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DEVELOPMENT OF NEW LUBRICANTS FOR METAL FORMING

Abstract

One of the goals of development of metal forming processes is certainly reducing the use of lubricants or use of green lubricants. The use of environmentally friendly lubricants is a part of the strategy of sustainable development in the metal forming. This paper provides an overview of the new lubricant that can be efficiently used in specific manufacturing conditions. These processes are characterized by the use of tools with hard coatings, which can be very different. The development of new lubricants composing is especially significant in the area of cold metal forming.
Key words: *Plastic metal forming, formability, ecology, lubrication*

1. INTRODUCTION

During the last ten years, the legislation in developed countries made the environmental requirements for manufacturers of lubricants increasingly severe. Such requirements establish safe and healthy working conditions, and restrictions and the elimination of hazardous substances in lubricants. Environmental problems in metal forming tribology can be divided into the following areas [1], [2]: (a) health and safety of people, (b) influence on equipment and buildings, and (c) destruction and/or disposal of waste and remaining products. Special efforts are made to eliminate hazardous chemicals, such as chlorine or phosphorus additives, as well as reducing waste and extending tool life, regeneration and re-use of lubricants.

In the field of cold forging currently used zinc phosphate has to be replaced with a benign lubricant that will not create a hazardous sludge from the deposit of heavy metals. In the field of hot forging so-called white lubricant that reduces workplace contamination and allows easier manipulation is increasingly being used instead of a black one. As regards sheet metal forming, commonly used chlorinated paraffin oil is harmful to the environment. During the processing of high strength material, requirements regarding quality of lubricants are highly pronounced and the replacement of these lubricants is difficult.

It is well known that the tribo-conditions in contact are described by contact pressure, relative sliding velocity in contact and surface temperature. The general model of the tribological system, considered for metal forming processes, is shown in Figure 1 [3]. Table 1 shows the ranges of significant forming conditions at various MF.

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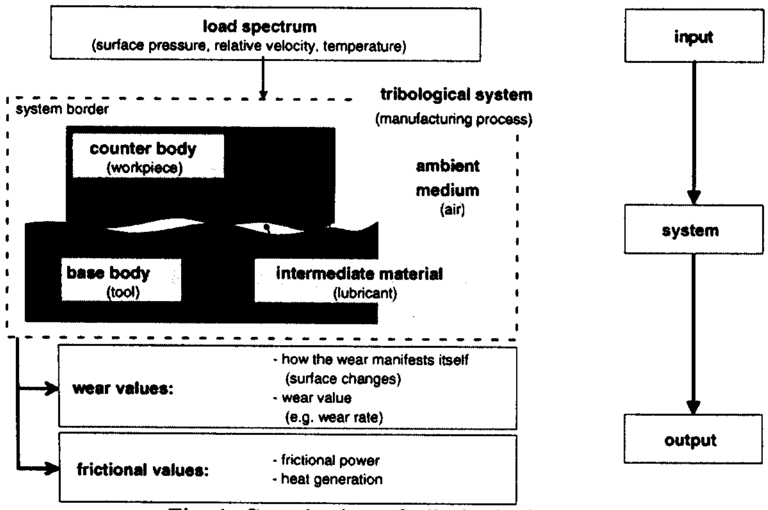

Fig. 1 Constitution of tribological systems

Table 1 Forming conditions in various MF procedures [5].

PROCESS → CONDITIONS ↓	Sheet-metal forming	Drawing, ironing	Rolling, orbital forming	Forging, extrusion
Pressure factor, p/Rp	0,1-1	1-3	1-3	2-5
Contact pressure, p, *MPa*	1-100	100-1000	100-1000	100-3000
Strain velocity, ms^{-1}	10^{-3} do 10^{-1}	10^{-2} do 10^{2}	10^{-2} do 10^{2}	10^{-3} do 10^{-1}
Relative sliding velocity	0 do 10^{-2}	10^{-2} do 10^{2}	10^{-2} do 0	0 do10^{-1}
Contact surface temperature, ^{0}C	Room t. up to 150	Room temp. up to 300	Room up to 150 or hot forming	Room up to 400 or hot forming
Change of surface	0,5-1,5	1-2	1-2	1-100

In line with forming conditions, i.e. defined requirements, various lubricants have been made for particular types of MF technologies. Generally speaking, the lubricant must have the following functional properties: reduction of metal-on-metal contact surface, especially in high pressure zones, reduction of tool wear by intensive heat transfer, as well as elimination of impurities, metal pieces etc., provision of desired MF friction, i.e. control of metal flowing at forming, achievement of the desired piece surface quality [4].

2. CHARACTERISTICS OF TRADITIONAL AND NEW LUBRICANTS

2.1. Cold forging

Tribological conditions in cold forging are unfavorable due to the high working pressure of touch. Therefore, the lubricant is applied on the prepared surface of the work piece. This preparation is usually performed by applying a zinc phosphate on the metal substrate. The coating procedure has several environmental drawbacks [1] : (a) sludge of (heavy) metal phosphates, which needs 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. The table shows the most commonly used lubricants.

Table 1. Oil lubricants for cold forging

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.

As an alternative to conventional phosphating, very different ways of applying the basic coating on a metal surface have been developed:

- New conversion coatings
    - Electrolytic phosphate coating
    - Microporous coating
- Lubrication without conversion coating
    - Dual bath systems
    - Single bath systems

New procedures are cleaner and energy efficient. The so-called white component lubricants include waxes and soaps, and black lubricants containing graphite and MoS_2. Many of the world's automobile factories have been developed and used lubricants from a group of white lubricants. For example, Toyota applied lubricants which are basically a fatty acid, phosphates, polymer dispersion, Zn and Mo components. Registered lower tribo-characteristics of new lubricants do not affect significantly the production. Fig. 2 shows the use of different lubricants in cold forging. Phosphate Zink and soaps are used for heavy machining conditions.

2.2. Hot forging

In hot forging steel piece is heated up to 1000 - 1200 ° C, and the tool surface is heated up to 600 ° C. Lubricating films have a role separate metal, lubrication and cooling tools. In complicated die forgings colloidal graphite dispersed in water or oil has been applied by spraying. Table 2 shows traditional lubricants for hot forging of steel and a comparison of their properties. Table 3 shows guidelines for lubrication in warm forging over different temperature ranges. Efforts to find alternatives for graphite based lubricants have been driven by: bad working environment, earth leakage (electric conductivity of oil), pipe corrosion due to electric conductivity, and low recovery rate due to poor oil separation.

Table 2. Properties of lubricants for hot forging of steel [1]

Lubricant	Sliding friction	Sticking friction	Gas pressure	Die friction
Saw dust	4	4	11	1
3.6% colloidal graphite in water	1	1	5	5
4% colloidal graphite in oil	3	3	2	2
Polyalkaline glycol	5	5	4	4
17% Na2CO3 aqueous solution	2	2	3	5

(1) very good; (2) good; (3) satisfactory; (4) poor; (5) bad

Table 3. Guidelines on lubricants for warm forging of steel [1].

Temp. [^{0}C]	Surface treatment	Lubricant	Application
200–400	Phosphate coating[a)]	Graphite, MoS_2	Workpiece
400–700	Phosphate coating[a)] may be applied but heating should be fast	Graphite, Graphite dispersed in water	Workpiece or tool[b)]
700–850	None	Graphite (rapid heating) Graphite dispersed in water	Workpiece and tool

[a)] Phosphate coating cannot be used for high alloy steel and stainless steel. Instead either oxalate coating or plating may be applied.
[b)] Lubrication of the tool surface only may be sufficient in upsetting and backward extrusion. Spraying is preferable as application method.

White lubricants are primarily made up of calcium stearate, water soluble high-molecular weight polymer, high-molecular weight carboxylate, water soluble glass, super high-molecular weight polyethylene, BN + glass + graphite, graphite + B_2O_3, graphite + resin, etc. The main part of some lubricants in the polymer base is alkyl maleate. The carvone base oils are essential oils such as volatile or ethereal oils from plants. The main contents of these lubricants are carboxylic acids such asfumaric acid and isophtalic acid. The liquid glass base lubricants are Si-glass containing colloidal silica. Overview of the use of white lubricants is shown in Fig. 3.

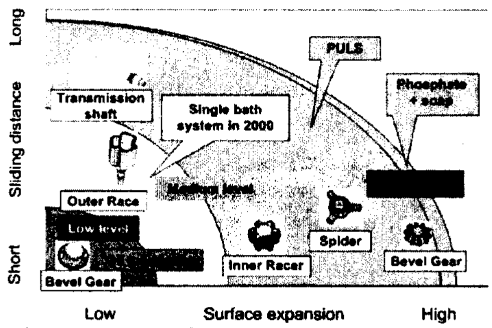

Fig. 2. Range of applicability of different cold forging lubricants [1].

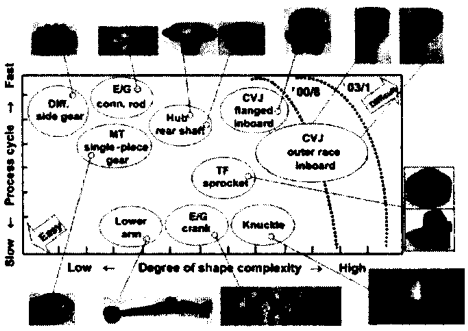

Fig. 3 Range of applicability of white. lubricants [1]

2.3. Sheet metal forming - Deep drawing

During the processing of sheet metals, like stainless steel or high strength steel, tribological conditions at contact are intensified. Local pressures and temperatures are high, and in the absence of lubricants lead to the appearance of galling. Lubricant used is chlorinated paraffin oil, which forms a reactive film lubricant on the surface of pieces and prevents metal to metal contact. However, these oils in the EU classification are carcinogenic and have a limited application.

Stamping lubricants can be divided into oil-based liquid lubricants and dry film or coil lubricants (DFL). The liquid lubricants may be mineral oils or emulsions. Dry film lubricants are divided into water-soluble dry film lubricants and water-free dry film lubricants. Water-soluble dry film lubricants are applied in amount of 0.5–1.5 g/m2 at the rolling mill.

In today's automotive stamping plants, DFL is increasingly popular, due to improved performance, cleanliness and reduced requirements for recycling and disposal. In addition, DFL: (a) provides uniform coating thickness on the sheet blanks, (b) reduces the amount of lubricant (typically 0.5–1.5 g/m2 vs. oil-based lubrication 1.5–3.0 g/m^2), (c) may eliminate washing of stampings which are necessary with wet lube, (d) is compatible with assembly operations (welding, bonding, clinching and riveting) and (e) is more environmentally benign than the petroleum based wet lubes.

Figure 4 shows three types of approach to the realization of main "green forming" principles [5]: soft coating on the metal, which serves as a lubricant, soft coating on the tool and lubrication by water or evaporable oil. Due to the increasing use of Al-alloys for car body special efforts are being made to replace mineral oil with a dry lubricant [1], [6]. The modern al-sheets have surfaces which during rolling create special procedures, per requirements set (MF, EST). Dry lubricants that do not contain water are used in many factories, cars, etc. Fig. 5.

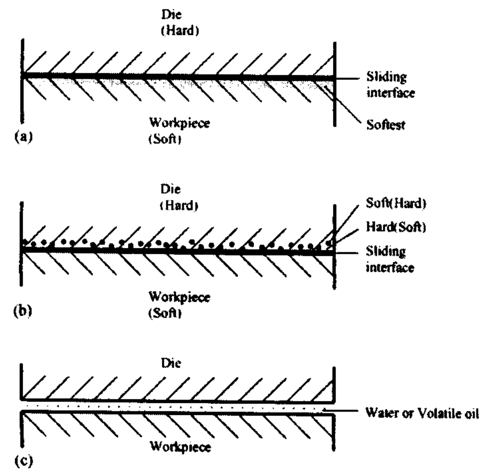

Fig. 4 Tribo-principle for the green forming process [5].

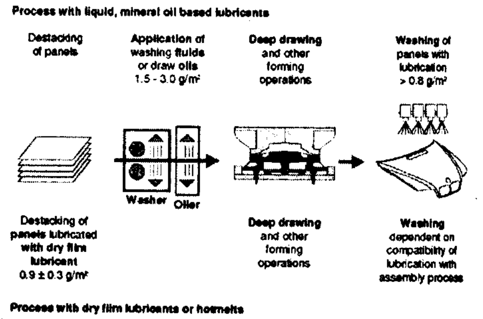

Fig. 5. Comparison of a process chain with liquid or dry lubricant

Some manufacturers are developing new, environmentally friendly biodegradable lubricants based on tall oil (pine tree). These fatty acid ester based oils have been successfully introduced in deep drawing production having good lubrication and antiwear properties, good corrosion resistance, good compatibility with paints. Different kind of green lubricants are basically refined mineral oils with special additives, synthetic oils, solid polymers and the like.

The lubricant which is being increasingly more used for sheet metal forming and which satisfies modern ecological requirements has boric acid (H_3BO_3) as a basis. It is a solid lubricant; it has good lubrication properties and does not require special disposal costs. Its development and application in MF have lasted for some twenty years. Boric acid is a standard term for orthoboric acid, which is a hydrate of boric oxide B_2O_3. At atmospheric pressure, boric acid dehydrates at 170^0C temperature and is converted into poorly lubricating substance – boric acid. For sheet metal forming at standard room temperature, the lubricant maintains good lubrication properties [7].

Researches regarding the use of eco-lubricants were performed in the Laboratory of Metal Forming Faculty of Engineering Sciences in Kragujevac. The comparative test with the classical black lubricants (L3 - MoS_2) and new synthetic lubricants (L2) was performed, using ironing tribo-test, Fig.6 and Fig. 7.

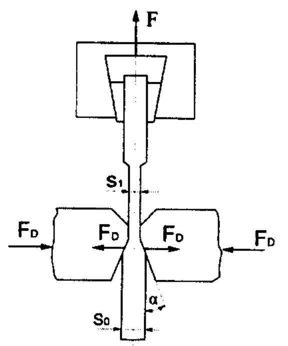

Fig.6 Stripe ironing test model

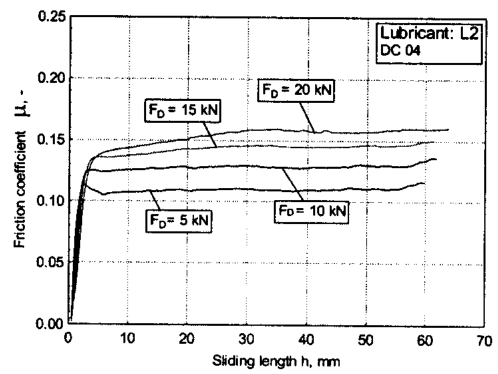

Fig. 7 Friction coefficient dependencies on sliding length

Experimental equipment is based on tribo model from fig. 1 and described with more details in [8]. Sliding process was one phase with side forces 5, 10, 15 and 20 kN. Sliding length was approximately 60 mm at speed of 100 mm/min. Stripe material is low carbon steel sheet with 2.5 mm thickness. L2 is a special dry ecological lubricant based on wax and metallic soap. Lubricant layer was obtained by dipping into bath with proper solution and then drying. The results show satisfactory efficiency of the new lubricants and in accordance with the results of the so-called ring-test [9].

3. CONCLUSION

The development of new materials and new production technologies is taking place in conditions of mass production, intensified sustainable development issues, especially issues of resource conservation and the environment. Accordingly, new compositions of lubricants in areas of hot, semi-hot forming and cold working are developed. In the field of cold forging application of zinc phosphate and soaps is replaced by very different processes of electroplating and use of synthetic lubricants. In a hot and warm forging the black lubricants have been replaced with white lubricants on either polymer base, carbon base or liquid glass base. During the processing of sheet metal, the dry film lubricant or water emulsions which are safely manipulated are used. At deep drawing of steel and Al-sheet metals, mineral oils with EP-additives can very successfully be replaced with lubricants based on vegetable oils with boric acid. Such lubricants are non-toxic and bio-degradable.

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