FUNDAMENTAL STUDY OF SEMI-DRY FORGING WITH MIST LUBRICATION

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Summary

Friction in cold forging with mist lubrication is measured with the ring compression test. Small quantity of mist lubricant is sprayed onto the surfaces of cemented tungsten carbide (WC) tools polished to mirror surfaces, and the specimens of pure aluminum are compressed. It is found that spraying small quantity of lubricant (0.5 g/m^2) is effective to reduce the friction in comparison with the dry condition. The mist particles stick to the tool surface as separated dots, and the behavior of the trapped mist lubricant between the tool and specimen during upsetting is discussed.

Keywords: friction, forging, semi-dry condition, ring compression test

1 Introduction

Since metal forming induces high friction and heat generation between the tools and the workpiece, lubrication is a critically important factor for reducing the forming pressure and avoiding seizure in many forming processes. Recently, however, many kinds of lubricants are considered not to be good for the environment, and dry metal forming process without lubrication, semi-dry metal forming process by spraying slight lubricants and non-polluting lubricants are desired to be developed [1,2]. If dry metal forming is realized, the influence to the environment and the cost of manufacturing could be reduced dramatically.

Dry metal cutting without lubrication has already become possible through the recent development of coating methods for cutting tools, for example, CVD (chemical vapor deposition) and PVD (physical vapor deposition) processes [3]. As well as dry metal cutting, the MQL (minimal quantity lubricant) process for metal cutting has been realized. While more than 100 m*l*/h of lubricant is used in conventional metal cutting, less than 10 m*l*/h of mist lubricant is sprayed in the MQL process on cutting part [4].

The authors observed the frictional behavior of various coated tools under dry and semi-dry conditions in order to realize dry metal forming processes [2,5]. In this study, a small quantity of mist lubricant (less than 3.0 g/m^2) is sprayed onto the surfaces of the compression tools using the mist spraying system for metal cutting. Surface profiles of the aluminum billet after upsetting is measured, and the behavior of the trapped mist lubricant between the tool and specimen during upsetting is discussed.

2 Experimental procedure

2.1 Ring compression test [6]

Coefficient of friction in forging with slight lubrication is measured with the ring compression test. In this test, a ring specimen is compressed between the flat parallel tools and the friction is measured through the change of the inner diameter of the ring. The tested material is pure aluminum, A1050 (annealed) and the roughness of the initial ring specimen is 0.30 – 0.50 μm.

The tool has a disc shape with a diameter of 60 mm and a thickness of 8 mm. The base material of the tool is a cemented tungsten carbide (WC: 85%, Co: 15%) and the tool is polished to mirror surfaces ($R_a = 0.02$ μm).

The experiments are conducted on a 0.6 MN (60 tonf) mechanical press with an average compressing speed of 150 mm/s at room temperature. The ring specimens are compressed with reduction in height $\Delta h/h_0 = 10$, 30 and 50%.

2.2 Apparatus of mist lubrication

To spray the lubricant on the tool surface, a commercial mist spraying system for metal cutting is used. As shown in Fig. 1, the lubricant supplied from the tank is mixed with compressed air and 1.6 m*l*/h of the lubricant with 0.1 MPa of compressed air is sprayed from the nozzle tips on the tool surface. Most of the lubricant sprayed from the nozzle tip is applied to the whole surface of WC tool (diameter of 60 mm). A mineral oil based lubricant (mineral oil: 70 wt%, alcohol (carbon: 12, 13): 30 wt%, kinetic viscosity: 27.7 mm^2/s (at temperature of 40 °C) and density $\rho = 885$ kg/m^3) is used.

3 Measurement of friction under semi-dry condition

3.1 Weight of sprayed lubricant and lubricated area

In order to measure the amount of sprayed lubricant accurately, the weight of mist lubricant applied on the tool surface is investigated from the weight change of a plastic sheet before and after spraying the lubricant. The plastic sheet with a diameter of 35 mm is fixed on the WC tool surface. The applied area on the tool surface of the mist lubricant is determined by the colored area of the BTB examination paper fixed on the WC tool surface. The color of BTB examination paper is changed from blue to red at only the applied area of the mist lubricant.

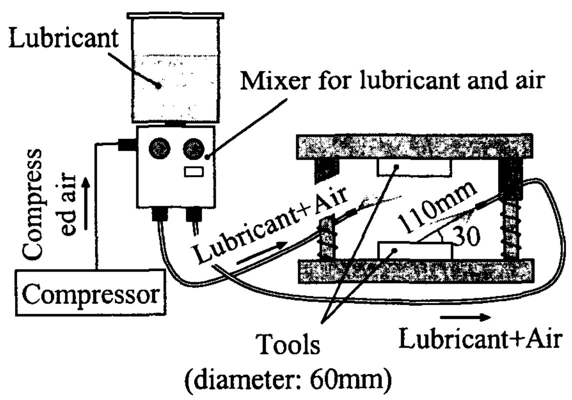

Fig. 1 Apparatus for mist lubricant spraying system

In Fig. 2, the relationship between the weight of the sprayed lubricant on the plastic sheet fixed on the tool surface and the spraying duration is shown. It is possible to control the amount of lubricant from 0.1 to 3.0 g/m^2 on the tool surface by spraying up to 90 seconds.

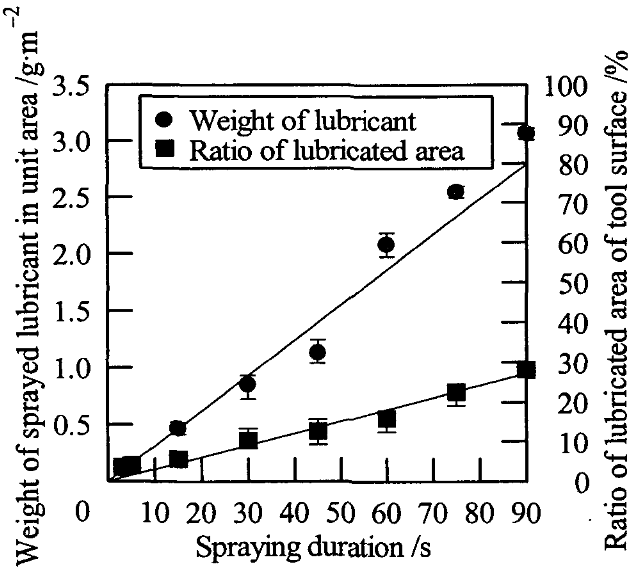

Fig. 2Relationship between weight of sprayed lubricant on tool surface and spraying duration

3.2 Effect of mist lubricant

Frictional behavior of aluminum billet lubricated with mist lubricant is measured using the ring compression test at room temperature. In Fig. 3, the effect of weight of sprayed lubricant on the friction of aluminum billet is shown. Under dry condition, the coefficient of friction is μ = 0.14 – 0.23 at room temperature. On the other hand, when 0.5 g/m^2 of lubricant is sprayed on the WC tool surface, the coefficient of friction decreases from 0.23 to 0.10. Even when the mist lubricant is sprayed more than 0.5 g/m^2, the coefficient of friction does not become less than 0.08. This result means that 0.5 g/m^2 is the minimum value of mist lubricant to keep the friction to be low in upsetting of the aluminum billet.

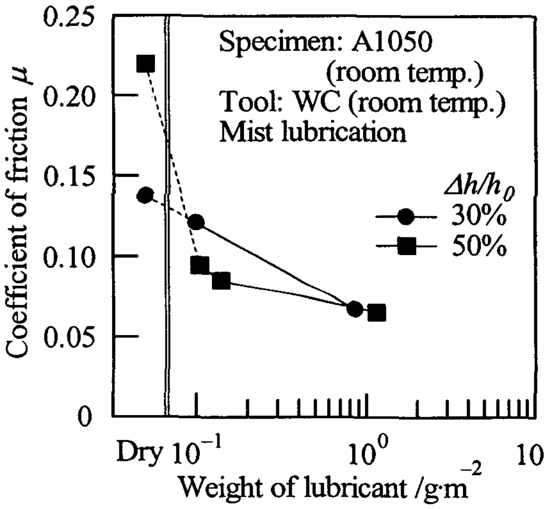

Fig. 3 Effect of weight of sprayed lubricant on coefficient of friction in ring compression test of aluminum billet

3.3 Measurement of friction under thin film lubrication condition

In mist lubrication, the mist particles stick to the tool surface as dots and the large part of the tool surface is left to be dry. In order to compare mist lubrication with thin film lubrication, the frictional behavior of aluminum billet with thin film lubrication is measured with the ring compression test.

To form a thin lubricant film on the tool surface, a known amount of lubricant is mixed with benzene and spread over the tool surface uniformly by pipet. Only the benzene is evaporated in about 20 seconds, and a lubricant film is left after evaporation of the benzene, the film thickness is estimated from the initial volume of the mixed lubricant. With this method, very thin lubricant films of 0.10 – 2.0 μm can be formed on WC tools at room temperature. In this study, the thickness of the lubricant film is controlled in the range t = 0.25 – 2.0 μm.

Fig. 4 shows the effect of thin lubricant film on the coefficient of friction when the aluminum specimens are compressed at room temperature. When the thickness of the lubricant film is greater than 0.50 μm (the lubricant is applied on tool surface more than 0.45 g/m^2), the lubricant gives a low frictions μ = 0.10. From Fig. 3 and 4, it is found that the frictional behavior of aluminum billet with mist lubrication is almost the same as that with thin film lubrication. Furthermore, because it is difficult to control the thin film of lubricant as less than 0.50 μm in film lubrication, mist lubrication is practical to realize metal forming with slight lubrication.

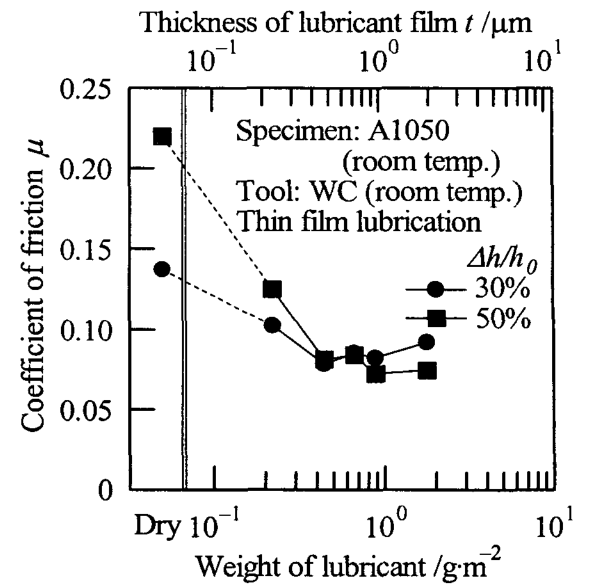

Fig. 4 Measured coefficients of friction for aluminum billet with thin lubricant film

4 Discussions

Fig. 5 shows the surface profiles of the aluminum billet after compression with the flat WC tools at room temperature. The thin film and mist lubricant are applied on the tool surface with an average thickness of lubricant t = 1.0 μm and the ratio of the lubricated area of the tool surface is about 10 % in mist lubrication. At all reductions in height, the surface roughness of the compressed aluminum billet under dry condition is smoother than that with lubricant. When the aluminum billets are compressed up to $\Delta h/h_0$ = 10% (the maximum contacting pressure is about 95 MPa), the surface roughness of the compressed aluminum billet with mist lubricant is smoother than that with thin film lubricant. The mist lubrication gives a coefficient of friction μ = 0.10, and the thin film lubrication gives μ = 0.07. It is considered that the thin film lubricant is trapped between the tool and the billet uniformly, but the mist lubricant does not spread over the whole contacting part during upsetting.

In the case of $\Delta h/h_0$ = 30, 50% (the maximum contacting pressures: 110, 130 MPa), the surface roughness of the compressed aluminum billet with mist lubricant is rougher than that with thin film lubricant, but the surface profiles and the coefficients of friction of aluminum are the same in both of the mist and thin film lubrication. It is considered that the mist lubricant spreads over the whole contacting part during the upsetting and becomes a film of less than 1.0 μm thickness.

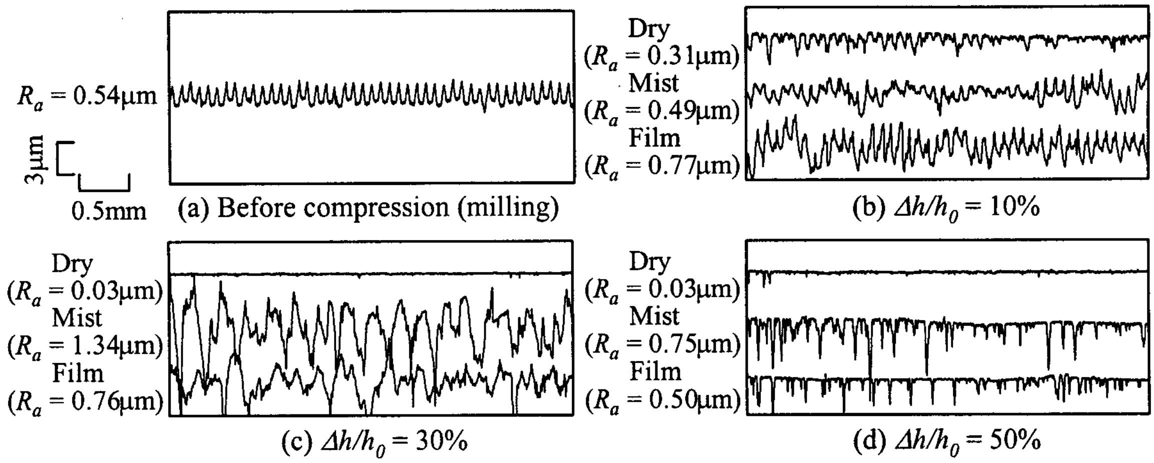

Fig. 5Surface profiles of aluminum billet after compression with flat WC tools (thickness of lubricant film t = 1.0μm)

5 Conclusions

In this study, very small quantity of mist lubricant is sprayed on the tool surface, and frictional behavior and mechanism of mist lubrication is investigated in upsetting of aluminum alloy. 0.5 g/m^2 of lubricant reduces the coefficient of friction in upsetting of aluminum alloy. Because the mist lubricant is extended to the thin film between the tool and the specimen, the friction is kept to be low in semi-dry forging.

References

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