Research on the drawing process with a large total deformation wires of AZ31 alloy

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Abstract. Magnesium and their alloys have been extensively studied in recent years, not only because of their potential applications as light-weight engineering materials, but also owing to their biodegradability. Due to their hexagonal close-packed crystallographic structure, cold plastic processing of magnesium alloys is difficult. The preliminary researches carried out by the authors have indicated that the application of the KOBO method, based on the effect of cyclic strain path change, for the deformation of magnesium alloys, provides the possibility of obtaining a fine-grained structure material to be used for further cold plastic processing with large total deformation.

The main purpose of this work is to present research findings concerning a detailed analysis of mechanical properties and changes occurring in the structure of AZ31 alloy wire during the multistage cold drawing process. The appropriate selection of drawing parameters and the application of multistep heat treatment operations enable the deformation of the AZ31 alloy in the cold drawing process with a total draft of about 90%.

1. Introduction
Magnesium alloys are promising light-weight metal alloys. Owing to their properties, these alloys have a wide range of application, starting from the automotive and the electronics industries, through to household equipment articles [1-5]. Moreover, magnesium alloys are beginning to have increasingly high importance as alloys intended for application in medicine, as they belong to a group of materials with good bio-compatibility with the human body (having the ability to dissolve in the body), thus being able to be utilized in cardiac surgery or orthopaedics. The main applications of medical magnesium alloys include bone implants, stents, as well as surgical threads designed for joining soft tissues [6].

As hexagonal close-packed structure alloys, magnesium alloys have limited plasticity and poor deformability at ambient temperature. They are also characterized by high mechanical anisotropy forming during plastic deformation. The application of the KOBO technology based on the cyclic strain path change effect during the plastic deformation of metal, enables a fine-grained material with good mechanical and plastic properties to be obtained [7]. The advantage of this method is the ability to extrude material with a high extrusion ratio at a low temperature. So obtained material is characterized by a homogeneous structure and can be subjected to a further cold deformation process, e.g. a drawing process, which will result in wire with good plastic properties and strength.
2. Experimental procedure
The AZ31 magnesium alloy ingots in the form of \( \phi 50 \times 150 \text{ mm} \) of chemical composition as given in Table 1, extruded by the KOBO method into \( \phi 2 \text{ mm} \)-diameter blank, was used for testing. The extrusion process was carried out under isothermal conditions using two-hole extruding die; the extrusion ratio was \( \lambda = 312.5 \).

**Table 1.** Chemical composition of the investigated alloy

| Component contents, wt% | Mg  | Al  | Mn  | Nd  | Sb  | Zn  | Fe  | Si  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|
|                          | 96.284 | 2.58 | 0.12 | 0.005 | 0.017 | 0.99 | 0.002 | 0.002 |

With the purpose of designation parameter optimally heat treatment was performed annealed in a resistance furnace according to the scheme given in Table 2.

**Table 2.** Heat treatment parameters

| Temperature °C | 150 | 200 | 250 |
|---------------|-----|-----|-----|
| Time [min]    | 15  | 30  | 45  |
|               | 60  | 15  | 30  |
|               | 45  | 60  | 15  |

Process of deforming stock carry after selection of optimal interoperative parameters of heat treatment according to scheme placed in table 3. The wire drawing process was carried out in laboratory conditions on a ZWICK Z100 testing machine at a speed of 0.83 [mm/s]. Sintered carbide drawing dies with a drawing angle of \( 2\alpha = 12^\circ \) were used for the drawing process. A unit draft of \( G \approx 10\% \) was applied.

**Table 3.** Scheme of drawing process

| Draw no. | 0-3 | Heat treatment | 4-8 | Heat treatment | 9-16 | Heat treatment | 17-24 | Heat treatment |
|----------|-----|----------------|-----|----------------|------|----------------|-------|----------------|
| \( G_T \) [%] | 27.75 | 42.42 | 56.58 | 58.13 |

To determine the changes occurring in the microstructure, metallographic examinations were performed on an AXIOVERT 25 optical microscope. The analysis of microstructure development during the cold drawing process and the examination of the effect of draft and heat treatment on structure refinement and mechanical properties of wire were carried out.

3. Experimental results and their analysis
The complex state of stress occurring during the process of drawing hard deformable materials causes an inhomogeneous structure to occur. The application of the interoperative annealing process during the magnesium alloy cold plastic working process is very important for two reasons: Firstly, softening of the material and the restoration of its plastic deformability is observed. Secondly, the recrystallization process is a very effective mechanism of the formation of a structure about small largeness of grain size.

![Figure 1](image-url)  
**Figure 1.** Relationship of mechanical and plastic properties as a function of heat treatment time and temperature **a)** \( R_m \) [MPa] = \( f(t) \); **b)** \( A \) [%] = \( f(t) \).
The first stage of the experimental procedure included the determination of the optimal temperature and time of interoperative heat treatment. To this end, the examination of the effect of holding temperature and time on the properties and structure of the material after deformation with a total draft of 27.75% (with a wire diameter of 1.7 mm) was performed. After carrying out experimental tests according to the scheme as shown in Table 2, the following relationships were obtained: $R_m = f(t)$ (Figure 1a) and $A_g = f(t)$ (Figure 1b).

From the obtained testing results it can be observed that with increasing heat treatment temperature an increase in plastic properties (Figure 1b) and a drop in mechanical properties (Figure 1a) follows. Establishment, that: an annealing temperature of 250°C, and a duration of 60 min., are optimal parameter interoperative treatment owing to the good mechanical ($R_m = 265.9$ MPa) and plastic ($A_g = 13.8\%$) properties of the wire tested. The determined value of the plasticity margin factor, $R_{0.2}/R_m$, is 0.69.

Other points to carry out the heat treatment was chosen on the basis of experimental studies including the analysis of the structure and the plastic and mechanical properties of wires after respective drawing process stages (Figure 2). Decrease of mechanical properties, a significant drop in plasticity and approaching to 1 ratio $R_{0.2}/R_m$ were the considerations that influenced the making of a decision about carrying out subsequent heat treatment.

The results of detailed tests for the determination of the mechanical properties of the wires under examination after respective drawing process stages and after performed heat treatment are shown in Figure 2. The drawing process was divided into 4 stages: Stage I encompassed 3 draws of a total draft of 27.75%; Stage II – 5 draws of a total draft of 42.42%; Stage III – 8 draws of a total draft of 56.58%; and Stage IV – 8 draws of a total draft of 58.13%. In total, the initial stock was deformed with a total draft of 92.4%. With increasing deformation, a decrease in the mechanical properties of the material under examination was observed at particular deformation process stages. The highest increase was noted at Stages II and III of the deformation process, where the stress level reached a value of 370 MPa, and at Stage IV with a stress level of 340 MPa. An increase in the actual strain value was observed at respective deformation process stages, as follows: Stage I, $\varepsilon = 0.35$; Stage II, $\varepsilon = 0.55$; Stage III, $\varepsilon = 0.83$; and Stage IV, $\varepsilon = 0.87$; which gives a cumulated actual strain value of 2.58.

Figure 2. Relationship of the reliability on extension as a function of the cumulated strain at respective deformation process stages (HT – the point of carrying out heat treatment).

Figure 3. Dependence of average grain size as a function of cumulative true strain after next processes of interoperative heat treatment.
Microstructure observations made after each stage of recrystallization annealing found increment structure refinement, as shown in Figure 3. Example wire structures are illustrated in Figure 4.

4. Summary
The investigation presented in the article has found that the factor that has a great influence on the deformability of the AZ31 magnesium alloy in the cold drawing process is the initial coarse-grained material structure. Assuring the correct parameters of the AZ31 alloy drawing process, such as a unit draft of approx. 10%, and optimal heat treatment parameters, enabled a 0.55 mm-diameter wire to be obtained from stock material of an initial diameter of 2 mm, as produced by the KOBO method, by carrying out 3 heat treatment operations. The properties of received wire in hard state are $R_m = 316$ MPa, and the true strain $\varepsilon = 0.6\%$; whereas in its soft state after annealing, they are as follows: $R_m = 225.5$ MPa, and the true strain $\varepsilon = 10\%$.

The drawing process carried out following the proposed scheme produced a thin wire of AZ31 alloy with a high level of cumulated actual strain of $\varepsilon = 2.58$.

The performed analysis of structure showed that the main mechanism of material hardening in the drawing process with preset process parameters was the dislocation slip. The application of big deforming accumulated and recrystallization annealing enabled a 3-fold disintegration of structure and fine-grained material about middle-sized $4\, \mu m$ to be obtained.

References
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