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Theoretical Analysis of the Buckling Phenomenon in the Upsetting Process of Magnesium Alloy Mg4AlZn

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BIOGRAPHICAL NOTES

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KEY WORDS

Upsetting process, Mg4AlZn magnesium alloy, FEM simulation

ABSTRACT

The issues present during simulations of the upsetting process of magnesium alloy Mg4AlZn are presented in this paper. The bar buckling, which is the main phenomenon limiting this process, was analyzed. The aim of the analysis was determining such conditions of simulations which would allow to obtain shape and eccentricity similarity to the real product. Two ways of buckling imposing in a theoretical model underwent research: non-axial movement and inclination of the upsetting tool working surface. The conducted analysis allowed to estimate the effectiveness of both analyzed ways of obtaining similarity between the theoretical model and the real process.

1. Introduction

In designing of aircrafts are applied elongated parts with changeable sections made from magnesium alloys. An example can be elements of control sticks in helicopters. Hence, it was assumed as purposeful to conduct research works on metal forming technology of such forgings. One of the ways of making of stepped elongated products is upsetting process, which can be realized as free upsetting or upsetting in impressions of various shapes (Fig.1). Specialist literature provides limiting conditions which determine the scope of the geometrical parameters of bar, product and tools at which the process runs properly [1÷5]. The main limiting of the upsetting processes is the bar buckling. As the research works presented in the paper [6] show, this phenomenon depends not only on geometrical parameters but also on, for example, material type. Because of that, the scope of process stability should be defined separately for each case. Precise analysis of the buckling phenomenon at the application of simulation by means of finite element method is, however, quite difficult, due to large divergence between the calculations results and experimental results. It was assumed as purposeful to conduct research works aiming at obtaining of buckling of the upset bar in accordance with the buckling present in the real process.

2. Theoretical Analysis Assumptions

The theoretical analysis of the upsetting process was based on numerical simulations made by means of the software DEFORM 3D which uses finite element method. Calculations were made for the Mg4AlZn magnesium alloy, which chemical constitution is given in table 1.

The analyses were made assuming three-dimensional state of strain. This assumption was necessary due to the fact that material buckling is one of the limiting factors. The application of axial symmetry would make the analysis of the buckling phenomenon impossible.

Table 1: *Chemical composition of Mg4AlZn magnesium alloy (% wt).*

Fe	Si	Mn	Ni	Al	Cu	Be	Zn	Mg	Inne
do 0,05	do 0,1	0,15÷0,5	do 0,005	3÷4	do 0,05	do 0,02	0,2÷0,8	94,4÷97,65	0,3

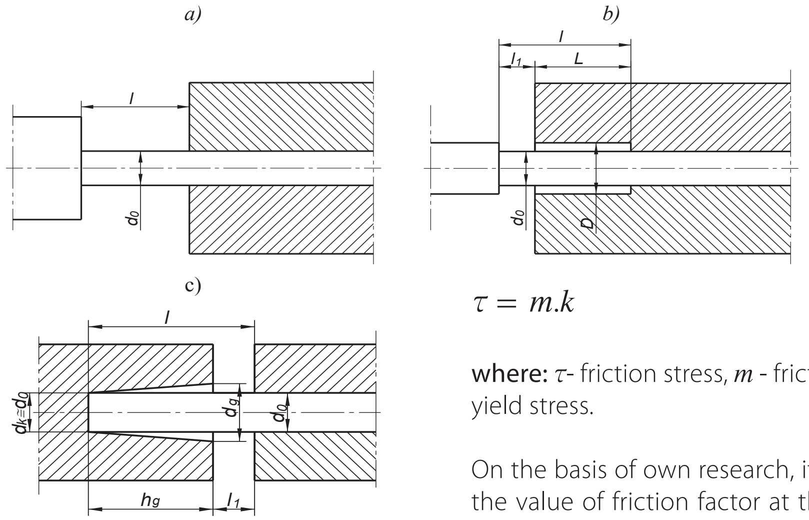

Fig. 1: *Schema of the upsetting process: a) free, b) in cylindrical impression, c) in conical impression [1].*

Material model was described by the equation (1), determined in own research [7]:

$$\sigma p = 451,14 \cdot \phi^{0,473} \exp(-1,403 \cdot \phi) \cdot \dot{\phi}^{0,132} \cdot \exp(-0,00285 \cdot t) \tag{1}$$

where: σ_p - flow stress, φ - strain, φ′ - strain rate, t - temperature.

The friction on the deformed material and tools surface was described by means of constant friction model, which is expressed by the dependency:

$$\tau = m.k$$

where: τ- friction stress, m - friction factor, k - shear yield stress.

On the basis of own research, it was assumed that the value of friction factor at the applied forming temperatures, for conditions without lubrication was $m=1$ [8]. It was assumed in calculations that bar with diameter d_0=20 mm was heated to the temperature 420°C, and tools were not heated.

3. Results of the Research

The theoretical analysis was made with the aim to determine technological conditions guaranteeing making of thickenings of the largest volume. This factor, however, decides upon the effectiveness of the analyzed process of forgings forming.

At the first stage of the research, numerous simulations of upsetting processes were made in order to define limiting values of the free upsetting ratio, described by the dependency $m=l/d_0$ (see Fig. 1a).

The results of calculations showed discrepancy in comparison with the experimental results. During simulation, the buckling effect in the theoretical forging took place at larger upsetting coefficients than in the real processes. These differences are presented in Fig. 2, in which the comparison of the shape of theoretical forging obtained in the process simulation at the upsetting ratio equal m=3.5 mm and the real forging obtained in experimental research at the upsetting ratio m=3.4 is given. As it can be observed in the theoretical model, the process runs without disturbances-material deforms equally and axi-symmetrical forging is obtained. In the real forging, although the upsetting ratio is smaller, the buckling appears, and, in the result of this, the eccentric forging is obtained. The causes of certain differences presence between calculations results and real processes should be searched in the idealization of the theoretical model. This model does not consider, however, the process real conditions such as: material anisotropy, faults connected with tools manufacturing, imprecise tools guiding, bar shape faults and other factors influencing directly the buckling effect.

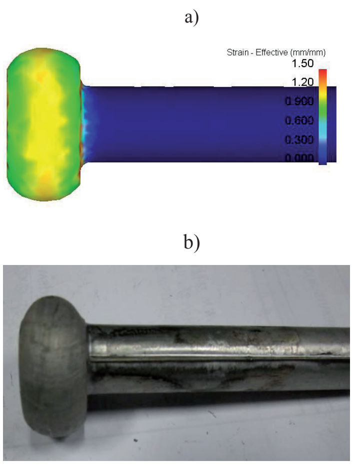

Fig. 2: *Comparison of the forgings shape obtained in: a) simulation at the upsetting ratio m=3.5, b) experiment at the upsetting ratio m=3.4.*

Due to the presence of differences between theoretical and experimental results, it was assumed that during simulation, the upsetting tool would be inclined at a certain angle, what would impose the earlier buckling of the formed forging (Fig. 3a).

Figure 4 presents the comparison of the forging obtained in experiment and in simulation, at the head surface inclination of the upsetting tool of 0.5° and of 1° for the case of forming with upsetting ratio m=3.4. As it can be seen, the shape of the real forging is different than in the theoretical forgings. In the first of them, the external outline is semi-circular, yet, in theoretical forgings this outline is close to obtuse angle. Applying the imposed buckling by inclination of the upsetting tool, it is also difficult to achieve convergence concerning eccentricity. The dependency of eccentricity on the upsetting tool inclination angle is presented in Fig. 5. For tools without inclination angle α=0°, the forging is almost axi-symmetrical (eccentricity e=0.06mm). The application of tools inclination even at small angle α=0.25° causes that the forging has eccentricity e=3.25mm. The further increase of the inclination of the upsetting tool increases the eccentricity in an insignificant way, which for the tool inclination angle α=1° equals e=3.31mm. In the real forgings, the eccentricity is e_{ex}=2.08mm, hence, it is lower than the eccentricity obtained in calculations. It can be stated that it is difficult to obtain the convergence of the theoretical and experimental results within the scope of forging shape by application in calculations of tools inclination.

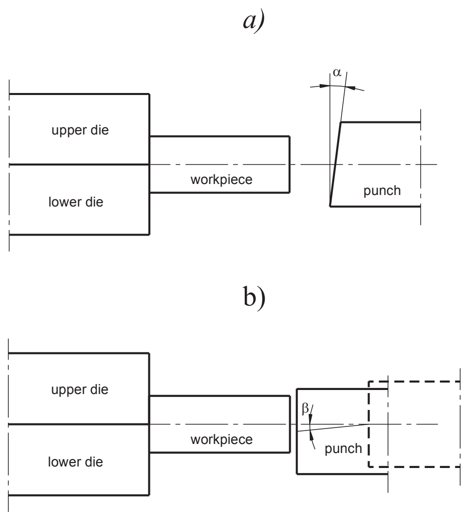

Fig. 3: *Schema of the workpiece buckling imposing by: a) inclination of the tool working surface at angle α, b) non axial tool movement.*

The second conception of buckling imposing, and, in the result of this, eccentricity, was based on angular displacement of the upsetting tool; that is, apart from axial displacement, the component of cross displacement was added (Fig. 3b). The dependency of eccentricity on tangent of the yaw angle of the tool movement from axial direction is given in Fig. 6. As it could be expected, there exists the dependency according to which the larger the yaw angle is, the larger is also eccentricity characterizing the forging. In this figure, the broken line stands for the trend line and the equation describing the dependency of eccentricity on tangent of the yaw angle of the tool movement. Using this equation, it was calculated that in order to obtain eccentricity e_{ex}=2.08 mm, corresponding to the real forging, the angle β=arctg(0.108) should be applied. The results of simulation showed that at such an angle the eccentricity e=2.35 (the point marked by a circle in Fig. 6) was reached, so it was a slightly larger value than it was expected. As it can be seen, this point differs from the trend line (the broken line), which means that in simulation a certain scatter of results takes place - dependency of eccentricity on the direction of the tool movement is not linear. Figure 7 presents the comparison of the real forging with the forging obtained in simulations with angular displacement of the tool. Differences of the upset forging shape can be observed. In the real forging the external outline of the edge is more rounded (arc of a smaller radius) than the outline of the theoretical forging edge.

From the above analysis results that it is difficult to obtain good convergence of the process course kinematics and the final shape in simulation and in the real process. Because of that, it was decided that limiting values of the free upsetting coefficient will be determined in experimental research.

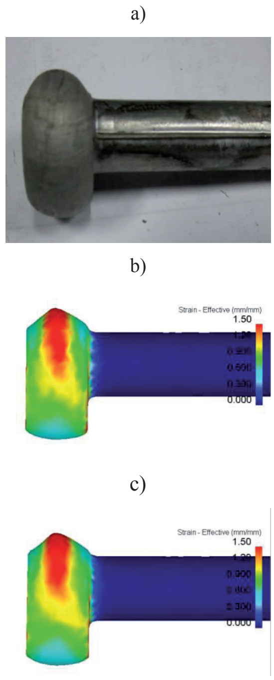

Fig. 4: *Comparison of the forgings shape obtained in a) experiments, b) simulation at inclination of the upsetting tool head surface of 0.5°, c) simulation at inclination of the upsetting tool of 1°, at the upsetting coefficient m=3.4.*

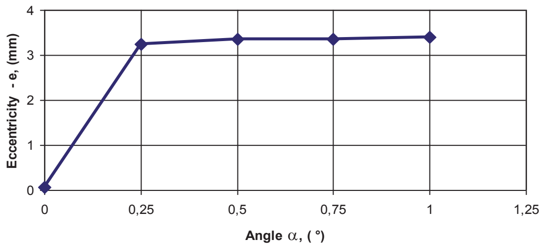

Fig. 5: *Dependency of forging eccentricity vs. inclination angle of the upsetting tool.*

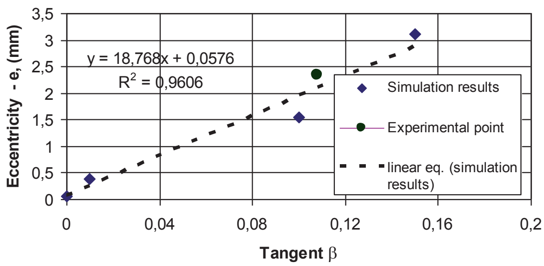

Fig. 6: *Dependency of eccentricity vs. tangent of the yaw angle of toll movement from axial direction.*

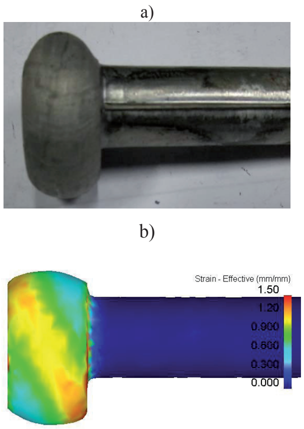

Fig. 7: *Comparison of shapes of real forging (a) and theoretical forging (b) at the upsetting coefficient m=3.4.*

4. Conclusion

On the basis of the obtained research results the following conclusions were drawn:

■ *The theoretical analysis showed differences in comparison with experimental results within the scope of the bar buckling and the forging eccentricity presence in the process of the free upsetting of magnesium alloy Mg4AlZn. In the theoretical model, the buckling takes place at larger upsetting ratio than in the real process.*

■ *Attempts of imposing earlier buckling of the upset bar through inclination of working surface and non-axial movement of the upsetting tool did not provide satisfactory results. In the case of using in the theoretical model the inclined head surface of the tool, there appear problems with achieving the appropriate eccentricity and the forging shape. In the case of applying non-axial displacement of the upsetting tool, it is possible to obtain eccentricity close to experimental results, yet, crucial differences in the final product shape are noticed.*

■ *Limiting conditions in the upsetting processes of bar from magnesium alloy Mg4AlZn should be determined on the basis of experimental research results.*

5. Acknowledge

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6. References

[1] GontarzA.: Efektywne procesy kształtowania w trójsuwakowej prasie kuźniczej. Wyd. Politechniki Lubelskiej, Lublin 2005.

[2] Gökler M.I., Darendeliler H., Elmaskaya N.: Analysis of tapered preforms in cold upsetting. International Journal of Machine Tools & Manufacture, vol. 39, 1999, p. 1-16.

[3] Wasiunyk P.: Kucie matrycowe. WNT, Warszawa, 1987, p. 1-684.

[4] Atrošenko A. P., Fedorov W. I.: Metallo-sberegajuščie technologii kuznečno-štampovočnovo proizvodstva. Leningrad, Mašinostro-enie, Leningradskoe Otdelenie, 1990, p. 1-280.

[5] Semenov E.I. pod red.: Kovka i štampovka. Goriaczaja ob'jemnaja sztampovka. Moskva, Mašinostroenije, t. 2, 1986.

[6] Gontarz A.: Kształtowanie skrajnych zgrubień w odkuwkach wydłużonych ze stopu magnezu Mg4AlZn. Hutnik-Wiadomości Hutnicze, 2011, artykuł zgłoszony do druku.

[7] Gontarz A., Dziubińska A.: Własności stopu magnezu MA2 (wg GOST) w warunkach kształtowania na gorąco. Rudy i Metale Nieżelazne, R55, Nr 6, 2010, p. 340-344.

[8] Gontarz A. Dziubińska A., Okoń Ł.: Determination of friction coefficients at elevated temperatures for some Al, Mg, Ti alloys. Archives of Metallurgy and Materials, Vol. 56, Issue 2, 2011, p. 379-384.