Available online at www.sciencedirect.com
SCIENCE DIRECT®
Wear 259 (2005) 1117–1122
WEAR
www.elsevier.com/locate/wear

Evaluation of coating-based lubricants for cold forging using the localised rod-drawing test

Liqun Ruan, Hiroyuki Saiki, Yasuo Marumo *, Yasuhiro Imamura

Department of Mechanical Engineering and Materials Science, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan

Received 12 October 2004; received in revised form 25 January 2005; accepted 4 February 2005
Available online 10 May 2005

Abstract

A tribo-test method that incorporates major interacting variables such as surface expansion, interface temperature, sliding velocity, pressure, etc. is introduced to evaluate the performance of lubricants in cold forging. To induce different deformation patterns, dies of different surface profiles are employed under localised rod-drawing setup. The tools are designed based on the maximum level of surface expansion they can induce. The tester includes facilities for heating dies and the workpiece to vary interface temperatures. The tribo-test results indicated that the lubricity of the coating-based lubricants is influenced by the interface temperature, the surface expansion and the multistage operations. The coefficient of friction decreased and then increased with the increasing interface temperature. In the case of large surface expansion, the lubricity deteriorates at a shorter sliding distance. The results of the two-stage tribo-tests revealed the effect of the deterioration and the thinning of the coatings on subsequent forging.

Keywords: Cold forging; Tribological test; Coating-based lubricants; Surface expansion; Interface temperature; Interface friction

1. Introduction

When the behavior of high-performance lubricants for cold forging is evaluated, factors during the forging such as surface expansion at the frictional interface, temperature, contact pressure, sliding velocity, the surface roughness of tools and the surface structure of the material should be reflected in the performance test with the highest possible accuracy. A number of tribo-test methods for cold forming have been developed to date [1–7]. In the evaluation of tribological conditions, interface temperature and the expansion of surface area occurring at the contact interface during processing are the important parameters. The former affects the physical and chemical properties of the lubricant. The latter decreases the thickness of the lubricant film. In order to evaluate the effects of such parameters, we previously reported the rigid plastic finite element analyses of the forward and backward extrusion as well as the indentation of gear-shaped tools and evaluated the surface expansion of the regions that experienced significant local deformation during forging [8]. Furthermore, we evaluated the processing heat generated due to plastic deformation and the increase in temperature at the interface between a tool and a workpiece caused by sliding on the tool's surface. Based on the results obtained, we developed a localised rod-drawing friction tester [8] that can realise actual cold forging conditions. With this tester, the significant expansion of the surface area during forging, thermal environment of die surfaces during continuous forging and changes in the tribological conditions up to the previous stage during multistage forging can be taken into account [9,10].

In this study, we primarily selected phosphate coating lubricants (phosphate coating + metal soap) as test lubricants and evaluated their performance using the tester under various thermal conditions and tools.

2. Experimental conditions and methods

Using the local-drawing friction tester [8–10], high-performance lubricants for cold forging were evaluated. In

* Corresponding author. Tel.: +81 96 342 3574; fax: +81 96 342 3729.
E-mail address: marumo@mech.kumamoto-u.ac.jp (Y. Marumo).

0043-1648/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.wear.2005.02.103

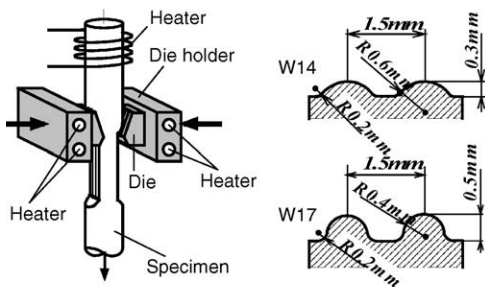

Fig. 1. Tool geometrical configurations.

the friction tests, we examined the properties of the selected lubricants using wavy dies [8–10] that accommodate various surface expansions as shown in Fig. 1. The surface expansion was evaluated by a rigid plastic finite element simulation. For example, the maximum values of W14 and W17 are 310 and 980%, respectively, under the conditions of plain strain, friction shear factor = 0.1, strain-hardening exponent = 0.06 and material reduction = 10%. Material reduction was calculated from the rate of the longitudinal elongation, in which tensile elongation was neglected, caused by the indentation of dies under plane strain and constant volume. The lubricants include oil lubricants, a high-performance phosphate coating lubricant.

In the performance test of the oil lubricants, we used SCR420 as drawing-rod steel. In the performance test of the coating lubricants, we used SCM435 ($\sigma = 904\varepsilon^{0.12}$ MPa) and S15C ($\sigma = 800\varepsilon^{0.1}$ MPa) as drawing-rod steel. These steel rods are treated with a lubricant prior to the test.

3. Evaluation of oil lubricant

Here, to confirm the superiority of the performance of phosphate coating lubricants, we tested the performance of four industrial oil lubricants, A–D, using the rod steel SCR420 (ϕ12 mm) and the wavy die W14. All the oil lubricants showed a large coefficient of friction of 0.4 or higher, as shown in Fig. 2. These lubricants do not remain on the frictional surface because the workpiece experiences a high contact pressure. Consequently, to maintain good lubrication, it is necessary to use a coating lubricant that adheres well to workpieces on which the lubricant film is difficult to break. Currently, phosphate coating lubricants are most frequently used as high-performance lubricant in cold forging. In Section 4, we discuss phosphate coating lubricants which are also used as the standard for comparison of lubricant performance in this study.

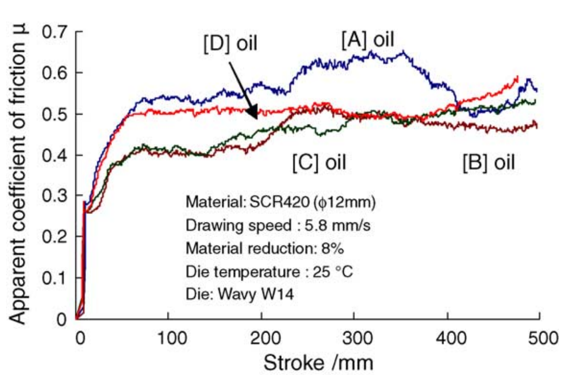

Fig. 2. Variation of apparent coefficient of friction with drawing stroke for oil lubricants A–D.

4. Performance tests of phosphate coating lubricant

In this experiment, we used SCM435 and S15C as drawing workpieces. A phosphate coating lubricant was applied to each of the rods; lubricants A and B were applied to SCM435 and S15C, respectively, and the compositions of the two lubricants are different as shown in Table 1. Drawing experiments were performed using the tester at the predetermined die temperature using both the flat and wavy dies.

4.1. Effects of temperature of processed surfaces on coefficient of friction

Within a predicted variable temperature range at the frictional interface in cold forging [8–10], we measured the coefficient of friction, μ, with a phosphate coating lubricant A applied to SCM435 using the flat die and the material's temperature T_{out} near the die outlet using a thermo-imaging device [8–10], the results are shown in Fig. 3. In this example, workpieces at room temperature (approximately 25 °C) were drawn with or without preheating of the die at 200 °C. When the die was preheated at 200 °C, T_{out} became almost constant as long as seizure did not occur or μ did not increase significantly. T_{out} was similar to the temperature of the frictional environment which was approximately 190 °C in this example. Under these conditions, μ is approximately 0.05. When the die was not preheated, the temperature increased to 80 °C or higher. The coefficient of friction, μ, is greater than that for a preheated die. When the coefficient of friction at a high T_{out} was evaluated, the workpiece was also heated. Fig. 4 shows the results for the flat die and the wavy die W14. In both the cases, the performance of the lubricant deteriorates when T_{out} exceeds 300 °C.

Fig. 5 shows the dependence of coefficient of friction on the temperature and includes results under other heating

Table 1
Two types of lubricants

Chemical compounds	Amount of residue (g/m^2)			
	Lubricant A (SCM435)		Lubricant B (S15C)	
	Before drawing	After drawing	Before drawing	After drawing
Sodium stearate	1.63	0	2.32	0
Zinc stearate	0.7	0	1.03	0
Zinc phosphate	10.35	5.65	16.03	3.35