Development of Tribo-simulator for Cold Forging Lubricants

Wataru Shimabukuro[1], Yusuke Nakamura[1], Shinobu Komiyama[2], Shohei Shimizu[3], Tomoyuki Hakoyama[4], Zhigang Wang[4]

[1]*Central Research Laboratories, Nihon Parkerizing Co., Ltd., 2784 Ohkami, Hiratsuka-shi, Kanagawa, 254-0012, Japan*
[2]*Corporate Planning Division, Nihon Parkerizing Co., Ltd., 1-15-1, Nihonbashi, Chuo-ku, Tokyo, 103-0027, Japan*
[3]*School of Engineering, Gifu University, Tokai National Higher Education and Research System, Yanagido, Gifu, Japan*
[4]*Department of Engineering, Gifu University, Tokai National Higher Education and Research System, Yanagido, Gifu, Japan*

As a method for evaluating the lubrication coating, we have developed a upsetting-ball ironing test. In this test, a range from low surface expansion area to high surface expansion area is given in a single operation, allowing the lubricant's anti-galling ability to be evaluated.

In addition, revised test was also developed. Since this test is conducted under more severe conditions, it is a test method that accelerates the seizure behavior.

Keywords: *cold forging, lubrication coating, tribology, FEM simulation, Upsetting-ironing test*

1. Introduction

In cold forging, a lubrication coating on the surface of the workpiece is to prevent galling. One of the oldest known lubrication coatings is zinc phosphate coating, which forms a crystalline film on the surface of the workpiece through a chemical reaction. However, the environmental impact of the coating treatment process has become an issue, so in recent years, there has been much consideration of replacing this method with environmentally friendly coating-type lubricants. Since these lubricants are used in a wide range of forging processes for various automotive parts and bolts, it is necessary to confirm the effects of lubricant components remaining after the forging process on the subsequent processes. For example, in the case of high-tensile bolts for weight reduction, if phosphorus is included in the remaining coating component after the forming process, it can easily penetrate the steel during the heat treatment process and cause delayed fracture under tension after the bolt is installed[1)]. For other parts, depending on the manufacturing process, there may be concerns about adverse effects on heat treatment, such as inhibition of carburization by the residual coating. In addition, the demand for cold forging has been increasing recently, and lubricants that can be applied to high forging difficulty are required. With the emphasis on improving the performance of lubrication coatings, the challenge is to enhance the practical performance of lubricants within the aforementioned.

We have developed the upsetting-ball ironing test as an evaluation method for the lubrication coating. This is a test method in which the lubricant film is subjected to upsetting damage and ironing damage by bearing balls. This is a summary of the upsetting-ball ironing test based on our published papers[2,3,4,6)] and technical reports[5)].

2. Original upsetting-ball ironing test

2.1 testing method for multi-stage cold forging

Fig.1 shows the principle of the developed testing method. In the test, the lubrication coating on the side surface of the billet is first subjected to free expansion in upsetting and then squeezed in ironing with bearing balls. The reduction in height in upsetting can be changed in accordance with the degree of surface expansion in the early forming stage.

In ironing, three bearing balls are pushed down to squeeze the coating film, and the three ironed surfaces of each billet are evaluated by the degree of galling.

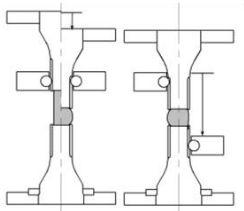
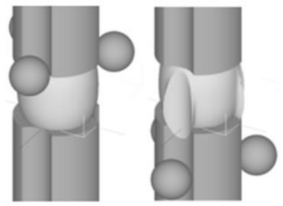
(a)  (b) 

Fig.1 Illustration of upsetting-ball ironing test(a) and ironed process(b).

2.2 Experimental results

Experimental conditions using a multi-action press are shown in Table 1. Lub.a is zinc phosphate with soap that chiefly used in the field of steel forging. Lub.b is dry in place type coating.

Table 1 Experimental conditions.[3)]

Billet	SWRK10K, dia.13.96 mm×32.0 mm
Ball	SUJ2, dia. 10.0 mm
Lubricant	・Zinc phosphate and soap(Lub.a) ・Dry in place type coating(Lub.b)
Processing conditions	Process temperature：25 ℃ Upsetting ratio：45 % Upsetting speed：10.0 mm/s Ironing speed：36.7 mm/s

[*3] Graduate student, Gifu University

This test result that Lub.b dropped out early and seizure is shown widely compared to Lub.a. Therefore, the anti-ability of dry in place type coating is inferior to the zinc phosphate and soap coating.[3)]

After the development of this method, the research and development of lubricants have progressed. When the lubrication coating is evaluated by the test, the area where seizure occurs is a small area at the end of ironing process, and it is difficult to determine the performance difference of the lubrication film. Therefore, we started developing a test method that expands the high surface expansion area that causes seizure.

3. Devised upsetting-ball ironing test

3.1 Design of testing method and FEM simulation

The upsetting process is revised as shown in Fig.3. A ring die is employed in upsetting to form a billet to a circular truncated cone. Cone shapes can increase the material volume at the early stage of ironing and thus increase the surface expansion ratio while keeping the first contacting point of the bearing ball at the free surface of the overhanging portion.

DEFORM-3D™ (SFTC) was used for the finite element method (FEM) analysis, and isothermal analysis was performed with a friction coefficient of 0.04. The upper and lower punches, fusing dies, and spherical dies were rigid, and the billet is assumed to be rigid-plastic. The flow curve of billet is $\sigma=(\varepsilon+0.273)^{0.08}$ MPa.

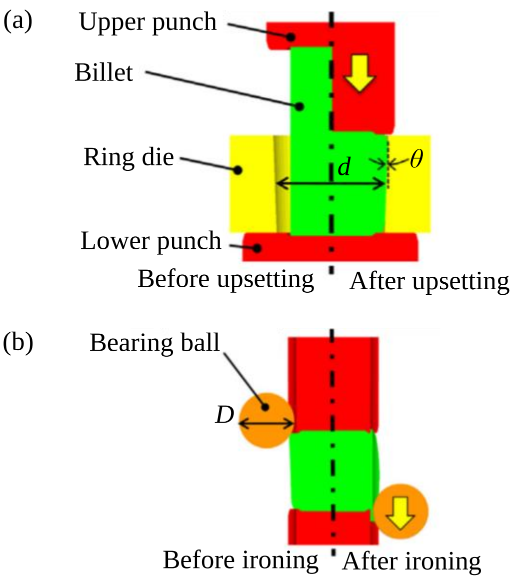


Fig.5 Schematic illustration of revised upsetting process (a) and ironing process (b).[5)]

Fig.4 shows a contour plot of the surface expansion ratio of the ironing surface. In the original, the surface expansion ratio increases rapidly after the middle of ironing, while in the revised model, it tends to increase gradually from the beginning of ironing.

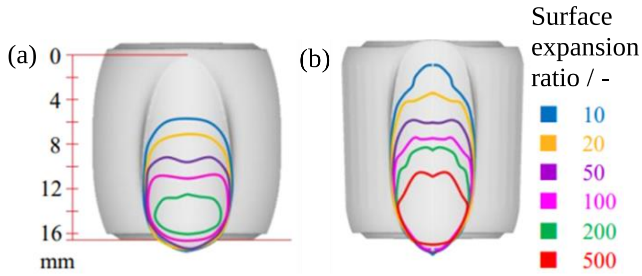


Fig.4 Surface expansion ratio of original(a), revised(b) model.[5)]

Fig.5 shows the results of the FEM analysis of the ironing load transition with respect to the ironing stroke. The maximum load value of the revised model is slightly lower than that of the original model. However, the load in half of ironing, when the surface expansion becomes larger, remains high.

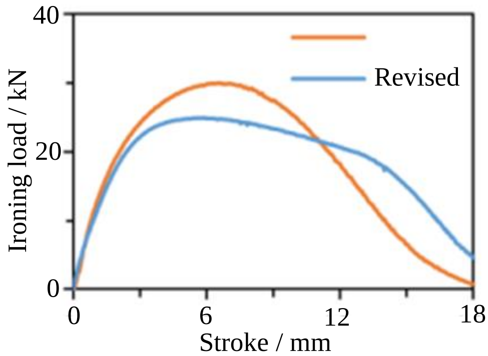


Fig.5 Variations of ironing load in simulation.[6)]

3.2 Experimental results

Experimental conditions are shown in Table 2. One difference from the original test is that the bearing balls are 12 mm. Experiments are carried out on a 1000 kN multi-action hydraulic press. A billet is upset to under an oil-lubricated condition, degreased and then treated with the lubrication coating.

Table 2 Experimental conditions of revised test.[6)]

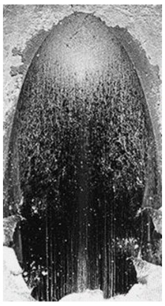
Billet	SWRK10K, dia.13.96 mm×32.0 mm
Ball	SUJ2, dia. 10.0 mm(original) dia. 12.0 mm(revised)
Lubricant	・Zinc phosphate and soap(Lub.1) ・Dry in place type coating(Lub.2) ・New dry in place type coating(Lub.3)
Processing conditions	Workpiece temperature：100 ℃ Upsetting ratio：45 % Upsetting speed：10.0 mm/s Ironing speed：60 mm/s

Table 3 shows surface appearance of the squeezed surface after the original and revised tests. The surface shows a metallic luster as it moves from top to bottom, resulting in seizure at the end of the process. This indicates that the lubricant film became thinner as the process progressed. In the revised test, the seizure was more extensive than in the original, starting at about 13 mm of the ironing stroke in Lub.1 and 11 mm of the ironing stroke in Lub.2, and the starting position of the seizure was earlier than in the original. In addition, the degree of seizure was more severe in Lub.2 than Lub.1, and the difference in anti-galling ability by lubricant type was also clearly shown.

The new lubricant shows an anti-galling ability even better than that of the zinc phosphate coating although its ironing load is slightly higher than that of the zinc phosphate (Fig.6). These differences among the lubrication coatings become apparent first by the devised upsetting-ball ironing test.[6)]

Table 3 Comparison of surface appearance among lubricants, original(a) and revised(b) model.[5,6)]

(a)

Original	
Lub.1	Lub.2
Zinc phosphate and soap	Dry in place coating
	

(b)

Revised		
Lub.1	Lub.2	Lub.3
Zinc phosphate and soap	Dry in place coating	New coating
		

Fig.6 shows the measurement results of the ironing load. In the original test, the load curve was similar to the FEM analysis results shown in Fig.5, and there was only a slight difference due to the lubricant type or load change during the occurrence of seizure. In contrast, in the revised test, a maximum load was observed approximately 4 mm of the ironing stroke, and an increase in load was also observed approximately 13 mm. If the friction condition is constant, the load should gradually decrease in the second half of ironing, as shown by the analysis results in Fig.5. Therefore, the increase in load in the second half of ironing process is considered to indicate a worsening of the friction condition. Comparing the load curves in Fig.6 and the ironed surface appearance in Table 3, the timing of the load increase for both lubricants was generally slightly before the galling position, and the magnitude of the load increase was correlated with the degree of seizure. The increase in load in the modified test was considered to represent the deterioration of the lubrication condition immediately before seizure and the degree of seizure, clearly indicating the difference of lubricants.

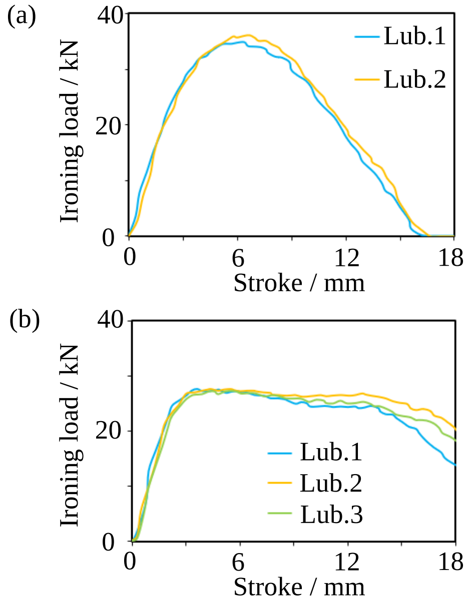


Fig.6 Experimental result of ironing load.[5,6)]

4. Conclusion

The original and revised upsetting-ball ironing test is proposed to discover a new lubricant that is better than the zinc phosphate coating for cold forging.

1) The surface expansion ratio reaches at 200 in the original upsetting-ball ironing test.
2) In the revised test, surface expansion progresses from the early stages of ironing processing, eventually reaching 500.
3) In the revised test, the difference in the anti-galling ability between lubricants with a good performance as the same level as the zinc phosphate coatings can be evaluated.

5. References

1) S. Yamane: *Kobe steel engineering reports*, **59**, (2009) pp.63-66
2) Z.G. Wang, S. Komiyama, Y. Yoshikawa, T. Suzuki, K. Osakada, *CIRP Ann.*, **64** (2015) pp.285-288
3) M. Hirose, Z.G. Wang, S. Komiyama: *Key Eng. Mater.*, **535**, (2013) pp.243-246
4) Z.G. Wang, T. Hakoyama, T. Yaguchi, Y. Nakamura, S. Komiyama: *CIRP Ann.*, **72** (2023) pp.251-254
5) Z.G. Wang, T. Hakoyama, T. Yaguchi, Y. Nakamura, S. Komiyama: *Nihon Parkerizing technical report*, **35**, (2023) pp.18-24
6) Y. Nakamura, T. Yaguchi, S. Komiyama, T. Hakoyama, Z.G. Wang: Proceedings of 54th ICFG Plenary Meeting, (2021), pp.85-90