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Anomalies in precipitation hardening process of 7075 aluminum alloy extruded by KOBO method

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ABSTRACT

In this paper the influence of the initial conditions of KOBO method extrusion of 7075 aluminum alloy on the structural and mechanical parameters of the products is presented; in particular the paper focuses on how heat treatment affects the course of the post deformation process. Moreover, our fundamental purpose is to attempt to answer the question regarding the role of point defects and their potential usage to control the material's properties.

The impetuses to conduct this research were the previous experimental studies of the kinetics of metal extrusion by KOBO method and the results of mechanical properties measurements and microstructural observations of the products. They allowed to formulate the thesis that the point defects generated in metals subjected to large and rapid plastic deformation, forming nano-dimensional clusters, constitute the dominant element of deformation mechanism and structural phenomena that take place both during and after the process.

In this paper it is shown that, based on the analysis of the experimental results, the clusters of point defects have a significant thermal stability which remains after extrusion, slows down or completely inhibit the process of diffusion of alloying elements at aging temperature (150 °C). On the other hand, a very fast decay of clusters occurring at high temperature (annealing/solutioning at 470 °C/5 min) creates an excess of point defects, which result in increased diffusion during subsequent aging at 150 °C.

1. Introduction

Xi et al. (2008) indicates that the neutron irradiation of a solid disturbs its thermodynamic equilibrium; this is associated with the generation of an over-balanced concentration of point defects (Kawasaki et al., 2011). However, the high excess in concentration of both vacancies and interstitial atoms may also be achieved via the processes of severe plastic deformation (SPD). The heterogenization of deformation in shear bands, characteristic to large plastic deformations, results in the development of particular areas that contain dynamically coexisting structural components including over-balanced concentration of point defects (Martin, 1984). This fact is of great importance because of the role that point defects play in the processes of self-diffusion and diffusion in substitutional solutions. The higher the density, the more intense diffusion and thus the more pronounced effect on the kinetics of formation, or decomposition of the supersaturated solid solution (Mazilkin et al., 2006).

There is empirical evidence for both the creation of point defects during plastic deformation and their redistribution during or after deformation. For example, the high-density of vacancies, which are gathered in clusters (Kiritani et al., 1999), was reported to form in the neck of stretched samples (Kiritani, 1999). On the other hand, it is known that a high density of clusters of vacancies and interstitial atoms can be produced during ultra-high-speed deformation (Fujita, 2002). However, some other studies exploring the above issues do not disclose these elements of the structure (Kiritani, 2003). The attention of researchers was focused rather on very low dislocation density inside of grains formed at heavy deformed materials (Matsukawa et al., 2003). Practically dislocation-free grains in the materials may result from the previous exceptional activity of dislocation climbing and annihilation processes caused by the enhanced diffusion of point defects.

Diffusion coefficients reported by Straumal et al. (2004) for some metals and alloys subjected to SPD processes, lead the conclusion that their value is about 6–10 orders higher ("anomalously fast

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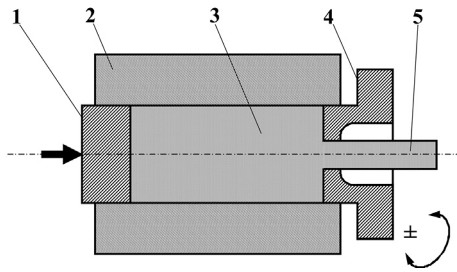

Fig. 1. Scheme of direct extrusion of metal by the KOBO method: 1—punch, 2—container, 3—billet, 4—reversibly rotating die, 5—product.

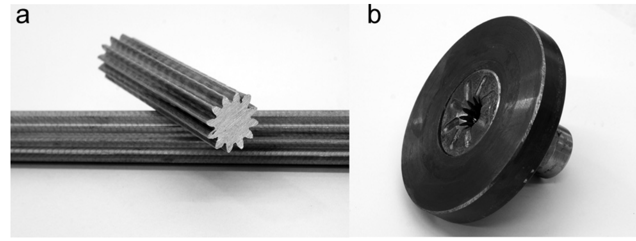

Fig. 2. Fragments of rods ("gears" having an external diameter equal to 13.8 mm) of 7075 aluminum alloy extruded by the KOBO method at 400 °C at an extrusion rate (ram speed) of 0.5 mm/s and air-cooled (a) and the appearance of the die used for their extrusion (b).

diffusion") than these under moderate forming conditions (Straumal et al., 2012). Interestingly, the energy needed for the creation of point defects for both vacancies and interstitial atoms, has a value of almost half than that corresponding to an unloaded state (Sato et al., 2002).

Within this scope, the point defects generated in metals subjected to severe and rapid plastic deformation, seem to be the dominant elements of the deformation mechanism as well as the dominant structural phenomena that take place both during and after the process. This thesis was also based on the previous studies of the kinetics of metal extrusion process by KOBO method (Korbel et al., 2011). The KOBO extrusion differs from the conventional extrusion process by additionally implemented cyclic torsion of metal, resulting from a forced reciprocal rotations of adequately configured die (Fig. 1).

Basing on the analysis of the experimental dates, the superplastic nature of metal flow subjected to KOBO extrusion has been revealed. A cyclic change of deformation path leads to shear banding and generates over-balance concentration of point defects, typically in the form of nano-dimensional clusters of interstitial atoms.

More importantly, this superplastic type of metal flow makes it possible to obtain a high quality product, even with complex shapes (a perfect match with the die). Low flow stress and lack of strain hardening at high strains, which characterizes superplastic flow, allows us to deform even hard alloys at low temperatures by the KOBO extrusion method (Korbel et al., 2011). Experimental verification of this behavior of 7075 aluminum alloy subjected to KOBO cold extrusion was the first stage of the study.

7075 aluminum alloy is one of the precipitation hardenable alloys. The increase in strength of the product manufactured by plastic forming, is obtained by subjecting it to a heat treatment including solution treatment and aging. The conventional extrusion process of 7075 aluminum alloy is usually carried out at a temperature close to 380 °C. The oversaturation of the solid solution takes place during the rapid cooling of the alloy after heating to a temperature of 465 °C. Hardening of the alloy is the result of decomposition of the supersaturated solid solution. From the product properties and processing parameters point of view are temperatures between 140 and 150 °C and an annealing time of 8–12 h; (the typical aging conditions after which the 7075 aluminum alloy obtains the maximum hardness of 170–180 HV). These parameters provided a benchmark for evaluation of the effects of KOBO technology.

The scientific and practical aim of this study is to attempt to obtain information on the influence of KOBO extrusion method on the structure and mechanical parameters of 7075 aluminum alloy products and the courses of post-deformation processes, particularly those resulting from heat treatment. Similarly, we seek to answer the question about the role of point defects and the ability to use them to control the material properties.

2. Testing methodology

Experimental tests were conducted on conventionally extruded 7075 aluminum alloy in the form of rolls with a diameter of 40 mm in 0 temper (extrudes cooled by air), and in T6 temper. The chemical composition is shown in Table 1.

Billets with a length of 40 mm were extruded by the KOBO method on a hydraulic press with a maximum pressure of 1.0 MN, which was equipped with a mechanical system allowing oscillating rotation of the die around its axis. Three types of dies were used; one of which was used to obtain extruded product (Fig. 2) with a "gear" profile, named "gear" afterwards, while the remaining two were used to produce rods having a diameter of 12 mm and 6 mm. These three extrudates were the object of research of structural phenomena occurring in the 7075 aluminum alloy after extrusion by KOBO method and heat treatment.

The extrusion ratio was $\lambda = 11.1$ for the "gear" as well as for circular in shape the rod with a diameter of $\varphi = 12$ mm (the true strain $\varepsilon = 2.4$) and $\lambda \approx 44$ for the rod with a diameter of $\varphi = 6$ mm ($\varepsilon \approx 3.8$).

Further conditions of alloy extrusion, regardless of its initial state (homogenized or T6), were as follows:

- extrusion temperature (temperature of the billet and of the container) was 400 °C for "gear" and 20 °C or 350 °C for the rods,
- extrusion rate (ram speed), defined as the speed of the punch movement, was equal to 0.5 mm/s, while for $\varphi = 12$ mm and $\varphi = 6$ mm rods it was 0.18 mm/s,
- the angle of die rotation was ±8 deg,
- the initial rate of die oscillations was 5 Hz and during the process it was systematically reduced in order to maintain a constant extrusion force equal to 750 kN.

In order to reach the required temperature of 350 °C or 400 °C before the extrusion, the billet had to be placed in a furnace container of the required temperature for 30 min. The furnace container was earlier heated through electrical resistance. The container automatically kept the desired temperature (±3 °C) during the whole extrusion process by the KOBO method. The accuracy of the heating conditions at the early stages of the experiment was

Table 1
The chemical composition of the 7075 aluminum alloy used for testing.

Material	Cu	Fe	Mn	Zn	Mg	Si	Ni	Ti	Cr	Zr	Al
7075	1.714	0.367	0.251	5.453	2.339	0.181	0.002	0.020	0.185	0.06	Balance