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Influence of a heat treatment prior to cold forging operations on the performance of lubricants

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ABSTRACT

Cold forging operations are subject to high tribological loads. In order to enable a reliable forging process, lubricants have to be chosen with respect to the occurring loads. However, it is known that well established lubricants can increase the surface roughness of a specimen in consequence of the forming. On the other hand, zinc-phosphate+molybdenum disulfide which is known to create a smooth specimen surface often shows higher friction coefficients. The paper at hand presents the results of a heat treatment prior to cold forging operations on the performance of polymer, saltwax, soap and molybdenum disulfide. The zinc-phosphate+molybdenum disulfide lubrication system indicates that a heat treatment of the lubricant results in a decrease of the friction coefficient.

1. Introduction

Cold forging operations are widely-used in industrial manufacturing chains due to their unique advantages. They offer an excellent material utilization and superior material properties [1]. Due to the forming at room temperature, cold forging has the ability to produce near net-shape components with tolerance classes between IT7 and IT11 [2]. The need for high quality surfaces which do not need further machining operations is of special interest in today's industry.

On the other hand, cold forging operations are subject to high tribological loads. During the processes, contact normal stresses can easily reach values of up to 3,000N/mm² [3,4]. Bay states that surface enlargements over 30 [5] may be reached for low alloyed steels. Relative velocities between workpiece and tool may reach 500 mm/s in combination with sliding distances up to 100 mm, depending on the actual forging operation [6]. Even though speaking of cold forging processes, Wibom et al. refers that tool temperatures may reach 200 °C [7] due to the conversion of forming and friction energy into heat. Locally distributed workpiece temperatures even exceed this value and may reach temperatures up to 600 °C [3].

Therefore, complex tribological systems are applied to the workpieces in order to enable a sound production. The tribological systems often consist of a conversion coating as lubricant carrier and a lubricant [8]. The most common system for the lubrication carrier is a zinc-phosphate coating [5,9]. Molybdenum disulfide (MoS_2), polymer or soap is typically used as a lubricant [3] while oils may also be applied for lower loads [3,10]. Single layer lubricants like salt wax coatings with integrated lubrication, polymers or molybdenum disulfide, which are applied directly onto the surface of the workpiece, become more and more important due to their environmentally friendly application [11]. Former investigations have proven that they are able to bear the tribological loads of most cold forging operations [12].

Regarding the final surface quality of the workpiece, molybdenum disulfide with or without conversion coating is believed to produce the best results. However, even though molybdenum disulfide is often used for processes where other lubricants fail due to severe tribological loads, its lubricating effects are inferior to polymers, soaps or salt wax coatings for processes with lower tribological loads [12]. This often results in higher forming forces, which is why other lubricants are preferred for these processes.

In order to combine the superior surface quality of the molybdenum disulfide with a better lubricating effect, especially at lower tribological loads, a heat treatment of the lubricant was conducted. The same treatment was adopted for other lubricants for reasons of comparability. The paper presents the results of a specific investigation of the influence of this heat treatment prior to cold forging operations on the performance of lubricants.

2. Test equipment

2.1. Sliding Compression Test

The first part of the investigations of the influence of the heat treatment was conducted with the Sliding Compression Test (SCT).

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This tribometer was developed at the Institute for Production Engineering and Forming Machines (PtU) and is able to reproduce the tribological loads of cold forging operations. It utilizes a hydraulic press to apply the necessary contact normal stresses up to 3,000N/mm^2, surface enlargements up to 11 and relative velocities up to 500 mm/s which may occur during cold forging. In comparison to other tribometers like the Double-Cup-Extrusion Test [14], the Ring Compression Test [15] or the Spike Test [16], it is possible to set a specific and nearly homogeneously distributed contact normal stress and surface enlargement. These are important parameters for a reliable determination of the friction coefficient. Fig. 1 displays the test principle of the SCT.

The process is divided into two sequences, a compression and a sliding sequence. First, the specimen is being placed on the sliding plate beneath the punch. During the compression sequence, the punch moves downwards, forms the specimen and fills the punch engraving. At this stage, the preset surface enlargement as well as the contact normal stress is reached. Both can also be set independently [13]. The sliding sequence follows the compression sequence. While the punch force is kept constant, the sliding plate moves with a defined velocity along a preset sliding distance. The force which is necessary to perform this movement equals the occurring friction force and is being measured by a load cell which is located beneath the sliding plate. The friction coefficient is determined by the division of the friction force through the punch force as it can be seen in the following equation:

$$\mu = \frac{F_R}{F_N} = \frac{\text{Friction force}}{\text{Punch force}} \tag{1}$$

This tribometer has already been used in former investigations focusing on the influence of macroscopic structured specimens on the friction coefficient [17] or the influence of the relative velocity [12], the temperature between workpiece and tool [18] or environmental effects [19] on the tribological system.

All specimens used in the experiments were prepared equally. The billet material for the SCT was 16MnCrS5 (1.7139). The rods were sawed into pieces of a length of 15 mm and a diameter of 15 mm. Afterwards, the burr was removed and the surface of the specimens were shot blasted with iron balls with a diameter between 1.0 and 1.6 mm (S390). All experiments were conducted with a number of three specimens per series. The experimental details which were kept constant during the tests are given in Table 1.

2.2. Rod extrusion process

In order to verify the results of the tribometer tests, an industrial rod extrusion process with a gearing in longitudinal direction was conducted. The rod extrusion tool and the formed specimen are displayed in Fig. 2. The specimen used for the experiments were made of C15 (1.0401) with a diameter of 18.2 mm and a length of 65 mm. The surface was shot blasted before the forming stage in order to guarantee a sound adherence of the lubricants. The rod extrusion process was carried out using a 250t direct driven servo motor press SWP 2500.

The experimental details for the rod extrusion process are given in Table 2.

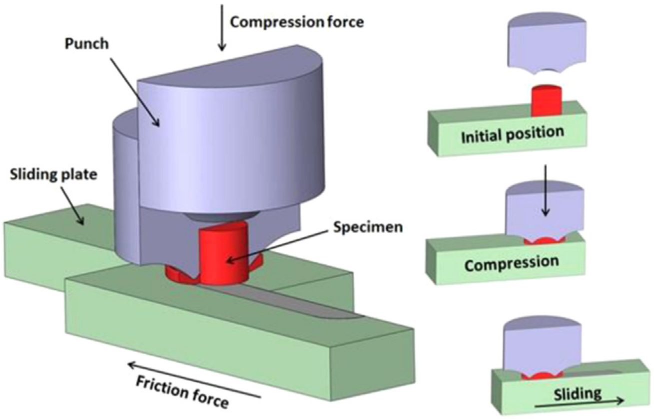

Fig. 1. Sliding Compression Test [18].

Table 1
Experimental details for the Sliding Compression Test.

Parameter	Value
Specimen height	15 mm
Specimen diameter	15 mm
Specimen material	16MnCrS5 (1.7139)
Sliding distance	60 mm
Sliding velocity	20 mm/s
Compression force	450 kN
Compression velocity	5 mm/s

Fig. 2. Rod extrusion tool and specimen.

Table 2
Experimental details for the rod extrusion process.

Parameter	Value
Specimen height	65 mm
Specimen diameter	18.2 mm
Specimen material	C15 (1.0401)
Stroke	50 mm
Stroke velocity	7 mm/s

3. Experimental results

3.1. Sliding Compression Test

In a first test series, a polymer (Gardomer L6332), a molybdenum disulfide (ZWEZ-Lube MD210) and a soap (Gardolube L61776), all of them on a zinc-phosphate conversion coating as well as a salt wax coating (Beruforge 120D) with integrated lubrication without conversion coating were used as lubricants. Each lubrication system was exposed to temperatures of 100 °C, 150 °C and 200 °C for 15 min, using a commercial furnace. Furthermore, tests without heat treatment were conducted in order to compare the gained results.

Afterwards, the SCT was conducted with specimens at a cold condition. Therefore, it could be guaranteed that the friction coefficient was not affected by an increased temperature of the