UDC 621.7

Milenin A.
Kustra P.
Furushima T.

FEM MODELING OF MANUFACTURING MAGNESIUM ALLOY TUBES BY DIELESS DRAWING PROCESS

This paper is devoted to the development of technological process of production of magnesium alloy tubs for industrial and medical application by dieless drawing process. This technology can achieve a great reduction of materials such as metal wire, bars and tubes in a single pass by the local heating, compared with conventional drawing process. In practice, was successfully fabricated microtube by using materials with high ductility and low flow stress at elevated temperature [1–2]. Thus, the dieless drawing may be an effective process for forming magnesium alloys. From other side, magnesium alloys are characterized by low technological plasticity during metal forming that is why optimization of production parameters is necessary [3–4].

The aim of this work is optimization of dieless drawing process to obtain tubes made of MgCa0.8 alloy.

For modeling of dieless drawing process ABAQUS software was used. Tubes with external diameter 3 mm was produced. Numerical simulation and sensitivity analyses showed, that during dieless drawing process the length of heating element and drawing velocity has an effect on diameter and wall thickness of the tube. That is why optimization of this process is possible. It is also possible to obtain tube with variable cross section and wall thickness.

Experimental verification of the model was made on the basis of experimental dieless process of tubes made of MgCa0.8 alloy. Experiment showed that for MgCa0.8 alloy it is possible to reduce cross section of the tube to 60%, which is significantly larger than deformation in a single pass of cold drawing.

In this work procedure for obtaining needed materials data for simulation and example of optimization dieless drawing process of Mg alloys are shown. For calibration of yield stress model and model of fracture tensile and compression tests was used. For the simulation of flow stress the equation of Henzel-Szpittel is used:

$$\bar{\sigma} = A\exp(m_1 t)t^{m_9}\bar{\varepsilon}^{m_2}\exp(m_4/\bar{\varepsilon})(1+\bar{\varepsilon})^{m_5 t}\exp(m_7\bar{\varepsilon})\bar{\xi}^{m_3}\bar{\xi}^{m_8 t} \tag{1}$$

where $\bar{\sigma}, \bar{\varepsilon}, \bar{\xi}$ – effective stress, effective strain and effective strain rate, respectively, t – temperature.

For the MgCa0.8 alloy are used the approach, based on the inverse analysis [5]. The following coefficients of equation (1) for extrusion conditions are obtained.

– MgCa0.8: A=1413.33; m_1 =-0,0046301; m_2= 0.53755; m_3= 0.13458; m_4= -1.3544 ; m_5=0.0; m_7=0.0; m_8=0.0; m_9=-0.0.

According to the work [5] the critical damage failure criterion is established:

$$\psi = \frac{\bar{\varepsilon}}{\varepsilon_f\left(k_f, t, \bar{\xi}\right)} \tag{2}$$

where: ε_f – effective fracture strain k_f – triaxility factor.

To describe the value of effective fracture strain the following formula can be applied:

$$\varepsilon_f = d_1\exp(-d_2 k)\exp(d_3 t)\bar{\xi}^{d_4} \tag{3}$$

The values of the coefficients of equation (3) are determined by the minimization of the square-least technique comparing the value of ε_f and the results obtained from processing of the experimental results of the compression and the tension tests. The following values of coefficients are obtained:

– MgCa0.8: d_1=0.0461; d_2=0.4759; d_3=0.01022; $d_{4=}$-0.07009.

A dieless drawing process with local heating and tensile deformation for tubes is a flexible drawing technique without using any dies. Fig. 1 shows the schematic illustration of dieless drawing process, in which heating devices are fixed and the tube moves from left to right through the heating zone. The tube is subjected to tension by the difference in speed between tensile V_1 and feeding V_2. The necking occurs at local heated area and diffuses out with moving the tube under tension. The relationship between the reduction in area R and the speed ratio V_2/V_1 is as follows:

$$R = 1 - \frac{A_1}{A_0} = 1 - \frac{V_2}{V_1} \tag{4}$$

where: A_0 is original cross sectional area and A_1 is cross sectional area after the drawing.

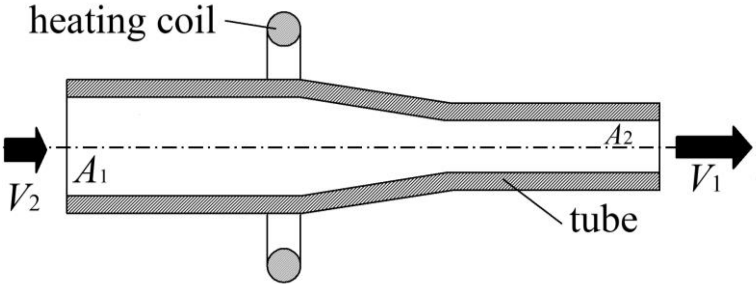

Fig. 1. Schematic illustration of dieless drawing process

Numerical model was build using ABAQUS software. Equation 1 was used as the flow stress model. Melting point of MgCa0.8 magnesium alloy is 516 °C. That is why temperature of heating element should be lower and was set as 450 °C. Additionally two more tensile tests were performed for 450 °C and the strain rates of 0.1 and $0.01 s^{-1}$ to cover the whole range of possible temperatures and strain rates. Initial temperature of tube was 20 °C. The feeding speed V_2 was fixed at 0.1 mm/s and the tensile speed V_1 was controlled to adjust reduction in the area R. Numerical simulations were carried out for different length of heating element and two reductions of 41% and 60%. Results of simulations are shown in Fig. 2 and 3. It is seen that length of heating element and deformation ratio has a significant impact on pipe diameter and wall thickness in dieless drawing process. Increase of reduction R during process results in decrease of tube wall thickness and decrease of external tube diameter because deformation is higher. Increase of the length of heating element causes that cross sectional of tube has more time for deformation in heating zone. That is why external diameter of tube is lower. As in is clear from numerical analysis, size of heating element has no significant effect on the thickness of the tube wall.

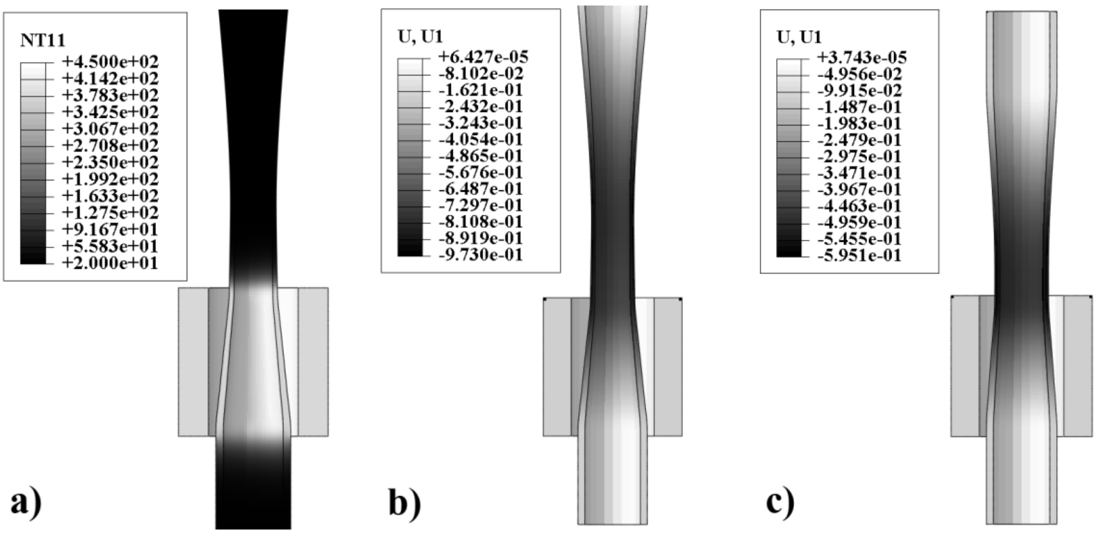

Fig. 2. Results of numerical simulation at the cross section of pipe for length of heating element equal to 10 mm: a) distribution of temperature for R = 60%, b) distribution of displacement for R = 60%, c) distribution of displacements for R = 41%

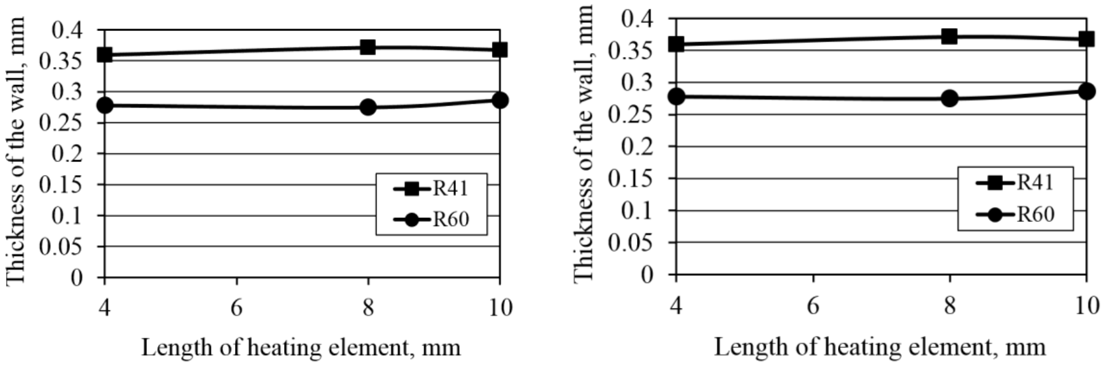

Fig. 3. Results of numerical simulation of drawing process for different length of heating element.

As a billet the tube Dout=5 mm, Din=4 mm was used. Extrusion technology was used for obtained billet [6]. On Fig. 4 show the photograph of the experimental setup of dieless drawing process used in this study. A tensile speed V_1 applied to the tube and a feeding speed V_2 can be independently controlled following Eq. 4 using two servo motors. A high-frequency induction heating device with a power of 2 kW and a frequency of 2.2 MHz was used as the heat source for the specimens. The temperature inside the heating coil was measured with a noncontact two-color pyrometer. In this experiment, the heating temperature was the same as in simulations and was set as 450 °C. The feeding speed V_2 was fixed at 0.1 mm/s. Two reductions were exanimated – 41% and 60%.

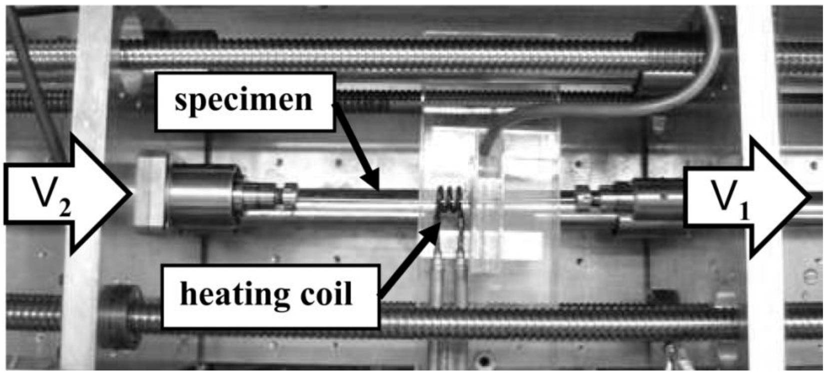

Fig. 4. Photo of the experimental setup of dieless drawing process.

Figure 5 shows the photograph of deformed tubes after dieless drawing process in a single-pass. Reduction in area and outer diameter after the drawing process can be obtained without using any tools and dies by controlling speed ratio V_2/V_1. In this experiment, maximum reduction in the area of 60% can be realized for MgCa0.8 magnesium alloy. Using this result, the validity of dieless drawing process for biocompatible MgCa0.8 magnesium alloy can be verified experimentally.

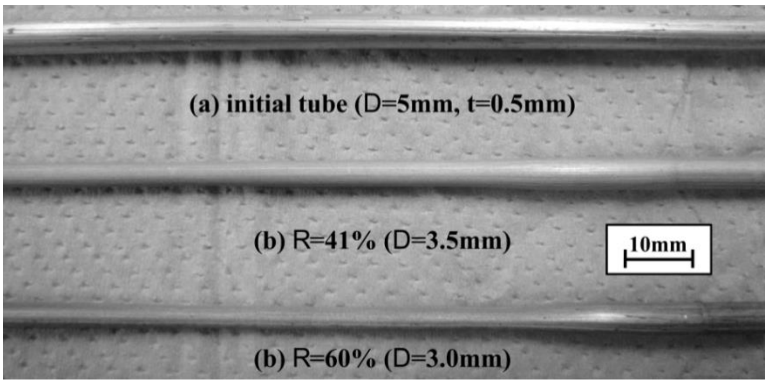

Fig. 5. Photograph of deformed tubes after dieless drawing process in a single-pass under a condition of heating temperature of 450˚C.

In the experiment, the length of heating zone was approximately equal to 10 mm. The results of numerical simulation were close to those in the physical drawing process. For reduction 41% in experimental process diameter of the tube was 3.5 mm and in simulation was 3.81 mm. Adequately for reduction 60% diameters of tube were 3 mm and 3.05 mm respectively for physical experiment and for simulation.

CONCLUSIONS

1. The new process for production of thin tubes from biocompatible magnesium alloy was presented. This process contains two stages – extrusion and dieless drawing process.

2. Extruded tubes were used as an input for dieless drawing process. Experiment showed that for MgCa0.8 alloy it is possible to reduce cross section of the tube to 60%, which is significantly larger than that of 5% in a single pass of cold drawing.

3. Numerical simulation showed that during dieless drawing process the length of heating element and drawing velocity has an effect on radius and wall thickness of the tube. That is why optimization of this process is possible. It is also possible to obtain tube with variable cross section and wall thickness.

Acknowledgements: Financial assistance from the Ministry of Science and High Education of Poland, project AGH no. 11.11.110.291 is acknowledged.

REFERENCES

1. Furushima, T., Manabe, K., 2007. Experimental study on multi-pass dieless drawing process of superplastic Zn-22%Al alloy microtubes. J. Mater. Process. Technol. 187-188, 236-240.

2. Furushima, T., Shirasaki, A., Manabe, K., 2014. Fabrication of noncircular multicore microtubes by superplastic dieless drawing process. J. Mater. Process. Technol. 214, 29-35.

3. Milenin, A. Byrska D., Gridin O., 2011. The multi-scale physical and numerical modelling of fracture phenomena in the MgCa0.8 alloy. Comput. Struct. 89, 1038-1049.

4. Milenin A., Byrska D. J., Grydin O., Shaper M., 2010. The experimental research and the numerical modeling of the fracture phenomena in micro scale. Comput. Methods Mater. Sci. 10, 61-68.

5. A. Milenin, M. Gzyl, T. Rec and B. Płonka, Computer Aided Design of Wires Extrusion from Biocompatible Mg-Ca Magnesium Alloy, Arch. Metall. Mater., 2014, 59, p 551-556

6. P. Kustra, A. Milenin, B. Płonka, T. Furushima, Production Process of Biocompatible Magnesium Alloy Tubes Using Extrusion and Dieless Drawing Processes, Journal of Materials Engineering and Performance, 2016, (in press).

Milenin A. – professor, dr. hab. inz., AGH University of Science and Technology, Head of Laboratory of Computational Mechanics

Kustra P. – dr. inz., AGH University of Science and Technology

Furushima T. – PhD, Tokyo Metropolitan University

E-mail: www.lcm.agh.edu.pl, milenin@agh.edu.pl, pkustra@metal.agh.edu.pl, furushima-tsuyoshi@tmu.ac.jp

Статья поступила в редакцию 20.03.2016 г.