cP. The mechanical properties of both Mg alloys are listed in Table 1.

Table 1. Mechanical properties of AZ80 and ZE10 magnesium alloys.

	Yield strength (MPa)			Ultimate tensile strength (MPa)			Elongation before break (%)			Hardness
	RD	AD	45	RD	AD	45	RD	AD	45	HV/300/10
AZ80	219	241	226	330	328	318	10.04	5.62	6.62	98.3
ZE10	161	129	141	193	185	187	24.0	21.5	24.8	44.0

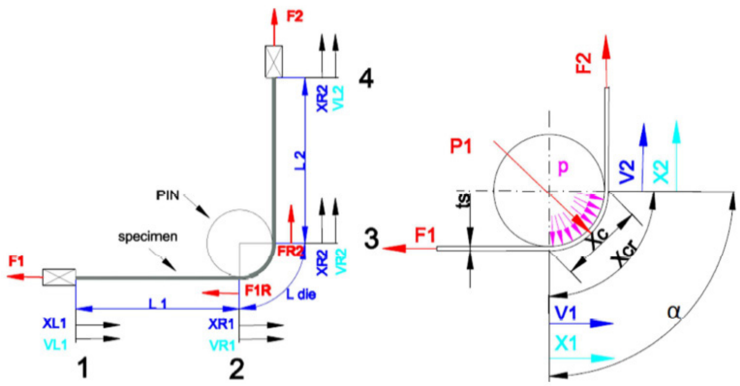

Fig. 2. Principle values measured or rather controlled by sheet metal forming simulator.

Optical microscopy and SEM pictures of AZ80 and ZE10 alloys are presented in Figs. 3 - 5. From Fig. 3(a) it is obvious that AZ80 was rolled, since there are many dislocations or twin lines induced by deformation. Large amount of second phase precipitates is present, majority of which concentrates at grain boundaries or imperfections, such as dislocation lines. Grains are of different shape and equiaxed; based on grain shape alone it is impossible to estimate the rolling direction. To better see the precipitates, SEM was used. From Fig. 4, large amount of precipitates can be seen even on micro-scale. Also it is obvious that there are at least two types of precipitates: spherical and needle-like, and needle-like precipitates are finely dispersed within α-phase matrix.

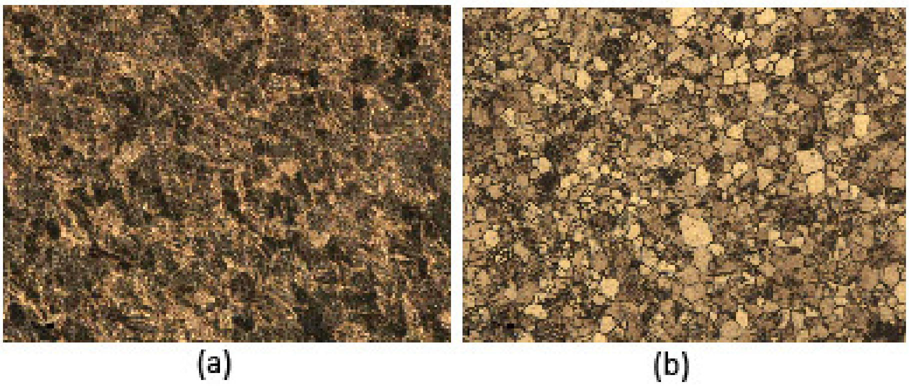

Fig. 3. (a) AZ80, (b) ZE10, 100x magnification.

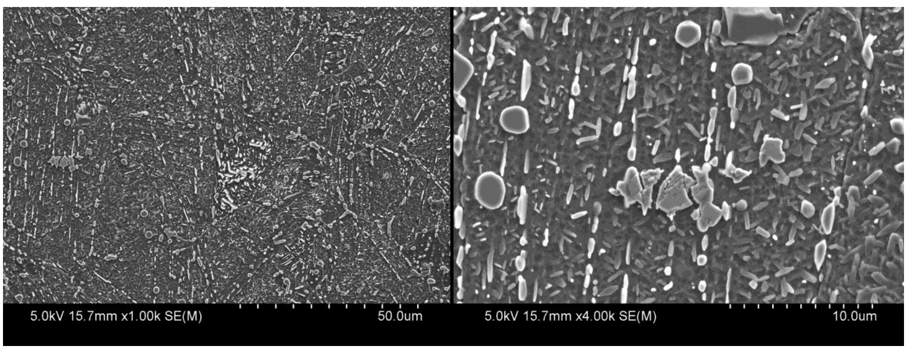

Fig. 4. AZ80, SEM, 1000x and 4000x magnification.

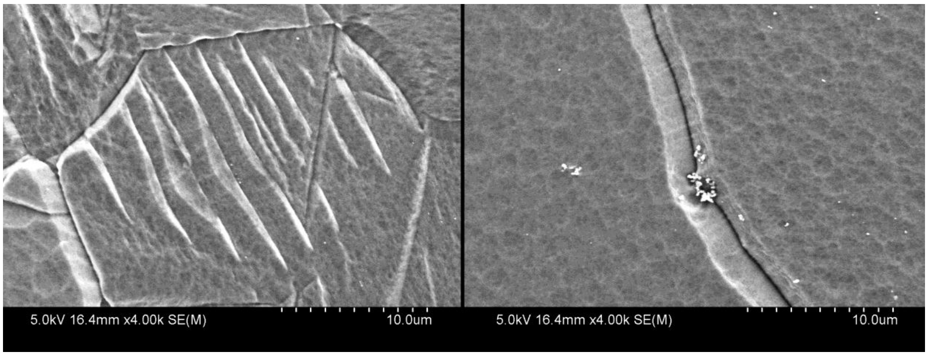

Fig. 5. ZE10, SEM, 1000x and 4000x magnification.

In Fig. 3 it can be seen that for ZE10 the number of dislocation or twin lines is much less than AZ80. Moreover, the number of precipitates is very small and they cannot be seen on optical microscopy pictures. Only at higher magnification SEM pictures (Fig. 5) small second phase precipitates can be observed, which tend to accumulate at grain boundaries or along dislocation and twin lines. Grains are equiaxed and of different size, and it is impossible to estimate the rolling direction. Based on received microstructure pictures and literature analysis results, it can be assumed that as-obtained ZE10 sheets were annealed after rolling.

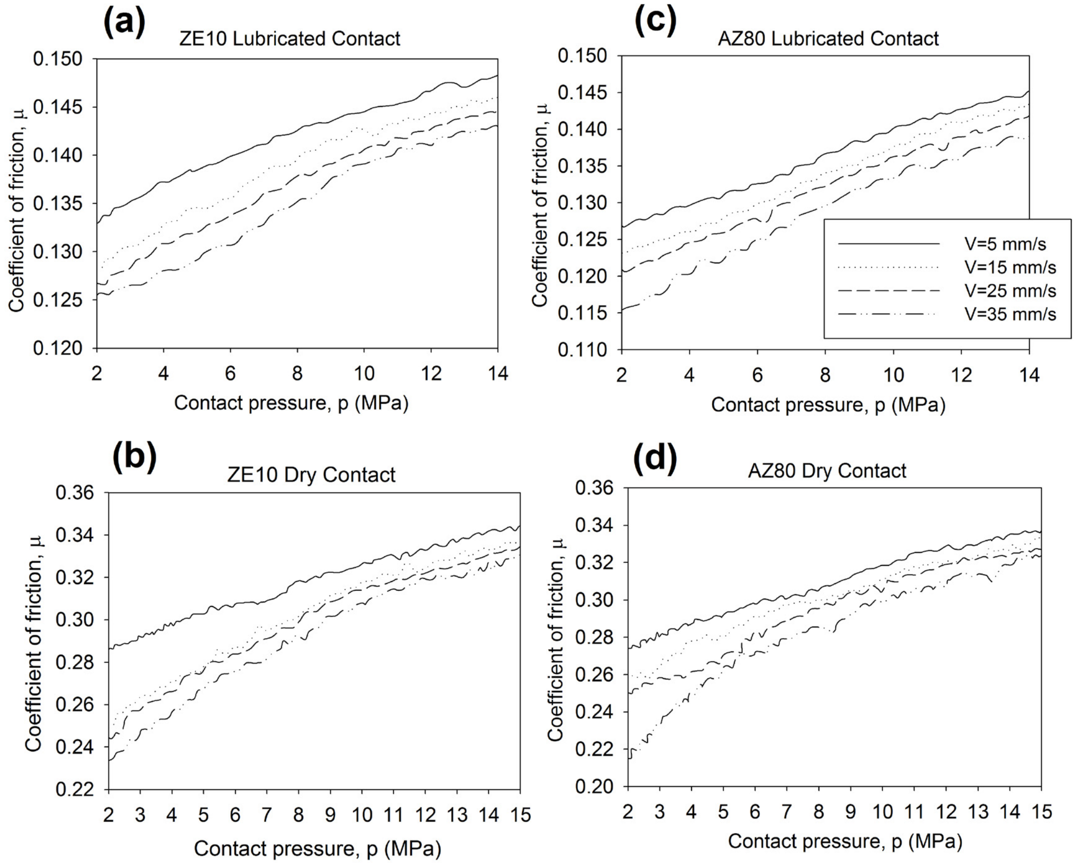

Fig. 6. Effect of sliding velocity and contact pressure on friction coefficient for ZE10 and AZ80 Mg alloys under dry and lubricated contacts.

Figs. 6 and 7 show the measured coefficients of friction for both alloys in lubricate and dry contact conditions. The figures show the coefficient of friction is a function of contact pressure and sliding velocity. Based on the results, ZE10 Mg alloy has slightly higher coefficient of friction compared to AZ80 Mg alloy. In all figures, an increase of the friction coefficient can be noticed with rising interface pressure. Contact pressure directly affects the real contact area between the strip and the steel pin and due to the elastic deformation of the surface asperities more asperities get in contact with the pin and therefore the friction force increases. Based on Fig. 7, the friction coefficient tends to decrease with higher sliding velocities, especially for lower contact pressure. The lower friction coefficient for higher velocities can be explained with the slip stick effect. Higher sliding velocities reduce the break off force and therefore the friction force decreases.

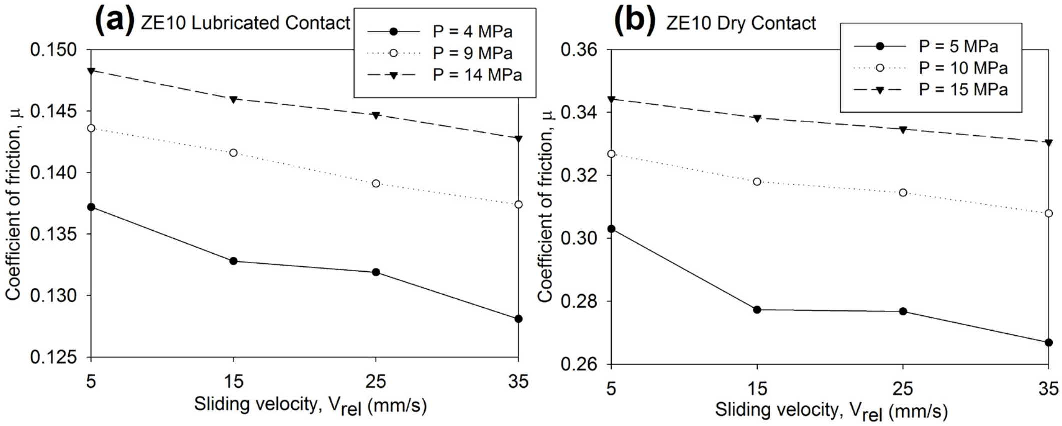

Fig 7. Variation of coefficient of friction with sliding velocity for ZE10 alloy and steel for lubricated and dry contact conditions.

4. Conclusions

In stretching operations, the shape is developed by thinning the sheet while sliding over a die. Friction, together with the tensile properties of the sheet material governs the strain distribution, the attainable depth of stretching and the location of fracture. To improve the formability of materials, friction should be controlled during the forming operations. The frictional behaviour of two magnesium alloys, i.e. AZ80 and ZE10 were investigated under stretch forming. Lubricated and dry sliding conditions were simulated and the effect of interface pressure and sliding velocity on friction coefficients were investigated. It was found that friction increases with increasing contact pressure and decreasing sliding velocity and the dry condition produces significantly higher friction.

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