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Procedia Engineering 207 (2017) 2274–2279

Procedia Engineering

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International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

A new design of friction test rig and determination of friction coefficient when warm forming an aluminium alloy

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Abstract

To facilitate reduced fuel consumption and increase environmental friendliness, in recent years, demands for lightweight vehicles have been increasing, and interest in hot or warm forming of sheet aluminium alloys for use in vehicle body structures, has grown. For better understanding and optimisation of the forming processes, knowledge of friction coefficient between tooling and work-piece, at elevated temperature, is critical. However, because of difficulties with measurement at elevated temperature, most studies on friction are limited to room temperature. In this study, a friction rig was designed for isothermal tests at elevated temperature. The test rig enables pure sliding between pins (made of a tool steel) and a metal sheet. The friction behaviour of Forge Ease 278, a water based solid lubricant pre-applied to aluminium alloy AA5754, was investigated, under isothermal warm forming conditions, using the test rig. The effects of testing temperature, sliding speed and applied pressure on the friction coefficient were studied. It was found that Forge Ease produced a low friction coefficient of around 0.05, above room temperature and below 250 °C. The lubricant performance degrades at 350 °C and the friction coefficient increases markedly. Both sliding speed (up to 150 mm s^{-1}) and applied pressure (up to 12.8 MPa) had no significant effect on friction coefficient of Forge Ease.

Keywords: Friction coefficient; friction test rig; warm forming; aluminium alloy

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Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.
10.1016/j.proeng.2017.10.994

1. Introduction

In recent years, demands for lightweight vehicles are increasing, to realise reduced fuel consumption and better environmental friendliness. Aluminium alloy has a high strength to weight ratio and use of aluminium alloys in car bodies is increasing. However, their formability at room temperature is limited and interest has grown in hot or warm forming of sheet aluminium alloys. To better understand and optimise the elevated temperature forming processes, knowledge of friction coefficient is important.

Friction is often undesired but unavoidable in sheet metal forming processes, especially at the entrance areas of the die cavity. Therefore lubricants are often employed in sheet metal forming. Many factors may affect friction during metal forming, including lubrication, temperature, contact pressure, forming speed, surface finish and/or texture, geometry, and use of drawbeads. The tribological behaviour of the system influences stress and strain distribution in the work-piece and therefore the forming process. Research has been carried out in different aspects of this field, including testing methods and apparatus [1-4], friction characterisation [3-6], and modelling [7-9]. Most studies have been focused on friction at room temperature with a few at elevated temperature. Recently Dohda et al. [10] reviewed tribology in metal forming at elevated temperatures and pointed out that tribo-characteristics of metal forming at high temperatures are still not well understood and that more test conditions should be further investigated by developing new tribometers. The purpose of this paper is to present a simple design of friction test rig for use under hot/warm isothermal conditions and use it to investigate the frictional behaviour of a solid lubricant (Forge Ease 278), when warm forming aluminium alloy sheet.

2. Test rig design

The purpose of the rig is for measuring friction coefficient between the sheet metal and pins made from tool steels which are used for tooling of metal forming. It should be under isothermal conditions at elevated temperature and capable of high sliding speed. Friction testers for similar purposes have been reported using hot flat strip drawing [4,11]. However, those tests were performed outside the furnace and so are not truly isothermal. The new friction test rig is shown schematically in Fig. 1a. The test rig is portable and can be fitted to any tensile test machines with a furnace. It was designed to ensure that the pressure applied by pins on either side of a test-piece is normal to the test-

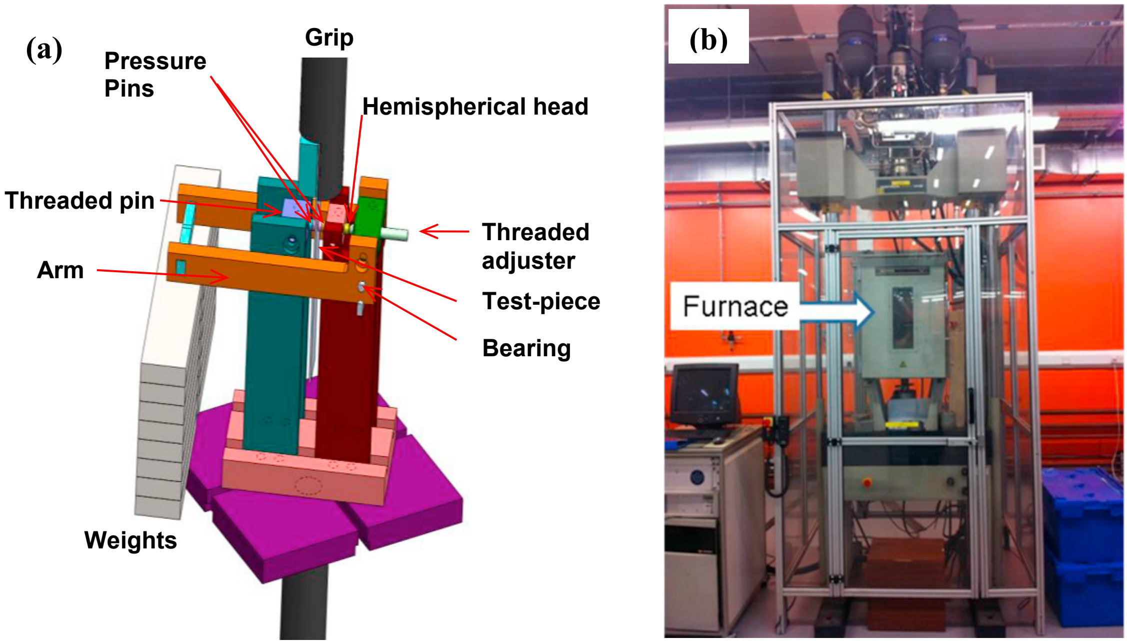

Fig. 1 (a) Schematic drawing of friction test rig, and (b) High rate Instron machine with furnace in which the test rig was mounted.

piece which is drawn vertically. The gravitational force of the weights is transferred to a force at the tip of the hemispherical head of a threaded pin, via a lever mechanism. This force is passed from the hemispherical head to one horizontal cylindrical H13 tool steel pin which is in contact with the test-piece. The hemispherical head ensures that the force acting on the H13 pin is axial and the knife edge bearings ensure loss in transmitting the force to the work-piece, is negligible. The horizontal force is calibrated with a load cell so that the relationship of the value of weights to horizontal force is known. The normal pressure on the test-piece may be changed in two ways: by changing the weight or by changing the size of the pins. In the current study, the head of the pins was a flat, circular area with a diameter of 8 mm. The contact area of the pin head can also be made to square, rectangle or other shapes.

The coefficient of friction (μ) can be calculated using the following formula:

$$\mu = \frac{F_f}{2F_n}$$

where F_f is the force required to draw the test-piece between the pins (frictional force) and F_n is the normal force applied to the test-piece by the pins.

Experiments were carried out using this friction test rig within a furnace for testing at elevated temperature. The test machine was a high rate Instron machine, of 20 kN maximum load capacity and 400 mm maximum displacement, with an operating speed of up to 25 m s^{-1}. The machine contained an Instron furnace (Fig. 1b). The friction rig was mounted in the furnace on a base plate which was connected to the load cell of the machine via a rod.

3. Experimental procedure

Test-pieces were strips of commercial aluminium alloy AA5754 the chemical composition of which is shown in Table 1. The material was supplied by Novelis UK Ltd in the form of 400 x 400 x 1.5 mm sheet, in H111 condition. It has 0.2% proof stress of 121 MPa, a tensile strength of 234 MPa and an elongation (A80) of 25% at room temperature [12].

Table 1. Chemical composition of AA5754 [12].

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt%	0.08	0.16	0.004	0.45	3.2	0.001	0.01	0.02	Bal.

The lubricant selected was Forge Ease 278 which is liquid based, designed to be pre-diluted, usually with water. The lubricant used in this study was ready mixed 50:50 with alcohol to aid both wet-out and dry time, supplied by Fuchs Lubricants (UK) Plc. The Forge Ease was pre-applied to the test-pieces before placed in an oven or furnace for drying.

Test-pieces were cut from the supplied sheets into strips of 200 x 35 mm and the existing pre-coated lubricant was removed using a degreaser before applying the test lubricant. Forge Ease was first applied to one side of the test-pieces and dried in a furnace at 50 °C for 30 min. The process was repeated for the other side of the test-pieces.

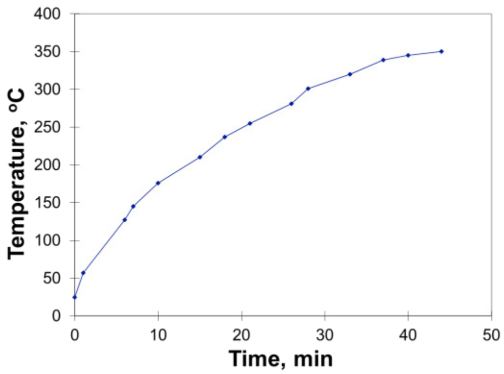

Fig. 2 Evolution of temperature during heating of the furnace containing friction rig.

Tests were carried out at different temperatures (20 – 350 °C), under different applied pressures (3.3 – 12.8 MPa) and with different sliding speeds (25 - 150 mm s^{-1}). When the test rig and the test-piece in the furnace reached the chosen temperature, the load was applied and the test-piece drawn through the pressurising pads. Fig. 2 shows the temperature evolution during the heating of the furnace, with a target temperature of 350 °C.

4. Results & Discussion

Fig. 3(a) shows a graph typical of the evolution of friction coefficient with sliding distance for a room temperature test, with a nominal pressure of 5.9 MPa and a sliding speed of 75 mm s^{-1}. The coefficient of friction (COF) quickly increases to a peak value (static friction coefficient) at the start of the test and then decreases to a steady state (dynamic friction coefficient). Examples of repeated tests under the same conditions are presented in Fig. 3(b). The difference of 0.01 in the average dynamic friction coefficient, demonstrates the reliability of the test rig. As the measurements were always made on new surfaces with solid lubricant, the sliding distance will not have any effect on the steady state friction coefficient when the lubricant does not degrade.

Three parameters have been investigated in the study, namely temperature, applied pressure and sliding speed. The effect of testing temperature on the static and dynamic friction coefficient is shown in Fig. 4. The results show that friction does not alter significantly at temperatures up to 300 °C if the test is carried out immediately after reaching

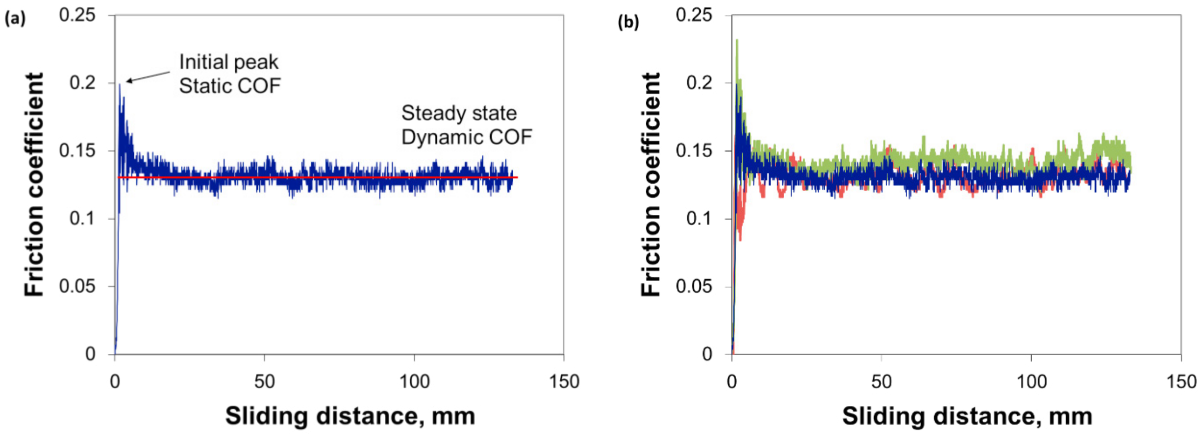

Fig. 3 (a) Evolution of friction coefficient during testing of Forge Ease at room temperature; (b) Three repeated test results under the same conditions showing the reliability of the test rig. Speed: 75 mm s^{-1}, Pressure: 5.9 MPa.

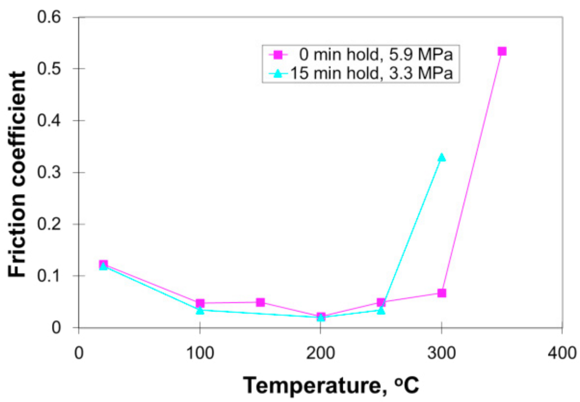

Fig. 4 Effect of testing temperature and holding time on the dynamic friction coefficient. Speed: 75 mm s^{-1}.

the test temperature. At 350 °C, the friction coefficient increases dramatically. This behaviour is possibly due to the oxidation of the lubricant, as it was seen to have become dark colour after tests. Further research is required to pin point the exact cause as well as the degradation mechanism of the lubricant. At 300 °C, the effectiveness of the lubricant depended on the holding time at this temperature. As shown in Fig. 4, for a holding time of 15 min, in addition to the normal heating up time of 30 min, the friction coefficient increased markedly at 300 °C. Below the 'breakdown' temperature but above room temperature, the dynamic friction coefficient was around 0.05. It was lower than at room temperature, with the lowest value occurring at 200 °C.

There have been many studies on the effect of sliding speed and applied load on friction coefficient and different trends have been reported because of different test setups and conditions, e.g., [4] at high temperature and [13] at room temperature. Sliding speeds of 25, 75 and 150 mm s^{-1} were used in this study and the results are shown in Figs. 5(a) and 5(b) for room temperature and 200 °C respectively. It can be seen that there is no significant change in friction coefficient across the speed range of 25 to 150 mm s^{-1}. This is in agreement with the findings in [4] which had a similar setup (hot flat strip drawing) and used hot rolling oil with an emulsion as the lubricant, where the friction coefficient became constant above 10 mm s^{-1}. Fig. 6 shows the effect of pressure on friction coefficient at room temperature and 200 °C respectively. Again, the dynamic friction coefficient appears independent of the pressure in the range used in the tests (up to 12.8 MPa), which is also consistent with [4]. It should be noted that the applied pressure range is suitable for blank holder area but is relatively low for the entrance area of die cavity. The frictional behaviour of the lubricant could be affected by severe stressing, e.g., through breaking of the lubricant layer.

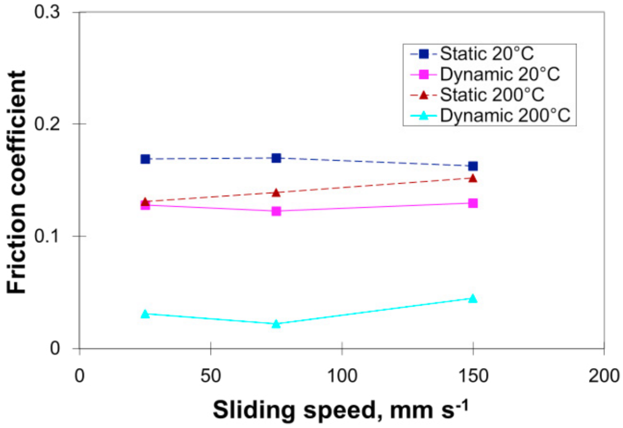

Fig. 5 Effect of speed on the static and dynamic friction coefficient. Temperature: 20 and 200 °C, Pressure: 5.9 MPa.

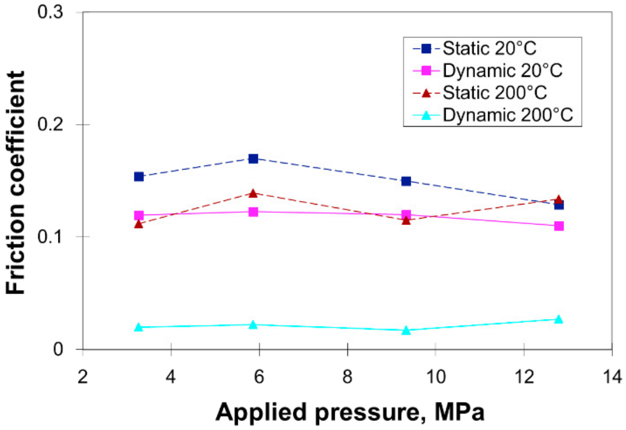

Fig. 6 Effect of pressure on the static and dynamic friction coefficient at 20 and 200 °C. Speed: 75 mm s^{-1}.

5. Conclusions

A new test rig has been designed and built to investigate friction behaviour during sheet metal forming under warm forming conditions. The friction behaviour between AA5754 sheet and H13 tool steel pins with Forge Ease as a solid-state lubricant has been investigated using the dedicated friction test rig. The following conclusions can be drawn:

(1) The design of the friction test rig is simple, portable and reliable, suitable for sheet metal forming.
(2) Forge Ease effectively decreases the friction coefficient at temperatures up to 250 °C, with an average dynamic friction coefficient value of about 0.05 for the warm forming temperature range which was lower than at room temperature.
(3) Increase in temperature to 300 °C and above, appears to cause degradation of Forge Ease and reduces its effectiveness for lubrication. Friction coefficient increases markedly at 350 °C. At 300 °C, the effectiveness of Forge Ease depends on its dwelling time at the temperature.
(4) Both sliding speed (25-150 mm s^{-1}) and applied pressure (up to 12.8 MPa) have no significant effect on friction coefficient.

Acknowledgements

Financial support from the UK Technology Strategy Board (TSB) High Value Manufacturing Programme for the project of Warm Aluminium Forming Technologies (WAFT) is gratefully acknowledged. The authors would like to thank all partners to the WAFT project for their critical input.

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