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PHYSICAL AND MATHEMATICAL MODELING OF STATIC RECRYSTALLIZATION PROCESS IN THE WIRES OF MgCa08 ALLOY AFTER DRAWING IN HEATED DIES

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Abstract

Modelling of the manufacturing process of thin wires made of MgCa08 alloy is described in the paper. This process is composed of 25 drawing passes in heated dies for initial wire diameter of 1.0mm and final diameter of 0.1mm. Parameters of the drawing process were chosen in such a way that complete recrystallization of the wire occurred in all passes. The model of static recrystallization (SRX) for MgCa08 alloy was developed to enable design of the drawing process. The parameters of the model were determined on the basis of stress relaxation tests. The tests were performed on GLEEBLE 3800 physical simulator for three temperatures 250, 300, 350ºC and three strains 0.1, 0.2 and 0.3.

SRX model was implemented into Drawing2d software, which allows simulation of drawing processes in heated dies. Two variants of drawing process were simulated. In the first variant all passes were performed with the die temperature of 350ºC. In the second variant every second pass was carried out with the die temperature of 21ºC. The verification of simulations was done on the basis of microstructures observed in experiments. The paper aims at showing that the model can predict correctly the final microstructure.

Performed experiments and numerical simulations showed that contribution of the dynamic recrystallization is small and it may be neglected in simulation of multi-pass hot drawing of MgCa08 alloy. The results of simulations of the SRX showed that in this process only every second pass has to be realized in a hot die. After each cold pass the hot pass is required in order to restore the plasticity by recrystallization.

Key words: recrystallization, magnesium alloys, MgCa08, drawing, numerical modelling

1. INTRODUCTION

Due to their numerous advantageous properties magnesium alloys have been in the scope of interest of scientists for a few decades. Several publications dealing with forming of these alloys have appeared, see (De Pari et al., 2010; Kawalla & Stolnikov, 2004). Aerospace and automotive industries are constantly seeking for more advanced materials characterized by high strength-to-density ratio, the requirements of which Mg alloys can easily meet. These alloys are frequently used in the automotive industry. Since they can reduce the weight of the component by 70% compared with the steel part and about 30% in case of aluminium components, magnesium alloys seem especially interesting (Mordike & Ebert, 2001). Ambrozinski et al. (2016) investigated the possibility of manufacturing car body parts made of AZ31 alloy. Analysis of the published research shows that there are still many problems associated with processing of Mg alloys. First of all, it has to be stated that manufacturing should be carried out at elevated temperatures, where these alloys have better plastic properties. Thus, despite of a large potential, the technology based on Mg alloys processing is still complicated and expensive. As stated in (Milenin et al., 2011), prediction of workability as a function of process parameters is crucial for the reliability of numerical modeling being used as a support for the technology design.

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Due to their good biocompatibility, Mg alloys containing calcium open a new wide range of applications in bioengineering. Authors of the present paper have for some time been involved in the research on in research on manufacturing of thin wires made of MgCa08 alloy (Milenin & Kustra, 2013a). The general objective of the present work is an application of modeling of microstructure evolution to design the best manufacturing technology for these wires based on multipass drawing. This manufacturing technology involves the wire heating prior to drawing and during drawing, which allows for multi-pass process without additional intermediate annealing (Milenin & Kustra, 2013a). The key problem, solved in this drawing technology, is restoration of plasticity of the Mg alloy after each pass. Condition for the restoration of plasticity is a **complete** static recrystallization (SRX) of the material after the pass in progress (Milenin & Kustra, 2013b). Therefore, determination of parameters of multi-pass drawing (single deformation per pass, temperature of processing zone in the drawing device, drawing speed) should be set in such a way that before the subsequent drawing pass the wire material is fully recrystallized. It is expected that numerical simulation of thermal, mechanical and microstructural phenomena in the investigated process should allow determination of such conditions of this process. Therefore, thermal-mechanical finite element (FE) model of the wire drawing process in heated dies was proposed by Milenin et al. (2014a) and Milenin et al. (2014c). The model was based on the general FE software Drawing2d for the simulation of the wire drawing (Milenin et al., 2014a). This model predicts strain and stress distribution as well as temperature changes during the process. Prediction of microstructure evolution is additionally needed to enable design of the multi pass drawing process in which recrystallization is completed in each interpass. An attempt to use the cellular automata (CA) method for modelling static recrystallization in Mg alloys was proposed by Svyetlichnyy et al. (2015). That study showed that determination of the influence of the scale factor on the rate of dynamic recrystallization (DRX) for wire with a diameter less than 0.1 mm is possible. On the other hand, the proposed CA model is so complicated in calibration and optimization that its practical application is not efficient enough. Therefore, in the present paper the model of SRX was based on JMAK approach (Johnson & Mehl, 1939;Avrami, 1939; Kolmogorov, 1937). The idea of the time for 50% recrystallization proposed by Sellars (1979) was used. The advantage of this approach is the simplicity of the model, high-speed calculations and easy calibration.

As it was shown by Milenin et al. (2014b), volume fraction of dynamic recrystallization in the investigated drawing process is about 4%. That is why DRX was not taken into account in the present work. The general aim of the present study was development, calibration and experimental verification of the static recrystallization model based on JMAK approach modified by Sellars (1979) for wire drawing process of MgCa08 alloy.

2. NUMERICAL MODEL OF THE DRAWING PROCESS IN A HEATED DIE

The complete model used in this work was composed of metal flow FE model, thermal FE model, conventional damage criterion and JMAK microstructure evolution model. All these four components of the model are described briefly in Chapter 2.

2.1. Thermal-mechanical FE model

The solution of boundary problem was obtained using variational principle of rigid-plastic theory (Milenin et al., 2014a). The stationary formulation of axisymmetric boundary problem was used. The strain tensor ε_{ij} was calculated by integration of strain rate tensor along the flow lines.

Thermal problem in metal was solved by applying the following method. The passage of a wire section through the deformation zone was simulated. For this section, the non-stationary heat transport problem was examined at each time step:

$$\lambda\left(\frac{\partial^2 t}{\partial r^2}+\frac{1}{r}\frac{\partial t}{\partial r}\right)+Q_d=c\rho\frac{dt}{d\tau} \quad (1)$$

where: t is the temperature, $Q_d = 0.9\bar{\sigma}\bar{\xi}$ is the deformation power, $\bar{\sigma}$ is the flow stress, $\bar{\xi}$ is the effective strain rate, c is the specific heat, ρ is the alloy density, τ is the time and λ is the thermal conductivity coefficient (for MgCa08 alloy: c = (1013.4+0.441t) J/kgK, ρ = (1741.4–0.173t) kg/m^3, λ = (156.32–0.023t) W/m^{2}K. The dependence of the thermal conductivity, specific heat and density on temperature is obtained by approximation of the literature data for pure magnesium (Friedrich & Mordike, 2006).

Heat exchange between the alloy and the die is defined as:

$$q_{conv} = \alpha\left(t - t_a\right) \tag{2}$$

where: q_{conv} is the heat flux due to convection, t_a is the ambient temperature which is either die surface temperature at the contact zone t_{die} obtained from temperature calculation in the die (synthetic diamond) or surrounding air temperature t_{air}, α is the heat exchange coefficient (between tool and wire: α = 2000 W/m^{2}K, between wire and air: α= 120 W/m^{2}K)(Pietrzyk, 1992).

The model of temperature distribution in the die was based on the two-dimensional solution of Fourier equation (1) in the cylindrical coordinate system. The results of temperature measurement at the hot drawing die were used as the boundary conditions. The thermocouples and the electronic system of the temperature control were used for this measurement.

Since preheating of the billet before the deformation zone (zone L_0 in figure 1) in the developed device is possible, the module for calculation of the billet temperature in this zone was added to the model of wire drawing. The length of heating zone L_0 was 150 mm. The preheating model was based on the solution of equation (1) for one-dimensional non stationary problem. Initial data for this model are the temperature in the zone of heating (it is assigned according to the results of measurements) and the time required to move the billet through this zone (it depends on the length of the zone and the velocity of wire drawing). After deformation in hot die the wire moves to the zone L_1 (figure 1) in which the temperature is still high. The length of this zone is approximately equal to 14 mm. Then the wire moves to the cooling zone L_2 with length 100 mm (figure 1).

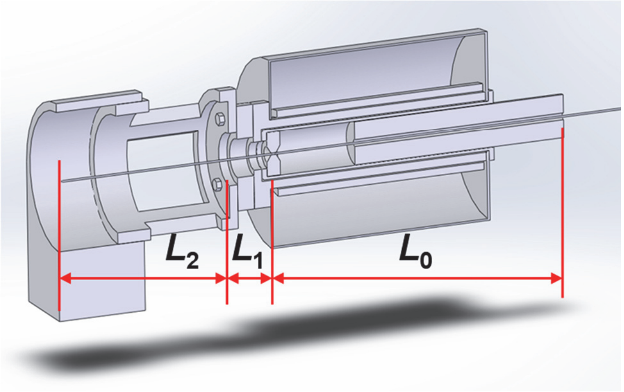


***Fig. 1.** Set of tools for drawing process in the heated die: L_0 – pre-heating zone, L_1 – high temperature zone, L_2 – cooling zone.*

2.2. Critical damage failure criterion

The key parameter representing fracture is called critical damage failure criterion Ψ and it is given by the following equation:

$$\psi = \frac{\bar{\varepsilon}}{\varepsilon_f\left(k_f, t, \bar{\xi}\right)} < 1 \tag{3}$$

where: $\bar{\varepsilon}$ - effective strain, k_f – triaxiality factor, $k_f = \sigma_0 / \bar{\sigma}$, σ_0 – mean stress.

Effective fracture strain $\varepsilon_f\left(k_f, t, \bar{\xi}\right)$ was obtained as follows:

$$\varepsilon_f\left(k_f, t, \bar{\xi}\right) = d_1 \exp\left(-d_2 k_f\right) \exp\left(d_3 t\right) \bar{\xi}^{\,d_4} \tag{4}$$

where: d_1- d_4 – empirical parameters.

Algorithm used to determine parameters of equation (4) was based on tensile and upsetting tests. Details of this algorithm were presented by Milenin & Kustra (2013b). The following values of coefficients were obtained for the temperature interval 20-400°C, k_f interval 0.3-0.5 and strain rate interval 0.01-2 s^{-1}: d_1 = 0.446, d_2 = 1.2393, d_3 = 4.46×10^{-3}, d_4 = -0.007366. Equations (3) and (4) were used in an incremental manner:

$$\psi = \int_0^{\tau} \frac{\bar{\xi}}{\varepsilon_f\left(k_f, t, \bar{\xi}\right)} d\tau \approx \sum_{m=1}^{m=m_\tau} \frac{\bar{\xi}^{(m)}}{\varepsilon_f\left(k_f, t, \bar{\xi}\right)} \Delta\tau^{(m)} \tag{5}$$

In this form the fracture model could be used to predict potential failure in a single pass. When the multi-pass process is applied, the restoration of plasticity takes place in the preheating zone.

Failure criterion for multi-pass processes is presented below. It is assumed that the restoration of plasticity in the preheating zone L_0, high temperature zone L_1 and during cooling after pass is proportional to the static recrystallization according to the following equation:

$$\psi^{(m+1)} = \psi^{(m)}\left(1 - \Delta X_{SRX}^{(m)}\right) \tag{6}$$

where: m is the number of time step and $\Delta X_{SRX}^{(m)}$ is the statically recrystallized volume fraction in the step m.

In the deformation process the value of Ψ increases according to equation:

$$\psi^{(m+1)} = \psi^{(m)} + \frac{\bar{\xi}^{(m)} \Delta\tau^{(m)}}{\varepsilon_f\left(k_f, t^{(m)}, \bar{\xi}^{(m)}\right)} \tag{7}$$

Described critical damage failure criterion was implemented into the FE software and used to evaluate plasticity of wires after subsequent passes.

2.3. Critical damage failure criterion.

Conventional model that characterizes the phenomena which occur in metallic materials during hot deformation uses equations describing recrystallization and grain growth. Kinetics of SRX is usually described by JMAK model (Johnson, Mehl, Avrami, Kolmogorov). The model which was developed for kinetics of phase transformations in general, has been adapted to the phenomenon of recrystallization by Sellars (1979):

$$X_{SRX} = 1 - \exp\left[c_4\left(\frac{\tau}{\tau_{0.5}}\right)^n\right] \tag{8}$$

or in the incremental form:

$$\Delta X_{SRX} = \frac{\Delta\tau}{\tau_{0.95}} \tag{9}$$

where

$$\tau_{0.95} = \tau_{0.5}\left[\frac{\ln(0.05)}{c_4}\right]^{\frac{1}{n}} \tag{10}$$

$$\tau_{0.5} = c_1\varepsilon^{c_2} D \exp\left(\frac{c_3}{RT}\right) \tag{11}$$

Deformation in equation (11) is determined by taking into account the increase due to geometric deformation and softening associated with static recrystallization:

$$\varepsilon^{(m+1)} = \varepsilon^{(m)}\left(1 - \Delta X_{SRX}^{(m)}\right) + \overline{\xi}^{(m)}\Delta\tau^{(m)} \tag{12}$$

Described SRX model contains coefficients which were determined on the basis of stress relaxation tests presented in the next Chapter.

3. EXPERIMENTAL STUDY PERFORMED FOR IDENTIFICATION OF THE SRX MODEL FOR MGCA08 ALLOY

Properties of MgCa08 (Mg 99.2 wt.%, Ca 0.8 wt.%) were studied with physical simulator GLEEBLE 3800. Stress relaxation tests (Karjalainen & Perttula, 1996) were carried out. During the tests, specimen was heated from the room temperature to the temperature of deformation with the rate of 20 °C/s, then kept at this temperature for 5 s and deformed with the rate of 1 s^{-1} to preset strain. After deformation, the specimen was still kept between the fixed dies at the same temperature. The strain rate dropped to the value near zero and stress decrease due to relaxation was measured. Nine tests were performed with all variants of three temperature values of 250, 300 and 350 ºC and three values of strain 0.1, 0.2 and 0.3.

Selected stress relaxation curves for the investigated alloy are shown in figure 2. Measured stress was used for the analysis of the relaxation. Analysis of stress changes as a function of time eliminates the effect of recovery, thus making it possible to evaluate static recrystallization, see (Karjalainen & Perttula, 1996) for details. The kinetics of recrystallization obtained from stress relaxation tests are shown by solid lines in figure 3. These data could not be used directly in the FE model of the drawing process. However, they could be used to perform calibration of the model of static recrystallization. Coefficients c and n in equation (10) were determined using the stress relaxation data and the following values were obtained: c_1 = 6.0932×10^{-6}, c_2 = 0.61466, c_3 = 43559.55, c_4 = -0.6095, n = 0.5697. The calculation results of kinetics of recrystallization with the use of the model with optimized coefficients are shown by dashed lines in figures 3 and 4. Relatively good agreement with the experimental data was obtained. As it is seen in figure 3, the time for full static recrystallization in temperature 350°C is very short and is equal to 4 seconds for strain equal to 0.2. So in this case the fully recrystallization occurs in wire because time of heating in L_0 zone is equal to 15 seconds. For lower temperature 300°C time for full recrystallization is about 18 s and in that case full wire recrystallization in L_0 zone is impossible.

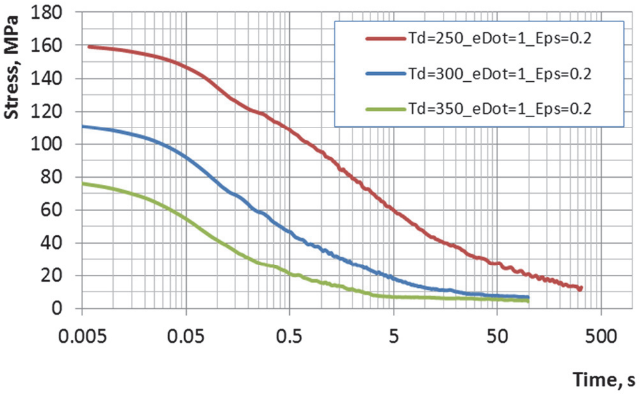


***Fig. 2.** Stress relaxation curves for strain 0.2 and temperatures 250, 300 and 350°C.*

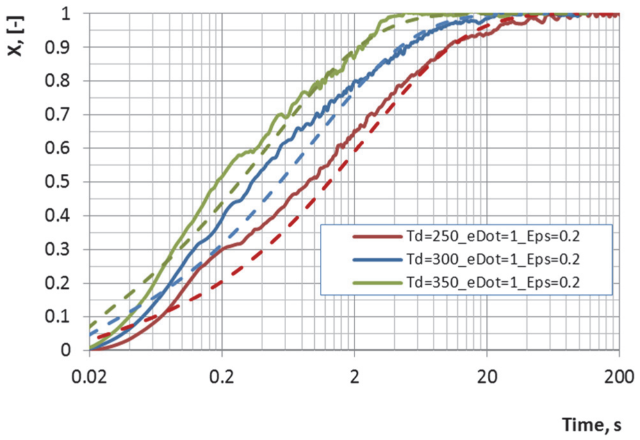


Fig. 3. *Changes of the recrystallized volume fracture in time for various temperatures and for the strain of 0.2. Solid lines - experimental data from stress relaxation tests, dashed lines – predictions of the numerical model of static recrystallization.*

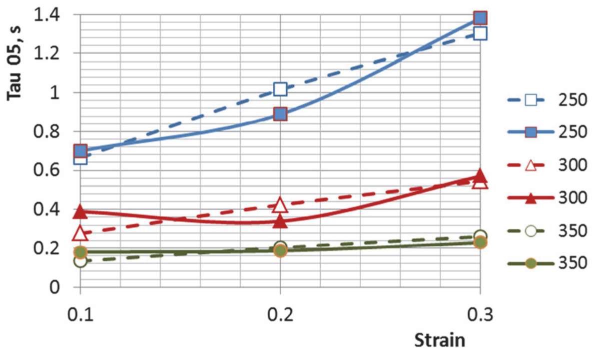


Fig. 4. *Dependence of the time $\tau_{0.5}$ on strain (before recrystallization) for temperatures 250, 300 and 350°C for the MgCa08 alloy. Solid lines - experimental data from relaxation tests, dashed lines - values calculated from equation (11).*

4. RESULTS OF NUMERICAL SIMULATION

The considered process consisted of 25 passes with initial wire diameter of 1 mm and final diameter of 0.1 mm. Diameters of wire after particular passes are shown in table 1. The temperature of the die was 350ºC and drawing speed was set as 10 mm/s. Figure 5 presents the results of simulation of multi-pass process. Change of wire temperature is plotted in figure 5a. The performed simulations proved that wires with lower diameter need less time to heat to the temperature of heating zone. Additionally, increased value of cooling speed (in cooling zone L_2) of the wire after each pass is the result of its smaller diameter. Figure 5b shows volume fraction of SRX. Recrystallization consists of two steps. First is recrystallization in heating zone L_0. The second step occurs after deformation in high temperature zone L_1. Simulations show that recrystallized volume fraction after deformation is higher for a wire with larger diameter. Such a wire is cooled more slowly than a thin one. Values of strain and ductility function during the process are shown in figures 5c and 5d. It can be observed that the maximum value of ductility function is 0.16.

Table 1. *Schedule of multi-pass drawing of MgCa08 alloy*

Pass	1	2	3	4	5	6	7	8	9
D, mm	0.913	0.833	0.761	0.694	0.634	0.579	0.528	0.482	0.440
Pass	10	11	12	13	14	15	16	17	18
D, mm	0.402	0.367	0.335	0.306	0.279	0.255	0.233	0.212	0.194
Pass	19	20	21	22	23	24	25		
D, mm	0.177	0.162	0.147	0.135	0.123	0.112	0.1		

D – diameter of the wire after the pass.

In the second simulation the 21st pass was carried out at room temperature. Simulation results of the process are depicted in figure 6. It shows that the maximum value of ductility function is in a save area and is less than one.

The obtained simulation results of the second variant of drawing show that one hot drawing pass is required to restore plasticity. Thus, it is possible to replace every second pass in the drawing schedule by a cold pass. However, after each cold pass the hot pass is necessary. After one cold pass the value of ductility function reaches the value of 0.622 which means that the subsequent cold pass without intermediate annealing could cause breaking of the wire.

5. EXPERIMENTAL STUDY PERFORMED FOR VALIDATION OF THE SRX MODEL FOR THE MGCA08 ALLOY

The experimental analysis, which included the multi-pass drawing process in hot dies, was performed on the laboratory experimental stand described by Milenin and Kustra (2013a). The aim of this set of experiments was to verify the obtained results of numerical modelling of the recrystallization.

5.2. Experimental setup

Details of the experimental setup are described by Milenin and Kustra (2013a). Main features of this setup are given below for completeness of this paper. The experimental stand consists of motor with spool, furnace with drawing die, unrolling system and temperature regulation system (figure 7).

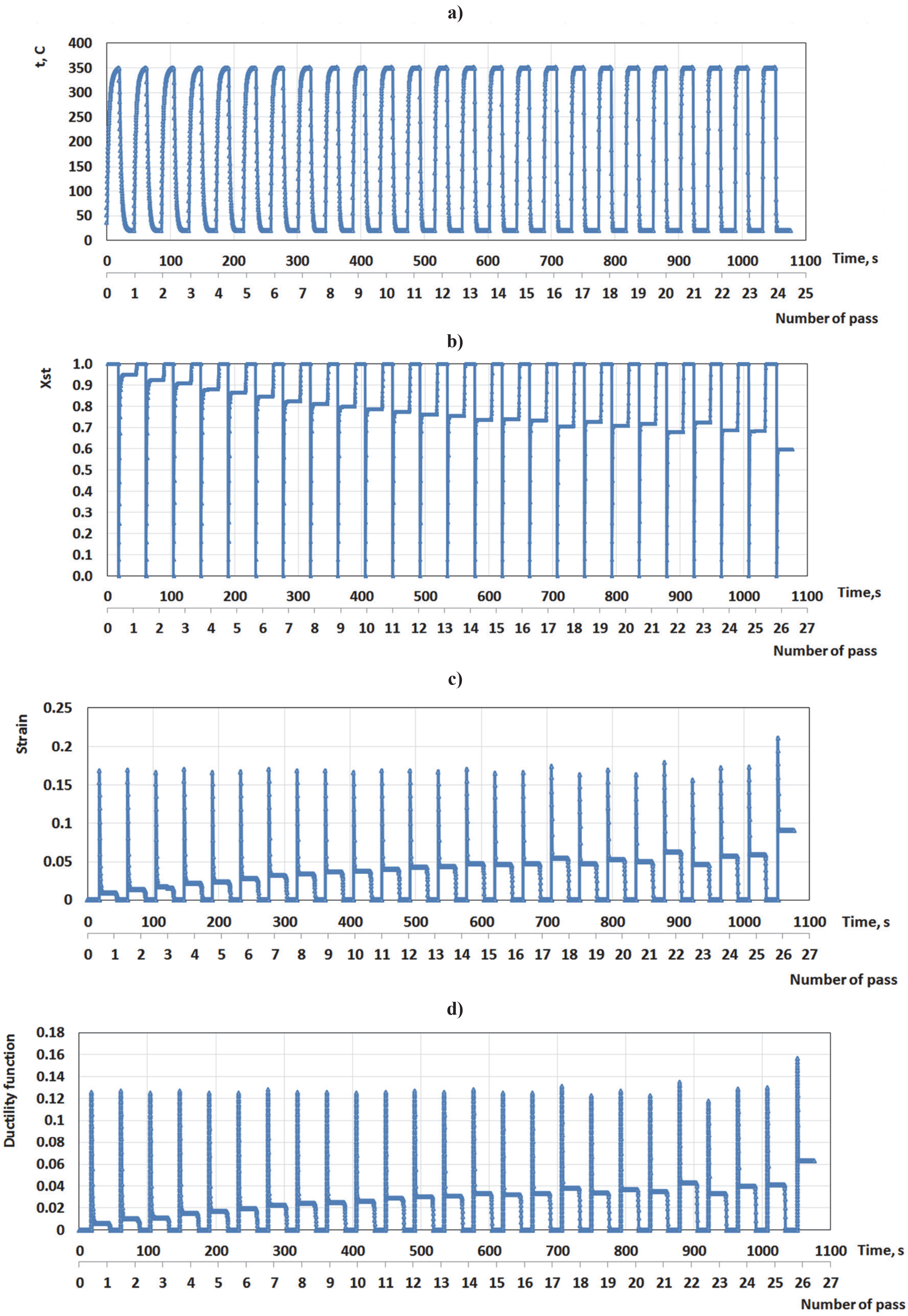


Fig. 5. *Results of simulations for drawing velocity 10 mm/s and temperature in the heating zone 350°C: a) temperature changes of the wire, b) statically recrystallized volume fraction, c) physical deformation, d) ductility parameter.*

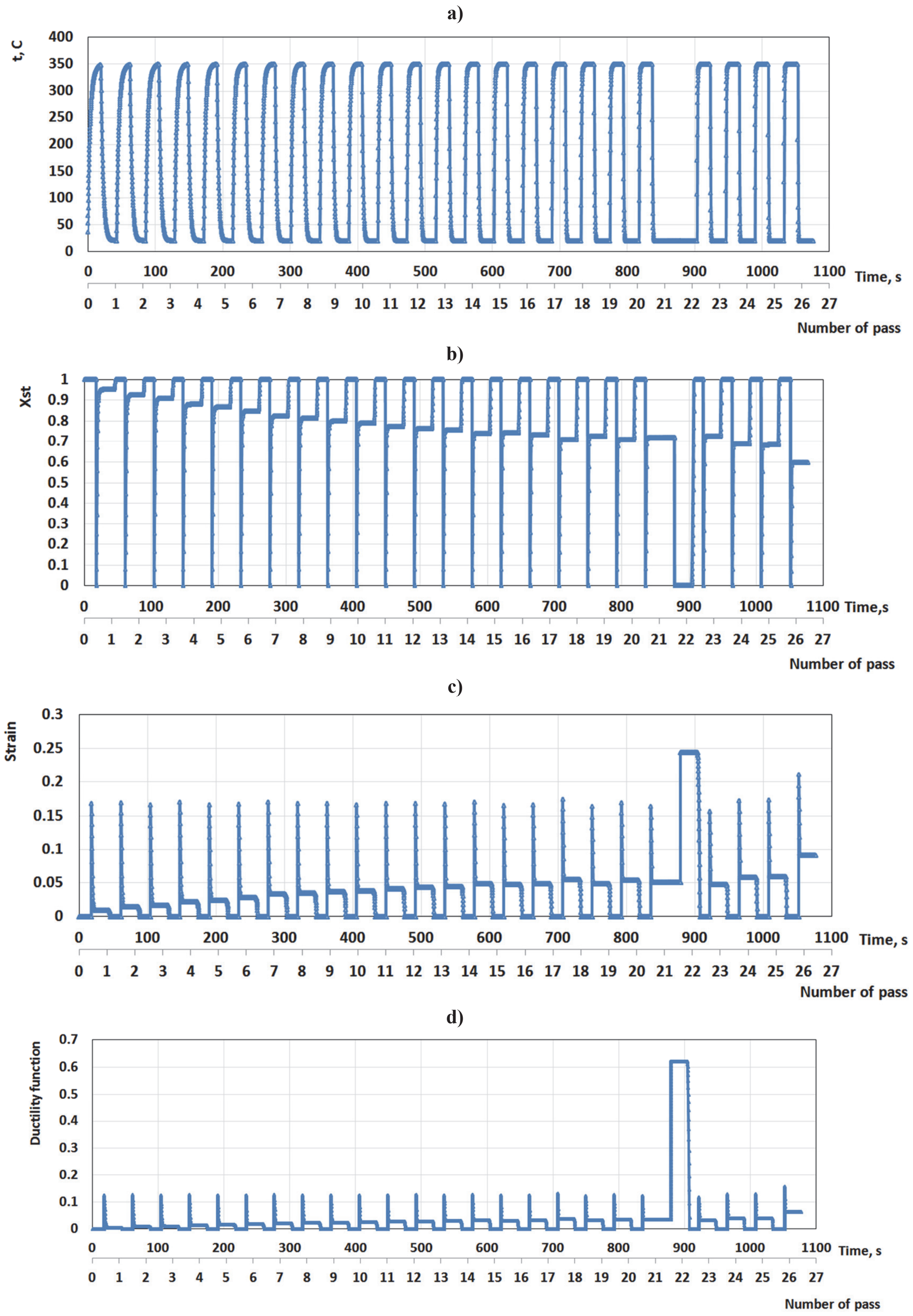


Fig. 6. *Results of simulations for drawing velocity 10 mm/s and temperature in heating zone 350 °C during all passes except pass 21: a) temperature changes of the wire, b) statically recrystallized volume fraction, c) physical deformation, d) ductility parameters.*

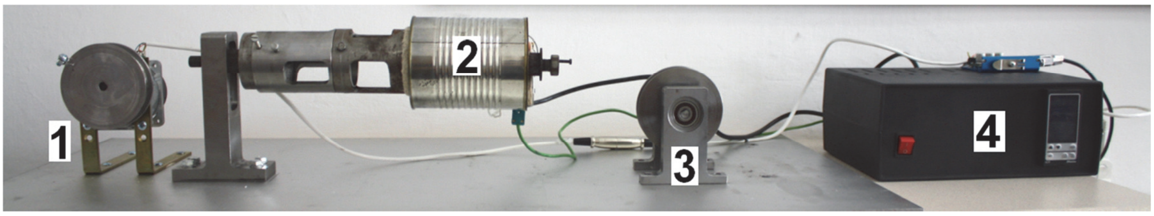


Fig. 7. Experimental setup for drawing process in heated die: 1 – motor with spool, 2 – furnace with die, unrolling spool, temperature regulator.

5.3. Results of experiments

The objective of the experiments was the validation of empirical model of static recrystallization. The comparison of microstructures of wire with model results was qualitative but not quantitative. Figures 7-10 present the wire microstructure at various stages of drawing process. The microstructure of MgCa08 alloy consists of matrix and precipitates of Mg_2Ca (dark points).

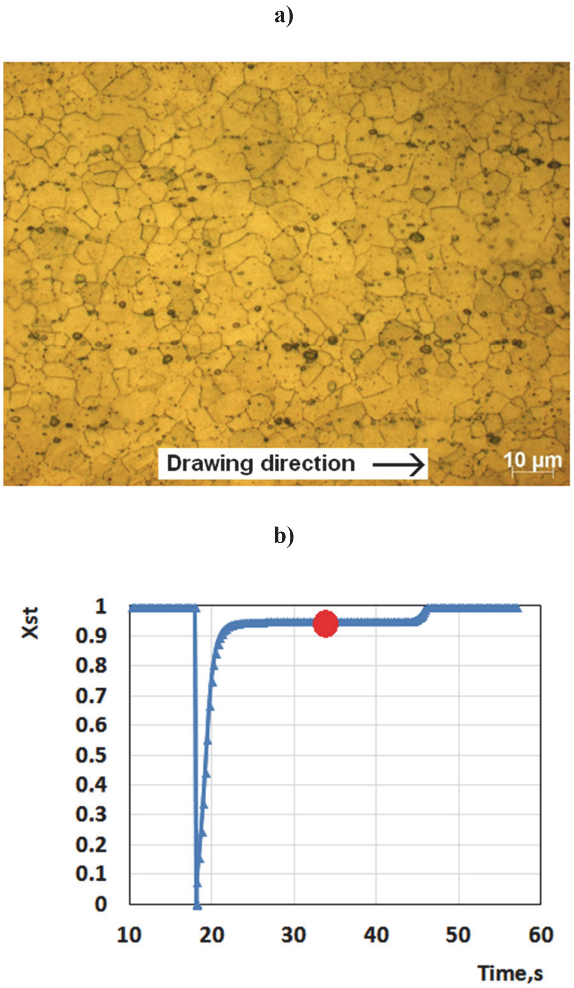


Fig. 8. The microstructure of the wire after the first pass at the moment marked by red dot (a) and values of calculated recrystallized volume fraction (b), diameter of the wire was equal to 0.913mm and the temperature was 350°C.

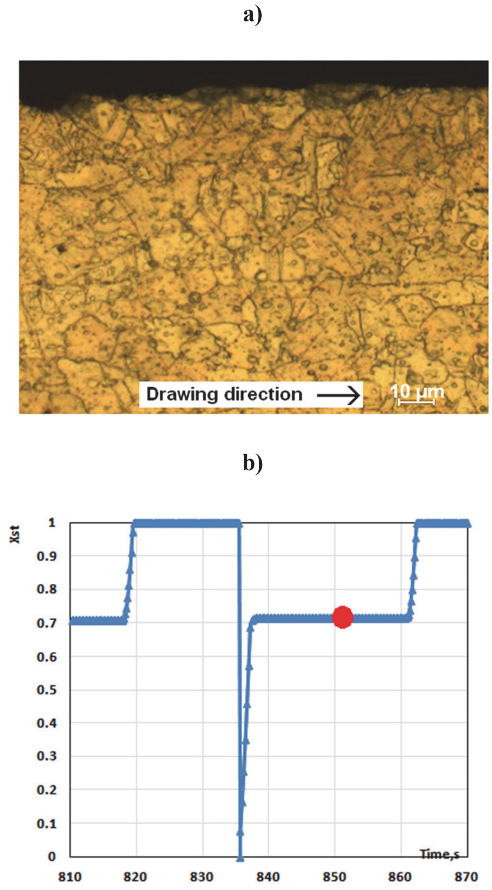
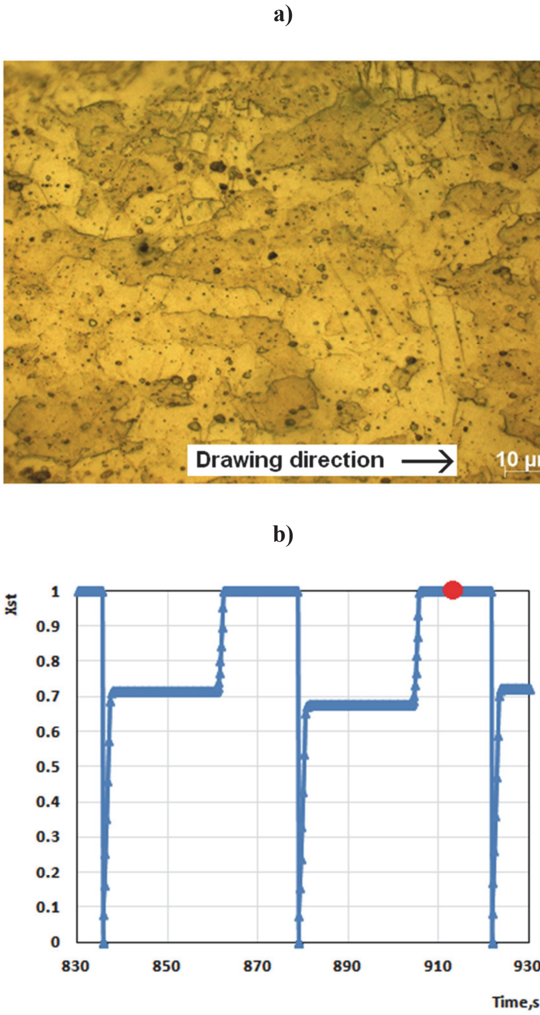


Fig. 9. The microstructure of the wire after 20 passes at the moment marked by red dot (a) and calculated recrystallized volume fraction (b), the diameter of the wire was equal to 0.162 mm.

The microstructures in figures 8a, 9a, 10a and 11a correspond to the red dots in figures 8b, 9b, 10b and 11b, where X_{st} dependency on time is shown.

Figure 8 shows the microstructure of wire after the first pass. The microstructure contains fully recrystallized and equiaxed grains. It can be also seen that there was not enough time for grain growth. Simulation results also indicate full recrystallization. Figure 9 shows the microstructure of the wire after 20 passes. In this case the microstructure consists of grains with different size and twin boundaries are visible, as well. The recrystallization is not completed and results of simulation also show that recrystallized volume fraction is about 70%.

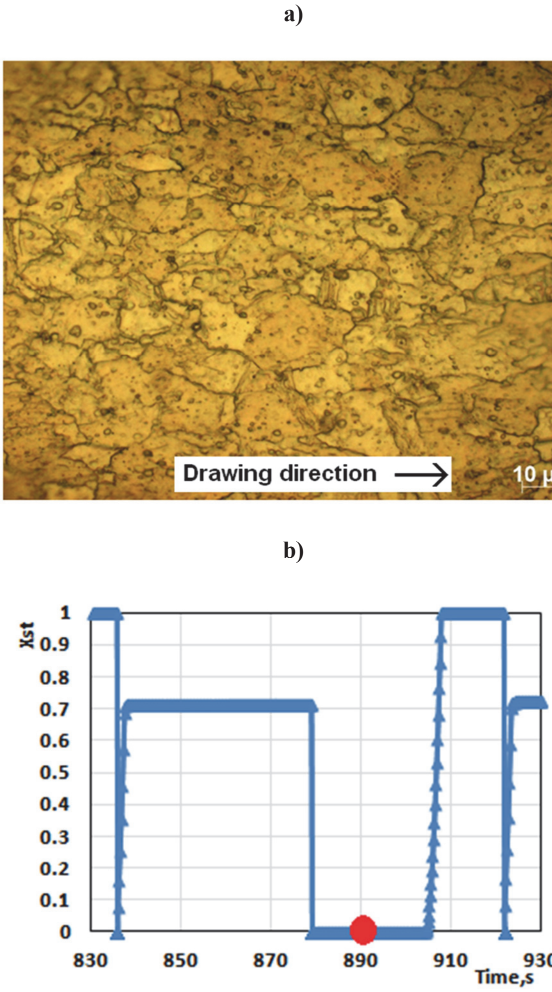
In figures 10 and 11 microstructures of the wire after 21th pass realized at temperature 350ºC and at room temperature respectively are shown. The microstructure of the wire obtained in a hot drawing pass includes bigger and elongated along drawing axis grains and aggregation of fine grains. Fine grains could be the result of recrystallization. The big grains are bigger than grains in the initial microstructure before drawing (figure 9), thus they could be an effect of grain growth process.


a)

b)

Fig. 10. *The microstructure of the wire after 21 passes at the moment marked by red dot (a) and calculated recrystallized volume fraction (b), the diameter of the wire was equal to 0.147 mm, temperature of drawing was 350 ºC, velocity of drawing was 10mm/s.*

The microstructure after cold pass is shown in figure 11. The grains are elongated in drawing axis direction (comparing to microstructure presented in figure 9) with visible twin boundaries, which gives evidence for the lack of recrystallization in the wire. The results of simulations prove this conclusion. So the next pass should be done in high temperature in order to restore the plasticity of the wire. The final product of proposed technology is wire with diameter 0.1 mm which is presented in figure 12. After drawing process this wire was moved through heating zone L_0. In this case microstructure of wire is common to this presented in figure 10.


a)

b)

Fig. 11. *The microstructure of the wire after the 21st pass at the moment marked by red dot (a) and calculated recrystallized volume fraction (b), the diameter of the wire was equal to 0.147 mm, temperature of drawing was 21ºC, velocity of drawing was 10mm/s.*

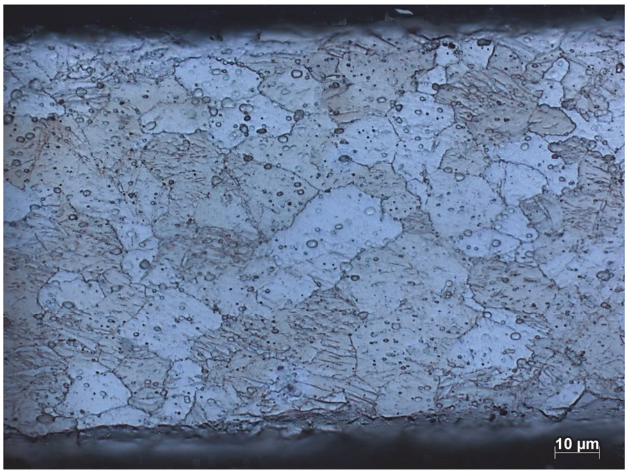


Fig. 12. *The microstructure of the wire after the 21st pass*

The results of mathematical and physical modelling allow to conclude that the forecast of recrystallization corresponding to physical process is within the permissible error. As it is shown in figure 8, the microstructure after drawing in a heated die has fully recrystallized grains and the SRX model predicts full recrystallization. Regimes of drawing, which allow to obtain a wire with a diameter of 0.1 mm, were proposed on the basis of the developed model. In consequence, the microstructure of wires was characterized by fully recrystallized grains with renewed plasticity.

5.4. Summary

The dynamic recrystallization was not considered in the model. This phenomenon could be neglected because the volume fraction of dynamically recrystallized material in the whole process was lower than 4%. The simulations performed with the static recrystallization model showed that in the hot drawing process the grains are fully recrystallized. Moreover, plasticity of material after each pass carried out in high temperature was successfully restored. It means that only one hot pass is necessary after cold pass to restore the plasticity. It leads to the design of technology in which only every second pass in a drawing schedule must be performed in hot dies. The aim of these hot passes is to restore the plasticity by recrystallization process after drawing the wire in a cold die.

6. CONCLUSIONS

Performed experiments and numerical simulations allowed to draw the following conclusions:.

1. Literature review has shown that dynamic recrystallization may be neglected in simulation of multi-pass hot drawing of MgCa08 alloy since the percentage contribution of the DRX in this process is lower than 4%.
2. The proposed model of static recrystallization in multi-pass drawing process allows to predict the effect of SRX on restoring the plasticity and to calculate the critical values of ductility function during the process.
3. The results of simulation showed that in a multi-pass drawing process only every second pass has to be realized in a hot die. After each cold pass the hot pass is required in order to restore the plasticity by recrystallization.

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FIZYCZNE I MATEMATYCZNE MODELOWANIE PROCESU REKRYSTALIZACJI STATYCZNEJ PODCZAS CIĄGNIENIA W PODGRZEWANYCH CIĄGADŁACH DRUTÓW ZE STOPU MAGNEZU MgCa08

Streszczenie

Praca poświęcona jest modelowaniu numerycznemu procesu ciągnienia cienkich drutów ze stopu magnezu MgCa08. Opisywany proces składa się z 25 przepustów wykonanych w gorących ciągadłach przy początkowej średnicy drutu 1 mm oraz końcowej 0.1 mm. Parametry procesu ciągnienia dobrano w taki sposób, by w czasie ciągnienia zachodziła pełna rekrystalizacja. Dlatego konieczne było opracowanie modelu rekrystalizacji statycznej (SRX). Parametry modelu SRX określono na podstawie badań relaksacji, które zostały wykonane na symulatorze GLEEBLE 3800 dla trzech różnych temperatur 250, 300, 350 ºC i trzech wartości odkształcenia 0.1, 0.2 oraz 0.3.

Model rekrystalizacji statycznej został zaimplementowany do oprogramowania Drawing2D, które umożliwia symulację procesu ciągnienia w podgrzewanych ciągadłach. Wykonano dwa warianty symulacji procesu ciągnienia. W pierwszym wszystkie przepusty w procesie ciągnienia zostały wykonane w temperaturze 350 ºC, w drugim zaś jeden z przepustów wykonano w temperaturze pokojowej. Weryfikacja modelu rekrystalizacji została wykonana w oparciu o zdjęcia mikrostruktur drutów po procesie ciągnienia.

Przeprowadzone badania doświadczalne i symulacje numeryczne wykazały, że udział rekrystalizacji dynamicznej w badanym procesie jest niewielki i może ona zostać pominięta w modelu. Wyniki symulacji rekrystalizacji statycznej pokazały, że w procesie wielostopniowego ciągnienia drutów ze stopu MgCa08 wystarczy, jeżeli co drugi przepust jest wykonywany w podgrzewanym ciągadle. Po każdym przepuście w temperaturze otoczenia wymagany jest przepust w podgrzewanym ciągadle.

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