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A study on the performance of environmentally benign lubricants at elevated temperatures in bulk metal forming

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ABSTRACT

The application of environmentally benign tribological systems becomes more and more important in cold forging operations. However, questions regarding the performance of these systems still oppose a widespread use in industry. Due to severe loads in cold forging, high tool temperatures of up to 200 °C may occur as a result of forming energy and friction in combination with a high output in a short range of time. The temperature at the tool–workpiece interface is even higher, though an exact identification proves to be difficult. Former investigations regarding the influence of the relative velocity indicated that the occurring temperatures are primarily responsible for the decrease of the friction. The paper at hand presents the results of a systematic investigation of the influence of the temperature at the tool–workpiece interface on the performance of environmentally benign tribological systems.

Introduction

In the year 2007, a new legislation, REACH, was introduced within the EU, which aims at a high level of protection of human health and the environment [1]. REACH holds the industry responsible for a safe handling of chemicals and fortifies suppliers to develop new and environmentally benign tribological systems. The application of these new tribological systems has become more and more important also in cold forging operations, even though the tribological loads in this area are known to be severe.

Contact normal stresses up to 3000 N/mm^2 [1,2] as well as surface enlargements over 30 [3] may be reached for low alloy steels. Relative velocities up to 500 mm/s in combination with sliding distances up to 100 mm may occur [4]. Even though speaking of cold forging processes, tool temperatures up to 200 °C [5] and locally distributed workpiece temperatures up to 600 °C [1] can occur due to the conversion of forming and friction energy into heat.

In order to face these tribological loads, complex tribological systems are necessary. These often consist of a conversion coating as lubricant carrier and a lubricant [6,7]. For low alloy steels, the zinc-phosphate coating is most common for the material separation [3,8]. Molybdenum disulfide, polymer or soap is typically used as a lubricant [1,9]. Oils may also be applied for lower loads [1,10,11].

From an ecological point of view, these tribological systems are critical due to the fact that the application of a zinc-phosphate coating is afflicted with a sludge accumulation in the baths. These are often associated with heavy metals, which are harmful to the environment [12–14].

Single bath systems, like salt wax coatings with integrated lubrication, polymers or molybdenum disulfide fulfill the requirements given by cold forging operations without the necessity for a zinc-phosphate conversion coating. Thus, they comply with the ecological requests [15,16]. However, many questions regarding the performance of single bath systems still exist and remain unanswered. Especially long sliding distances and high relative velocities in multistage operations are believed to be crucial.

A specific investigation of the influence of the relative velocity was conducted due to the fact that the application of servo presses in cold forging has gained more and more interest. In contrast to mechanically or hydraulically driven presses, these enable a flexible regulation of the stroke curves and, therefore, the possibility to specifically set the relative velocity between tool and workpiece. The investigations with common tribological systems consisting of a zinc-phosphate coating and a lubricant have proven that there is a significant influence of the relative sliding velocity on the friction coefficient. However, the results also indicated that the occurring temperatures in consequence of the combination of high sliding velocities and friction are primarily responsible for the decrease of the friction coefficient [17,18].

The paper at hand presents the results of a systematic investigation of the influence of the temperature on the performance of environmentally benign tribological systems.

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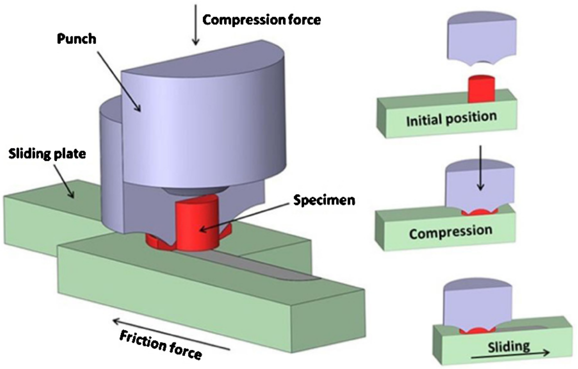

Fig. 1. Principle of the Sliding Compression Test [19].

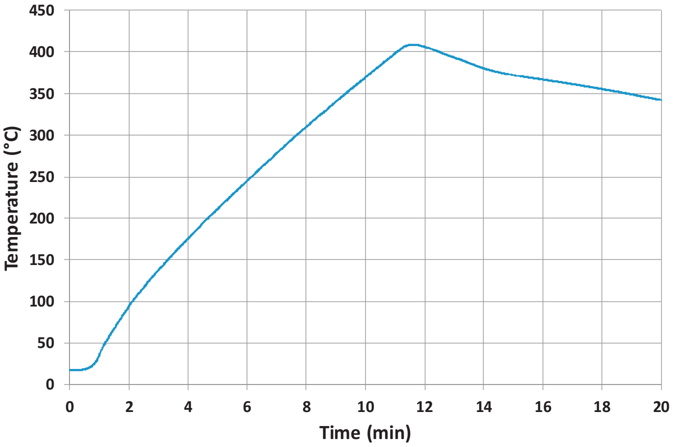

Fig. 2. Heating curve of the sliding plate.

Experimental details

The examinations were conducted with the Sliding Compression Test (SCT), a tribometer specifically developed for the reproduction of the tribological loads occurring in cold forging operations. It consists of a hydraulic press with a maximum punch force of 1000 kN. The test principle of the SCT is displayed in Fig. 1.

The process is divided into two sequences, a compression and a sliding sequence, which can be seen on the right-hand side of Fig. 1. In the initial position, the specimen is being placed directly beneath the punch. Afterwards, the compression sequence starts and the punch moves downwards resulting in a forming of the specimen and filling of the punch engraving. The predefined punch force sets thereby the surface enlargement and the contact normal stress, which can also be set independently [20]. An adequate punch engraving is chosen as a function of the surface enlargement and the contact normal stress. After the compression, the sliding sequence starts. Therefore, the sliding plate moves with a defined velocity along a preset sliding distance while the punch force is kept constant. A three-dimensional load cell beneath the sliding plate enables an online measurement of the punch and the sliding forces. The friction coefficient is calculated by the division of the sliding force through the punch force.

In comparison to other tribometers used for cold forging, this concept offers many advantages. An inhomogeneous distribution of the surface enlargement and of the contact normal stresses is a drawback of many common tribometers like the double-cup-extrusion test [21–23], the ring compression test [24,25] or the spike test [26–28]. Furthermore, long sliding distances as well as high relative velocities cannot be realized with these tribological test stands. The application of a heating system is often difficult due to complex tools. Also, a direct measurement of the friction forces cannot be achieved with the tribometers named above. Since the Sliding Compression Test offers many solutions to the above-mentioned requirements, it qualifies itself for a specific investigation of the influence of the temperature on the tribological system [4,29].

The SCT was used in former investigations regarding the influence of macroscopic structured specimens on the friction coefficient [30,31] or the influence of the relative velocity [17,18,32] and the environment [33,34] on the tribological system. Furthermore, the SCT is a useful tool for the evaluation of newly developed lubricants [15,16].

The SCT enables the reproduction of most of the tribological loads occurring in cold forging operations. Sliding velocities up to 500 mm/s and distances up to 100 mm can be set, while surface enlargements of more than 11 and contact normal stresses up to 3000 N/mm^2 for low alloyed steels can be achieved.

In order to investigate the influence of the temperature at the tool–specimen interface on the tribological system, the Sliding Compression Test is equipped with six heating-elements. Each heating-element induces a power of 1000 W and is integrated into the tooling insert. The functionality for the force measurement at higher temperatures is guaranteed by an insulation layer between tooling insert and load cell as well as a water cooling. The heating system allows tool temperatures up to 400 °C which can be reached in about 12 min. The heating curve of the sliding plate is shown in Fig. 2.

The tool temperature is measured by three temperature sensors. Two of them are displayed in Fig. 3. The thin wire measures the temperature beneath the sliding plate and remains at this position throughout the test procedure. The second sensor measures the temperature on the surface of the sliding plate. However, this sensor has to be removed before the test starts. The third sensor is positioned at the load cell and triggers an emergency stop when reaching a critical temperature.

A heating of the specimens prior to the SCT can be conducted with an induction unit or a furnace. The temperature measurement of the specimen on the skin surface during the test sequence is enabled by means of a noncontact temperature sensor. The used pyrometer (optris CT laser LT) can detect temperatures in a range of −50 °C to +975 °C. The pyrometry setup is shown in Fig. 3. Two laser spots secure that the measuring point of the pyrometer is focused correctly.

All specimens used in the experiments were treated equally. The billet material was 16MnCrS5. The rods were sawed into pieces of a length of 15 mm and a diameter of 15 mm. The burr was removed and the relevant side of the specimen was shot blasted with iron

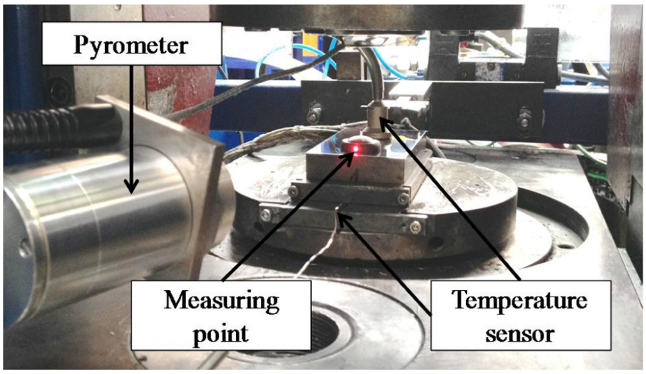

Fig. 3. Pyrometry setup.