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LIMITATIONS OF PHYSICAL TRIBO-MODELING IN METAL FORMING PROCESSES

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Summary: *The significance of contact friction in metal forming processes is very known. The general approach in this area involves the recognition of the influence of the main tribological parameters – pressure, speed and temperature in metal forming. The developed methods are very different for physical modeling of tribological phenomena and influence in a very specific types of metal forming. These methods basically have the appropriate physical model which imitates local area or a complete work piece in metal forming. The indicators of models can be very different: the deformation forces, forming limit parameters, coefficient of friction, temperature distribution, etc. This paper analyzes the physical models in cold metal forming processes, according to their characteristics and limitations.*
Keywords*: Metal forming, friction, tribo model, cold forging*

1. INTRODUCTION

Modern plastic forming technology is characterized by the production of parts of small mass, high productivity and low cost. Metal forming (MF) process depends on many factors, such as material properties, the structure of the system workpiece / tool, strain rate, the operating pressure and temperature. In addition to these factors, the friction is very important and it affects the forming force, energy consumption and limit deformability, accuracy of design, piece surface quality and tool life.

Friction at MF is highly nonlinear phenomenon that is related to (interacts with) many forming parameters, Fig. 1 [1]. The following characteristics of friction have a significant and complex influence on the quality of the piece:

- The process of deformation and deformation forces depend on the friction forces and vice versa.

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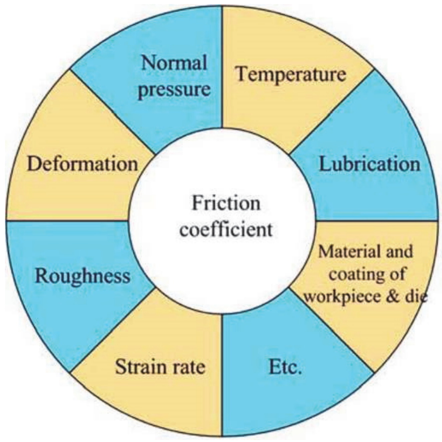

Fig. 1 *Factors affecting friction in metal forming* [1]

- The friction is generated in the high-pressure conditions, where the pressure is higher than the yield limit in the contact-layer (interface) in many cases.
- Friction is generated at high temperature, where lubricating film has a key role.
- New metal surfaces that appear during forming change with time.

The research in this area is expected to contribute to the development of green technologies, reduced mass production of parts and complex geometries for the purposes of highly developed industries such as cosmic, aerospace and automotive industries.

The current development of tribology in MF can be described as progress in [1,2]:

- Friction tests in MF,
- Characterization of friction,
- Models of friction,
- Controlling and optimization of friction.

Development of suitable friction tests explains the nature of the frictional contact of pieces and tools, optimizes tribological conditions and raises formability.

In general, there are two categories of tribo tests - direct and simulation procedures. All of these methods have their qualities and limitations. In direct tests normal pressure and tangential stress are measured by the sensors which are implanted in the surface of the tool, during real time of processing operations. The method is limited by the sensitivity of the sensor and the selection of measuring points, as well as by the cost of installation.

In the simulation tests in laboratory conditions the loading conditions are different, with mainly the limitations of kinematic conditions. The essential reason for the further development of tribological model is the need for a more complete optimization and controlling of friction in the manufacturing process – e.g., increase of friction in punch zone in deep drawing delays the destruction of the sheet in the region.

Tribo system in MF area can vary highly from one operation to the other. Chemical, mechanical and micro-structural characteristics of components of tribo system are very different in hot, warm and cold MF. There are different sliding speeds, contact pressures and temperatures, stress strain states etc.

In general, the friction coefficient in MF operations depends on the type and chemical composition of contact pair materials, the state of the interface between the tool and the material, temperature, pressure and velocity in contact, as well as the achieved degree of deformation.

Tribometers, as special devices, are used for optimization of technological processes. They are used in the analysis of the phenomenon of friction, wear and lubrication influence in defined tribological conditions. Increase of the efficiency of work processes, achievement of the limit possibilities of process, longer tool life and enhancement of environmental elements are typical goals.

Results of tribological investigations are often used for determining the certain parameters in analytical description of the laws of friction and wear. Such data are essential in numerical simulation of the processing.

In MF, two laws of friction are typically used, depending on the amount of work pressure. Coulomb friction model is used for lower pressures and has the form:

$$\tau = \mu \cdot p$$

τ - tangential friction stress,
μ - coefficient of friction,
p - local normal pressure.

Constant friction model proposes that friction stress is constant and proportional to the yield stress in pure shear "τ_{max}" and friction factor (m):

$$\tau = m \cdot \tau_{max}$$

2. TRIBOLOGICAL MODELS IN COLD METAL FORMING

Methods of cold MF, such as compression, extrusion, heading and drawing, are realized in conditions close to the net shape forming. Working pressure between the tool and the material can reach a value of up to 2500 MPa. The expansion of the surface goes up to 3000% and the local temperature goes up to 200^0C. Tribological conditions have a dominant influence on the process. Various lubricants are used in processing, most of them not ecological. In recent years efforts have been made to replace this lubricant (black), based on MoS_2, with ecological (white) lubricants [2].

Ring compression test is a standard method for evaluation of coefficient of friction ***μ*** or friction factor ***m*** in bulk metal forming processes. In investigation, the ring is compressed between parallel flat plates. Relative change in height is on the abscissa, a change of the inner diameter of the ring is on the ordinate. Limitations of the procedure are a very simple deformation path and a relatively small expansion of the new surface, about 20%. Before testing is performed, the surface of specimen is prepared and lubricant is applied. For small values of ***μ*** or ***m***, inner and outer diameters of the piece are enlarged; increasing friction leads to decrease of inner diameter. Appearance of specimen at testing and calibration and the measured value are shown in Fig. 2 and Fig. 3 [3].

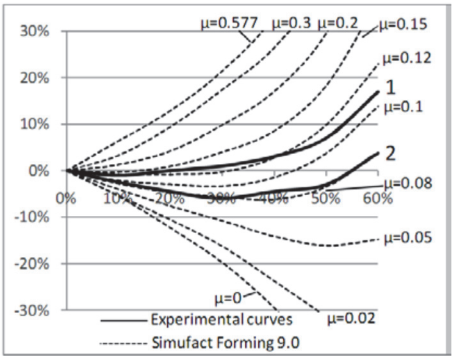

Fig. 2 *Determination of friction coefficient in experiments :1 - oil, 2- phosph. sulphate +* MoS_2 [3]

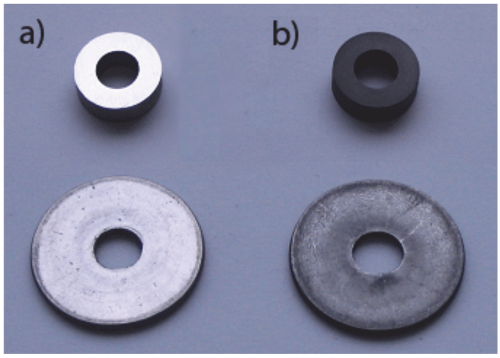

Fig. 3 *Rings before and after compression (a – oil; b – phosph. sulphate + MoS2.)* [3]

In addition to the oldest primary ring compression test, doubles cup extrusion test (DCET) is often used as a tribo-model, Fig.4. The result of this test is the ratio of actual height after deformation H1 / H2. This value increases with increasing friction. In Fig. 5 calibration curve of the DCET is shown. This test has the following advantages in relation to the compression ring model [4]: strain state is similar to real cold forming operations, the results of the tests are easier to compare and rank, for example in lubricants testing. Limitation of the procedure relates to low values of achieved working pressure, e.g., up to 700 MPa for the carbon steel.

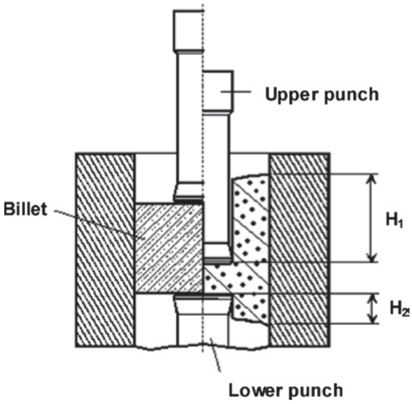

Fig. 4 *Double cup extrusion test (DCET)* [4]

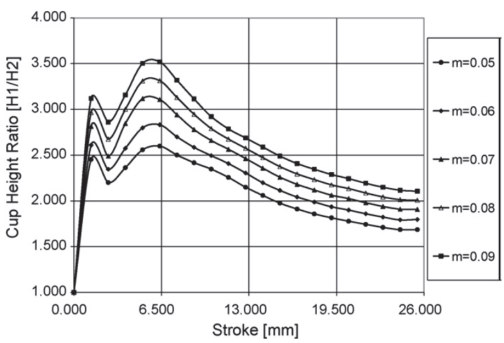

Fig. 5 *Friction factor calibration curves obtained for AISI 1018 for a specific tool geometry* [4]

Spike test is a new model in this area, and it presents unsymmetrical forging process, which combines compression and extrusion, Fig.6. It is suitable for tribo modeling, since load and spike height are directly related to friction. The lubricant is easily applied to the surface of the lower die, the expansion of the surface goes to 50%, and pieces of different diameters can be examined in the same tool. Fig.7 shows a change in height extrusion for different factors of friction in contact [5].

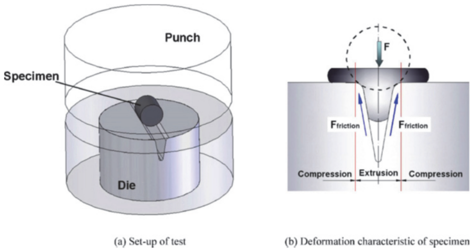

Fig. 6 *The principle of T-shape compression* [5]

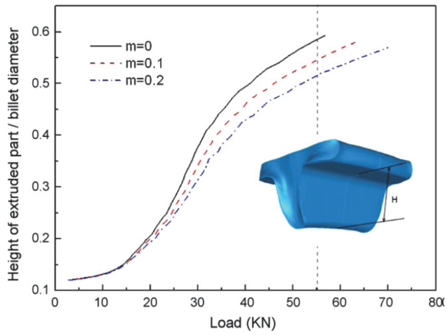

Fig. 7 *Effects of friction factor on height of extruded part with different loads* [5]

The sliding compression test (SCT) is a specific tribo test for simulation of the cold forming, Fig. 8 [6]. It is realized in two steps. The first step is the compression of the flat and profiled surface tool. In the second phase material caught in the upper part slides across the bottom part. Phase tests are shown in Fig. 9. The friction force increases with increasing sliding length. The test combines two kinematic schemes, and the results strongly depend on the geometry of the upper tool profile.

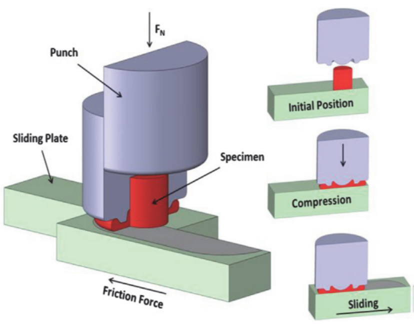

Fig. 8 *Principal of SCT with barrel setup* [6]

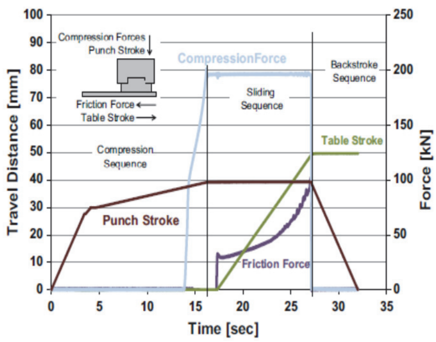

Fig. 9 *A measured result of the SCT* [6]

Similarly to the previous test, the authors of [7] have proposed a new method of tribo-modeling of cold processing with extremely high contact pressure, called upsetting sliding test (UST), similar to the scratch test, Fig. 10. This test takes into account the mechanical properties (speed and the contact pressure), as well as the physical parameters of the contact (the material, the roughness and temperature). The test results correspond to the cold MF methods, such as extrusion. The test can be successfully used in comparative tests of lubricants. Fig.11 also shows the method of determining the sliding length at which characteristic changes in contact occur.

A key disadvantage of this test is the difference from real processes, considering that only one local region of piece is significantly deformed. Surface expansion ratio is small.

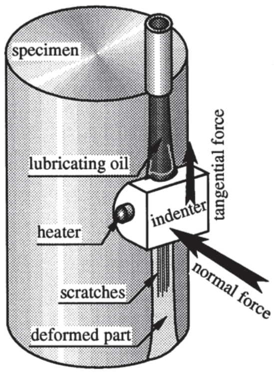

Fig. 10 *Principle of the upsetting sliding specimen* [7]

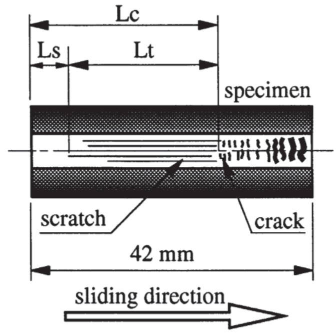

Fig. 11 *Scheme of the UST deformed test. Measurement of the: sliding length at the first scratch and first crack occurrence (Ls and Lc), transition zone (Lt)* [7]

The following tribo models have been developed in the Laboratory of Metal Forming at the Faculty of Engineering Sciences in Kragujevac. Sliding of specimen between contact pairs of different geometries, with intense reduction of the initial specimen thickness, enables achieving of high values of the contact pressure, Fig.12. Strip ironing test can be successfully used in tribo-research, as well as for evaluating the quality of lubricants for cold forming, Fig.13. [8]

Experimental equipment is based on tribo model from fig. 12 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 special dry ecological lubricant based on wax and metallic soap. Lubricant layer was obtained by dipping into bath with proper solution and than drying. The results show satisfactory efficiency of the new lubricants and in accordance with the results of the so-called ring-test [3].

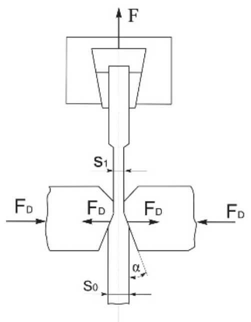

Fig. 12 *Stripe ironing test model sliding* [8]

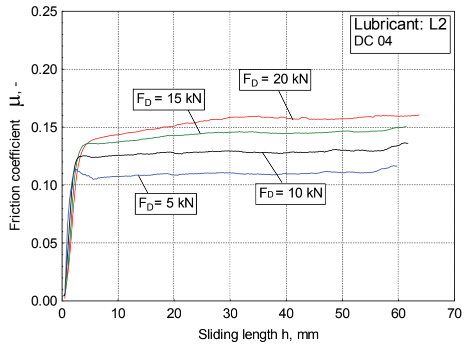

Fig.13 *Friction coefficient dependencies on length* [8]

Model at Fig. 14 imitates the zone of contact with die and punch with double-sided symmetry during modelling of ironing. This device enables the realisation of high contact pressures and respects physical and geometrical conditions of real process (material of die and punch, contact surfaces topography, different semi-angle of die cone , etc). The scheme of strip ironing device, with presentation of forces which act upon the work piece, i.e. die and punch, as well as specimen shape, is shown in Figure 14 [9].

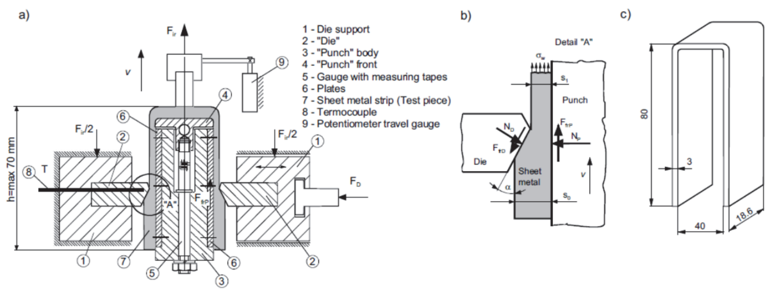

Fig. 14 *Scheme of strip ironing device with measuring chain for data acquisition (a), presentation of forces in deformation zone (b) and specimen shape (c)* [9]

3. CONCLUSION

The most important tasks that are currently being imposed upon MF are the use of green technologies and efficient and economical production, which are in close connection with the controlling of tribological conditions in the forming process. This includes information on the influence of tribological factors in MF on other important parameters of forming systems and their optimization. In the conditions of production of high-precision parts for the needs of the cosmic, airline and the car industry, MF tribology is becoming more and more important from the aspect of tasks and achieved results.

Tribo system in MF can vary highly from one operation to the other. Chemical, mechanical and micro-structural characteristics of components of tribo system are very different in hot, warm and cold MF. There are different sliding speeds, contact pressures and temperatures, stress strain states etc. Full modeling of real tribo-conditions in the realization of laboratory tests is usually impossible. The laws of similarity of physical process modeling with recognized limitations and the corresponding results must be complied with.

Reliable interpretation of results of tribo modeling of MF processes requires the laboratory tests and simulations, computer modeling and industrial experiments. The current development of tribology in MF can be described as progress in the ongoing development of friction tests in the MF, the characterization of friction, friction models, controlling and optimization of friction.

REFERENCES

[1] Wang D., Yang H., Heng L. (2014). Advance and trend of friction study in plastic forming, *Trans. Nonferrous Met. Soc.* China, Vol. 24, p.263−1272.

[2] Stefanović M., Adamović D., Đorović-Stanojević M., Gulišija Z., Aleksandrović S. (2013). Development of new lubricants for metal forming, *XI International Conference- Maintenance and Productiona Engineerning, KODIP - 2013*, Budva, Proceed., p. 161-168.

[3] Kacmarcik I., Movrin I., Lužanin D.,kakun P., Plančak M., Vilotoć D. (2011). Determination of friction in bulk metal forming processes, *SERBIATRIB '11, 12th International Conference on Tribology*, Kragujevac, Proceed., p.111-116.

[4] Schrader T., Shirgaokar M., Altan T. (2007). A critical evaluation of the double cup extrusion test for selection of cold forging lubricants, *Journal of Materials Processing Technology*, Vol. 189, p. 36–44.

[5] Zhang Q., Felder E., Brusch S. (2009). Evaluation of friction condition in cold forging by using T-shape compression test, *Journal of Materials Processing Technology*, Vol. 209, Issue 17, 19, p. 5720-5729.

[6] Groche P., Müller C., Stahlmann J., Zan S. (2013). Mechanical conditions in bulk metal forming tribometers - Part two, *Tribology International,* Vol. 66, p. 345-351.

[7] Lazzarotto L., Dubar L., Dubois A., Ravassard P., OudinJ. (1998). Three selection criteria for the cold metal forming lubricating oils containing extreme pressure agents, *Journal of Materials Processing Technology,* Vol. 80–81, p. 245–250.

[8] Aleksandrović S., Đorđević M., Stefanović M., V. Lazić, Adamović D., Arsić D. (2014). a Different Ways of Friction Coefficient Determination in Stripe Ironing Test, *Tribology in Industry* 6, No. 3, p. 293-299

[9] Adamović D., Stefanović S., Aleksandrović S., Živković M., Gulišija Z. (2011). The Influence of Various Process Parameters on Coefficient of Friction on Die at Ironing of AlMg3 Sheet Metals, *12th International Conference on Tribology, SERBIATRIB 2011*, Kragujevac, Proceed. pp. 342-348.

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