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THE INFLUENCE OF DEFORMATION METHOD ON THE MICROSTRUCTURE AND PROPERTIES OF MAGNESIUM ALLOY WE43

The article presents tests results of the influence of deformation methods on the microstructure and properties of alloy WE43. There were direct extrusion tests and extrusion with KoBo method performed. An assessment of the influence of the methods of deformation on the microstructure and the mechanical properties of the achieved rods from alloy WE43 was conducted. There was an analysis of microstructure carried out with the use of light and scanning microscopy techniques in the initial state and after plastic deformation. Static tensile test was conducted in temperature of 350°C at a speed of 0.0001 $m \cdot s^{-1}$ and microhardness measurements were performed of HV0.2. On the basis of the achieved mechanical tests results it was stated that in the temperature of 350°C for samples deformed with the use of KoBo method there was an effect of superplastic flow found. The value of elongation achieved was 250% which was 3 times higher than in case of classic extrusion (80%).

Keywords: magnesium alloys, SPD method, microstructure, static tensile test

1. Introduction

Magnesium and its alloys are characterised with interesting properties such as: high proper strength, good castability and good weldability which causes that they are the most attractive materials for application in aviation and automotive industry. So far, the application of magnesium alloys has been limited mainly to the products achieved with the use of casting which limits the range of their use. Thanks to the processes of plastic working the magnesium alloys can be used as an interesting alternative, but technology of their plastic forming can be difficult due to their low plasticity in room temperature [1-3]. Processes of plastic working of magnesium alloys have specific character and their conduction in industrial conditions is often hampered. Application of unconventional methods of deformation for magnesium alloys results in increase of their plasticity [4-5]. It allows for the achievement of grain refining of submicrometric or nanometric sizes. That is why new trends in modification of classic plastic forming methods are observed in order to prepare new products which have improved qualities [4]. There are tests conducted in the Institute of Materials Engineering of Silesian University of Technology within performed research tasks which include tests of plastic forming of alloy WE43 with the use of conventional methods (direct extrusion) and KoBo method extrusion. Extrusion with the use of KoBo method can be found among the unconventional methods of plastic forming with the use of big deformations called SPD – Severe Plastic Deformation methods. In extrusion with KoBo method there is an additional oscillatory movement of the die in orthogonal plane to direction of extrusion (flow of material), the method is described in detail in papers [2,4]. Application of this method allows for replacement of the high-temperature deformation with processes conducted in cold temperatures, that is without the initial heating of the charge, with high speed of the process and much increased degree of deformation with smaller work of deformation. Additional advantage of this process is the achievement of the beneficial mechanical properties which are not typical in case of other methods of deformation [5-8]. Literature data shows the possibility of plastic forming with the use of such methods in case of magnesium alloys from group Mg-Al-Zn (AZ91, AZ80, AZ31, AZ61). The authors of the paper [9] have proved that for alloys which underwent KoBo methods deformation there was a significant refinement of microstructure achieved. For that reason, this paper presents results concerning the influence of the deformation method (direct extrusion, KoBo method extrusion) on the microstructure and properties of alloy WE43. Static tensile test was conducted in temperature of 350°C.

2. Experimental procedure

Materials for tests were ingots sized 90 mm and diameter of 40 mm from alloy WE43. After casting process, the ingots underwent heat treatment in temperature of 400°C in time of 40 minutes with cooling in air. Chemical composition and mechanical properties of alloy WE43 are presented in table 1.

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TABLE 1

Chemical composition and mechanical properties of WE43 alloy

<table>
<tr><td rowspan="6">Alloy WE43</td><td colspan="9">Chemical composition [%]</td></tr>
<tr><td>Y</td><td>HRE+Nd</td><td>Nd</td><td>Zr</td><td>Zn</td><td>Si</td><td>Cu</td><td>Ag</td><td>Fe</td></tr>
<tr><td>4%</td><td>3%</td><td>2,2%</td><td>0,54%</td><td>0,03%</td><td>0,01%</td><td>0,01%</td><td>0,01%</td><td>0,002%</td></tr>
<tr><td colspan="9">Mechanical properties</td></tr>
<tr><td colspan="3">Rp_{0,2}</td><td colspan="3">Rm</td><td colspan="3">A</td></tr>
<tr><td colspan="3">213 MPa</td><td colspan="3">280 MPa</td><td colspan="3">24%</td></tr>
</table>

The presence of neodymium and yttrium in the chemical composition of alloy WE43 beneficially influences the improvement of mechanical properties both in room and in elevated temperatures [7]. In the first stage of tests the ingots from alloy WE43 after process of casting and heat treatment underwent the process of direct extrusion and the KoBo method extrusion. Direct extrusion was conducted in temperature of 450°C with load force of 300 kN and speed of traverse equalling 0.1 mm. The effect of the conduction of the process was the achievement of rods with diameters of 8 mm. The extrusion with the use of KoBo method, on the contrary, was conducted in room temperature, without prior heating of the charge, at a speed of extrusion ram traverse of 0.33 mm/s and die torsional angle of ±8° and frequency of 5 Hz (Fig. 1). The material was intensively cooled with water on the exit of the press. Rods with diameters of ϕ 8 mm were achieved as a result of the use of KoBo method extrusion.

The analyses of microstructures after casting and extrusion processes were conducted with the use of light and scanning microscopy techniques. Structures of both samples underwent quantitative analysis and the stereological parameters of grain were marked with the use of program METILO. An X-ray phase analysis was conducted on X-ray diffractometer JEOL JDX-7S, with application of lamp with copper anode ($\lambda_{\mathrm{CuK}\alpha} = 1.54178$ Å) powered with current with intensity of 20 mA and voltage of 40 kV and graphite monochromator. The registration was conducted with the use of stepwise method with steps of 0.05° and counting rate of 5 seconds in range from 10 to 100° 2θ. Tests were conducted on solid samples after casting and heat treatment processes. There were samples prepared from the achieved rods for plastometric tests. Samples had shapes of cylinders with 12 mm height and 10 mm diameter. Plastometric tests were conducted on Gleeble 3800 simulator in temperature range RT-350°C with deformation speed of 0.1 s^{-1} to the value of deformation of $\varepsilon = 1$. Achieved results of plastometric tests were used for marking the flow curves in the system yield stress σ_p to deformation ε with the use of Excel and Matlab programs. Tests of mechanical properties from achieved rods were conducted

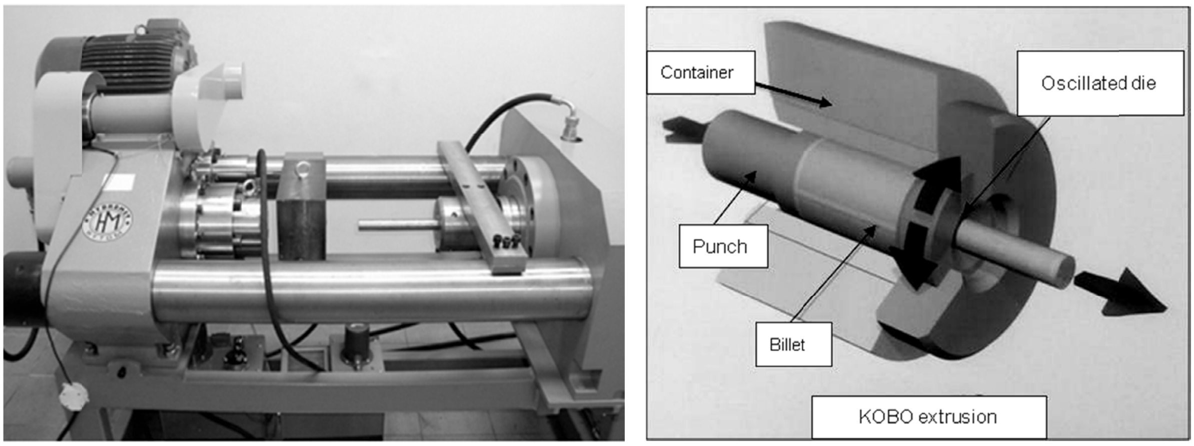
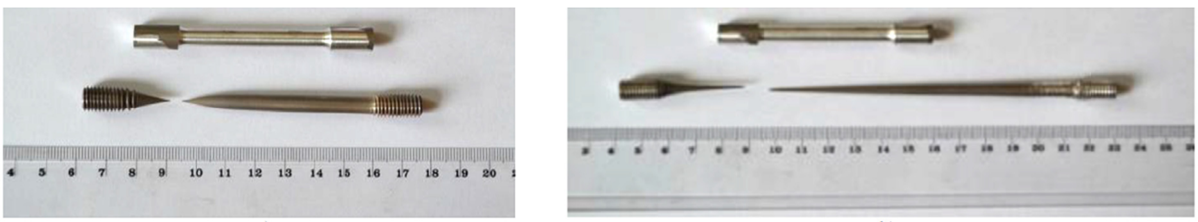


Fig. 1. KoBo extrusion press at AGH University of Technology, Kraków, Poland



a) b)

Fig. 2. View of samples after static tensile test: a) after conventional extrusion b) after KoBo extrusion

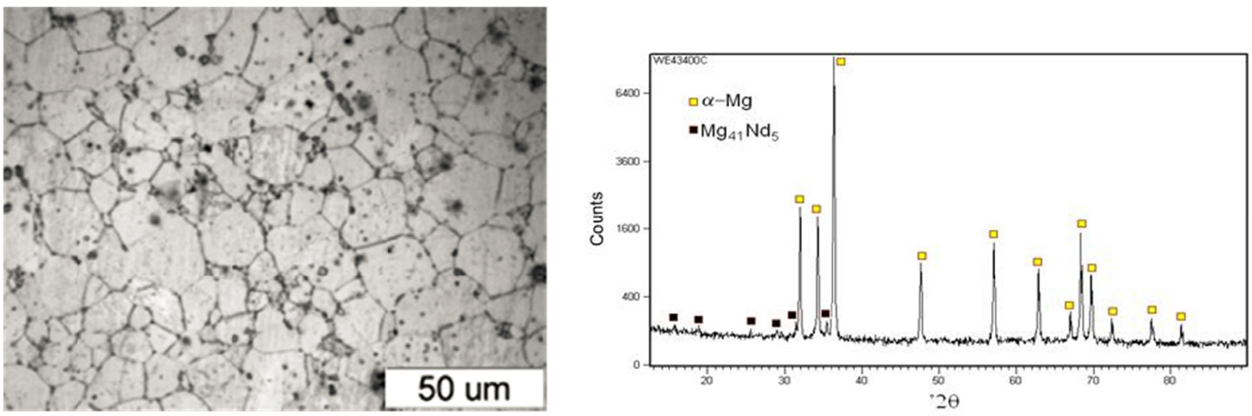
on testing machine ZWICK/Z100. Samples with measurement base of 32 mm underwent drawing in temperature of 350ºC at a speed of 0.0001 m·s^{-1}. Figure 2 presents view of samples after static tensile test after classic extrusion and after KoBo method extrusion. Micro-hardness measurements HV0.2 were done with the use of hardness tester ZWICK.

3. Results and discussion

Figure 3 presents an example microstructure of alloy WE43 and X-ray diffraction pattern after the process of casting and heat treatment. Alloy WE43 after casting process and heat treatment was characterised with coarse-grained microstructure with varied sizes of grains (Fig. 3a). Identification of phase composition of alloy WE43 after casting and heat treatment was conducted with the use of X-ray phase analysis. There were phases α-Mg and $Mg_{41}Nd_5$ present in the composition (Fig. 3b).

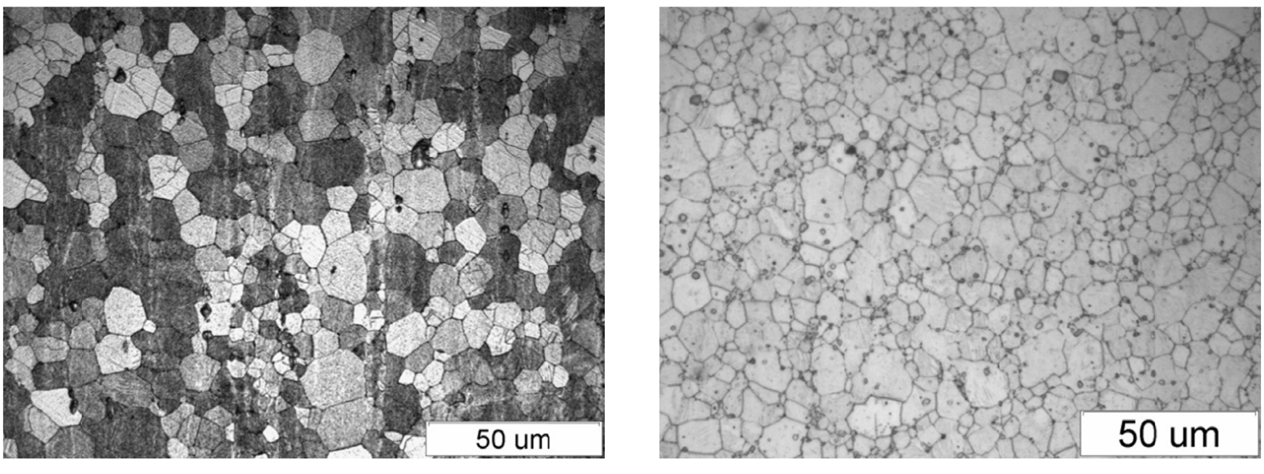
Figure 4 presents example microstructures from rods from alloy WE43 achieved as a result of direct extrusion and after extrusion with KoBo method. Conducted analysis of microstructure of rods after direct extrusion and after extrusion with KoBo method has shown refining of microstructure of alloy WE43 (Fig. 4 a, b). Refining of grains was found in the microstructure of rods prepared with the use of KoBo method (Fig. 4b). Mean diameter of grain equals d = 69 μm. After classic extrusion in microstructure of alloy WE43 the grain size had a mean diameter of 55 μm.

Another stage of conducting research was performance of plastometric tests on samples taken from rods achieved with classic extrusion and from ones after KoBo method extrusion. The aim of the plastometric tests conducted on the samples was to assess the plasticity and deformability of alloy WE43 in temperature range of RT-350°C. On the basis of achieved test results there were flow curves marked in the system yield stress σ_p – deformation ε. Presented flow curves for alloy WE43 from samples after classic extrusion and after KoBo method in temperature range of RT-250°C look similar. Limited range of presented curves proves the limited deformability of tested alloy (Fig. 5 a, b). As presented in literature [1,11] the main fault of magnesium alloys is their low deformability in room temperature which results from the type of their crystallographic network. In



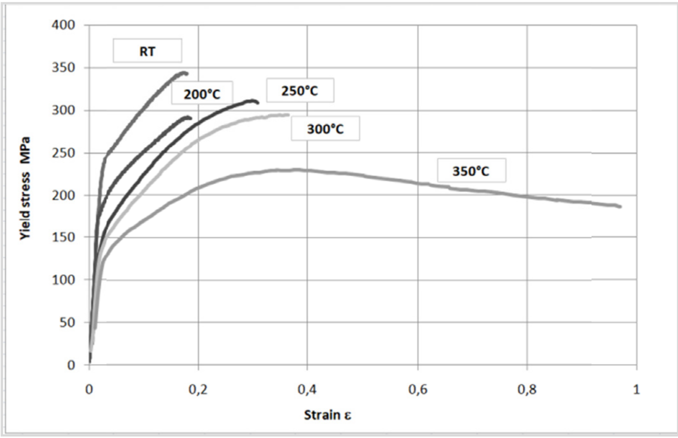
a) b)

Fig. 3. a) Microstructure of alloy WE43, b) X-ray diffraction pattern after casting and heat treatment processes

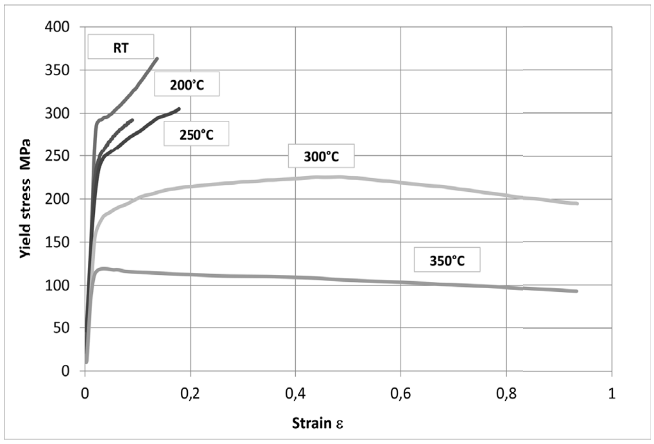


a) b)

Fig. 4. Microstructure of alloy WE43 after plastic deformation a) direct extrusion, b) KoBo method extrusion



a)



b)

Fig. 5. Flow curves in the system yield stress σ_p – to strain ε: a) after conventional extrusion, b) after KoBo extrusion

room temperature there is one system of glide in plane activated (0001). Due to that fact magnesium alloys can be deformed, depending on their chemical composition, in temperatures above 250°C when the additional glide planes are activated. Achieved results from the axisymmetrical compression test confirm the low deformability of alloy WE43 in temperature range RT-250°C for samples after classic extrusion and extrusion with KoBo method and a slight influence of applied deformation methods on the properties of alloy WE43 (Fig. 5 a, b). During the axisymmetrical compression in temperature range RT, 200°C, 250°C the samples cracked by the deformation value of $\varepsilon = 0.2$ which also confirms the limited deformability in this range of applied temperature. For alloy WE43, due to its complex chemical composition, the deformability of the classically extruded alloy increases slightly in temperature of 300°C, whereas in case of shaping with KoBo method the alloy shows big deformability. For temperatures 300°C and 350°C the shape of flow curve (Fig. 5a) proves the reconstruction of structure occurring in the microstructure and that is probably the reason of deformability increase (Fig. 5b). In temperatures 300°C and 350°C the shape of flow curves shows significant decrease of yield stress value σ_p which proves that the strengthening is eliminated by processes of structure reconstruction (Fig. 5 a, b). In the whole deformation temperature range RT-350°C there were lower values of maximum yield stress σ_{pp} (Fig. 5) achieved for samples which were extruded with KoBo method. There were maximum yield stress values marked depending on the temperature of deformation (Fig. 6).

Figure 7 presents example microstructures for samples after classic extrusion and KoBo method in temperature range of RT-350°C. In microstructure after classic extrusion in room temperature there was microstructure observed with varied grain sizes and with presence of deformation twins. On grain boundaries there were precipitations found. Precipitations had round and elongated shapes mainly on grain boundaries. In temperature of 250°C there were elongated grains and deformation twins found inside the grains in the microstructure of alloy WE43 (Fig. 7a). Conducted microstructure analysis has shown a significant refining of microstructure for samples after extrusion with

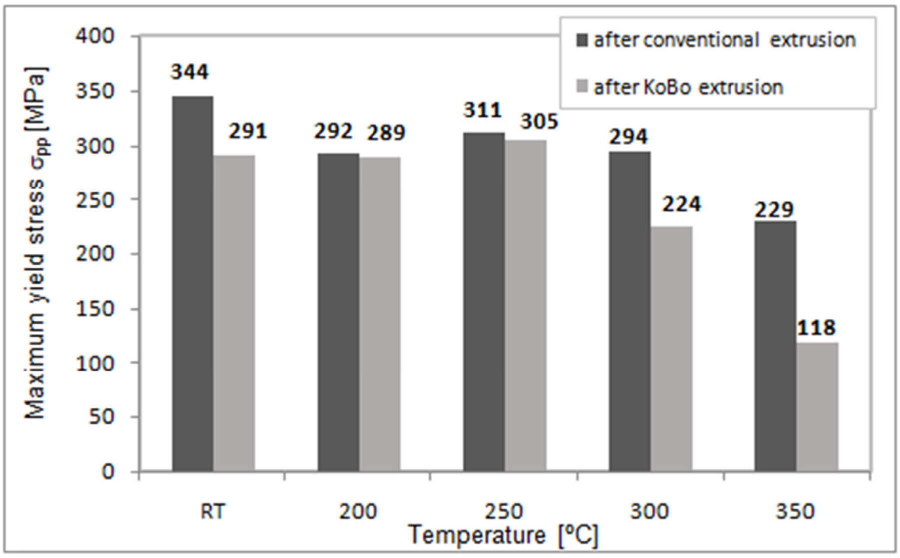


Fig. 6. Influence of deformation temperature on the maximum yield stress σ_{pp} of alloy WE43

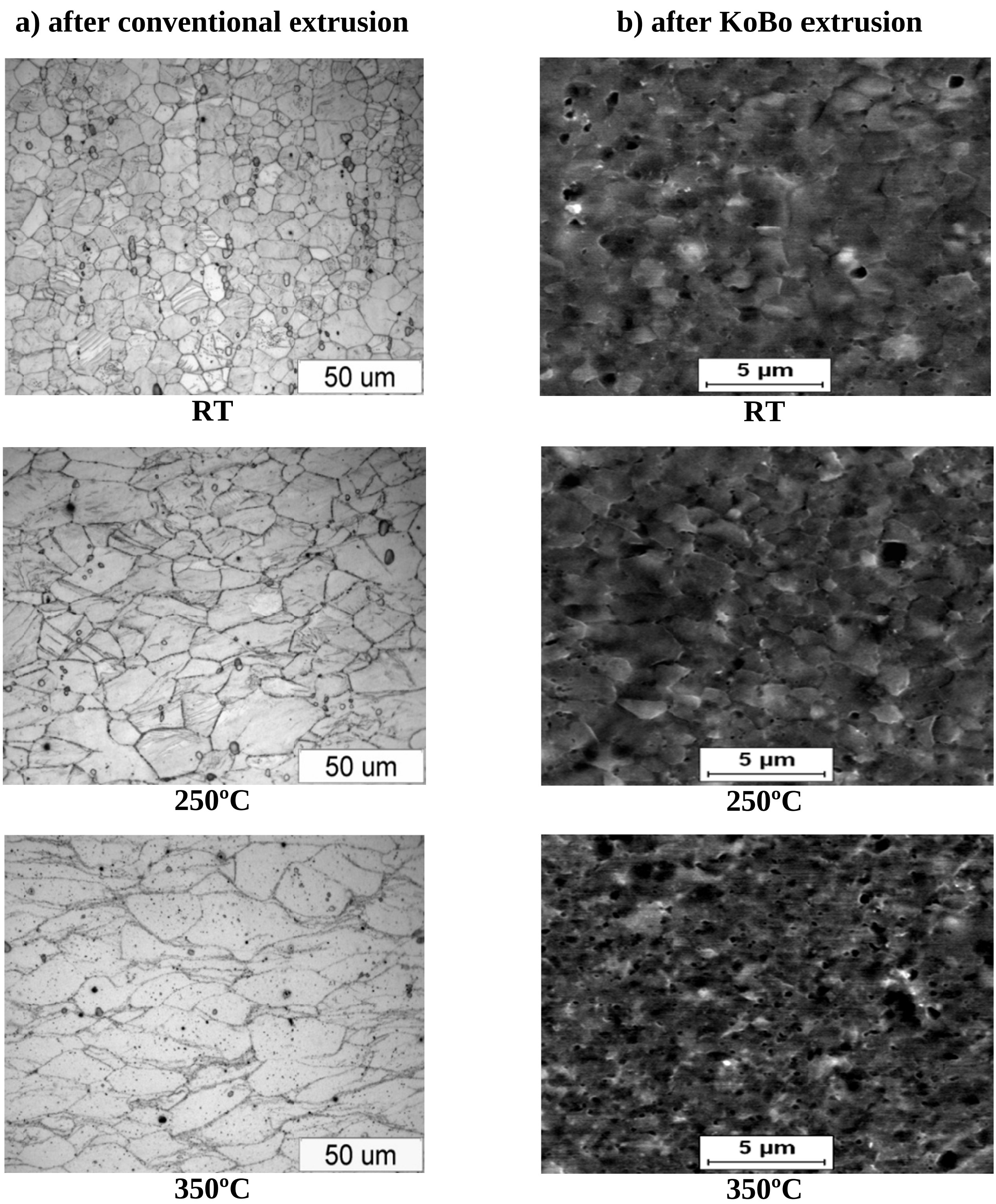


Fig. 7. Microstructure of alloy WE43: a) after conventional extrusion, b) after KoBo extrusion, in temperature range RT-350°C

KoBo method in comparison with microstructure after classic extrusion in temperatures 300°C and 350°C. The refining of microstructure was achieved in temperature of 350°C (Fig. 7b). Results of mechanical properties of alloy WE43 achieved in tensile tests were determined in temperature of 350°C and are presented in figure 8.

There were more beneficial properties achieved for samples deformed with the use of KoBo method. There was an effect of superplastic flow observed. The value of elongation equalled 250%, whereas for samples after classic extrusion the elongation value equalled 80% (Fig. 8). Figure 9 presents results of microhardness measurements HV0.2 in temperature range of RT-350°C. It was concluded for the whole temperature range that microhardness values were lower in case of samples after direct extrusion. It is probably connected with bigger microstructure refining and bigger amount of grain boundaries.

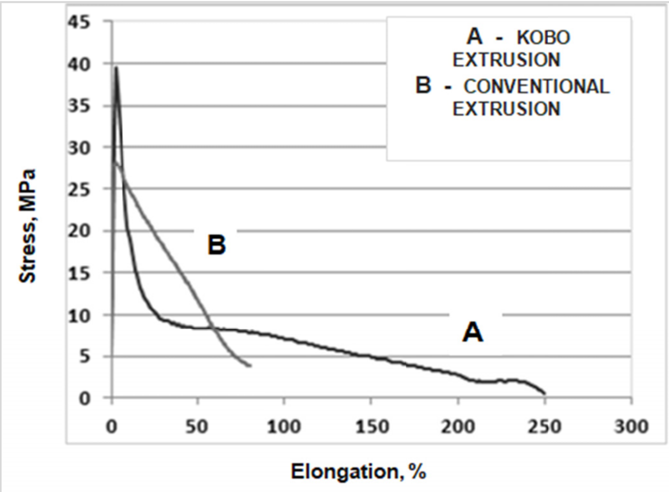


Fig. 8. Results of static tensile tests at 350°C and strain rate of 0.0001 $m \cdot s^{-1}$

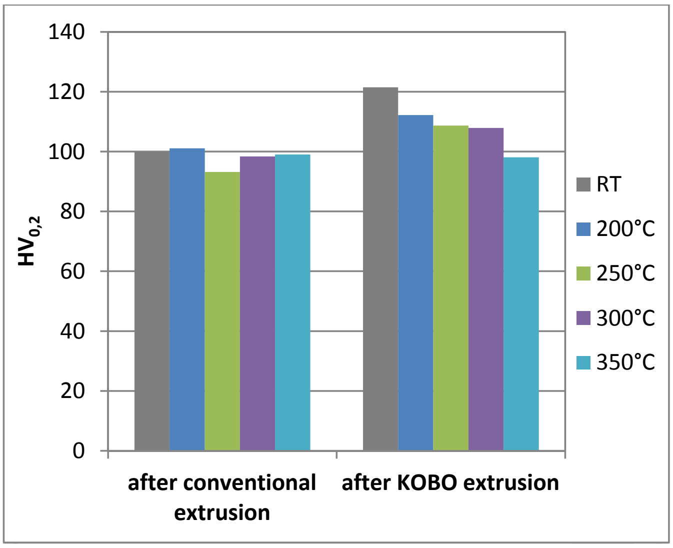


Fig. 9. Results of micro-hardness measurements after classic extrusion and KoBo method extrusion in temperature range of RT-350°C

4. Conclusions

It was shown in the presented test results that there is a possibility of plastic forming and improvement of plasticity of alloy WE43 with the use of KoBo method extrusion in temperatures of 300°C and 350°C. Alloy WE43 in room temperature, in 200°C and in 250°C shows limited deformability. After extrusion with KoBo method of reverse matrix there was significant microstructure refining achieved. Achieved microstructure of alloy WE43 is characterised with bigger homogeneity. In temperature of 350ºC for samples after KoBo method extrusion there was a liability of alloy WE43 observed to superplastic flow and the value of elongation equalled 250%. Conducted tests and achieved results will complete the information possessed so far on the possibilities of plastic forming of alloy WE43.

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