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Environmentally benign tribo-systems for metal forming

N. Bay (1)[a,*], A. Azushima (1)[b], P. Groche (2)[c], I. Ishibashi[d], M. Merklein (2)[e], M. Morishita[f], T. Nakamura[g], S. Schmid[h], M. Yoshida[i]

[a] Department of Mechanical Engineering, Technical University of Denmark, Denmark
[b] Department of Mechanical Engineering and Materials Science, Yokohama National University, Japan
[c] Technical University of Darmstadt, Germany
[d] Sumico Lubricants Co., Japan
[e] Chair of Manufacturing Technology, University of Erlangen-Nuremberg, Germany
[f] Toyota Motor Corp., Japan
[g] Department of Mechanical Engineering, Shizuoka University, Japan
[h] Department of Aero & Mechanical Engineering, University of Notre Dame, USA
[i] Nihon Parkerizing Co., Japan

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ABSTRACT

The growing awareness of environmental issues and the requirements to establish solutions diminishing the impact on working environment as well as external environment has initiated ever increasing efforts to develop new, environmentally benign tribological systems for metal forming. The present paper gives an overview of these efforts substituting environmentally hazardous lubricants in cold, warm and hot forging as well as sheet forming and punching/blanking by new, less harmful lubricants and furthermore describes other measures directed towards the same goal such as development of anti-seizure tool materials and coatings and application of structured workpiece and tool surfaces.

1. Introduction

Since 2000 legislation in Europe and Japan has been increasingly restrictive with respect to the industrial application of hazardous lubricants [53,80,81], and in 2006–2007 the EU introduced new legislation, REACH, aiming at a high level of protection of human health and the environment from the risk posed by chemicals. REACH makes industry responsible for assessing and managing the risks posed by chemicals and providing appropriate safety information to their users. Due to these legislative initiatives, manufacturers are increasingly focused on environmental concerns and request their suppliers to act proactively to establish safe and healthy working conditions while limiting the strain on the environment. In the United States, exposure to harmful chemicals is regulated by the Occupational Safety and Health Administration and control of pollutants in wastewater or atmosphere exhaust by the Environmental Protection Agency. Proposed standards suggest limitation or elimination of certain carcinogenic chemicals commonly used in metalworking lubrication [78].

Environmental problems in metal forming tribology, can be divided into the following areas [89]: (a) health and safety of people, (b) influence on equipment and buildings, and (c) destruction and/or disposal of waste and remaining products. Improvement efforts are concentrated on (1) elimination of hazardous chemicals, e.g. chlorinated additives or phosphates with (heavy) metal sludge, and (2) reduction of waste, including prolonging tool and lubricant life, recovery and reuse of lubricants and minimal quantity lubrication (MQL).

Regarding cold forging the substitution of zinc phosphating plus soap with environmentally benign lubrication systems is of interest due to sludge accumulation in the baths and its associated content of heavy metals [90,138,147,154,218]. Regarding warm and hot forging, graphite based, "black" lubricants are being replaced by "white" lubricants due to bad working environment, leakage to soil and groundwater or pipe corrosion due to their electric conductive properties and low recovery rate due to their inferior oil separation [138].

As regards sheet metal forming, chlorinated paraffin oils are often used in forming of materials prone to galling such as advanced high strength steels, stainless steel and titanium, as well as in tribologically demanding processes such as punching and ironing, and present a serious environmental concern. Significant research has been expended towards finding alternatives by combining new lubricants with anti-seizure tool materials and coatings [25,90,115,147,202].

The present paper gives an overview of the development and testing of alternative, environmentally benign lubricants for cold forging, warm/hot forging, rolling, and sheet metal forming and punching/blanking. Furthermore, other measures towards substitution of hazardous lubricants with alternative, more environmentally friendly ones are discussed. These measures include anti-seizure tool materials and coatings and application of structured workpiece and tool surfaces.

* Corresponding author. Tel.: +45 45254764; fax: +45 45930190.
E-mail address: nbay@mek.dtu.dk (N. Bay).

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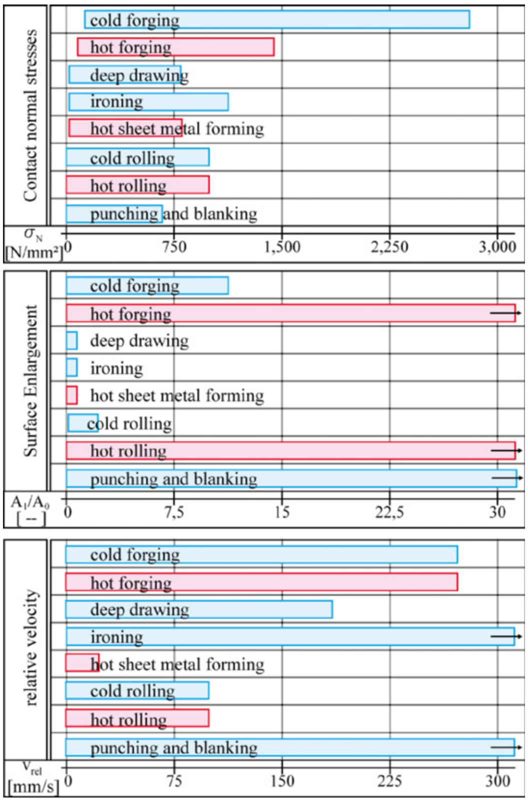

Fig. 1. Characteristic loads for typical tribological systems.

2. Tribological loads in metal forming

Suitable tribological systems for metal forming impede direct contact between tool and workpiece. By this separation reduced tool wear is achieved because the risk of adhesion is minimized. Additionally, in most cases friction forces are reduced.

Quality and type of lubrication which are required to realize tool workpiece separation and friction reduction depend strongly on the tribological loads that appear in a specific process. The tribological load can be mainly characterized by the following parameters: contact normal stresses, surface enlargement, relative velocity between tool and workpiece as well as initial temperature. Fig. 1 shows characteristic loads for typical forming processes. Sometimes the sliding distance plays another important role for the design of a tribological system.

The large range of loads illustrates the need for different special lubricants, antiwear coatings and additional tribological components like functional surfaces, to efficiently maximize tool life. Due to the fact, that tribological systems depend strongly on the kind of metal forming process, the structure of the following sections follows the classification of forming processes.

3. Cold forging

Development of the cold forging process of steel and its successful application in the automotive industry since 1960 is closely connected to the development of efficient lubrication systems consisting of a conversion coating of zinc phosphate chemically bonded to the metal substrate. The coated part is provided with a lubricant by dipping into a hot bath of alkaline soap (typically sodium stearate) that reacts with the zinc phosphate to form zinc stearate, which is eventually covered with excessive sodium soap [24,88]. The crystalline layer of zinc phosphate partly acts as a chemical agent binding the soap to the surface, and partly as physical carrier for the soap. The coating procedure has several environmental drawbacks [48,59,147,183,186]: (a) sludge of (heavy) metal phosphates, which need to be reclaimed or buried, (b) large water requirement in the rinse baths, (c) periodic replacement of baths for degreasing, neutralizing, pickling and lubrication required, and (d) large amounts of waste water, typically containing grease and tramp oils, acid, and soap. In addition to these environmental concerns, the phosphating process requires prolonged treatment time, typically 5–15 min and high bath temperature, 80–90 °C [88,147].

Table 1
Oil lubricants for cold forging [212].

Ingredient	Main compounds
Base oil	Mineral oil, fat and oil, synthetic ester
Extreme pressure additives	Phosphorus, chlorine and sulphur
Oiliness improving agent	Fatty acid, higher alcohols
Solid lubricant	Graphite, MoS_2, PTFE, metal soap, etc.

Zwez and Holz [221] report that modification of zinc phosphate coatings with calcium reduces the load of heavy metal zinc by 33% thus reducing the impact on environment. Within this conventional chemical treatment much progress has been made in the last decades to reduce the consumption of chemicals and the amount of waste water. The use of advanced products for cleaning, pickling, phosphating and lubrication as well as improved monitoring and adjustment of the chemical process prolongs the service life of baths considerably and reduces the consumption of chemicals by approximately 20%. For drawing of wire, tubes and profiles as well as for cold heading phosphating agents with nitrite or chlorate as accelerator are still widely used. This so-called "iron-free" phosphating process results in huge amounts of sludge of iron and heavy metal phosphates, which has to be disposed by burying. By introducing new phosphating agents without the accelerating compounds of nitrite and chlorate, the consumption of phosphating agents can be reduced by one-third and the amount of sludge by 80–90%. Recent developments have led to new, advanced aqueous dispersions both of polymer lubricants and MoS_2. The improved adhesion and increased forming capability allow a reduction of the number of complete chemical pre-treatment steps, e.g. lubrication without phosphating.

For less demanding cold forging operations such as bolt production, the soap is replaced by oil. Table 1 presents an overview of their major content [147,212]. The effects of sulphur and phosphorus based extreme pressure additives were intensively studied in the period 1986–1991 by Komatsuzaki et al. [119,120] and Ohmori et al. [155,156]. As shown in Fig. 2 phosphate compounds assist lubrication at lower temperatures, sulphur compounds in a somewhat higher range, but none of them is effective in the intermediate range from 200 to 300 °C.

Adding phosphate compounds like alkyl acid phosphate to a lubricant formulated with sulphur additives feasible for high temperatures makes it possible to obtain stable lubrication in this medium temperature range [147,212]. Attempts to add metallic

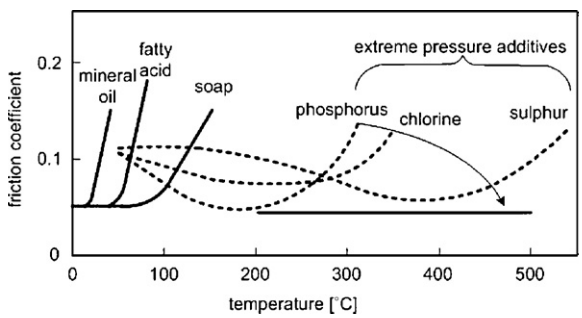

Fig. 2. Applicable temperature range of extreme pressure additives [178,212].