A new lubricant carrier for metal forming

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ABSTRACT

A lubricant carrier for metal forming processes is developed. Surfaces with pores of micrometer size for entrapping lubricant are generated by electrochemical deposition of an alloy, consisting of two immiscible metals, of which one metal subsequently is etched away leaving 5 μm layers with a sponge-like structure. The pores will act as lubricant reservoirs during severe forming processes. The deposited microporous layer is created by friction tests in the form of ring compression tests and double cup extrusion tests. Furthermore the anti-seizure properties are investigated by single cup extrusion at high reduction and excessive stroke comparing with conventionally lubrication using phosphate coating and soap.

1. Introduction

The large surface expansion and high normal pressure combined with elevated contact temperature between workpiece and tool, which prevail in cold forging of metals cause the necessity of a high performance lubrication system [1–7]. The objective of lubrication is to reduce friction and thereby lower the deformation forces and increase tool life and more importantly to avoid galling, i.e. breakdown of lubricant film, metal to metal contact between tool and workpiece, pick-up of workpiece material on the tool surface leading to scoring of subsequent workpiece surfaces. An efficient lubrication system is therefore essential for ensuring production with satisfactory quality. Conventionally, a conversion coating of zinc phosphate with dual function is applied. Due to its topographic nature, a large surface area is created with pockets suitable for entrapment of lubricant. Dipping the zinc phosphated slugs in a liquid bath of sodium stearate, the conversion coating forms zinc stearate which is chemically bonded to the workpiece surface and covered with excessive sodium stearate as shown in Fig. 1. The total thickness of the coating is 10–20 μm. The costs of producing such a lubricant film amount in average to 3% of the total costs of the formed component. The major part of the costs is related to disposal of the sludge, which in case of alloyed steel slugs besides iron may contain chrome and molybdenum. These environmentally hazardous heavy metals, which appear in the sludge due to etching of the base metal during phosphating, have to be disposed by burying.

2. Novel method for creating porous lubricant carrier

The authors have invented a new, patented lubrication system, based on a novel type of lubricant carrier, created by an alloy electrochemically deposited on the workpiece surface [8,9]. The alloying elements are specifically selected to ensure deposition of a two phase layer, consisting of a mixture of fine grains of two metals. After deposition, one of the two metals is selectively etched leaving a micro- or even nanoporous layer of the remaining metal on the workpiece surface. When a lubricant subsequently is applied to the porous coating, it will be trapped in the pores acting as numerous small lubricant reservoirs. In Fig. 2, the steps in creating the new tribological system are illustrated.

The deposited two phase alloy in the present work is SnZn creating a film of typically 5 μm thickness. The film is subsequently etched with diluted hydrochloric acid, whereby the Zn is removed, leaving a porous Sn layer. The diluted acid is considered environmentally harmless. If requested, the Zn can, by a simple precipitation procedure, be recycled. Deposition rate is 0.5–1 μm/min. The topography of the etched surface depends on the chemical composition of the SnZn alloy and on the concentration, time and temperature used in the etching procedure. Fig. 3 shows the porous sponge-like coating. The cross-section in Fig. 3 left, clearly shows the pores for entrapment of lubricant.

The new, porous coating may be used not only as lubricant carrier in conventional cold forging, but also in cold forging of microcomponents. For such components, the conventional solid film lubrication is often inappropriate due to packing of dies with excess lubricant and inability to obtain satisfactory close tolerances, since the total film thickness is of the same order of magnitude as the requested tolerances. Liquid lubricants are preferred, but due to risk of galling, when using liquid lubricants without a conversion coating, the combination of an ultra-thin, porous, metallic film and a liquid lubricant is proposed to overcome these problems. Other possible two phase alloys include: AgCo, AgFe, BiSn, CoCu and AgCu. Ag is corrosion resistant, bactericidal and has a significantly higher melting point as compared to Sn, properties which may be utilized in special cases.

3. Experimental work

The capability of the new porous layer is tested by conventional friction tests in cold forging; a ring compression test [10] and a...
3.1. Ring compression test

In the initial ring compression tests, pure silver is chosen as base material, since deposition on silver is expected to be a non-complicated procedure. The stress–strain curve is determined by uni-axial compression test and found to follow the Hollomon expression: \( \sigma = 295e^{0.27} \) [MPa]. The initial ring has the prescribed ratio 6:3:2 between outer diameter (OD), inner diameter and height, with OD = 15 mm. The rings are compressed between overhanging tool steel planes (AISI M3:2 PM, 62 HRC) polished to a surface roughness \( R_a = 0.03 \) mm. Height reductions are chosen as 20, 40 and 60%. Four different lubrication systems are tested: the new, porous coating lubricated with Molykote DX paste (in the following abbreviated MoDX) or mineral oil and the same lubricants without any coating. The MoDX paste is a high viscosity grease containing distilled, heavy naphthenic petroleum, lithium soap, solid lubricants and additives in a paraffinic base oil. The mineral oil is made as a mixture of two oils, i.e. 50 wt.% Sunoco Sun 60 (low viscosity naphthenic mineral oil) and 50 wt.% Houghton Plunger CRS (high viscosity mineral oil). A resulting viscosity of 60 cSt at 40 °C is obtained. No boundary lubrication additives are added to the oil.

3.2. Double cup extrusion test

A double cup extrusion test is carried out with high reduction to stress the coating. The container and lower punch is kept stationary. In case of zero friction along the container wall the upper and lower cup will develop equally, i.e. \( h_u/h_l = 1 \), whereas increased friction will enhance upwards flow implying larger cup height ratio. The test principle is illustrated in Fig. 5. The diameter of the container and billet is \( D_0 = 27 \) mm and the reduction \( r = (D_p/D_0)^2 = 69\% \), where \( D_p \) is the punch diameter. The shape of the punch nose is chosen according to the recommendations of ICFG [12]. The height to diameter ratio of the billet is \( h_0/D_0 = 1 \). Punches as well as container core are made in AISI M3:2 PM, hardened and tempered to 62 HRC. They are polished to a surface roughness \( R_a = 0.1 \) mm. Experiments are performed in the same pure silver as used for the ring test with three different lubrication systems: the new porous coating lubricated with (i) MoDX paste or (ii) oil or (iii) MoDX added directly on a clean surface. The relative punch travel \( z/h_0 \) is aimed at 20, 40 and 60%. In Fig. 6, the experimental data is plotted together with a set of calibration curves for the workpiece material calculated by Deform 2D. Some scatter is observed in the experimental results, but it is evident that the coated specimens lubricated with the mineral oil create low friction conditions \( \mu \approx 0.05 \) whereas no effect of the coating can be identified when lubricating with MoDX.

The promising results obtained in testing the new conversion coating on silver specimens encouraged the authors to carry on testing the coating on conventional cold forging steel comparing with the conventional phosphate coating lubricated with soap as reference.

The steel is a common unalloyed C-steel, Ma8, with the stress–strain curve determined by uni-axial compression test to:

![Fig. 1. Conventional lubricant film of phosphate coating reacted with sodium soap.](image1)

![Fig. 4. Ring test of silver.](image4)

![Fig. 2. (A) Deposited SnZn alloy. (B) Coating after selective etching of Zn. (C) Porous coating lubricated with oil. (D) Porous coating lubricated with grease.](image2)

![Fig. 3. Cross-section and top view of porous coating.](image3)

![Fig. 5. Principle of double cup extrusion test.](image5)
The test design is similar to the one for the silver specimens, i.e. a reduction \( r = \left( \frac{D_0}{D_0} \right)^2 = 69\% \), a height to diameter ratio of the slug \( h_0/D_0 = 1 \) and a container diameter \( D_0 = 27 \text{ mm} \). The relative punch stroke is aimed at \( z/h_0 = 20, 40 \) and \( 60\% \).

Six different lubrication systems are tested: coated and non-coated with MoDX grease or mineral oil, conventional phosphating or the new coating both lubricated with soap.

In Fig. 7, the inner wall of the upper cup is shown for the maximum stroke obtained with various lubrications. As seen, severe scoring due to galling appears for the non-coated parts, whereas no scoring appears when applying conventional phosphate coating plus soap or the new coating plus any of the three lubricants. Roughness measurements are carried out in circumferential direction on the inner cup wall with \( \lambda_s = 2.5 \text{ mm} \) and \( \lambda_c = 0.8 \text{ mm} \) to quantify the amount of scoring as shown in Fig. 8. A distance of 4 mm along the periphery is measured at three different positions, i.e. 19, 20 and 21 mm from the top of the upper cup. The \( R_a \) value is calculated as the average value of the three measurements and can be used as an indicator for the level of galling, but scoring is clearly visible from the roughness plot. Smooth surfaces without any sign of galling are obtained for the coated surfaces.

Due to severe galling, the friction test is not carried out on the non-coated parts at larger punch strokes. In Fig. 9, the cup height ratio \( h_u/h_l \) as a function of the relative punch stroke \( z/h_0 \), is shown for all six lubrication systems. Some scatter can be identified due to the limited number of available test samples. It is, however, quite clear, that the Sn-coated and soap lubricated specimens are at the same level as the conventional phosphated and soap lubricated ones. The Sn-coating lubricated with MoDX or oil show somewhat higher cup height ratio indicating larger friction even though the obtained surfaces are smoother than the soap lubricated ones as shown in Fig. 8.

3.3. Single cup extrusion, galling test

To stress the lubrication system, a single cup extrusion with high reduction \( r = \left( \frac{D_0}{D_0} \right)^2 = 69\% \) and large relative punch stroke \( z/h_0 = 0.75 \) is carried out with the same steel Ma8 as used for the double cup extrusion tests. The height to diameter ratio of the slug is kept at \( h_0/D_0 = 1 \). To avoid any influence from previous testing, the punch is polished between each experiment.

Four different lubrication systems are tested: Sn-coating lubricated with (i) MoDX grease, (ii) mineral oil or (iii) soap and (iv) conventional phosphating and soap lubrication. The tests are carried out on a 2.5MN press with a speed of app. 50 mm/s. Fig. 10 shows the formed parts. The specimen Sn-coated and lubricated with MoDX grease show severe scoring marks all over the inner cup wall, whereas specimens with Sn-coating lubricated with oil or with soap and phosphate coating plus soap all result in smooth surfaces. This is further clarified in Fig. 11, showing roughness profiles of the inner cup wall in circumferential direction. The roughness is measured over a distance of 4 mm along the periphery at three different positions, i.e. 19, 20 and 21 mm from the bottom of the cup. It is seen that the Sn-coated and MoDX lubricated specimen has significantly higher roughness than the other specimens, which all lie on a rather constant level of \( R_a \approx 1.03 \text{ mm} \).

4. Discussion

The ring compression test is due to low temperature, surface expansion and sliding length considered a light deformation.
As stated earlier, low friction is important in order to achieve low forming forces and thereby improve tool life, but the ability of the lubrication system to impede galling is more important since lubrication problems in severe cold forging processes avoiding hazardous environmental impact. It is an electrochemically deposited coating of two insoluble metals, of which one is subsequently selectively etched in diluted acid to create a porous layer acting as carrier of the lubricant. The system has been tested in conventional ring compression tests and double cup extrusion test. Its performance to impede galling has furthermore been tested by severe stressing in single cup extrusion.

When lubricating with a low viscosity mineral oil, which can penetrate into the porous coating, promising results are demonstrated with regards to significantly lower friction as well as increased resistance towards galling compared to non-coated surfaces. When the coating is applied to a common cold forging steel and lubricated with soap, the friction and resistance to galling is at the same level or even better than the conventional phosphate coating. An advantage of the new coating is the expected improved environmental impact compared to the phosphating process.

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