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MICROSTRUCTURE AND PROPERTIES OF MAGNESIUM ALLOY AZ61 AFTER EXTRUSION WITH KoBo METHOD

The article presents tests results of metalforming of magnesium alloy AZ61. Materials for tests were ingots sized ϕ 40×90 mm from magnesium alloy marked with symbol AZ61. Before the shaping process the ingots underwent heat treatment. As a result of conduction of the deformation processes there were rods achieved with diameter of 8 mm. There were axisymmetrical compression tests conducted on the samples taken from rods in temperature range from RT to 350ºC in order to determine the plasticity and formability of the alloy AZ61. Static tensile test was conducted in room temperature (RT), in 300ºC and in 350ºC. With the use of light and electron microscopy techniques the changes which occurred in the microstructure of AZ61alloy in initial condition and after plastic deformation (classic extrusion, KoBo method extrusion) were described. The deformation of alloy AZ61 using the KoBo method contributes to an increase in strength and plastic properties. The effect of superplastic flow was found at a temperature of 350ºC, where a 300% increase in plastic properties – elongation value was obtained. The analysis of the microstructure showed a significant grain size reduction in the microstructure of alloy AZ61 after deformation by the KoBo method and after an axisymmetric compression test, where grains of an average diameter of d = 13 μm were obtained.

Keywords: AZ61 magnesium alloy, KoBo method extrusion, static tensile test, microstructure, plastic deformation

1. Introduction

Magnesium alloys with low density (1.74 g/cm^3) as well as high specific strength has been considered as a promising substitution for most engineering materials. In fact, the use of magnesium alloys causes weight reduction and, as a consequence, reduction in fuel and energy consumption [1]. Therefore, investigations on these alloys are currently considered by various research groups around the world. Despite the promising properties, most magnesium alloys have low formability, and this limited their uses in the automotive, transportation and aerospace industries. The low cold deformation of magnesium alloys is related to their single slip system; the basal system. By increasing temperature, other slip systems, pyramidal and prismatic, are activated and the critical resolved shear stress of basal system decreases [2]. As a result, the workability is improved. On the other hand, deformation at high temperatures is usually accompanied by dynamic recrystallization (DRX). This phenomenon causes nucleation of some fine recrystallized grains to form, and through this decreases the required deformation stress in thermo-mechanical treatment results in the enhancement of formability of magnesium alloys. On the other hand, the fine grains improve the strength and the elongation of magnesium alloys. Alloys from group Mg-Al-Zn are the most common. In this group there are four basic kinds: AZ21, AZ31, AZ61 and AZ80. Alloys from group Mg-Al-Zn are the most common. In this group there are four basic kinds: AZ31, AZ61 and AZ80. Alloys AZ21 and AZ31 possess average mechanical properties, they are weldable and can be easily rolled and extruded. These alloy types are used for preparing metal sheets which are meant for sheet metal stampings [3-4]. Magnesium alloy AZ31 has alloy additives in the form of aluminium – 3%, zinc – 1% and manganese below 0.5%. Alloy additives improve the strength of the alloy as well as the resistance to brittle cracking. Alloys AZ61 and AZ80 contain bigger amount of alloy elements and show more beneficial mechanical properties. Alloy AZ61 is plastically processed with the use of extrusion and forging and alloy AZ80 has the best strength properties in the group of alloys which are undergoing plastic working whereas its susceptibility to plastic formation is relatively low. Alloy AZ61 is plastically processed with the use of extrusion and forging [5-7]. The article presents the influence of the deformation method on the microstructure and properties of alloy AZ61. One of the methods was extrusion with the use of KoBo method. The KoBo extrusion method, used in experiments, consists of the extrusion with reversibly oscillating die. All the conducted operations with the use of KoBo method allow for significant reduction of energy consumption of the process through decrease of the force needed to deform the metal, sometimes even 50% less than in conventional methods of deformation. Besides, they enable the achievement of bigger plastic deformations by smaller deformation forces and at the same time a bigger throughput of the material. The method allows

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for „cold" extrusion, (i.e. without the need of billet preheating), that usually results in high strength properties of extrudates, often unavailable by the conventional extrusion process [8-16]. The method is based on the application of the additional reversible torsion of die with defined angle and determined frequency. Deformation conducted with the use of die torsion leads to creation of viscoplastic character of material flow. The results of the tests which have been conducted so far show that there is a possibility of shaping magnesium alloys with the use of very big deformations without the necessity of prior heating of the charge. Additionally, the achieved products are characterised with good resistance properties and good plastic properties [16-19].

2. Experimental procedure

Material for tests was a set of ingots with diameter of 40 mm and 90 mm height from AZ61 alloy after casting and heat treatment in temperature of 400°C for 40 minutes cooled with furnace.

TABLE 1

Chemical composition and mechanical properties of AZ61 alloy [mass %]

Al	Zn	Mn	Si	Fe	Mg	Others
5,92	0,49	0,15	0,037	0,007	93,33	0,066
Mechanical properties A = 8% R_m = 260MPa $R_{0,2}$ = 180MPa						

Alloy AZ61 was forward extruded with the use of KoBo method in room temperature (RT) – without prior heating of the charge with the travel rate of punch of 0.33 mm/s and the torsional angle of the die of ±8° with frequency of 5 Hz. Rods of a diameter of f 8mm were achieved as a result of extrusion and the calculated extrusion ration λ for them equalled 100.The results, after conduction of the process, were rods with diameter of 8mm. Before the classic extrusion process, the batch was heated to 400ºC. In order to compare the achieved results within the conducted deformation process with KoBo method there was a classic extrusion process conducted a temperature of 380ºC on Hydromet press. Samples for plastometric tests were prepared from the achieved rods. Samples were cylinder shaped with the height of 12 mm and diameter of 10 mm. Plastometric tests were conducted on Gleeble 3800 simulator in temperature range of RT-350ºC with strain rate of 0.1 s^{-1} to the value of deformation ε = 1. Achieved results of plastometric tests were used to mark the flow curves in yield stress σ_p – strain system with the use of Excel and Matlab programs. Static tensile test was conducted on a Zwick/Roll machine in room temperature (RT), 300°C, 350°C with strain rate of 0.0001 $m \cdot s^{-1}$.

Microstructure tests were conducted with the use of techniques of light and electron microscopy. Analysis of microstructure was completed with the quantitative analysis with the use of Metilo program. Stereological parameters were marked such as mean grain diameter, mean surface area and shape factor. Measurement of grain size was conducted with the use of surface method based on the images registered by light and scanning microscopes.

3. Results and discussion

Figure 2 presents an example microstructure in condition after casting and heat treatment and diffraction pattern after casting and heat treatment.

For alloy AZ61 the microstructure after casting has shown coarse-grained structure with varied sizes of grains (Fig. 2). Mean grain diameter after casting process was around 27 µm (Table 2). Identification of phase composition of AZ61alloy after casting and heat treatment was conducted with the use of X-ray phase analysis. There were phases α-Mg present in the composition. Figure 3 shows examples of microstructures from achieved rods after classic and KoBo extrusion methods.

In microstructure of AZ61alloy both after classic and KoBo extrusion methods there was significant refinement of microstructure observed especially for samples achieved as a result of conduction of deformation process with the use of KoBo method (Fig. 3b). In microstructure of alloy AZ61 achieved as a result of deformation with the use of KoBo method the grain achieved had mean diameter of about 20 µm (Table 2). The next stage of conduction of tests was performing plastometric tests in temperature range RT-350ºC with strain rate of 0.1 s^{-1}. Those tests were conducted in order to assess the influence of deformation parameters such as temperature, strain rate, the deformation factor on the plasticity and formability of alloy AZ61. On the basis of results which were achieved in the plastometric tests there were flow curves prepared in the system yield stress σ_p – deformation ε (Fig. 4)

They differ essentially in the initial phase by their conventional (convex) or atypical (concave) shape. As it can be observed, the decrease of deformation temperature, below 300ºC

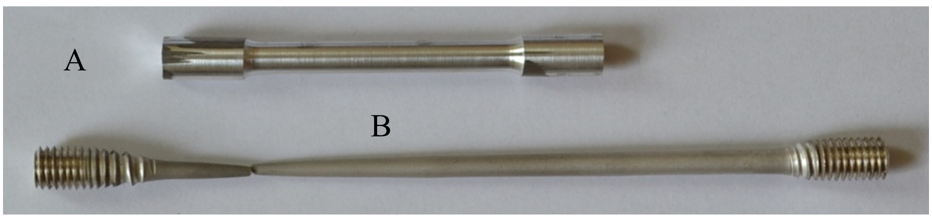
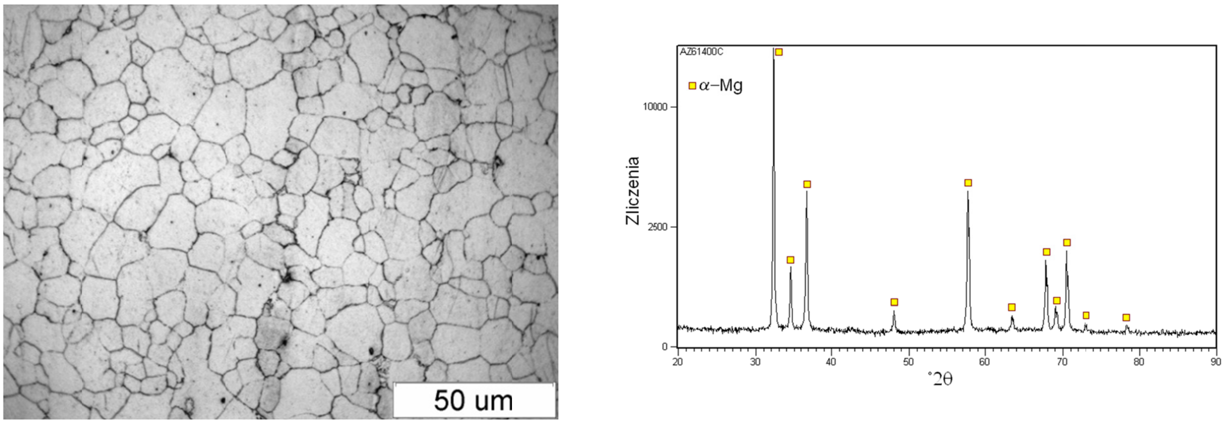
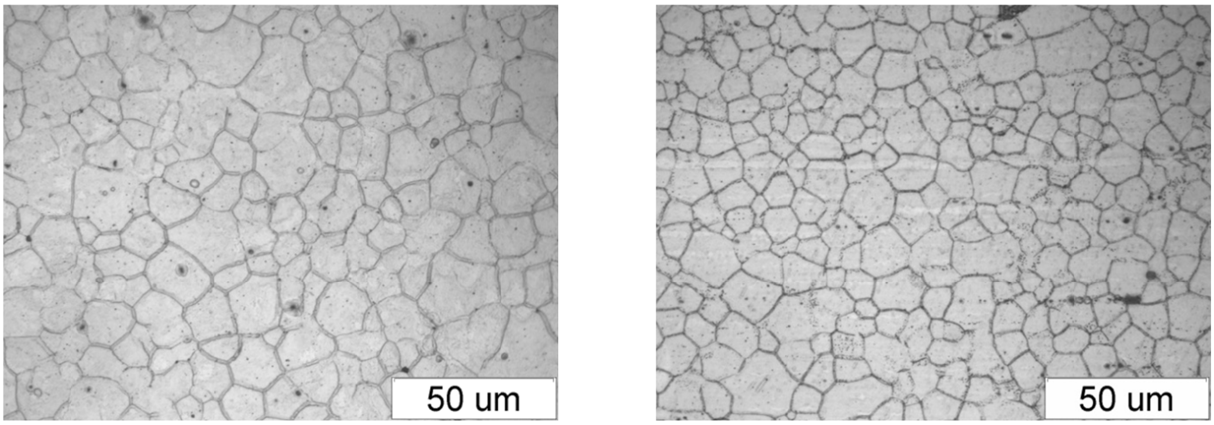


Fig. 1. a) View of samples for a static tensile test, b) after a static tensile test



a) b)

Fig. 2. a) Microstructure of alloy AZ61 after casting, b) X-ray diffraction pattern after casting and heat treatment processes



a) b)

Fig. 3. Microstructure of alloy AZ61 after plastic deformation a) conventional extrusion, b) KoBo method extrusion

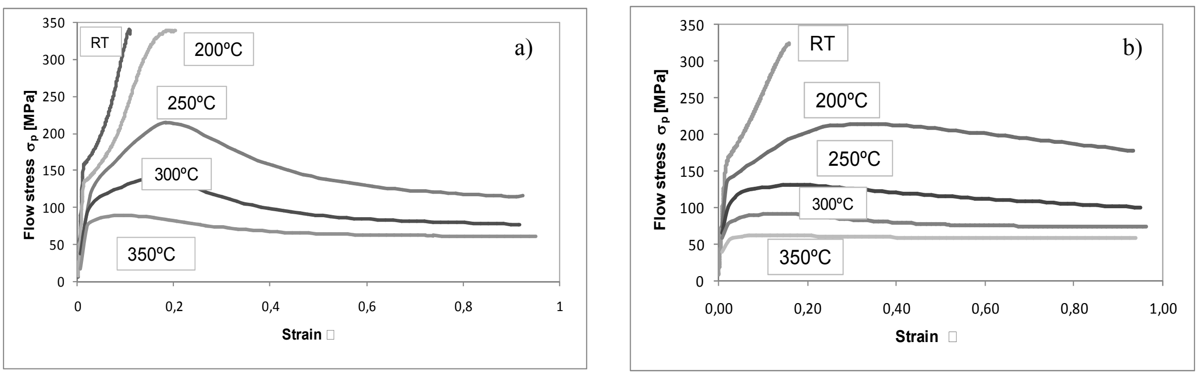


Fig. 4. Flow curves in the system yield stress σ_p – to strain ε: a) after conventional extrusion, b) after KoBo extrusion

changes the shape of flow curve for all tested alloy. A curve is achieved which initially has concave shape, which is connected with intensive course of twinning in microstructure. After reaching the peak stress, together with the increase of deformation, the stress intensively drops [12,13]. For room temperature and 200ºC after classic extrusion the samples have shown limited plasticity of alloy AZ61. On the contrary, for samples extruded with KoBo method in temperature of 200ºC there was an improvement of plasticity properties achieved which is confirmed by the right shape and course of flow curve. For the remaining temperatures of deformation of 250ºC, 300ºC, 350ºC there were satisfactory results achieved in each case (Fig. 4a, 4b). For samples after deformation with KoBo method in the whole range of given temperatures of deformation there were lower values achieved in comparison with classic extrusion (Fig. 4b).

The metallographic analyses (Fig. 5) proved the known fact that the curves of the conventional shape (Fig. 4) arose as a result of joint influence of the dislocation hardening and the

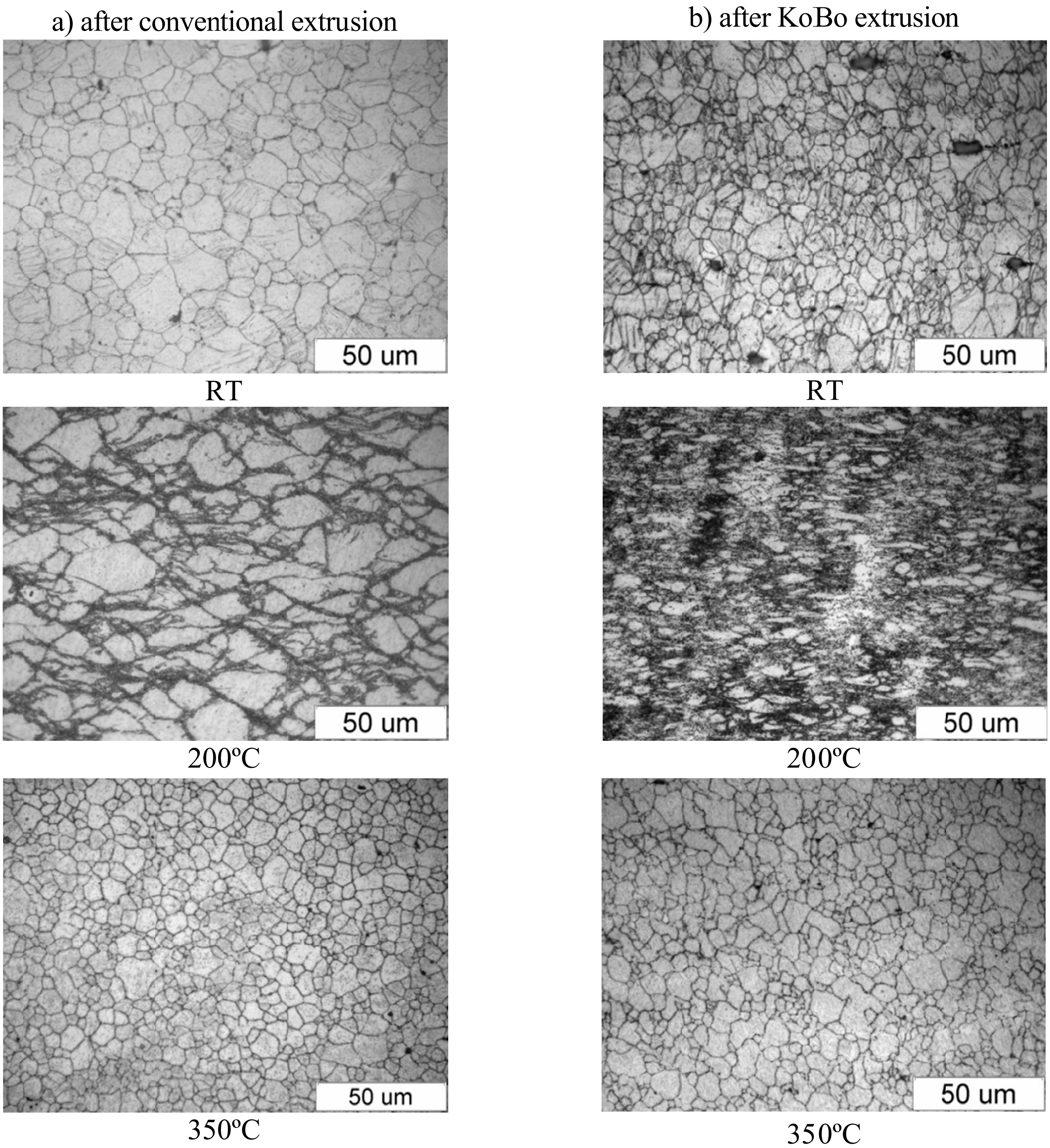


Fig. 5. Microstructure of alloyAZ61: a) after conventional extrusion, b) after KoBo extrusion, in temperature range RT-350ºC

dynamic recrystallization (Fig. 5), whereas the atypical curves with the concave starting phase (Fig. 4) were essentially affected by twinning. A big drop in stress after reaching the maximum is the effect of extension of surface of existing grain boundaries because of appearing twins (Fig. 5a).

In room temperature (RT) in microstructure after classic extrusion and after KoBo method extrusion there were grains of varied shapes found together with deformation twins (Fig. 5a,b). However, in case of microstructure of alloy AZ61 after classic extrusion in temperature of 200ºC there were initial effects of recrystallization process observed, that is presence of new grains which were recrystallized along the boundaries of primary grains on the boundaries of the old grains (Fig. 5a). Conducted microstructure analysis after extrusion with KoBo method has

TABLE 2

Results of quantitative characterization

AZ61 alloy	Average equivalent diameter of grains [μm]	Average surface area [μm^2]	Shape factor
after casting	27	97	0,70
after hot extrusion	23	96	0,69
after cold extrusion by KoBo method	20	96	0,73
after cold extrusion by KoBo method/ axisymmetrical compression tests T = 350ºC	13	94	0,72

shown more advanced process of recrystallization. Recrystallization which began on the boundaries of grains goes deeper and slowly takes over the whole area of grains (Fig. 5b). Table 2 shows results of quantitative characterization. KoBo processing results in grain refinement microstructure.

The results of recrystallization process is evident in the microstructure after KoBo because grain sizes range from 15 µm to about 9 µm and this means that the microstructure is heterogeneous. This shows that the mean equivalent diameter of grain is about 13 µm.

The shape factor presented in Table 2, calculated for the AZ61 alloy microstructure after extrusion by the KoBo method and axisymmetric compression test, amounts to 0.72, which shows the presence of grains of an equiaxial shape.

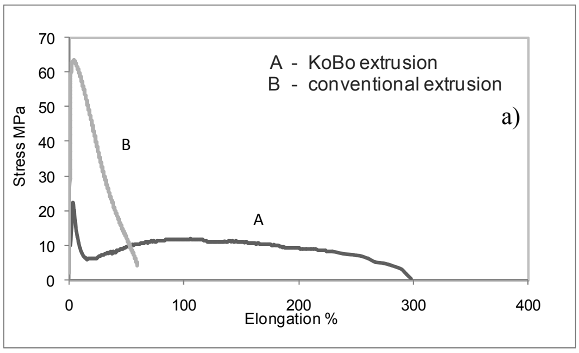
Figure 6 shows results of static tensile test for room temperature (RT) and 350ºC.

In temperature (RT) and 350ºC after extrusion with KoBo method there was an improvement of plasticity properties achieved.In room temperature RT for samples after extrusion with KoBo method the value of elongation was about 16% and in temperature of 350ºC the value of elongation was about 300%, which is 5 times higher than in case of classic extrusion (elongation of 60%). Both in room temperature and in 350ºC there were lower values of tension achieved after extrusion with KoBo method. Figure 7 shows example microstructures after static tensile test.

There was grain growth found in microstructure both after classic extrusion and KoBo method extrusion (Fig. 7a,b).

4. Conclusions

The aim of conducted tests presented in the article was to determine the influence of deformation method on the microstructure and properties of alloy AZ61. The process of plastic deformation was conducted with the use of classic extrusion and KoBo method extrusion. As a result of those conducted processes of deformation there were rods with 8mm diameter achieved. Analysis of microstructure on that stage of tests has shown the refinement of microstructure. As a result of conduction of KoBo method extrusion the achieved grain had a mean diameter of about 20 µm. Conducted plastometric tests in temperature range in room temperature (RT) to 350°C have shown the improvement of plasticity properties of alloy AZ61 from temperature of 200°C and above. In the whole range of analysed temperature of deformation there were lower values of maximum yield stress achieved in comparison with classic extrusion. In the microstructure of alloy AZ61 after extrusion with KoBo method and plastometric tests there was a further refinement of microstructure achieved. Mean diameter of grain was about 13 µm. The effect of superplastic flow after extrusion with KoBo method was found due to the conducted mechanical



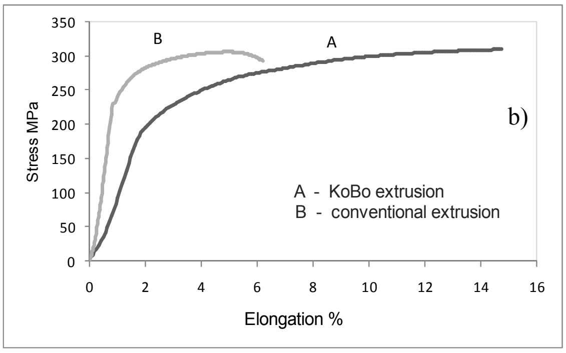
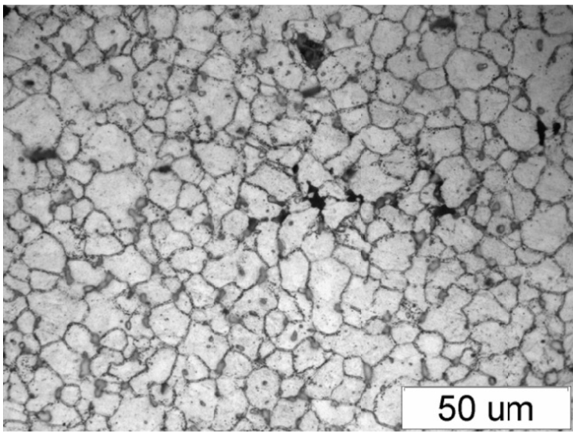
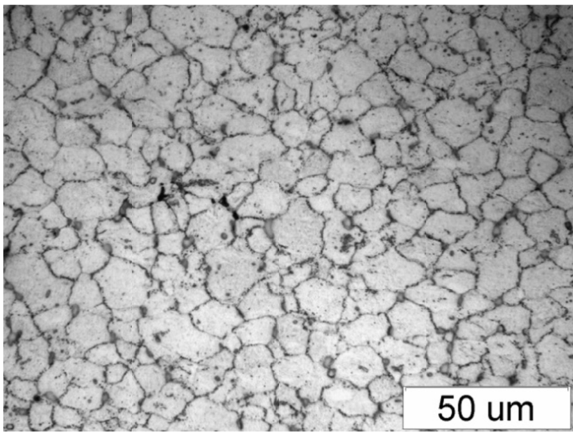


Fig. 6. Results of static tensile tests at : a) 350°C, b) room temperature strain rate of 0.0001 m·s^{-1}



a)



b)

Fig. 7. Microstructure of alloy AZ61 afterstatic tensile test: a) after conventional extrusion, b) after KoBo extrusion

tests. The value of elongation in temperature of 350°C equalled about 300 %. Cold forming aided by additional shear stress can be applied as an alternative method for obtaining products of required density and strength. Presented results of tests will become the basis to conduct further tests in order to prepare technologies of metalforming of magnesium alloys with the use of unconventional methods of deformation.

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