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ECOLOGICAL METAL FORMING TECHNOLOGIES - POSSIBILITIES AND LIMITATIONS

Abstract

Preservation of the existing energy resources on one hand and the reduction of the environmental-pollution on the other hand represent the basic requirements which so called "eco-friendly-green" production technologies must satisfy. Such technologies imply a different approach to solving tribological problems at forming (efficient forming, high piece surface quality, prolongation of tool life etc.). In that sense, in addition to the development of coating procedures, application of dry lubrication films etc., particular attention is given to the development of new lubricants which do not pollute the environment when being removed, and are as efficient as traditional lubricants. In this paper, a systematic approach to recognition of eco-technologies is presented and review of researches in this area is given together with recommendations for ecological "Friendly lubricants" application in particular plastic metal forming procedures.

Keywords: Plastic metal forming, formability, ecology, lubrication

1. INTRODUCTION

Production technologies, especially metal forming (MF), have been subjected to a rapid development during the last few decades. The main properties of MF are: development of procedures of numerical-physical modelling of forming process – metal flowing, defining of stress-strain fields etc., with the aim of optimizing the forming parameters, application of CAD/CAM system for design and manufacture of tools, development and application of artificial intelligence and expert systems within the development of forming and tool construction processes, development of various procedures, tools and machines for parts which are not additionally formed ("Net Shape Forming" - NSF forming) etc [1].

From the ecological aspect, as in other technologies, the main issues in MF area are:

- Preservation of available resources, and
- Reduction of influence on the environment

These main two issues can be organized into several complex activities [2], which must be integrated into particular elements of industrial systems systematically:

- Preservation of basic resources and materials,

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- Optimal product construction,
- Optimal production,
- Reduction of energy consumption,
- Environmental protection.

Recommendations for optimal construction are related to the use of renewable and recyclable materials, tribologically acceptable constructions and materials; optimal production implies automatic control, high efficiency and reduction of lubricant consumption. The best methods for realisation of the environment protection are: use of ecologically acceptable materials (which are recycled, easy to dispose of, do not influence the environment if not recycled, are produced without generating harmful refuse), application of lubricants which are not so harmful for the environment (prevention of flowing out, prolongation of lubricant life, use-recycling-disposal, use of ecologically acceptable lubricants).

2. ECOLOGICAL ASPECTS IN MF AREA

Particular phases in development and exploitation of new products, such as construction, production, servicing, maintenance and recycling are being investigated and improved constantly. In mass production, every detail must be investigated from the aspect of environmental protection. For example, transition from hot to cold forging preserves energy significantly. Net shape forming reduces material losses.

Tribological approach is related to the reduction of pollution coming from wastewaters and lubricants, provision of acceptable friction coefficient in order to obtain quality piece surface and reduce tool wear.

Without getting into all details of complex eco-tribology [2], figure 1 shows the possible sources of influence on the environment in the course of production by using MF technologies [3, 4]. It is often necessary to use special strategies and considerable investments in order to solve the problem of waste substances and harmful emissions related to disposal, recycling, substitution or complete elimination. A complex character of appearance and of the specified problems solving, with the aim of creating so called „pure" MF, is obvious. The first step, as a rule, includes solving of the difficulties occurring at application and removal of lubricant, without which it is most often impossible to realize the production.

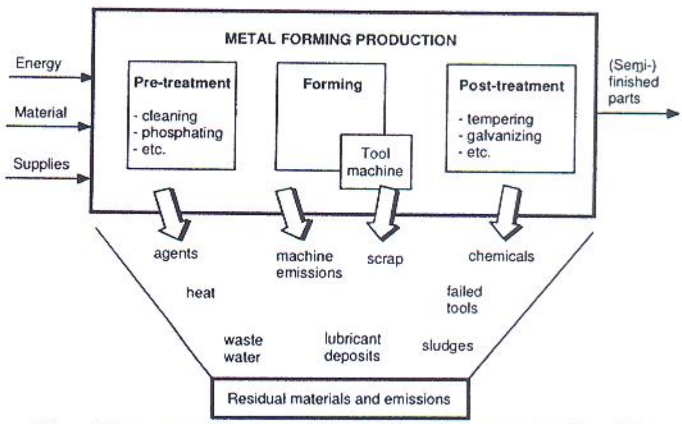

Fig. 1 Input and output of metal forming production [3]

It is well known that the tribo-conditions in contact are described by contact pressure, relative sliding velocity in contact and surface temperature. Table1 shows the ranges of significant forming conditions at various MF.

Table 1 Forming conditions in various MF procedures

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. Consideration of complex tribo-processes in contact, according to [5], must be realized in several measuring-dimensional levels, ranging from macroscopic do nanoscopic, Fig. 2.

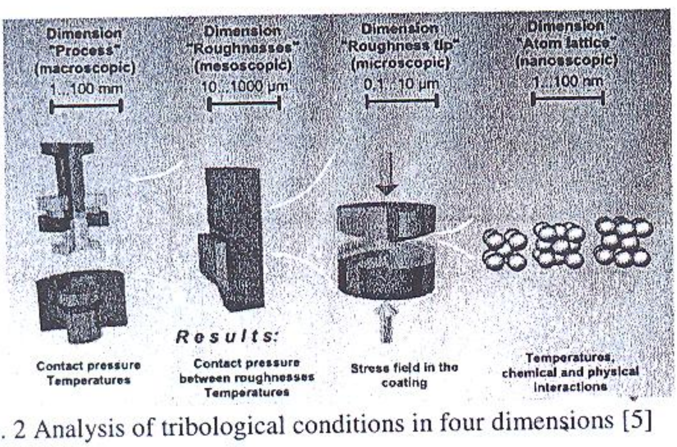

Fig. 2 Analysis of tribological conditions in four dimensions [5]

The macroscopic scale, on which the whole processes and the tools can be analysed; the mesoscopic scale, on which the roughness of the tool and earpiece can be included in the analyses, the microscopic scale, on which tool coatings can appear as objects on their own within the analysis, and the nanoscope scale, on which the tribological processes are analysed for a few contacting atoms or molecules.

3. MODERN PRINCIPLES OF ACCEPTABLE LUBRICATION

The requirement of eco-environment is the ultimate use of dry technologies or use of lubricants which exist in the surroundings, do not change in the forming process and should not be additionally removed afterwards. For example, water is a highly acceptable lubricant.

However, in some MF procedures, in high contact pressure conditions, friction regimes are extremely unfavourable, so ecological MF cannot be based on dry friction realization. In the first approach to these problems solving, friction and pollution of waste liquids must be reduced. In order to reduce friction, it is necessary to realize limit film, i.e. soft coating between contact surfaces. In classic technologies, this film can be provided by oil or so called carrying layer (e.g. zinc phosphate), but the process of creation and removal of such a film is always harmful for the environment.

Figure 3 shows three types of approach to the realization of main "green forming" principles [6].

- Soft coating on the metal, which serves as a lubricant,
- Soft coating on the tool,
- Lubrication by water or evaporable oil.

Within the area of thin sheet metals forming, deep drawing is special from the lubrication aspect. In the conditions of large serial production, such as car industry, there are certain difficulties related to the use of lubricants. In the course of forming, the lubricant is applied in sheet metal and tool contact zone, in order to increase sheet metal formability. Classic lubricants, which provide boundary lubrication regime at forming, are most often of mineral origin with Extra pressure (EP) additives. Metal soaps which get formed on sheet metal surface provide good lubrication with difficult removal and water pollution at degreasing and cleaning prior to painting.

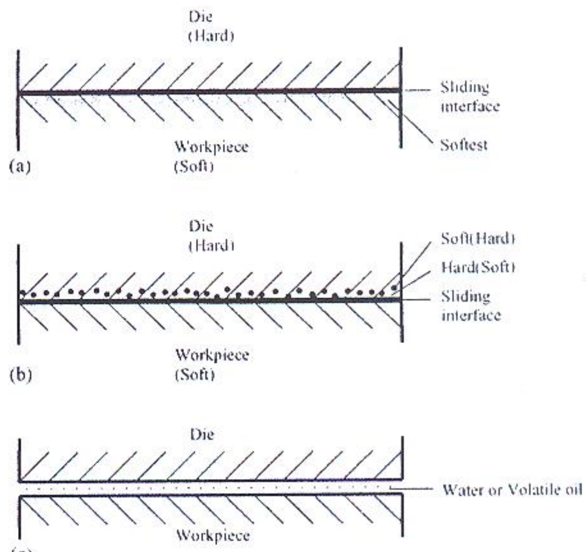

Fig.3 Tribo-principle for the green forming process [6]

At cold bulk forming, e.g. extrusion, local pressures reach the values of up to 3000 MPa; therefore, in such cases, so called lubricant carrier must be formed on piece contact surface; for steel materials, it is often zinc phosphate, Fig. 4 *[5]* . Formation of such a layer and additional degreasing of piece surface is a well known problem which not even the use of new generations of lubricants can completely overcome.

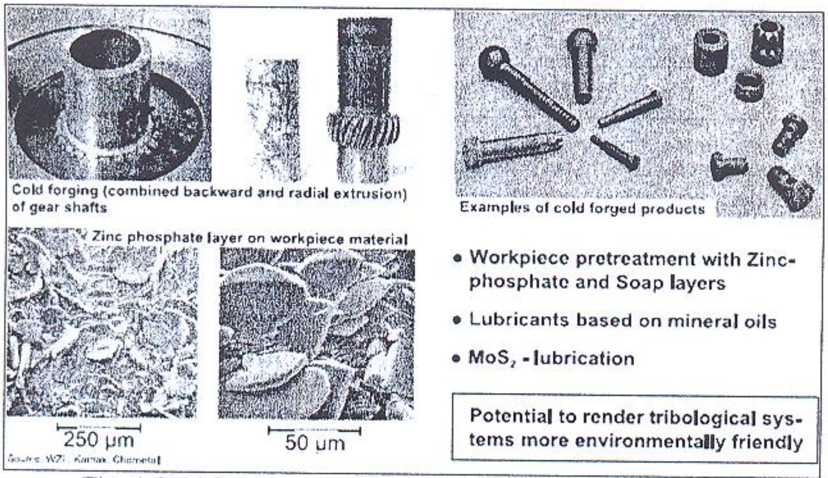

Fig. 4 Cold forging example parts and tribological issues [5]

In recent years appear lubricants for the use of which should not be pre-prepared surface of the workpiece. The classic test for assessing the quality of lubricants in the cold forging is compression ring [7]. For example, in the paper [8], ring compression test was used for determination of friction coefficient for three different types of lubricants. Two conventional lubricants were used (oil for cold forging, phosphate coating with MoS_2,) and one environmental friendly lubricant, Bonderlube FL 741. Comparing with conventional ways of lubrication there are several advantages in both economical and environmental way, when Bonderlube FL 741 lubricant is used. Experimental results showed that value of friction coefficient for Bonderlube lubricant is lower ($\mu \approx 0.09$), compared to conventional lubricants ($\mu \approx 0.11$), Fig. 5.

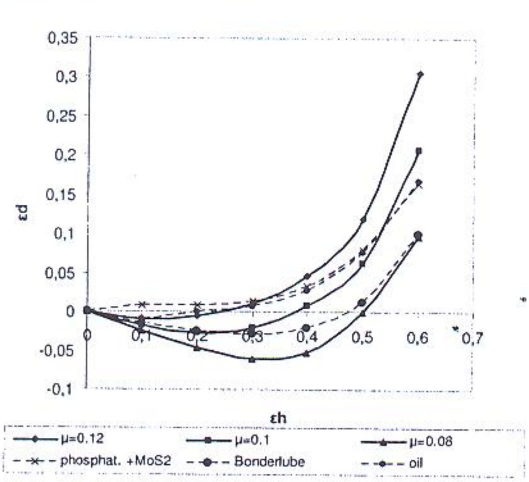

Fig. 5 Calibration and experimental curves

Table 2 Experimentally determined friction coefficient values for different lubricants

No	Lubricant	Friction coefficient
1.	Oil for cold forging	≈ 0.11
2.	Phosphated surface + MoS_2	≈ 0.11
3.	Bonderlube FL 741	≈ 0.09

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 usual, room temperature, the lubricant maintains good lubrication properties.
Figure 6 shows a lamellar molecular structure of boric acid at temperature below dehydration point. During crystallization, there are strong hydrogen links in boric acid within the layers. That makes possible easy sliding over layers, with high capacity of load carrying in contact.

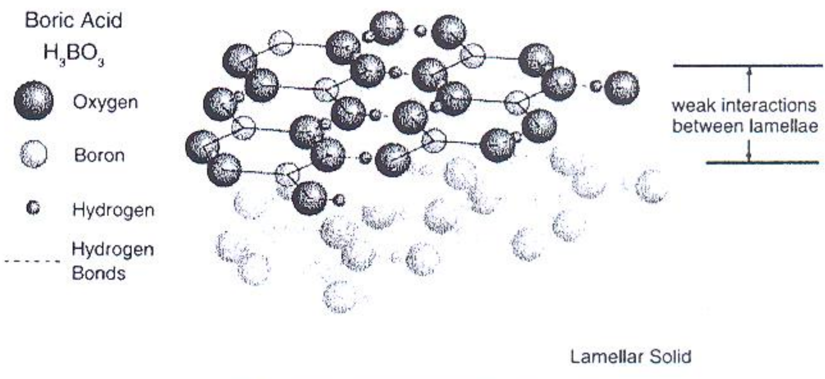

Fig. 6 Lamellar structure of boric acid

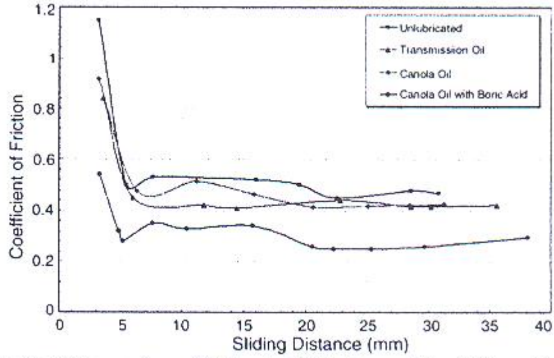

Fig. 7 Variation of coefficient of friction with sliding distance

Boric acid looks like a white powder, it dissolves in hot water, it is stable and easy to handle. It costs about 4,5 \$/*kg*. It is most often used in combination with canola oil, 5% in weight, with particles of about 100 μm. At lubrication, boric acid particles in vegetable oil represent the third body, which separates the surfaces of tool and material and enables mixed lubrication. Fig. 7 shows the results of sliding test when various lubricants are applied. The use of canola oil and boric acid gave satisfactory results [9].

5. CONCLUSION

Development of plastic metal forming technology implies, among other things, adjustment to modern requirements for introduction of so called „pure" production procedures, based on: preservation of basic resources and materials, optimal construction of products and production, reduction of energy consumption and environmental protection, which is also something that eco-tribology deals with. The use of ecologically acceptable lubricants is just one of the aspects of global approach in MF area.

Advanced MF, adjusted to NSF procedures, make possible considerable savings in material and are ecologically acceptable. However, since forming is performed in high contact pressure conditions, it is necessary to use quality lubricants, most often with so called carrying coating, whose application and removal require the use of various substances from the aspect of environmental preservation. In such cases, reengineering of the forming process must be adjusted to ecological requirements.

In some technological processes, it is possible to use lubricants based on vegetable oils with natural material additives, which do not pollute the environment. The use of such lubricants also requires adjustment of production equipment and additional structures. E.g. at deep drawing of steel and Al-sheet metals, mineral oils with EP-additives can very successfully be replaced by lubricants based on vegetable oils with boric acid. Such lubricants are non-toxic and bio-degradable.

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