THE INFLUENCE OF DEFORMATION METHOD ON 7075 ALUMINUM ALLOYS DEFORMABILITY PARAMETERS

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Abstract

The paper presents the results of physical modelling of 7075 aluminum alloys in T6 state deformation. The tests were performed using STD 812 torsion plastometer. The influence of different deformation schema on the level of stress, selected properties and changes in structure of the alloy was determined. Preliminary experimental studies of the rolling process in a three high skew rolling mill for the selected variant were also performed.

Keywords: Physical modelling, deformability, 7075 aluminum alloy

1. INTRODUCTION

The importance of aluminum alloys is unquestioned for many years. Due to its high mechanical properties, the 7xxx series alloys are often used in aviation (wings, aircraft fuselage) and for the manufacture of carrying elements of bridges, trucks, trailers, passenger semitrailers, ships, cranes or rail cars. They are also used as components of tanks, mining equipment, hydraulic systems and in the shipbuilding industry [1-3].

The 7xxx series of Al alloys are the most resistant alloys from commercially available group of aluminum alloys. They are precipitation hardened alloys. High strength is due to the presence of elements such as zinc, copper, magnesium and chrome [4]. Applied zinc and magnesium additions, as well as very often copper, increase not only the strength but also the resistance to stress corrosion. These elements form the precipitations of the ternary or quaternary compounds formed by the supersaturation process and then aging. Their presence, size and layout affect the level of alloy strengthening. The effect of strengthening in these alloys is influenced by the grain refinement, the solution strengthening and the work hardening. Significant is the ratio of Zn:Mg, which affects the level of properties of the obtained products [5]. The important advantages of these alloys are very good thermal conductivity, average corrosion resistance and good machinability [6-10].

One of the important elements influencing the properties of the finished product is the plastic processing method used during its forming. It is therefore reasonable to conduct research to improve the properties of alloys with such a wide application potential.

One of the basic elements is to determine the value of the material's susceptibility to plastic forming. This parameter is the yield stress (σ_p), which under uniaxial stress state is a function of the deformation (ε), strain rate ($\dot{\varepsilon}$), the temperature (T) and the history of the deformation way. The values of the yield stress can be determined using methods such as: tension, compression and torsion tests [11-13]. In the case of a torsion test carried out at elevated temperatures it is possible to determine the yield stress indirectly, using the hypothesis of material effort.

In hot plastometric studies [11,12], the formula (1) or (2) applies to the calculation of the τ_{max} on the surface of the twisted sample:

$$\tau_{\max} = \frac{3M_s(3+m+n)}{2\pi \cdot r^3} \tag{1}$$

where:

$$m = \frac{N}{M_s}\frac{\partial M_s}{\partial N}, \qquad n = \frac{\dot{N}}{M_s}\frac{\partial M_s}{\partial \dot{N}} \qquad \tau_{\max} = \frac{3{,}2M_s}{2\pi r^3} \tag{2}$$

where: *r* - outer radius of the sample (*r* = *d*/2), *m* and *n* are the coefficients that take into account the velocity and the value of deformation depending on the material properties and the temperature of the tests.

The basic advantages of the torsion test are: no friction, time stable stress state and the ability to achieve much larger deformations than in the compression or upsetting test [13]. An additional advantage of conducting a hot torsion test is such a selection of process conditions in which it is possible to obtain a constant deformation rate or a modeling of a complex deformation pattern including, for example, simultaneous torsion and compression [14]. Applicationability of the torsion plastomer tests is well founded, among other things, to analyze the behavior of the material during the complex plastic forming process. The application of a plastic deformation process involving several deformation stages or combining several deformation patterns affects the improvement of mechanical properties and the refinement of deformed material structure. The processes in which the material is subjected to high plastic deformation are the SPD (Severe Plastic Deformation) methods such as: high pressure torsion (HPT), equal channel angular pressing (ECAP), cyclic accumulative roll bonding (ARB) and plastic working methods such as: rolling of rods or tubes in a three-high skew rolling mill [14-17].

Designing of methods for obtaining finished products with appropriate level of properties using complex deformation states requires knowledge of the characteristic parameters and behavior of the structure during the deformation process. It is therefore essential to carry out a basic research in this area.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

The material used for the study was the 7075 series aluminum alloy in the T6 state. The chemical composition of the alloy is shown in **Table 1**.

Table 1 Chemical composition of 7075 aluminum alloy (wt.%):

Al	Zn	Mg	Cu	Fe	Si	Mn	Cr	Zr	Ti	others
Rest	5.1-6.1	2.1-2.9	1.2-2.0	max. 0.50	max. 0.40	max. 0.30	0.18-0.28	max. 0.25	max. 0.20	max. 0.05

The test procedure involved carrying out tensile, torsion and simultaneously torsional stretching tests. The examinations were made using STD 812 torsion plastometer. The examinations on the torsion plastometer were carried out at temperatures of 200 °C, 300 °C and 400 °C for strain rates equal 1 s^{-1}. The tests were made under the vacuum, at a constant deformation temperature of the sample and at a constant rate of deformation. An analysis of the material structure on the scanning microscope was also carried out using EBSD and EDX technique. Pre-trial verification was also made by rolling the rods from the 7075 aluminum alloy on a three high skew rolling mill. The process was performed at 400 °C and the applied deformation factor was 1.4. The obtained product was analyzed by measuring the hardness on the cross-section and observation of the structure.

3. EXPERIMENTAL RESULTS

After making the experimental tests (tensile, torsion tests and simultaneous torsional stretching) collected data were analyzed. **Figure 1a** shows the work-hardening curves of the aluminum alloy tested during the tensile test at different temperatures, while in **Figure 1b**, the work-hardening curves obtained in the torsion test are presented. **Figure 2** shows the curves obtained during conducting the combined deformation process.

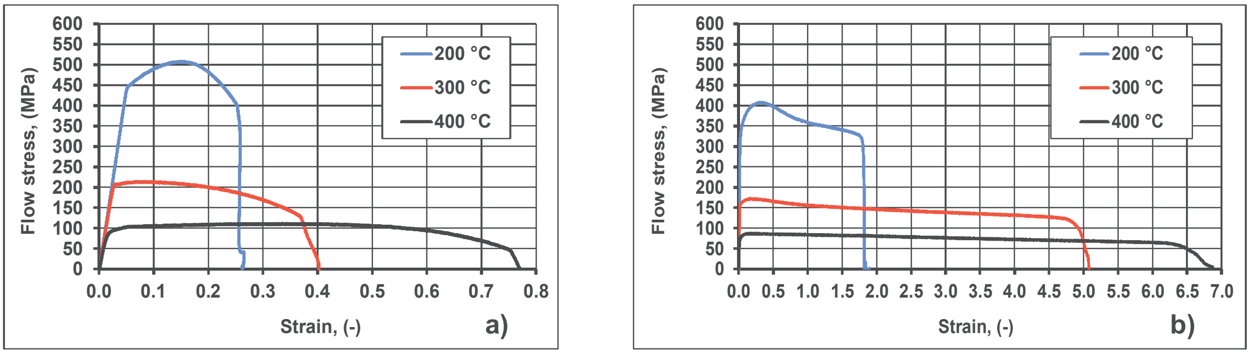


Figure 1 Stress-strain dependence obtained in a) tensile test at a deformation rate of 1 s^{-1} and temperature of 200, 300 and 400 °C; b) torsion test at a deformation rate of 1 s^{-1} and temperature of 200, 300 and 400 °C

The data analysis carried out showed that during the tensile test of 7075 aluminum alloy the highest yield stresses occurred at temperature of 200 °C. For these temperature-velocity conditions the limiting (critical) strain was 0.25. Analyzing the remaining curves shown in **Figure 1a**, it can be stated a significant influence of the temperature on reduction of the yield stress level and improving the plasticity of tested alloy. The limiting strain was about 0.37 at deformation temperature of 300 °C and 0.75 at the temperature of 400 °C.

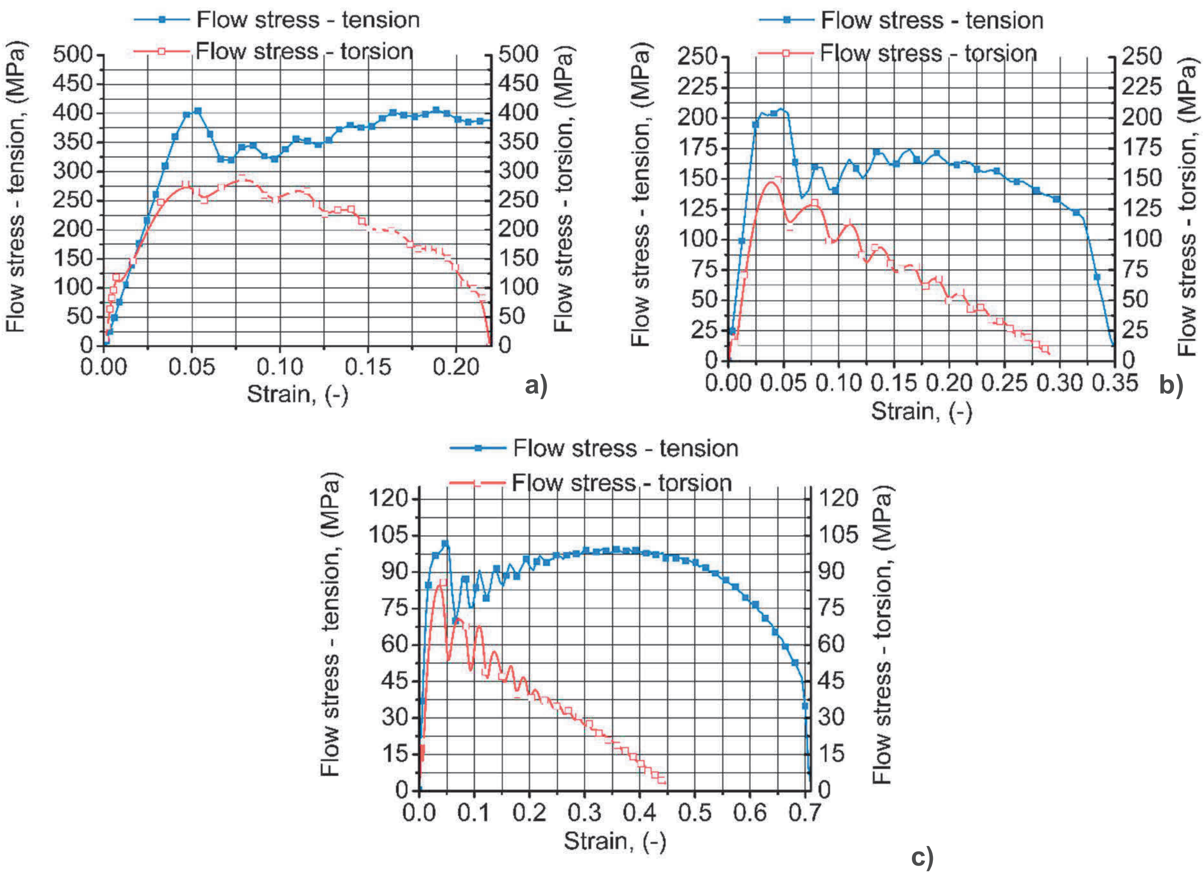


Figure 2 Stress-strain dependence obtained in combined torsional stretching test at a deformation rate of 1 s^{-1} and temperature of: a) 200 °C; b) 300 °C; c) 400 °C

Different character of the curves was observed during the non-free torsion test (**Figure 1b**). Analyzing the limiting strain of the alloy tested under these conditions it was found the beneficial influence of the change in the deformation pattern on the limiting strain value which was 1.7 (at temperature of 200 ºC), 4.75 (at temperature of 300 ºC) and 6.3 (at temperature of 400 ºC) at a slightly lower level of yield stress than obtained in tensile test.

Introducing a complex deformation pattern by combining the tensile and torsion processes (**Figure 2**) resulted in decrease of a plasticity value that reached a level close to that obtained during the tensile tests (**Figure 1a**). The different nature of the curves $\sigma-\varepsilon$ has also been observed, which influences changes in the material structure. Images obtained by scanning microscopy using EBSD technique depict maps of the crystallographic orientation of particular grains in microstructure of the alloy (**Figure 3**) for selected deformation variants. During deformation at 400 ºC, smaller grains were obtained.

Using the combined deformation process, additional shear bands are shown in **Figure 4**. Conducting simultaneously the tensile and torsion tests strongly affects the nature of the structure observed inside the deformed material (**Figure 4**).

For more detailed analysis of the influence of the phases present in the structure, an EDS analysis was performed to identify the chemical elements of the material under study. The result obtained for the deformation variant comprising a combined tensile and torsion test with a strain rate of 1 s^{-1} at temperature of 400 °C is shown in **Figure 5**.

Conducted analysis showed the presence of Al_3Fe, $MgZn_2$ particles in the structure and also iron rich precipitates, which size and distribution influences the level of obtained mechanical properties. Large white particles (**Figures 5 a, b**) are particles of the Al_3Fe intermetallic phase, while smaller ones are designated as Spot 3 **(Figure 5d)** which are $MgZn_2$ particles in the aluminum matrix.

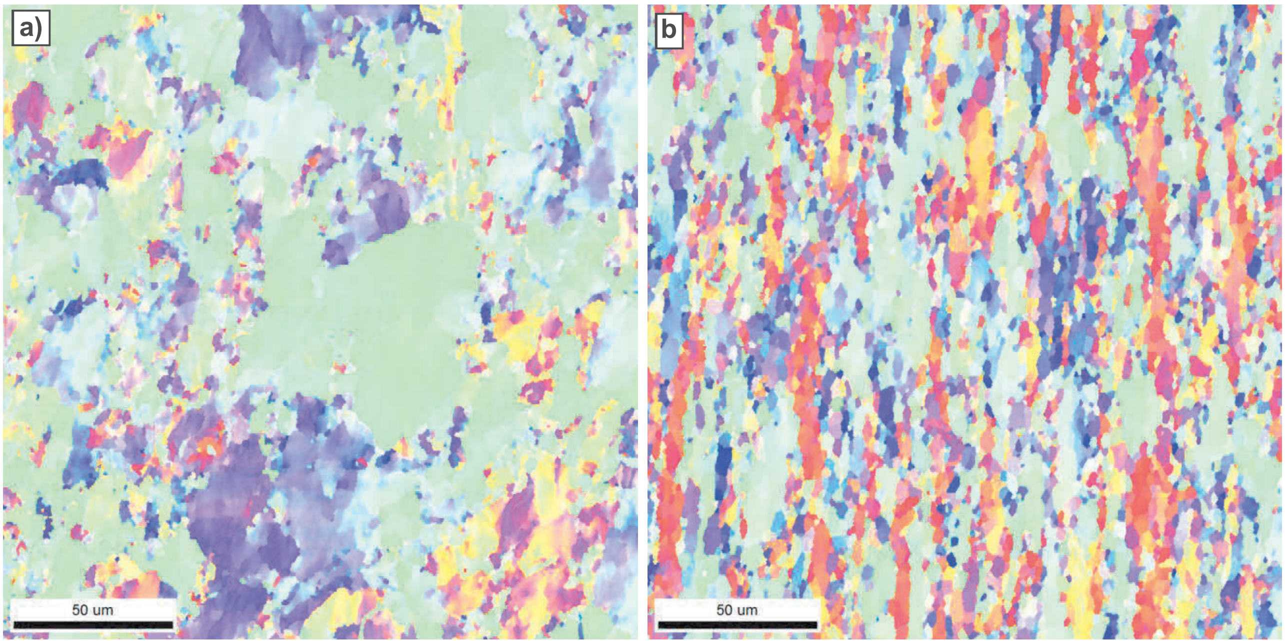


Figure 3 Microstructure image of the alloy deformed in torsion test with the strain rate of 1 s^{-1} at the temperature of a) 200 ºC; b) 400 ºC

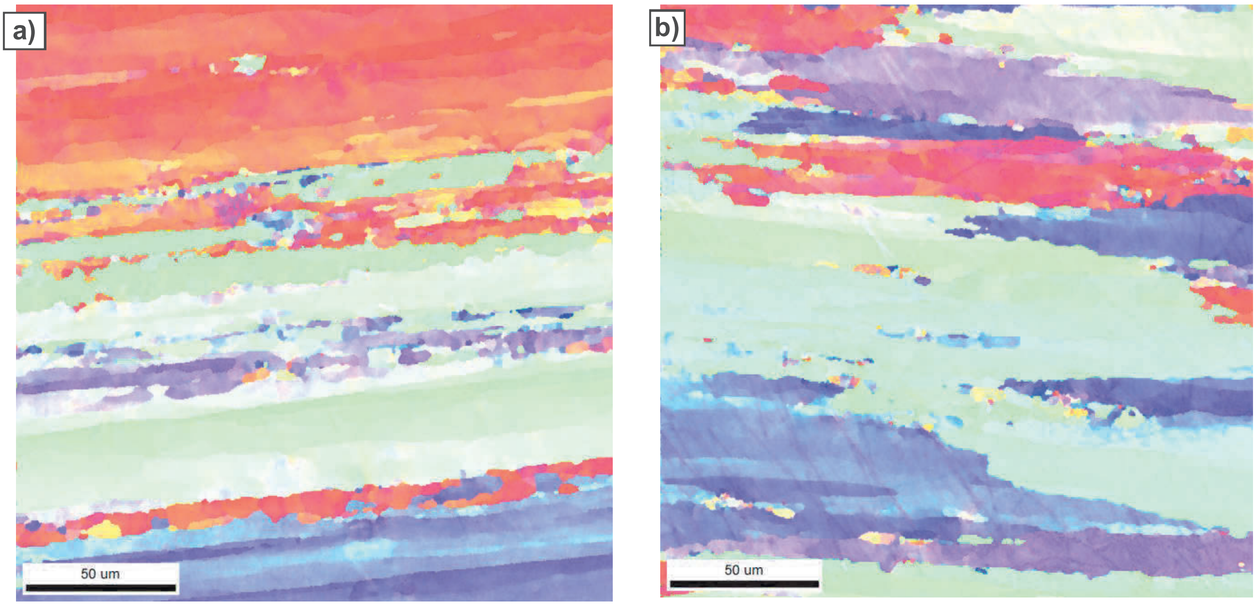
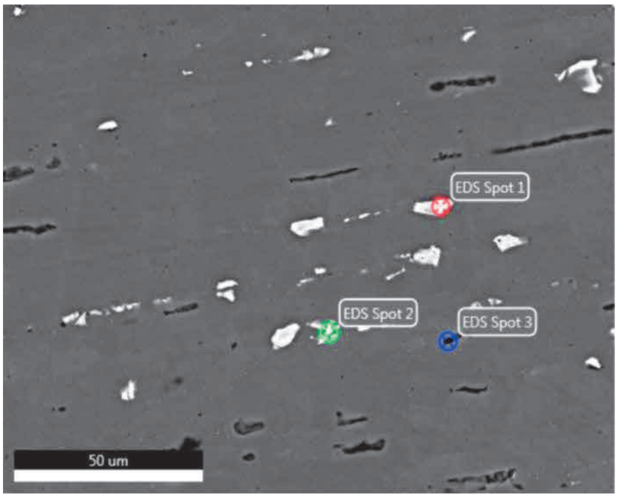


Figure 4 Microstructure image of the alloy deformed in simultaneous tensile and torsion test with the strain rate of 1 s^{-1} at the temperature of a) 200 °C; b) 400 °C

a)



b)

Element	Weight %	Atomic %
F K	2.46	4.11
MgK	0.61	0.79
AlK	62.64	73.58
SiK	4.19	4.73
CrK	2.12	1.29
MnK	2.24	1.29
FeK	20.12	11.42
CuK	4.03	2.01
ZnK	1.59	0.77

c)

Element	Weight %	Atomic %
MgK	5.43	6.27
AlK	79.04	82.29
SiK	8.27	8.27
CrK	0.19	0.1
CuK	1.49	0.66
ZnK	5.57	2.39

d)

Element	Weight %	Atomic %
F K	2.03	3.25
MgK	1.26	1.58
AlK	71.54	80.49
SiK	2.75	2.97
CrK	0.27	0.16
MnK	0.98	0.54
FeK	14.22	7.73
CuK	4.2	2.01
ZnK	2.74	1.27

Figure 5 Analysis of aluminum alloy 7075 microstructure a) SEM image; b) EDS analysis results for Spot 1; c) EDS analysis results for Spot 2 d) EDS analysis results for Spot 3

For verification of combined tensile and torsion test, a preliminary laboratory test of the rolling of investigated alloy were made in a three high skew rolling mill. During the process of deformation under such conditions there is a complex deformation pattern. The tests showed that the material at investigated temperature and speed range deforms satisfactorily, as shown in **Figure 6**.

Figure 6 Shape of the 7075 aluminum alloy bars obtained in three-high skew rolling mill

The structural examinations of the obtained finished bars were carried out within the study. The specimens were taken in cross section of the rolled bars. As the rolling process may lead to the formation of an inhomogeneous structure on the finished product, the analysis of the microstructure of finished bars was made in the central zone bar and in the edge zone of rolled bars. The obtained image of the alloy microstructure on the cross-section of the deformed bar is shown in **Figure 7**.

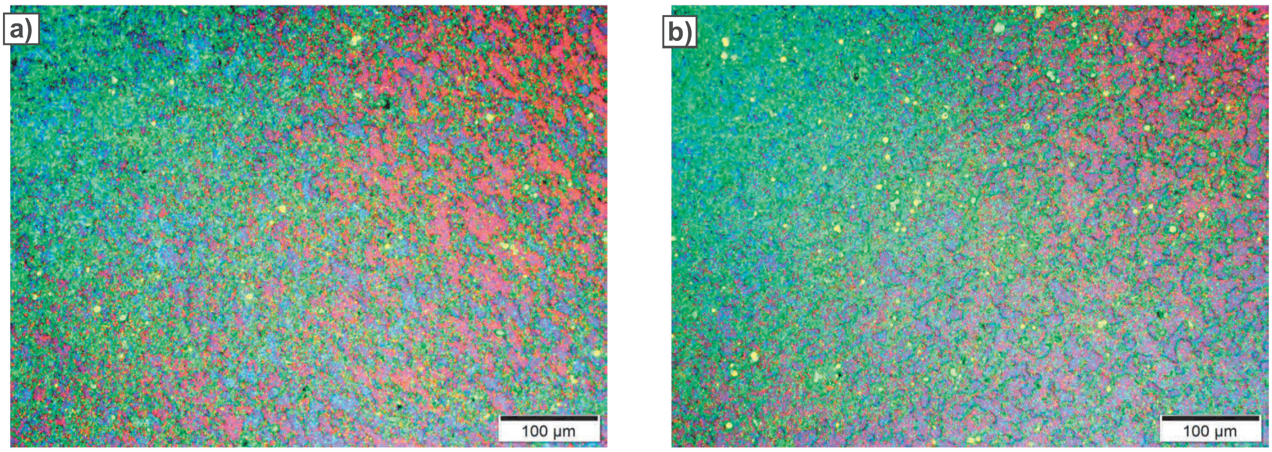


Figure 7 Structure of rod from 7075 alloy after rolling (from 26 mm to 22 mm) a) external layer of the rod; b) axis of the rod

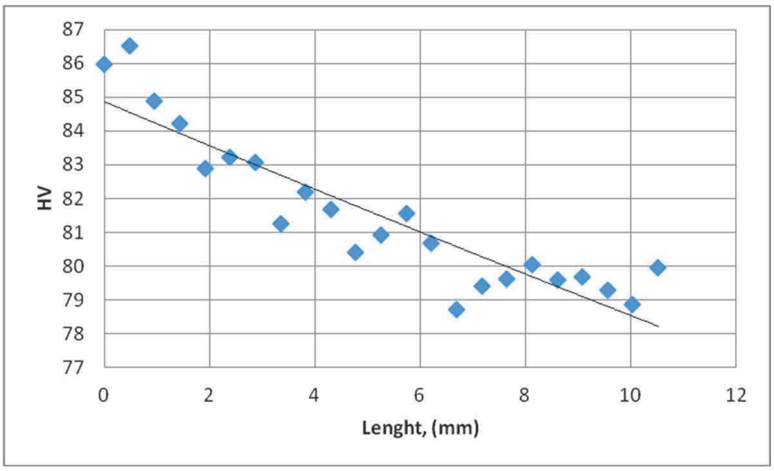


Figure 8 Hardness distribution of HV tested on bar cross section (half section)

Comparing the obtained images of the structures, it can be seen that the given strain did not result in homogeneous refining across the cross-section of the rolled rod. In the subsurface layer there are areas with finely divided grains, but larger grains are also visible, which is the result of the specificity of the rolling process in a three high skew rolling mill that manifests itself by appearing the relief on the surface of bars resulting from the rotation of the material during the rolling process. The microhardness tests conducted with the FM 700 microhardness tester/Japan FutureTech (**Figure 8**) using a load of 300 g showed that the hardness of the material in the surface layer was higher then in the axis of the bar. Measurement of hardness was made on the cross section of the half rod. The change in hardness shown in **Figure 8** is due to the different degree of grain fragmentation on the bar cross section during the rolling process.

4. CONCLUSION

This paper demonstrates the significant influence of the deformation path on the microstructure and the mechanical properties of the tested 7075 aluminum alloy. After the plasticity tests of the 7075 series aluminum alloy, it was found that the plastometric tests carried out showed the significant influence of the deformation scheme and temperature on the values of yield stress and the plasticity limit. The highest limiting strain value of 6.3 was obtained during the torsion test at temperature of 400 ºC and the strain rate of 1 s^{-1}. Conducting simultaneously the tensile and torsion tests reduced the mechanical properties of the alloy. This is also reflected in the analysis of the microstructure, where shear bands can be observed. The rolling test carried out in a three high skew rolling mill gave a satisfactory result. Presented results of theoretical and experimental studies may be the basis for the development of the rolling technology of 7075 aluminum alloy in a three high skew rolling mill in the industrial scale.

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