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Evaluation of lubricants without zinc phosphate precoat in multi-stage cold forging

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ABSTRACT

The performance of lubrication coatings developed for replacing zinc phosphate conversion coating in multi-stage cold forging is evaluated with a newly devised testing method. In this test, the coated film on the side surface of the billet is first subjected to free expansion in upsetting and then squeezed in ironing with bearing balls. It is revealed that the coated film is peeled off in the upsetting stage, and cannot show good anti-galling ability in the subsequent stage. The billet surface treated by wet blasting before coating improves the performance by preventing the coated film from peeling off.

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1. Introduction

In cold forging, the role of the lubrication coating on the billet surface is to prevent direct contact between the tool surface and the billet, and to provide a low friction to ensure smooth sliding between them. The conversion coating of zinc phosphate with metal soap has been contributed to successful operation of cold forging of steel materials for a long time.

However, in the treatment process of zinc phosphate coating, the waste water, energy consumption and enormous amount of sediment of phosphorus compound are caused [1]. These problems were closed up from the viewpoint of global environment in the 1990s and brought about the motivation for development of new non-reactive type coating methods [2].

The developed coatings were examined by various testing methods [3] and generally showed low frictional coefficients. But, in many cases, they could not realize good performance as the conversion coating under the actual forming conditions. A coating used in cold forging should satisfy two functions; (1) a low friction coefficient and (2) a high sticking strength to the base metal to prevent galling. In the present paper, a testing method is proposed to evaluate the coating by separating the two functions.

2. Development of new lubrication coating

2.1. Structure of lubrication coating

A typical non-reactive type coating is generated on the billet surface by applying water-based lubricant with subsequent vaporization of water. Fig. 1 shows an illustration of coating process, named as “dry in-place coating”, because the coating can be done in a forging line [4]. The structure of the dry in-place coating is similar to that of zinc phosphate coating, i.e. the coating film consists of two layers: the upper layer providing low friction with the tool surface and the lower layer protecting the tool surface from direct contact with the billet surface.

The main ingredient of the lower layer is a water-soluble alkali metal salt. Alkali metal salt has high affinity with the surface of the steel billet and resists against the high contact pressure and temperature, and thus protects the billet surface physically.

The upper layer consists of inorganic or organic lubrication ingredients, which are initially dispersed in water. As for the inorganic ingredients, graphite, molybdenum disulfide and zinc phosphate are used. Inorganic ingredients have high resistance against temperature rise and contact pressure and thus may be used in the severe working situations such as closed die forging. Inorganic ingredients have weak cleavage faces in their crystal structure and thus give low frictions. In contrast, organic ingredients have hydrophobic agents with molecular structures having a few side chains and thus provide low frictions. As organic ingredients, fats, soaps and waxes are used.

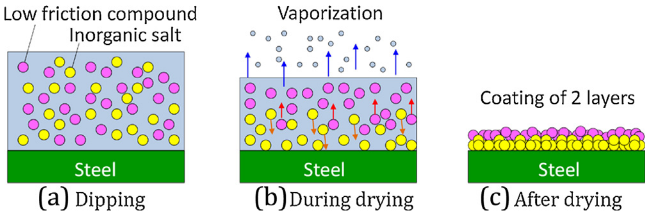

Fig. 1. Formation process of dry in-place coating.

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Table 1
Performance of zinc phosphate and dry in-place coating in various evaluating tests of forging.

Test method	Evaluation factor	Zinc phosphate coating	Dry in-place coating
Ring compression test	Friction coefficient	0.065–0.075	0.045–0.055
Spike test	Forging load (arbitrary unit)	1	0.987
	Spike height (arbitrary unit)	1	1.007
Backward extrusion test	Critical depth (arbitrary unit)	1	1.071
Closed forward extrusion test	Forging load (arbitrary unit)	1	0.918

2.2. Friction property of lubrication coating

Four kinds of forging simulation test are carried out and the experimental results are shown in Table 1. In these tests, the performances of the dry in-place coating are equivalent to or better than those of zinc phosphate coating.

By using the tribometer reported in the previous paper [5], relations between frictional stress and contact pressure are measured and shown in Fig. 2 for the dry in-place and the zinc phosphate coatings. In the Figure, the previous data for dry condition with a DLC coated tool are also shown for reference: a constant friction coefficient $\mu = 0.13$ up to a critical pressure of about $p_a/Y = 2.5$, and a constant frictional stress $\tau_a/k = 0.56$ for higher pressure. It is clear that the coatings provide linear relations, i.e. constant friction coefficients, up to $p_a/Y = 4.5$ and no bending phenomenon is observed.

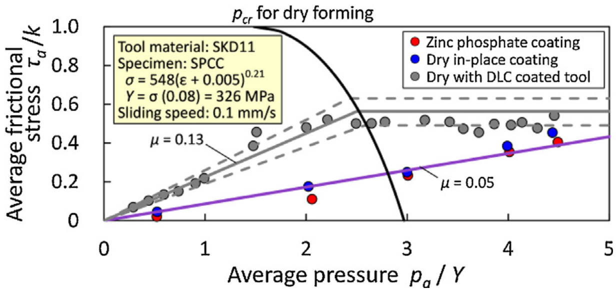


Fig. 2. Friction law of dry in-place coating and zinc phosphate coating.

2.3. Problems in multi-stage forging

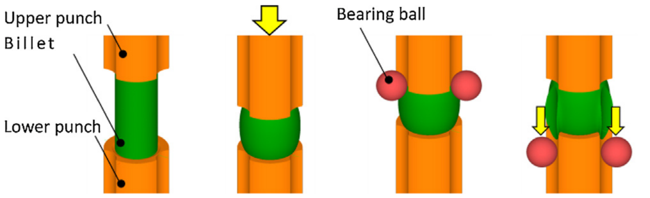
In spite of the good performances in the laboratory tests, the dry in-place coating tends to cause galling and is often inferior to the zinc phosphate coating in forging shops [6]. This problem is particularly serious in the forging processes of tripods, bevel gears etc., where the billet is upset in the first stage. In the previous paper [7], the experimental results evaluated by an upsetting-extrusion type testing method showed that the lubrication coating is damaged in the upsetting stage and cannot realize a good anti-galling ability in the extrusion stage. It was also clarified that the anti-galling ability of the lubrication coating is very sensitive to the surface roughness of the extrusion punch, which is difficult to be controlled strictly in the experiment.

3. Testing method for multi-stage cold forging

3.1. Principle of developed testing method

Fig. 3 shows the principle of the developed testing method that consists of the upper punch, lower punch and bearing balls. In the test with this testing method, 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 to 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. The test can be repeated under almost the same condition by renewing the balls.



(a) Before upsetting (b) After upsetting (c) Before ironing (d) After ironing

Fig. 3. Schematic illustration of multi-stage forging test.

3.2. Experimental conditions

Experimental conditions are shown in Table 2. The billet material is a 0.10% C carbon steel S10C with the flow curve of $\sigma = 600(\varepsilon + 0.315)^{0.2}$ MPa. The billet size is 13.96 mm in diameter and 32.00 mm in height. Bearing balls are made of high carbon chromium steel and their surface roughness is 0.027 μmR_z. The zinc phosphate coating and dry in-place coating are subjected to this test to clarify the difference in multi-stage process.

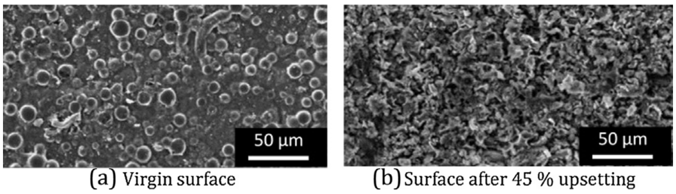
Table 2
Experimental conditions.

Billet	Material	S10C (JIS: 0.10% C carbon steel)
	Diameter	13.96 mm
	Height	32.00 mm
	Lubrication coatings	Zinc phosphate coating Dry in-place coating
Upsetting conditions	Reduction in height	45.0%
	Speed	10.0 mm/s
	Temperature	RT
Ironing conditions	Material of bearing ball	SUJ2 (JIS: 1% Cr bearing steel)
	Diameter of bearing ball	10.00 mm
	Speed	60.0 mm/s
	Temperature	RT

Experiments are carried out on a 1100 kN multi-action press. The ironing load and ironing stroke are measured with a load cell and a laser displacement gauge, respectively. After 45% reduction in height in upsetting, ironing is carried out at room temperature with a speed of 60 mm/s.

3.3. Damage of lubrication coating by upsetting

Fig. 4 shows the change in the surface appearance of the dry in-place coating by upsetting. After upsetting, the spherical particles of the solid lubricant on the initial surface disappear and the coating layer becomes roughened.



(a) Virgin surface (b) Surface after 45 % upsetting

Fig. 4. Changes in surface appearance of dry in-place coating by upsetting.

Fig. 5 shows the changes in the thickness of the lubrication coating by upsetting. The thickness of lubrication coating is calculated from the difference of the weights before and after coating. The initial thicknesses of the zinc phosphate coating and dry in-place coating are 11.01 μm and 5.20 μm, respectively. After upsetting, the thickness of zinc phosphate coating is 1.8 μm, and that of dry in-place coating is 2.9 μm.

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