



## MODELLING OF THE TOOL WEAR IN TR FORGING OF FASTENER

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### Abstract

This paper presents the technology of forging of the Putanker 1.3 T fastener type by the TR method and the results of modelling the wear of the tools used in this process. A preliminary analysis showed abrasive wear to be the dominant wear mechanism in the first forging operation. Numerical modelling by means of the MARC computing software package was carried out to predict the wear of the tools in the forging of the Putanker fastener. The changes in the shape of the dies surface after the forging of 2200, 6500, 9600 and 23500 pieces were determined by surface scanning. The Archard model was used to describe the abrasive wear.

**Key words:** forging, TR method, abrasive wear, Archard model

## 1. INTRODUCTION

Due to the severe conditions prevailing during the hot die forging the durability of the forging dies is unstable and relatively low (Altan, 2005). Hot die forging is characterized by the impact of the very high temperature of the hot charge on the active surfaces of the forming tools and by very high unit pressures (Kocańda, 2003). In recent years rapid advances have been made in numerical methods which are capable of modelling increasingly complex phenomena, such as die wear. The data obtained from the models help to modify forging processes in order to achieve longer tool life (Kocańda, 2003). The most common types of tool damage (causing premature tool wear) observed in die forging are: plastic deformations, mechanical microcracks, thermal microcracks, abrasive wear as

well as fracturing and chipping of tool parts. According to the literature on the subject, the dominant wear mechanism is abrasive wear (amounting to 70%), followed by plastic deformations and thermomechanical fatigue resulting from the dynamic cooling of the forming tool surface (Lavtar et al., 2001).

The aim of this research was to analyze the wear of the tools used in the industrial forging of the Putanker 1.3 T fastener in the first operation and to evaluate the suitability of the Archard model for predicting tool wear. For forging tool life determination the Archard model of abrasive wear (Archard 1953) has been implemented in the FE software.

Since the cooling of the tools with a lubricating medium has been completely eliminated from the industrial process of the fastener forging, one can expect abrasive wear to be the dominant degrading

phenomenon leading to a permanent change in the active die impression geometry, as a result of the abrasion of the forming tool material by the formed material moving against it.

## 2. DESCRIPTION OF PROCESS

A specially prepared station for TR forging was used to carry out the actual forging process. In the TR method an articulated system is used to replace the press load with forces automatically clamping the rod to be forged and forces forming the forging. TR forging equipment is universal and simple in design. It can be installed on forging presses with a maximum load of 100 MN. A characteristic feature of TR forging processes is that press working stroke generates both a horizontal force and a vertical force whereby the stock is simultaneously clamped, bent and upset (Rut and Walczyk 2007) (figure 1). The fastener was hot forged from steel 18G2 without cooling or lubricating the forming tools. The temperature of the preforms is about 1100°C, the stock in the form of a rod is induction heated only in its part, which is being formed. The fastener is formed in TR devices on a PMS-160 eccentric press. The die inserts are made of steel ORVAR SUPREME (WCLV). Their hardness after heat treatment amounted to 58 HRC.

The forging is obtained as a result of three operations:

- the closed-die forging of the flange (figure 2a),
- the closed-die forging of the cylindrical grip part (figure 2b)
- the open-die forging of the conical grip part (figure 2c).

The analyzed tools for the first operation consist of two pairs of dies. During the forging the half's dies are closed and the upsetting is carried out in the axisymmetric condition. The left die performing the first operation, i.e. the closed-die forging of the flange (figure 2d), was analyzed.

## 3. EXAMINATION OF TOOL WEAR

Figure 3 shows macrophotographs of changes on the die cavity surface after the forging of 2200, 6500, 9600 and 23500 pieces. The research presented in (Ziółkiewicz at al., 2012) confirms that the main wear mechanism is abrasive wear. The small grooves contacted with thermomechanical fatigue appear after forging of 6500 pieces but their size is not changed until forging of 23500 pieces.

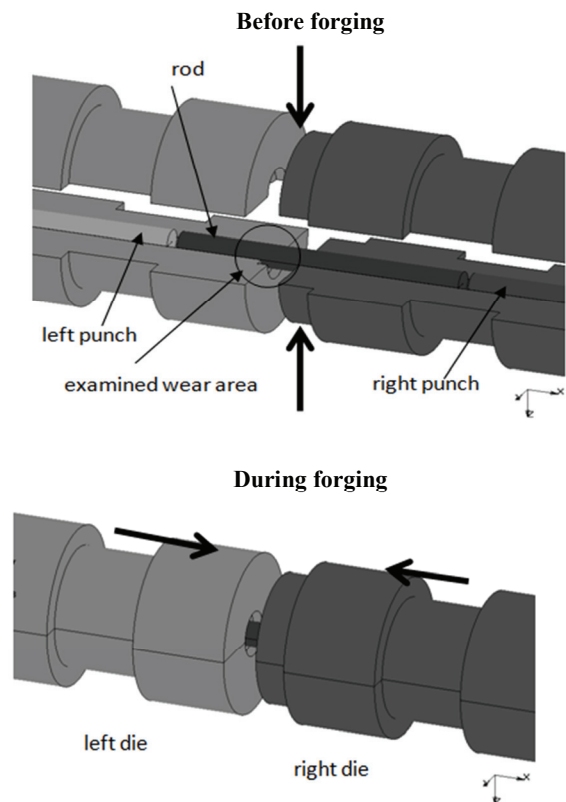


Fig. 1. Schematic of process before and after forging.

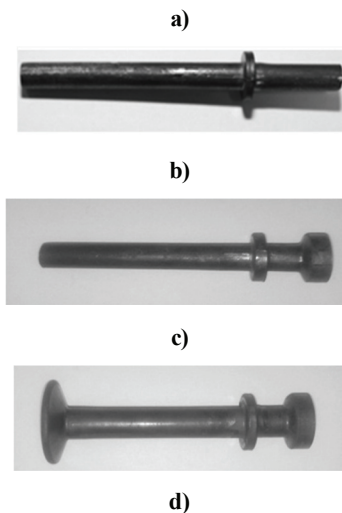
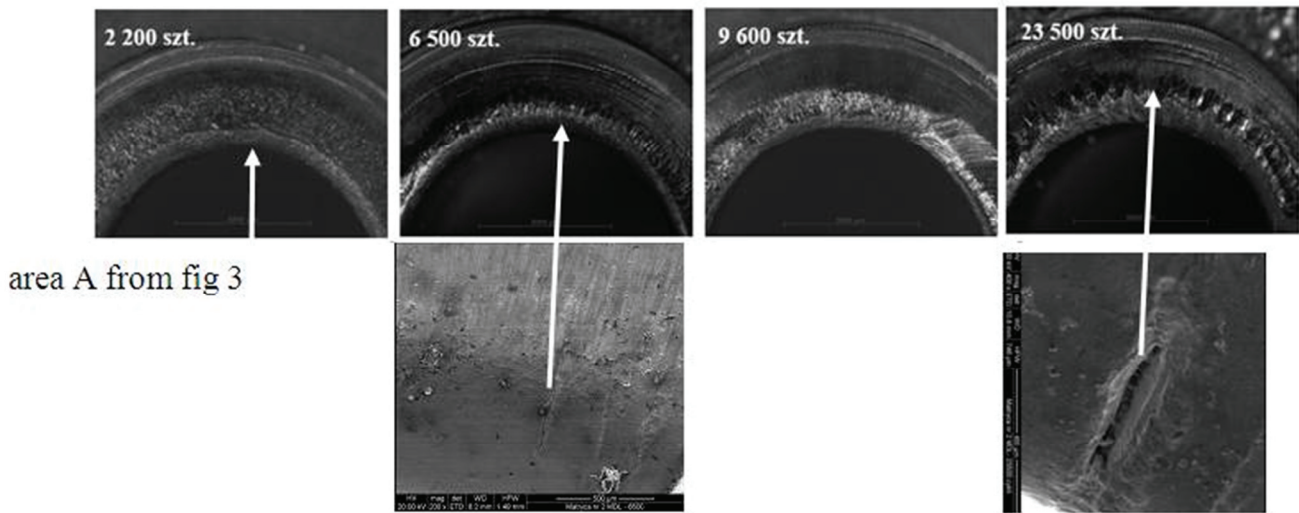


Fig. 2. Forgings after a) first operation, b) second operation, c) the final forging and d) die inserts for first operation.





area A from fig 3

Fig. 3. Changes in appearance of die cavity surface within hole radius area after forging 2200, 6500, 9600 and 23500 pieces.

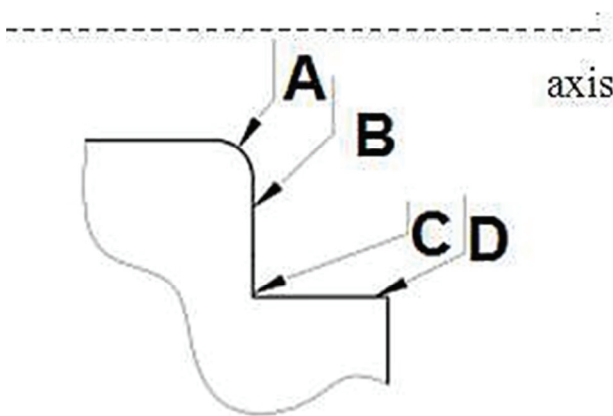


Fig. 4. A scheme indicating the places examined for wear.

x 44 x 30 mm or by scanning a part of the surface with high resolution (max. 0.04) for an active area of 55 x 44 x 30 mm. As a result, digital images of the examined objects, in the form of a cloud of points in 3D space, were obtained. Using image analysis software one can determine the changes in the shape of the examined surface in two ways: by comparing the image with the CAD model or by comparing it with a previously scanned surface of the unused tools. In order to avoid errors due to die workmanship tolerances, the dies were scanned before their use and after the manufacture of a certain number of forgings. A scheme indicating the places of examined wear and the amount of wear form optical

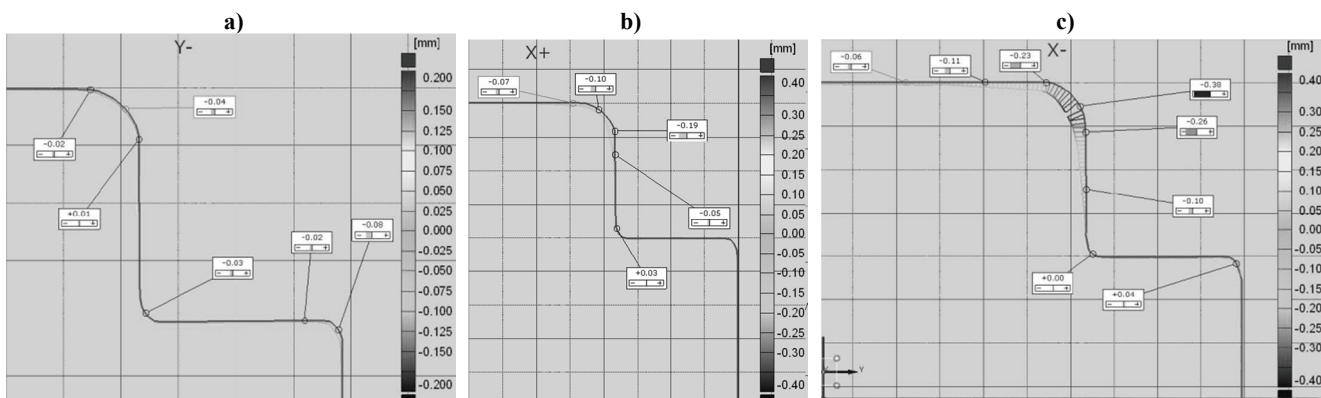


Fig. 5. The amount of wear from optical scanner after a) 2200 b) 6500 and c) 23500 pieces.

In order to determine the degree of the tools wear in the particular operations for the adapted number of pieces, the active surfaces were scanned by means of a GOM ATOS II optical scanner. The shape of the outer surface of the investigated objects was measured by surface scanning (microanalysis) with a resolution of 0.17 mm for an active area of 55

scanner are shown respectively in figures 4 and 5 (Ziółkiewicz at al., 2012).

#### 4. NUMERICAL SIMULATION

Numerical simulations of the forging of the fastener were run using the MSC MARC software. All



the simulations were run for the axisymmetric state of strain for the most complex thermomechanical model with deformable dies and rigid punches. The geometry of the tools and that of the preform were implemented in the program on the basis of 2D models and operation sheets (figure 6). The geometric parameters of the crank press and the punch speed (determined by the angular position of the press) were adapted in accordance with the technical documentation.

The temperatures in the particular forging operations were determined on the basis of thermovision examinations (pointwise measurements by a thermovision camera). The initial tool temperature for the first operation was assumed to be 100°C and the preform temperature, according to the process recommendations, amounted to 1100°C.

The coefficient of heat transfer to the environment, in contact and in close contact (0-0.105 mm) amounted to respectively 0.35 N/s/mm/°C, 20 N/s/mm/°C and 8 N/s/mm/°C.

A bilinear friction model of the SHEAR type and a friction coefficient of 0.2 for friction between the tools and the material being deformed were assumed.

In order to determine the wear of the tools, the elementary Archard abrasive wear model based on the stress in contact and on the rate of displacement of the material at the forging-tool contact was used (Archard 1953).

The rate of wear at any instant of forging can be expressed as:

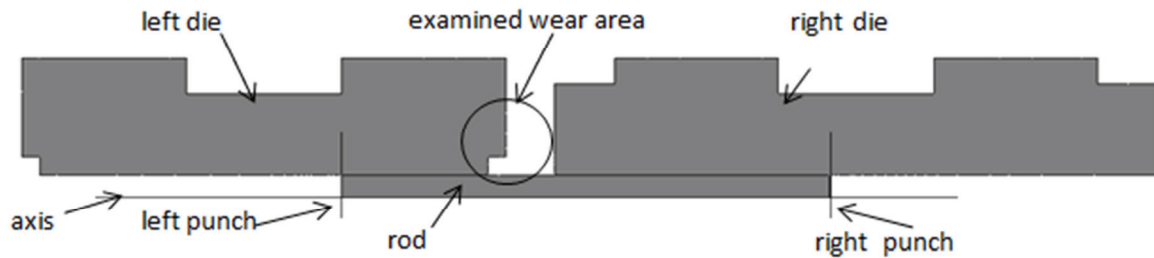


Fig. 6. Schematic illustration of the computing model before and after forging.

The material specifications (the specific heat, thermal conductivity, thermal expansion, the Poisson ratio and Young modulus of the tools and the forging as well as the strain-strain rate-stress characteristic) were taken from the Matilda materials database. The elastic material model with a Young modulus of  $2 \times 10^5$  MPa was adapted for the tools.

$$\dot{w}(1) = \frac{k}{H} \sigma V_{rel} \quad (1)$$

the wear in one cycle:

$$w(1) = \frac{k}{H} \int \sigma V_{rel} dt \quad (2)$$

and assuming that the same volume of material wears out in each cycle and that the material's hard-

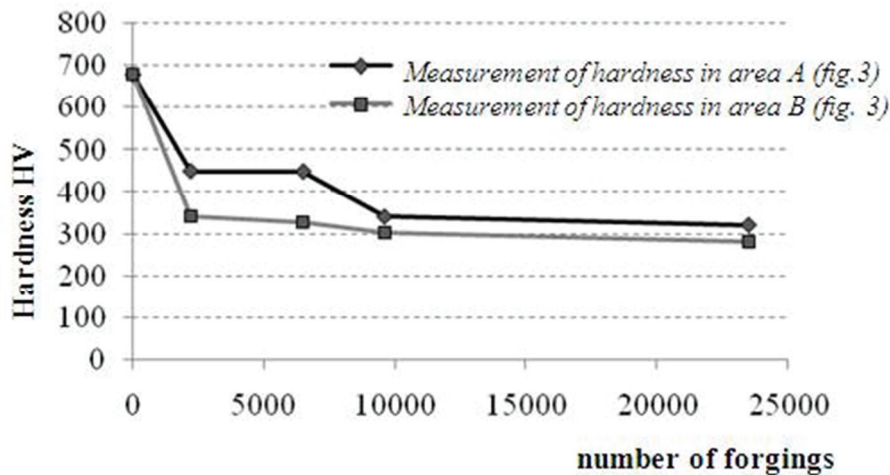


Fig. 7. Changes in material hardness in selected measuring points.



ness does not change, the wear for any number of cycles is:

$$w(c) = \sum_1^c \frac{k}{H} \int \sigma V_{rel} dt = C w(1) \quad (3)$$

where:  $w$  – amount of wear [mm],  $\sigma$  – normal stress [MPa],  $V_{rel}$  – relative friction velocity [mm/s],  $H$  – material hardness [MPa],  $k$  – a dimensionless coefficient of wear.

Since the hardness of the tools was measured after forging 2200, 6500, 9600 and 23500 pieces, the change in hardness in the course of the successive work cycles of the tools was taken into account in the wear model. The hardness variation results for the different numbers of forgings for two selected measuring areas are shown in figure 7. Decrease in the hardness of tools is associated not only with abrasive wear but also with tempering and cracking. Analysis of hardness was carried out on the hardness testing machine LECO 100AT. The load of 1000 g and 10 s of loading time were applied.

## 5. ANALYSIS OF TOOL WEAR

The main problem involved in the application of the Archard model is the determination of the coefficient  $k$ . In the literature this coefficient is selected on the basis of tribological tests or on the basis of the real wear for the given process (Altan, 2005). This means that there are no formalized procedures for determining coefficient  $k$ , which could be applied to real forging processes. In the modelling,  $k = 0.000205$  was assumed in order to obtain similar tool wear values as in the real process (figure 8). The

diagram shows the results for the dies after the forging of 6500, 9600 and 23500 pieces.

The distributions of die cavity surface wear for the different numbers of cycles coincide with the tool scanning results. In both cases, the highest wear occurred on the die's radius, where the material being deformed stays longest in contact with the tool and where large pressures and material displacement along the tool surface occur. The comparison of the tool wear diagrams for constant (initial hardness was assumed in the whole process) and varied tool hardness in the Archard model for 23500 forgings are presented in figure 9. Wear values are about twice smaller than in the simulation with varied hardness from experimental studies.

It is necessary to take into account in the wear model the changes in tool hardness in the successive cycles, because of the softening of the material under the impact of the thermal field during the forming process (figure 10), especially in the tool outer radius area. In the plastic strain diagram (figure 11) a higher level of strains is observed in the area of contact with the die cavity, in the place where tool wear is the highest, which is indicative of the most intensive flow of the forging material with respect to the tools.

The results obtained from the mathematical modelling, in which the Archard model accurately describes the wear of the dies and the results of the metallographic examinations as well as the wear distributions determined by Ziółkiewicz et al. (2012), confirm that abrasive wear is the dominant mechanism of the wear of the forming tools in the considered process.

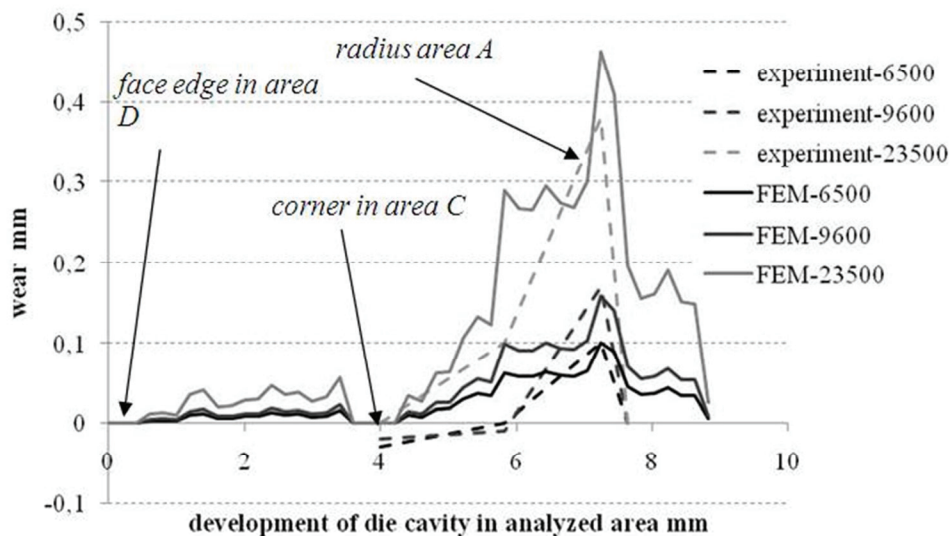


Fig. 8. Comparison of tool wear results on left die in the first operation for 6500, 9600 and 23500 forgings obtained from modelling – continuous lines and experiment – dashed lines.



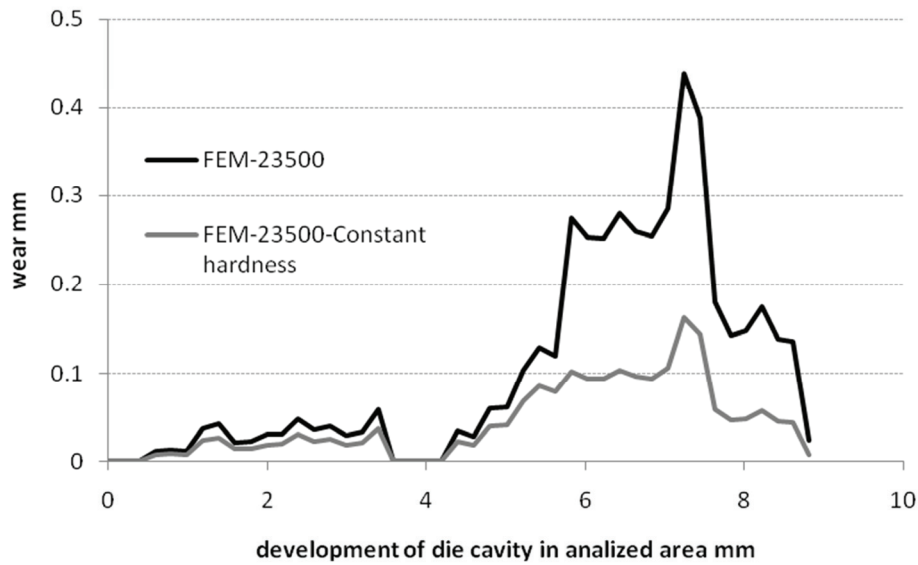


Fig 9. Comparison of the tool wear diagrams for constant and varied tool hardness in the Archard model for 23500 forgings.

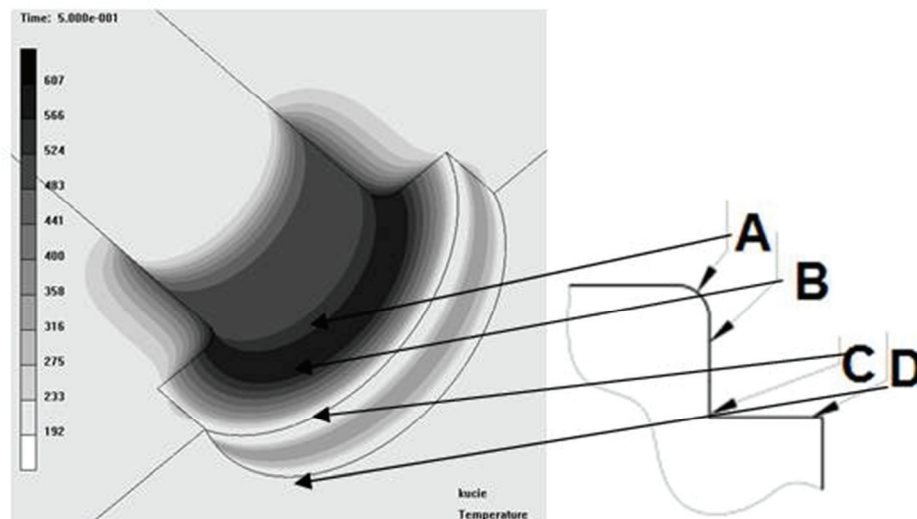


Fig. 10. Distribution of the temperature on left die in final forging step.

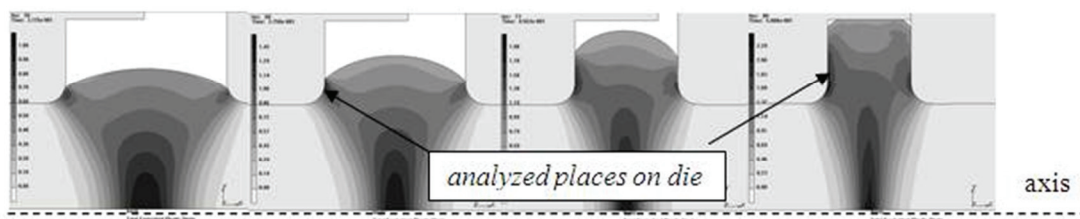


Fig. 11. Distribution of plastic strains during forging.

## 6. CONCLUSION

The Archard model of abrasive tool wear quite accurately describes the actual changes in tool dimensions in the considered process if the decrease in hardness is taken into account in equation (3).

As a result of the impact of the hot material on the tool during the forging of the fastener, the surface layer's hardness decreases from 700 HV to below 300 HV. When the drop in hardness is taken into account in the tool wear model, one obtains results very similar to the experimental ones for various numbers of cycles.



In the case of processes where other wear mechanisms (e.g. thermal fatigue) dominate, probably more complex model will have to be used.

## REFERENCES

- Altan, T., 2005, Cold and hot forging fundamentals and applications, *ASM International, Ohio*.
- Archard, J.F., 1953, Contact and rubbing of flat surfaces, *Journal of Applied Physics*, 24, 981-988.
- Lavtar, L., Muhič, T., Kugler, G., Terčelj, M., 2011, Analysis of the main types of damage on a pair of industrial dies for hot forging car steering mechanisms. *Engineering Failure Analysis*, 18, 1143-1152.
- Kocańda, A., 2003, Określenie trwałości narzędzia w obróbce plastycznej metali, *Informatyka w Technologii Metali*, eds, Piela, A., Grosman, F., Kusiak, J., Pietrzyk, M., Wydawnictwo Politechniki Śląskiej, Gliwice, 213-256 (in Polish).
- Rut, T., Walczyk, W., 2007, Nowe zastosowania i możliwości technologiczne metody TR, *Obróbka Plastyczna Metali*, 18, 3-10 (in Polish).
- Ziólkiewicz, S., Pachutko, B., Szkudelski, S., Gronostajski, Z., 2012, Mechanizmy zużycia narzędzi kuźniczych, *Proc. Conf. Advanced technologies for forming tool life improvement*, Poznań-Opalenica, 95-108 (in Polish).

## MODELOWANIE ZUŻYCIA NARZĘDZI W PROCESIE KUCIA ZACZEPU METODĄ TR

### Streszczenie

W pracy przedstawiono technologię kucia odkuwki zaczepu typu P 1.3T metodą TR oraz wyniki z modelowania zużycia narzędzi w tym procesie. Na podstawie skanowania powierzchni określono zmiany kształtu powierzchni matryc po odkuciu 2200, 6500, 9600 i 23500 sztuk. Wstępna analiza wykazała, że dominującym mechanizmem w pierwszej operacji kucia jest zużycie ściernie. W celu przewidywania zużycia narzędzi podczas kucia zaczepu Putanker przeprowadzono modelowanie numeryczne za pomocą pakietu obliczeniowego Marc, do opisu zużycia ściernego zastosowano model Archarda.

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