Feasibility study on lubrication of water-based siloxane polymer lubricant under hot forming condition of aluminum alloy

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Aluminum alloy hot stamping is an important means to achieve automobile lightweight, and the friction and wear caused by aluminum alloy adhesion in the production process is an inevitable problem. Lubrication can reduce friction and wear, but there is no special lubricant for aluminum alloy hot stamping, and the tribological properties of these lubricants at high temperatures are not clear. In this study, we used thermogravimetric analyzer and Baxter laser scattering particle size distributor to analyze the physicochemical properties and thermogravimetric ratio of lubricants, and used the pin-disk friction test equipment to simulate the actual conditions of hot stamping through reasonable experimental design. A water-based release agent with similar working conditions was selected for friction experiment to evaluate its lubrication performance under hot stamping conditions and explore its lubrication mechanism. The experimental results show that the water-based siloxane polymer lubricant still maintains good thermal stability at up to the hot stamping temperature of aluminum alloy. In addition, the surface roughness also has a certain influence on the lubrication performance of the lubricant.

Keywords: Water-based siloxane polymer lubricant; Aluminum alloy hot stamping; Pin-disk friction test; Friction coefficient.

1. Introduction

At present, lightweight technology can effectively improve fuel efficiency, which has become the development trend of the automobile industry [1]. Because of its high strength-to-mass ratio, good corrosion resistance and good thermal conductivity, aluminum alloy has become the preferred alloy for automotive, aerospace, shipbuilding and other industries [2]. Forming at high temperatures both improves formability and reduces springback, allowing for the design of more complex shape parts geometry [3]. Therefore, hot forming, especially hot stamping, is a common manufacturing technology for aluminum alloy components. One of the important boundary conditions in hot forming process is friction and wear. In particular, the adhesive wear occurs during the hot forming process of aluminum alloy. The adhesion of aluminum alloy increases with the increase of temperature, resulting in the intensification of the transfer of aluminum elements [4, 5]. These wear mechanisms affect the die life as well as the surface quality and mechanical

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properties of the parts produced [6-9]. In order to solve the tribological challenges, the industry uses lubricants and surface engineering technology to solve friction and wear. Polymer lubricants can optimize their properties by combining different compounds [10, 11].

Based on the experimental device of high temperature pin-disk friction, this study approximates the hot forming condition of aluminum alloy by designing experimental parameters. In order to obtain the transition process of friction state from stable to abrupt change, a shorter friction time was used in this study. A water-based release agent containing a commercial siloxane polymer was selected for friction experiments. Based on the control of the roughness of the contact surface, the feasibility of the release agent as a lubricant for aluminum alloy hot forming was investigated by analyzing the lubrication performance. The relationship between the preparation of water-based lubricating emulsions and the film-forming mechanism is beyond the scope of this study.

2. Experimental part

2.1. *Pin-disk friction test*

The Rtec MFT-5000 friction and wear tester used in the study includes a pin-disk motion device that reciprocates in a straight line. The solution heat treatment of seven series aluminum alloys often takes place between 460℃ and 500℃ [12]. Therefore, in the experiment, the heating module can heat the ambient temperature of the experimental area to 500 ℃ at a rate of 2.9 s/℃, and the maximum measurement value of the piezoelectric sensor is 50 N. As shown in Figure 1, the electromagnetic drive causes the upper sample pin to reciprocate friction on the fixed lower sample (disc). The sample pin is loaded on the lower sample block by a spring deflection loading device. Friction force and positive pressure were measured at 1000Hz respectively during the test.

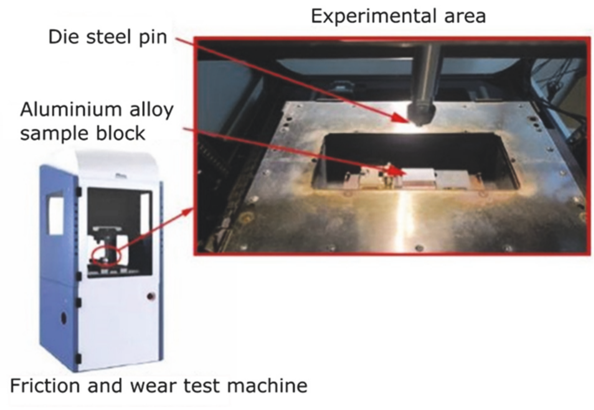

Fig. 1. Rtec MFT-5000 instrument and the test platform

2.2. *Test materials*

In the experiment, the size of the sample disc is 30×20×5 mm, made of 7075 aluminum alloy, and the surface is turned to Ra= 0.5μm, which is equivalent to the roughness of the plate in actual production. The die steel pin is made of Caldie, a hot work die steel provided by ASSAB, Sweden. The size is ø6×20 mm cylinder with a circular contact end of R1. The material parameters are shown in Table 1. The surface of the die steel pin is set by the manufacturer without special polishing, and the measured roughness is about Sa= 0.7μm. In the experiment, the sample block was heated to 400 °C in the heating module and kept for 300 s. Then the positive pressure on the die steel pin reached 10 N within 10 s, and then it was placed on the sample block to start the friction experiment. The pressure of 0.8MPa is selected in this experiment as the preliminary study. The friction track is 10 mm and the frequency is 5 Hz, that is, the friction speed of 0.1 m/s. The friction direction is 90° from the surface roughness of the aluminum alloy sample. The friction process lasts for 90 s and the equivalent slip distance is 9 m. According to the slip distance of each stamping 0.06 m, it is equal to about 150 stamping times [13]. Experimental parameters are shown in Table 2. Each group of experiments was carried out twice, and the average of the friction coefficient and wear amount of the two experiments was taken to ensure repeatability.

Table 1 Alloying composition of the tool steel (wt-%) (Fe makes up the balance), initial hardness and surface roughness

alloy composition	C	Si	Mn	Cr	Mo	V	HRC	Sa/μm
Price	0.7	0.2	0.5	5.0	2.3	0.5	60-61	0.7

Table 2 Test parameters used in the high temperature tribological test

Variate	Price
Load/N	10
Intensity of pressure/MPa	0.8
Temperature/℃	400
Frequency/Hz	5
Slip length/mm	10
Time of duration/s	90

The tribological test was carried out under dry and lubricating conditions. The lubricant, Die Slick 1838C, a commercial aluminum alloy hot forging press release agent suitable for high temperature conditions, was selected as the experimental material, provided by Quechaoferton. Its physical parameters are shown in Table 3. The morphology of the samples was collected by white light interferometer Bruker Contour GT and ultra-depth microscope.

Table 3 Physical properties of the water-based lubricant of siloxanes polymer emulsion

Parameter	Price
Density（20℃）	0.99 g/cm3
pH	8.6
Appearance	White

3. Results and analysis

3.1. *Analysis of the effect of experimental temperature on dry friction results*

It is estimated that the friction coefficient of aluminum alloy is high at high temperature, and a lower temperature (200 °C) and 400 °C are quantitatively selected as the control to evaluate the friction process, both of which do not use lubricants. The statistical results of the friction coefficient are shown in Figure 4. When there is no lubricant at 200 °C and 400 °C, the average friction coefficient obtained during the single experiment 90s is 0.45 and 0.93, and the variance is 0.062 and 0.091 respectively, which are combined with the corresponding wear marks for analysis.

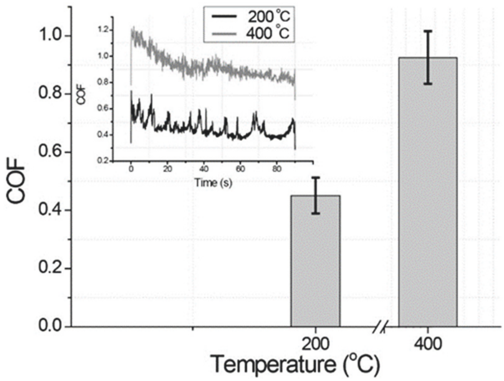

Fig. 2. Statistics of COF of the tests at 200 °C and 400 °C

At the experimental temperature of 200 °C, the friction coefficient is generally low, and the fluctuation is caused by the abrasive wear formed by the hard die steel after furrowing on the aluminum alloy surface to form wear particles. The wear trajectory is narrow and deep, as shown in Figure 3a. However, at the experimental temperature of 400 °C, the wear gully on the aluminum alloy surface is not obvious, and more is the compaction and accumulation of adhesives. As shown in Figure 3b, the wear track is basically consistent with the diameter of the sample pin, and there is accumulation of wear debris at both ends of the friction track. Fig. 4 is a scanning electron microscope image of the cross-section of adhesives in the friction trajectory. There are obvious dimps on the cross-section, indicating that the deposits have obvious plastic deformation characteristics, which is consistent with the structural description of adhesives. On the other hand, because the friction time in this experiment is 90 s, the wear marks on the die steel pin are not obvious. Repeated experiments show that the friction coefficient tends to be close, and the mean difference is about 20%, and the wear morphology on the contact surface is similar with good consistency.

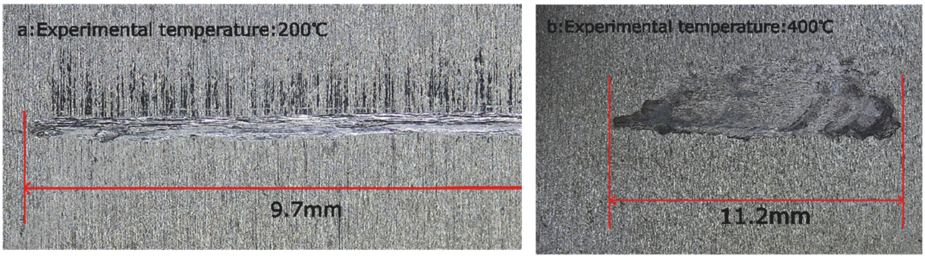

Fig. 3. Wear track on the sample of aluminum alloys after the test at a: 200 °C, b: 400 °C

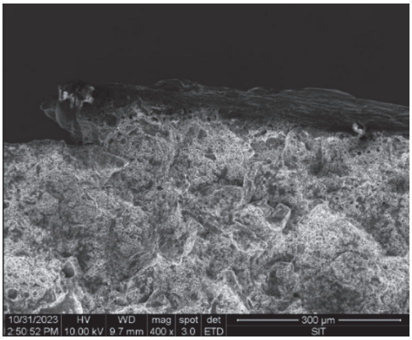

Fig. 4. Scanning electron micrographs in secondary electron of longitudinal section of the wear track at aluminum alloys block at test temperature of 400 °C

3.2. *Friction test analysis using water-based siloxane lubricant*

The water-based siloxane lubricant was sprayed on the surface of the aluminum alloy sample by a watering can, and the friction experiment was carried out after it was kept at room temperature for 4 hours and dried naturally. Figure 5 shows the friction coefficient during the experiment. In the initial stage of the experiment, the friction coefficient remained low, gradually increased to 10 s, and stabilized at about 0.3 after about 40 s of friction process. In the interval of 10 s-70 s, the average friction coefficient is 0.24 and the variance is 0.064. A sudden rise of the friction coefficient after about 70 s of friction process, reaching a maximum of about 0.8 and then a little shock drop until the end of the experiment. According to the analysis experience of the test results without lubricant, the trend of friction coefficient is related to the change of friction mechanism and wear morphology. The friction track on the surface of the aluminum alloy sample is narrow and dominated by furrow formed by abrasive wear, and there is a little adhesive flattening layer in the friction track. The discontinuous debris layer can alleviate part of the furrow action, but it does not form a sufficient "protection" effect on the contact pair, as shown in Figure 6. Slight wear marks on the die steel pin. The friction coefficient of repeated experiments is close to the trend, and the wear morphology of the contact surface is similar.

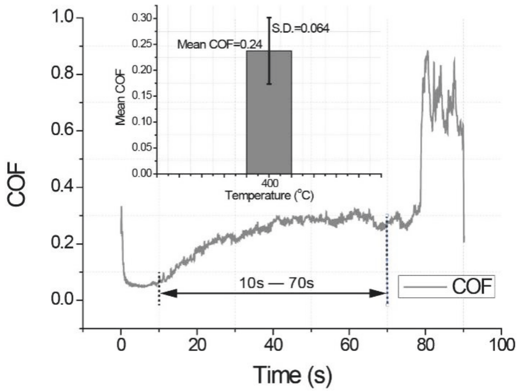

Fig. 5. COF of the tests at 400 °C with the lubricants

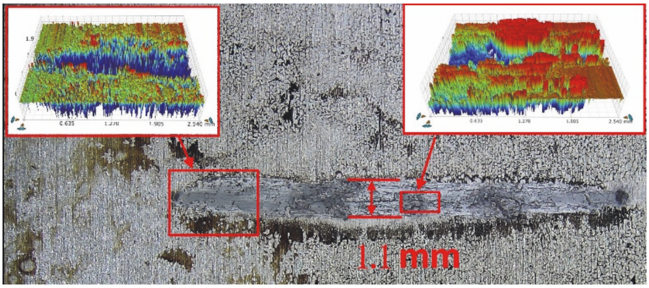

Fig. 6. Surface of aluminum alloys after the test with the lubricant at 400 °C

4. Conclusion

In this study, the feasibility scheme of lubrication in the process of aluminum alloy hot forming was explored. Through the high temperature friction test equipment, the water-based siloxane lubricant whose application range is close to the target condition is selected to carry out the experiment. The friction coefficient and the surface morphology of the sample were analyzed. Summary and outlook are as follows:

(1) According to the results of the friction experiment with 200 °C and 400 °C as experimental conditions, the high temperature in the hot forming process of aluminum alloy is the decisive factor leading to adhesive wear. In a smaller range, temperature difference changes the microstructure of the workpiece itself, and whether the application of water-based lubricants changes the temperature field in the contact sub-area will be the focus of application-level discussion.

(2) The water-based siloxane lubricant forms a good lubricating film on the contact surface, effectively reducing the element adhesion between the samples, making the contact pairs mainly wear particles, and the resulting friction coefficient is significantly reduced and the retention time is longer. Combined with the production rhythm of hot forming, the frequency of applying lubricant will be a problem that needs to be considered in the production practice of enterprises.

(3) At present, the preliminary research on the lubricant of aluminum alloy hot forming has been carried out, and the experimental results are limited to the analysis and discussion of macroscopic observations. Combining chemistry and mechanics, based on the use of more characterization instruments, establishing the connection between lubricant preparation methods, physical and chemical parameters and lubrication properties will be the focus of production practice.

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