THE METHOD OF DETERMINING THE TENDENCY TO GALLING IN VIBRATION ASSISTED MICROFORMING

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Abstract

The method of determining the tendency to galling in microforming processes is introduced. The method consists in the drawing process of the strip with a width of 1-3 mm and a thickness of 0.3-1 mm using a cylindrical tool with a radius of 2.5 mm. The process force as a function of sliding distance is recorded. On the basis of the character of the force course, the coefficient of galling tendency is determined. The process is carried out in a specially designed device placed on the table of testing machine. The device is equipped with a piezoelectric vibrator that allows the tool to be vibrated in accordance with the tape drawing direction with adjustable frequency and amplitude. The stand has been tested statically and dynamically, achieving the assumed construction parameters, i.e. the vibration amplitude in the range of 0-10 μm and the frequency 0-300 Hz. In the initial tests carried out, the effect of using vibrations with specific parameters on the tendency to galling and the surface condition of deformed materials was found.

Keywords: Microforming, galling, vibration-assisted

1. INTRODUCTION

The development of micro-electromechanical systems and micro-opto-electromechanical systems as well as various types of micro-mechanisms used in telecommunications, defence and medicine causes a rapid and accelerating increase in the demand for micro-parts. A large part of them can be made of metals and their alloys [1]. The technology of metal forming due to its characteristic feature which is the creation of the surface of objects by means of plastic deformations, and not through the loss of material consistency, is particularly suitable for the production of miniature parts with high accuracy and low surface roughness [2]. Proven for centuries the law and successfully used practical methods have proved to be insufficiently accurate or even incorrect in the application of plastic deformation of miniature objects. The observed deviations were called "size/scale effects" [3]. They concern not only such aspects of forming processes as: grain size [4,5] , friction [6,7] and cracking of deformed material [8] but also the design of tools [9]. For this reason, at the end of the last century, the principles of designing metal forming processes in relation to micro-parts were begun, which resulted in the separation of a new part of metal forming called microforming [10]. This field has been going through stormy development for several years, also in the aspect of compound objects [11], tooling systems design [12] and design of tools dedicated to micro processes [13]. The necessity of obtaining the highest possible dimensional accuracy and the associated expected low surface roughness forces the interest in contact phenomena. Mainly in the aspect of reducing forces and the effects of friction and preventing adhesion phenomena with the smallest possible amount of lubricant [14], whose too thick layer reduces the accuracy of micro-parts. For this reason, interest in research on dry friction [15] or very similar to it has increased, as well as on methods that reduce the risk of adhesion joints. In this matter the “state” of billet is analysed [16] and its surface roughness [17,18] and preparation [19] in the aspect of influence on adhesion. An extreme example of which is the phenomenon of galling. The resulting build-up due to the very high hardness is a threat to the product and tools. In the area of influencing contact phenomena regarding the reduction of friction forces and counteracting adhesion processes for over 60 years [20], the beneficial effects of using tool vibrations in the metal forming processes are reported [21]. It is already widely accepted knowledge that the effects of vibrations may affect the impact on the structure of formed elements [22, 23] also in the aspect of cracking [24] - “volume effect" and on contact phenomena - "surface effect". On the other hand, the methods used to support vibration can be divided into so-called: "Direct excitation" [25] referring to the vibration of the "whole" tool in this respect treated as a rigid body and the induction of a standing wave with a resonant frequency in the tool volume, which results in surface displacements of the active tool [26]. The first method (direct excitation), for reasons of inertia forces, applies to low frequency vibrations - up to several hundred Hertz and only causes "Surface effect" [27]. The second method mainly concerns ultrasonic vibrations, i.e. frequencies greater than 20 kHz and induces both effects: volume effect [28,29] and surface effect [30,31] also in the aspect of dynamic impact [32]. Both methods face energy difficulties in application to large masses and forces that are characteristic of metal forming processes. This problem disappears in relation to microforming processes in which objects with a mass close to 1 g are most often involved. It is the energy aspect that, according to the author, is one of the main reasons for the currently observed dynamic increase in interest in the use of vibration support. This applies to virtually all groups of microforming processes: sheet metal forming [33] and bulk metal forming cold and hot [34] and in superplastic conditions [35]. The presented work is part of this trend. Its aim is to develop a method for investigating the effect of using direct excitation on contact phenomena occurring during cold metal forming, in particular on the phenomenon of galling.

2. EXPERIMENTAL SET UP

The stand consists of the Hounsfild H10KS testing machine -1, the "Vib-Tester" - 2 mounted on it and the vibrator control system. The control system includes: power supply -3, function generator -4 and oscilloscope -5.

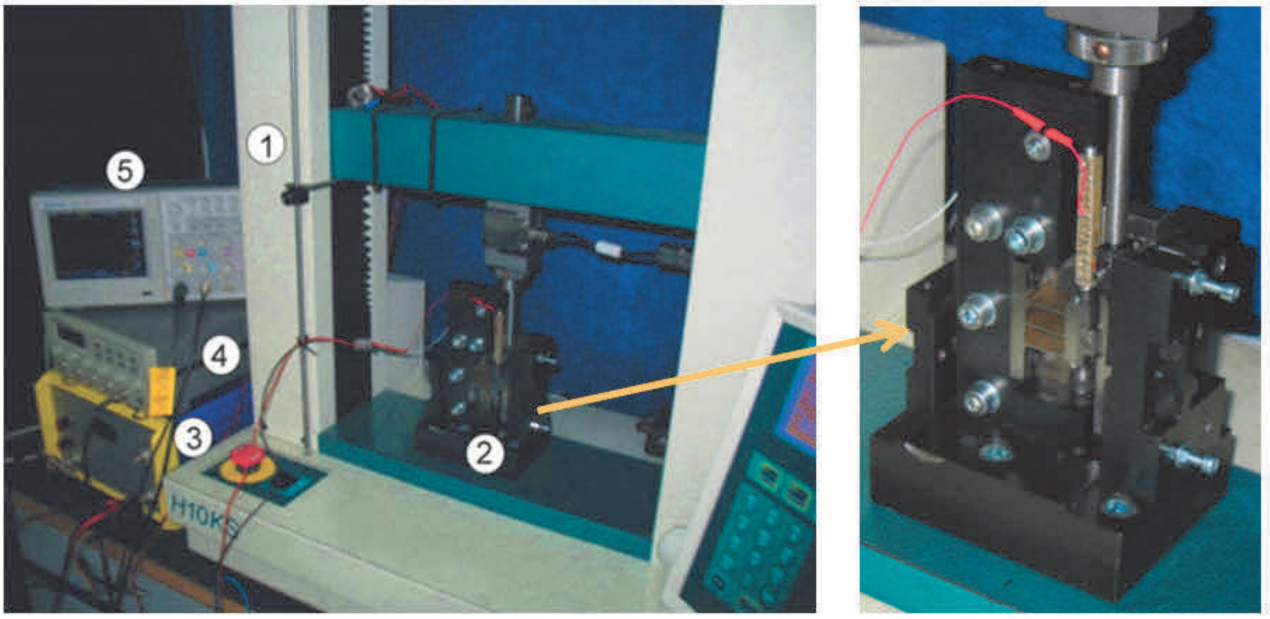

Figure 1 Stand for testing the influence of vibrations on dry friction curves: 1- Hounsfield H10KS testing machine, 2- Vib-Tester, 3- power supply, 4- function generator, 5- oscilloscope

The Vib-Tester (**Figure 2a**) consists of a base -1, intermediate plate -2, vibrator unit -3, beam assembly -4, a beam guide unit -5, side wall -6 and a retaining wall 7. The vibrator unit (**Figure 2b**) allows vibrating the tool - 1 placed in the holder -2 by means of screws -3. The holder is located on the gate elastic element -4, whose oscillation causes the piezoelectric stack -5 terminated by ball joints -6. The piezoelectric stack is pre-stressed with disc springs -7 acting on the bumper -8 and placed on the adjusting screw -9. Tool - 1, can be used 3 times in different positions. The method of deformation adjustment is shown in **Figure 2c**. The sample -1 is placed on the beam -2 supported by bearings -3, placed on the swing elements -4 fixed on the bolts -5 and supported by screws -6, with bushings -7. The deformation volume is also regulated by spacers -8 resting against the retaining wall. The stand was tested statically and dynamically. In the frequency range of 50-300 Hz, achieving a vibration amplitude in the range of 0-10 um. It allows you to carry out the process of strip ironing of the widths of 1-3 mm and thickness up to 1 mm with a cylindrical tool with a radius of 2.5 mm. The deformation speed, distance and force registration is provided by a testing machine.

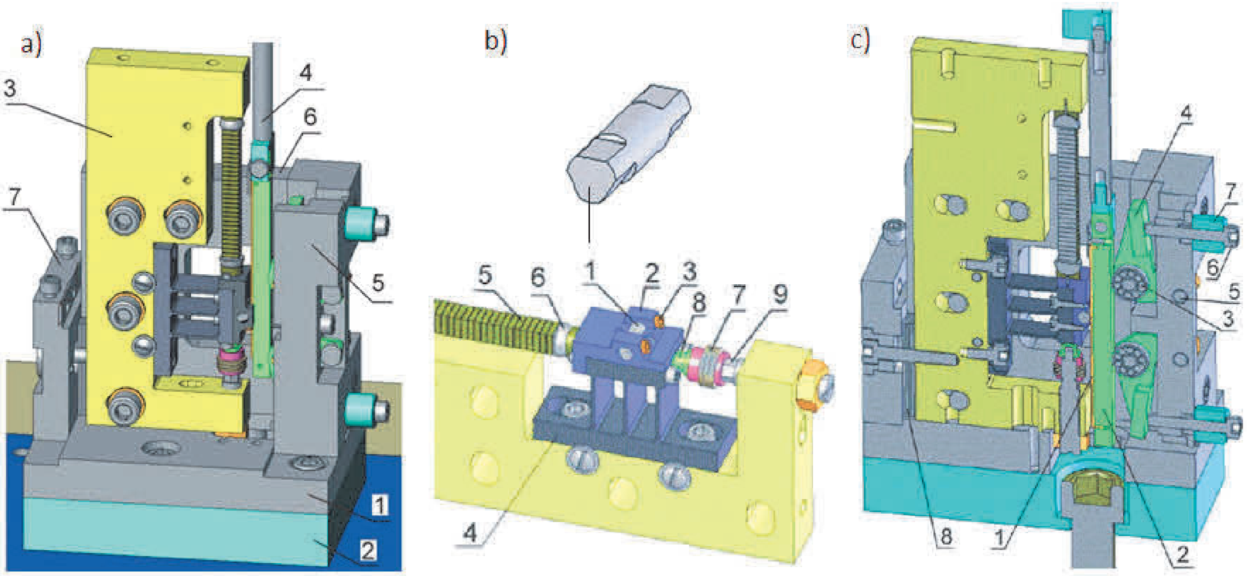

Figure 2 Experimental set up: a) main parts of Vib-Tester, b) vibrator unit, c) the method of deformation adjusting

3. EXPERIMENTAL PROCEDURE

The tendency to galling is determined by the coefficient *Z* (1) calculated on the basis of recorded waveforms of forces called "dry friction curves"(DFC). The coefficient of tendency to galling is determined by the dependence (1) and is the change in the force of the process on the initial path of the tray under the conditions of dry sliding friction.

$$Z = \frac{\Delta F}{\Delta S} \tag{1}$$

where: *Z* - tendency to galling (N/mm), ΔF - the force increse (N), ΔS - the length of action (mm)

The deformation achieved is determined by the logarithmic cross-section reduction according to (2).

$$\varepsilon_r = ln\frac{A_0}{A_1} \tag{2}$$

where: ε_r - cross-section reduction, A_0 - initial cross-section (mm^2), A_1 - final cross-section (mm^2).

4. EXPERIMENT RESULTS

Figure 3 shows influence of strip material on the DFC corresponding to the tool for the test at the ram velocity 12 mm / min with a cross section reduction of $\varepsilon_r = 0.34$ of. Strips 3 mm wide and 0.8 mm thick were deformed from aluminum, stainless steel and copper. The following coefficients were obtained: $Z_{Al} = 48.1$ (N/mm), $Z_{SS} = 45.0$ (N/mm), $Z_{Cu} = 6.0$ (N/mm). These results are reflected in the appearance of a tool surface. In the case of an aluminum sample, a marked build-up edge along the entire contact line and on a large part of the contact surface were created. The build-up edge created on the tool after forming of the stainless steel sample has a small height but is evenly distributed over the entire contact surface. The copper sample was only covered in two relatively narrow bands.

Figure 4 shows influence of tool vibrarion frequency on the DFC. Almost 3 mm wide and 0.8 mm thick aluminum samples were tested. The deformation process was carried out at a speed of 12 mm / min using a tool of alloy steel for cold work hardened to a hardness of 60-62 HRC and ground surface R_a = 0.6 µm. The tests were carried out in the conditions of dry friction by cleaning the surfaces of tools and samples with acetone before each test. Three vibration frequencies were used: 50 Hz, 200 Hz and 300 Hz with the same amplitude A = 7.5 µm and cross-section reduction ε_r = 0.34. Galling tendency factors Z are as follow: Z_{50} = 23.2 (N/mm), Z_{200} = 44.8 (N/mm) and Z_{300} = 59.7 (N/mm).

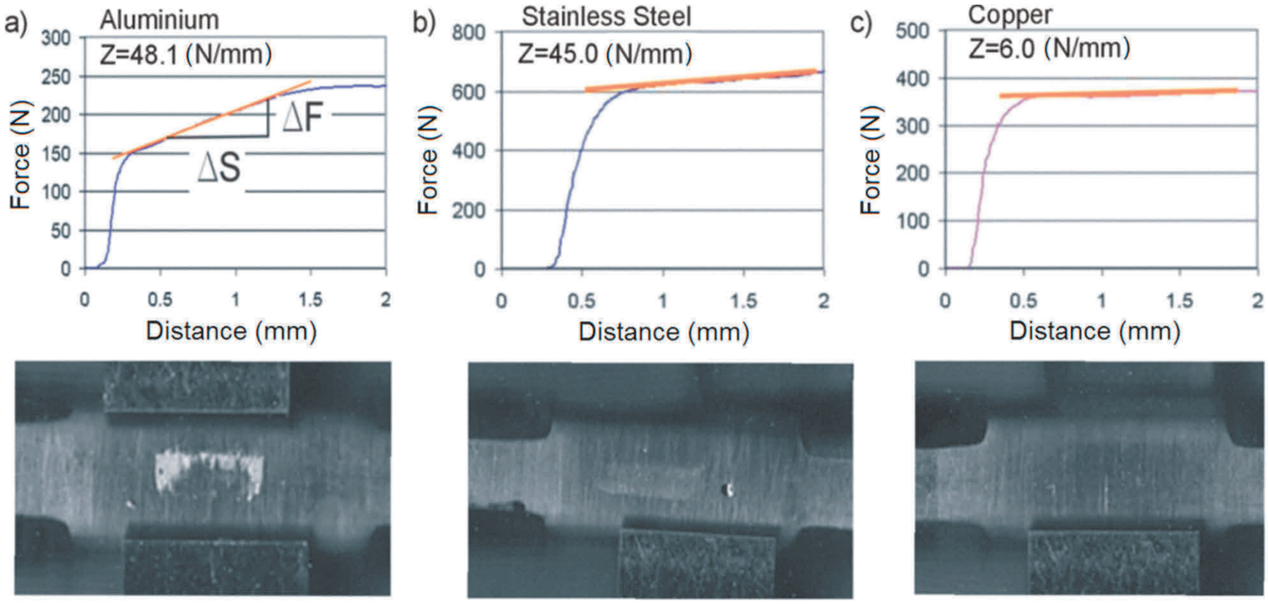

Figure 3 Dry friction curves and tool surfaces after deformation for Aluminium, Stainless steel and Copper

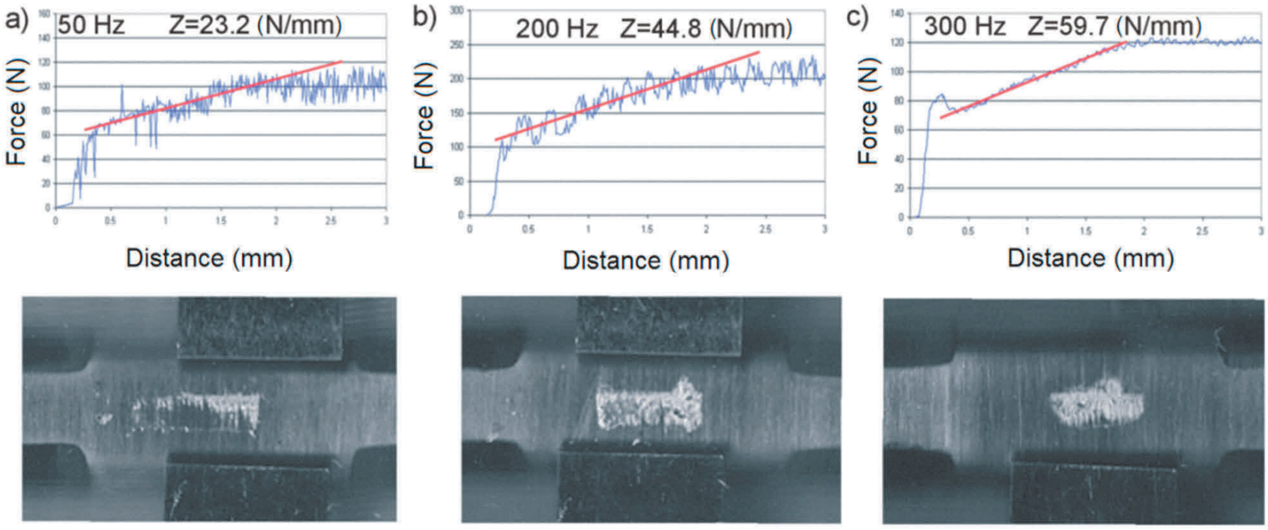

Figure 4 Dry friction curves and tool surfaces after vibration assisted deformation of Aluminium strip under tool vibrarion freguency: 50, 200, and 300 Hz

5. ANALYSIS OF RESULTS

There was a decrease in the tendency to galling factor Z with the introduction of vibrations of the tool in relation to two used frequencies: 50 and 200 Hz. As a reason, one can postulate the mechanism of breaking micro-connections between the material of the tool and the material deformed in the return movement. This return movement is responsible for changing the mechanism of temporary wear. The following course of phenomena can be suggested. In the translational movement, the creation of micro-bild-up edges begins, which gradually grow leading to an avalanche galling process. Growing, through its presence, increases local pressure, deepening the tendency to create metallic connections. We are dealing here with a positive feedback leading to the avalanche accumulation of an unfavorable phenomenon. With the use of periodic return movement, in many places the micro-bild-up edges are torn off and pushed into the roughness valleus, causing local pressure reduction. There is therefore a local negative feedback, which inhibits the galling process, temporarily and in some places contaminating it with abrasive wear. Globally, this causes a reduction in the speed of process force increase, which is reflected in the decrease in the Z-factor. The lowest tendency to galling was obtained using a frequency of 50 Hz (with an amplitude of $A = 7.5$ µm). With these parameters, the tendency to galling Z for the vibration test $Z = 48.1$ N / mm decreased to the level $Z = 23.2$ N / mm, which is a reduction of 52%. Raising the frequency to 200 and 300 Hz increased the tendency to galling to $Z = 44.8$ N / mm and $Z = 59.7$, which means a slight decrease in Z-propensity to Z without vibration: 7% (for 200 Hz) and in the case of 300 Hz increase in Z of 24 %. This increase may be due to the temperature increase at the place where the tool contacts the deformed material, which may affect the formation of diffusion-based micro-joints. In the case of vibrations with a frequency of 200 Hz, the beneficial effect of vibrations and the adverse effect of temperature are almost compensated. In the case of 300 Hz, the adverse effect of the elevated temperature is clearly dominant.

6. SUMMARY AND CONCLUSIONS

A research method leading to the determination of the tendency to galling of the test materials representing the tool and workpiece under the conditions of microforming without participation and with the participation of low vibration (50-300 Hz) frequency has been proposed. This method consists in analyzing the course of the forming force of miniarure strip (width up to 3 mm and thickness up to 1 mm) with a cylindrical tool inserted into a vibrating motion in a direction consistent with the strip movement direction. The process takes place under dry friction conditions, and the curves analyzed are taken to be called "dry friction curves".

A test stand has been designed, constructed and tested, in which the longitudinal vibration of the tool generates a piezoelectric actuator enabling the regulation of the vibration frequency in the ranges f = 0-300 Hz and the amplitude $A = 0$-10 µm. The translational movement is carried out with the help of a precision testing machine enabling the adjustment of the deformation speed and the registration of "dry friction curves". The stand also allows for smooth adjustment of the given deformation.

As a result of the conducted research, it was found that the use of vibrations with frequencies of 50 and 200 Hz reduces the tendency to galling by 52% and 7%, which is most probably caused by a periodic backflow that allows breaking micro-build-up edges in their initial phase of growth. Raising the frequency to 300 Hz increases the tendency to galling by 24%, which is probably caused by the temperature increase favoring the development of diffusion micro-joins.

REFERENCES

[1] GEIGER, M., ENGEL, U., et al. Metal forming of micro parts for electronics. *Prod. engineer*. 1994. vol. 2, pp. 15-18.

[2] SANTOME, Y., et al. Superplastic backward microextrusion of microparts for micro-electro-mechanical systems. *Journal of Materials Processing Technology*. 2001. vol. 119, pp. 307-311.

[3] RAULEA, L.V., et al. Size effect in the processing of thin metal sheets. *Journal of Materials Processing Technology*. 2001. vol. 115, pp. 44-48.

[4] GHASEMALI, E., et al. Grain size and workpiece dimension effects on material flow in an open-die-micro-forging/extrusion process. *Materials Science and Engineering.* 2013. vol. 582, pp. 379-388.

[5] JIANG, M., FENG, G., et al. Microdeep drawing of C1100 microsquare cups using microforming technology. *International Journal of Advanced Manufacturing Technology*. 2016. vol. 82, pp. 1363-1369.

[6] TIESLER, N., et al. Forming of microparts - effects of miniaturization on friction. *Advanced Technology of Plasticity*. 1999. vol 2, pp. 889-894.

[7] ENGEL, U. Tribology in microforming. *Wear*. 2006. vol. 260/3, pp. 265-270.

[8] RAN, J.Q., et al. The influence of size effect on the ductile fracture in micro-scaled plastic deformation. *International Journal of Plasticity*. 2013. vol. 41, pp. 65-81.

[9] PRESZ, W., Scale effect in design of the pre-stressed micro-dies for microforming. *Computer Methods in Material Science.* 2016. vol. 16, pp.196-203.

[10] GEIGER, M. et al. Microforming. *CIRP Annals - Manufacturing Technology*. 2001. vol. 50, no. 2, pp. 445-462.

[11] PRESZ, W., CACKO, R. Determination of material distribution in heading process of small bimetallic bar. In: *Esaform 2018: Int. conf. on material forming.* Palermo: AIP Conf. Proc. 2018. vol. 1960 no.1, p.050014.

[12] PALDAN, L.A., et al. Piezo driven prestressing of die-system for microforming of metal com-ponents, *International Journal of Material Forming*. 2006. vol. 1, pp. 467-470.

[13] PRESZ, W., CACKO, R. Application of Complex Micro-die for Extrusion of Micro-rivets for Micro-joining. In *METAL 2017: 26rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 514-520.

[14] SHIMIZU, T. et al. Micro-texturing of DLC thin film coatings and its tribological performance under dry sliding friction for microforming operation. *Procedia Engineering.* 2014. vol. 81, pp.1884-1889.

[15] HOLINSKI, R. Fundamentals of dry friction and some examples. *Industrial Lubrication and Tribology*. 2001. vol. 53, no.2, pp. 61-65.

[16] KOCANDA, A., PRESZ, W, et al. Contact pressure distribution in upsetting of compound metals. *Journal of Material Processing Technology*. 1996. vol. 60, no.1-4, pp.343-348.

[17] MUSTER, A., PRESZ, W. Influence of initial surface roughness on galling behaviour of steel-steel couple. *Scandinavian Journal of Metallurgy*. 1999. vol. 28, no. 1, pp.5-8.

[18] SALACINSKI, T., CHMIELEWSKI, T., et al. Roughness of Metal Surface After Finishing Using Ceramic Brush Tools. *Advances in Materials Science*. 2018. vol. 18, no. 1, pp. 20-27.

[19] SALACINSKI, T., WINIARSK,I M., et al. Surface finishing using ceramic fiber brush tools, In *METAL 2017: 26rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 1222-1226.

[20] BLACHA, F., LANGECKER, B. Plastizitätsuntersuchungen von metallkristallen in ultras-challfeld. *Acta Metallurgica.* 1959. vol. 7, pp. 93-100.

[21] DAWSON, G. R. et al. Application of high- and low-frequency oscillation to the plastic deformation of metals. *Metal Forming*. 1970. vol. 4, pp. 158-162.

[22] ZHOU, H., et al. A comparative study of mechanical and microstructural characteristics of aluminium and titanium undergoing ultra-sonic assisted compression testing. *Materials Science and Engineering*. 2017. vol. 682, pp. 376-388.

[23] ABHISHEC, P., et al. Dislocation density based constitutive model for ultrasonic assisted deformation. *Mechanics Research Communications*. 2017. vol. 85, pp. 76-80.

[24] PRESZ, W., CACKO, R. Ultrasonic assisted microforming. In *METAL 2017: 26rd International Conference on Metallurgy and Materials*. Ostrava: TANGER, 2017, pp. 521-526.

[25] PRESZ, W, ANDERSEN, B. Flexible tooling for vibration-assisted microforming. *Journal of Achievements in Materials and Manufacturing Engineering*. 2007. vol. 21/2, pp. 411-414.

[26] LIU, Y. et al. Comparison Between Ultrasonic Vibration-Assisted Upsetting and Conventional Upsetting. *Metallurgical and Materials Transactions*. 2013. vol. 44, no. 7, pp. 3232-3244.

[27] CHOWQDHURY, M. A., HELALI, M. M. The wear behavior of mild steel under vertical vibration. *Industrial Lubrication and Tribology*. 2009. vol. 61, no. 6, pp. 296-300.

[28] SIDDIQ, A., SAYED, T., Acoustic softening in metals during ultrasonic assisted deformation via CP-FEM. *Materials Letters.* 2011. vol. 65, pp. 356-359.

[29] YAO, Z., et al. Acoustic softening and residual hardening in aluminum: Modeling and experiments, *International Journal of Plasticity*. 2012. vol. 39, pp. 75-87.

[30] HUNG, J-C., et al. Frictional effect of ultrasonic-vibration on upsetting. *U-sonics*. 2007. vol. 46, no. 3, pp. 277-284.

[31] DJAVANRODI, F., et al. Ultrasonic assisted-ECAP. *Ultrasonics*. 2013. vol. 53, no. 6, pp.1089-1096.

[32] PRESZ, W. Dynamic effect in ultrasonic assisted micro-upsetting. In: *Esaform 2018*: Int. conf. on material forming. Palermo: AIP Conf. Proc. vol. 1960, p. 100012

[33] JIMMA, T. et al. An application of ultrasonic vibration to the deep drawing process. Journal of Materials Processing Technology. 1998. pp. 80-81.

[34] HUNG, J. C. The influence of ultrasonic-vibration on hot upsetting. *Ultrasonics*. 2005. vol. 43, pp. 692-698.

[35] MYSHYAEV, M.M. et al. Change in Characteristics of Superplastic Deformation of the Aluminum-Lithium Alloy under the Effect of Ultrasonic Vibrations. *Physics of the Solid State*. 2015. vol 57, no. 10, pp. 2039-2044.