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HOT-ROLLING DEFORMATION BEHAVIOUR OF 7075 ALUMINIUM ALLOY

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This study investigates the influence of hot-rolling deformation behavior of 7075 aluminium alloy, regarding the different stage of deformation temperatures, deformation degree and the microstructural and mechanical properties of alloy. The alloy was preheated at three different temperatures (225°C, 350°C and 475°C) and deformed by hot rolling (HR) with a final deformation degree of 50%. The alloy was microstructurally investigated with SEM-BSE, SEM-EDS and optical microscopy and with regards to its mechanical properties by tensile and Charpy impact. With regards to the alloy structure, the results show that the phases/compounds were discovered, and after hot rolling deformation, the grains size are elongated and the most advantageous results for mechanical testing are related to the increase of the deformation temperature.

Keywords: rolling deformation, phases/compounds, microstructural and mechanical characteristics, deformation degree

1. Introduction

Alloy 7075 is an Aluminum alloy that has zinc as its main alloying element [1]. This alloy is used in a wide range of aeronautical products, from simple components to primary load-bearing structures, such as the Airbus A340 and Boeing 777. From 1940, 7075 alloys type began to be introduced in the construction of airplanes, their mechanical resistance being almost double that of the previously used alloys. It has excellent mechanical properties and exhibits good ductility, high strength, toughness, and good fatigue resistance [2]. Due to its high strength, low density, thermal properties and its ability to be highly polished, 7075 alloy is widely used in the manufacture of mold tools. The alloy is highly resistant to corrosion in different atmospheres, and it has a protective oxide layer which is generally stable [3]. Due to its good plasticity and malleability, the 7075 alloy can be deformed very well by hot rolling. Considering the specific case of 7075 alloy, several modern machining operations such as rolling, forging, extrusion, etc. can be used to apply a certain plastic deformation. Also, several

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heat treatment operations such as annealing, quenching, aging, etc. can be used All of this are capable to inducing changes in the microstructure of the alloy and, therefore, changes in the mechanical behavior of the alloy [4].

2. Experiments

The objective of this experiment was to have a better understanding of how to properly process 7075 alloy, using different thermomechanical processing parameters and quantify the induced effects on the microstructure of the alloy and its mechanical behavior; to use various investigation techniques, such us electron microscopy for microstructural properties, tensile and resilience testing for mechanical characteristics; to optimize the final microstructural and mechanical characteristics of the 7075 alloy. To achieve the objective, test specimens were cut and scalp to the following dimensions: 12 x 70 x 120 mm (h x l x L), to be investigated.

The 7075 alloy selected for the present study has the following nominal chemical composition:

Table 1

Zn, %gr	Mg, %gr	Cu, %gr	Fe, %gr	Cr, %gr	Si, %gr	Mn, %gr	Ti, %gr	V, %gr	Al, %gr
5,57	2,38	1,38	0,25	0,19	0,16	0,095	0,029	0,01	rest

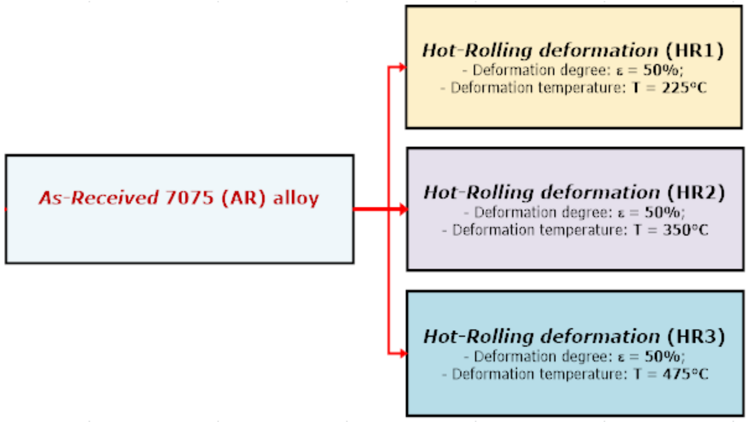
The most important chemical elements on the composition of the 7075 alloy is zinc (5.57%), magnesium (2.38%), copper (1.38%) and bellow one percent are: iron, chromium, silicon, manganese, titanium and vanadium.

The zinc in aluminum is large at high temperatures, therefore the expectation is high regarding the good age hardening capacity. Magnesium addition has benefits in terms of age hardening. The addition of copper is normally considered as favourable to reduce or prevent stress corrosion cracking [5].

An experimental program was realized on alloy 7075 as follows.

Before deformation, the samples were heated to the nominal deformation processing temperature, after removing the samples from the furnace, the samples were subjected to hot deformation (HD) by rolling, using a duo rolling mill ∅180 x 150 mm. The total reduction of 50% applied degree produces structural changes and the variation of their mechanical properties.

Three different rolling temperatures (225°C, 350°C and 450°C) were used in the experiments. The thickness of the hot-formed samples decreased during deformation, from 12 mm to 6 mm.



Legend: AR – As Received; HR1 – Hot Rolling deformation at 225°C; HR2 – Hot Rolling deformation at 350°C; HR3 – Hot Rolling deformation at 475°C; ε – deformation degree.

Fig.1. Thermomechanical processing scheme applied to 7075 alloy

By applying such a processing route, the microstructure evolution of 7075 alloy can be investigated in the complex space of thermomechanical processing conditions, which can provide important observations/clues in understanding the microstructural evolution during thermomechanical processing.

The alloying elements dispersion was determined by Energy Dispersive Spectroscopy (EDS) using a BRUKER xFlash® 6/30 EDS detector connected with a Scanning Electron Microscopy (SEM) - TESCAN VEGA II – XMU (TESCAN, Brno, Czech Republic).

On the other hand, the alloy's phase analysis was performed using a backscattered electrons (SEM-BSE) analysis, at raises one hundred times, in order to understand the influence of thermomechanical processing conditions on the exhibited microstructure of this alloy.

Microstructure tests were performed on an Olympus BX53M optical microscope and Stream Essentials 2.1 image analysis system. Tensile strength (Rm), yield strength ($Rp_{0.2}$) and elongation (A_{50}) tests were performed at room temperature using a Zwick 250 kN static mechanical testing machine.

The alloy's microstructure analysis is completed with X-ray diffraction (XRD) investigations. The XRD investigations were performed using a Malvern Panalytical Empyrean diffractometer. The XRD investigations allowed rapid phase identification.

Mechanical tests for resilience were performed on a Charpy impact test hammer.

Regarding the tensile test and Charpy impact test, for each sample are test another one and mediate the data to have an accuracy of the results.

3. Results

The results obtained in the experiment consisted in: optical microstructural analysis of all the processed samples, backscattered electron microscopy and dispersive spectroscopy of the as-received sample, the discovery of the phases/compounds in the 7075 alloy analyzed by X-ray diffraction and the analysis of the results obtained in the mechanical properties of all processed samples.

3.1. Microstructural characterization for AR (As-received) samples.

The XRD analysis on the alloy 7075 in its initial state (AR) (fig. 2), showed that the following phases and compounds are present in its microstructure: α-Al, phase - η ($MgZn_2$); phase - S (Al_2CuMg); phase - T ($Al_2Mg_3Zn_3$); phase - θ (Al_2Cu_3) and intermetallic compounds of the Al-Mn-Cr-Fe type: $Al_6(Fe,Mn)$, $Al_5Si_2(Fe,Mn)$, $Al_3(Fe,Mn,Cr)$, etc.. Also, the XRD analysis shows that the majority phase present is constituted by the basic phase α-Al.

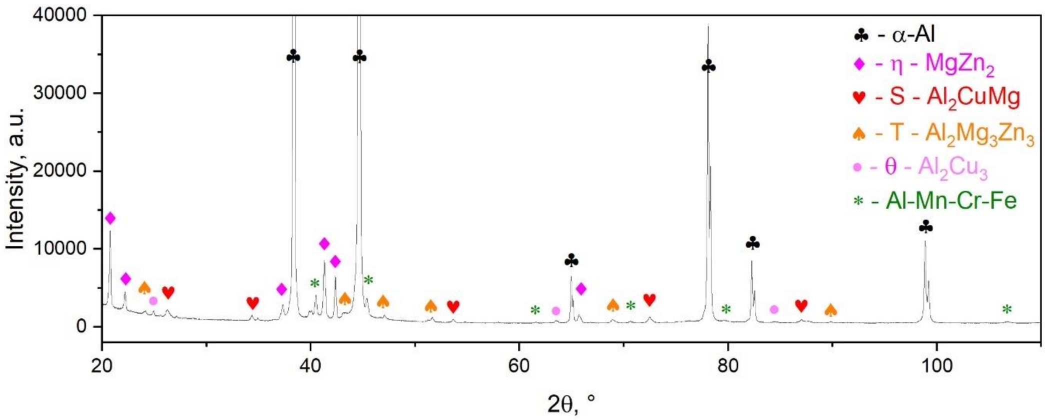
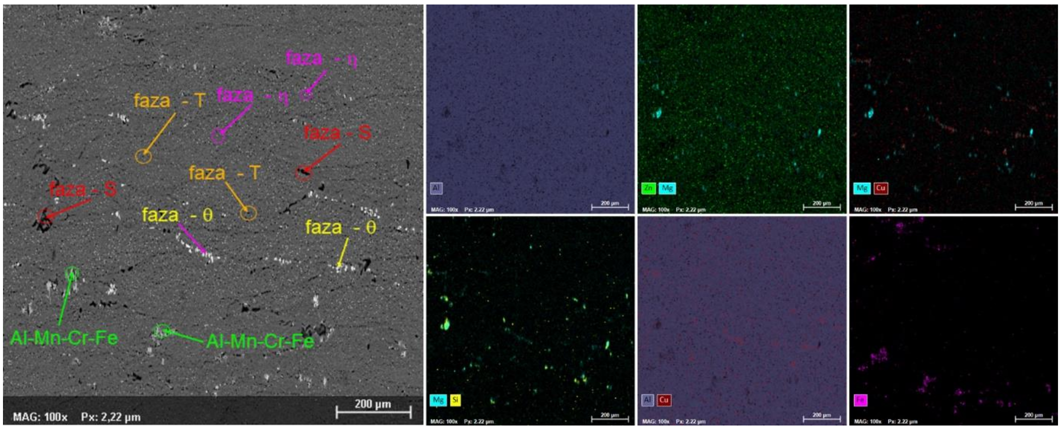


Fig.2. XRD spectra of as-received (AR) 7075 alloy

The analysis of the microstructure on the alloy 7075 in the initial state (AR) are based on scanning electron microscopy SEM (fig. 3-a) who confirms the observations resulting from the XRD analysis, showing that in the base mass (the α-Al phase) a series of secondary phases and compounds are present dispersed, as follows: phase - η ($MgZn_2$); phase - S (Al_2CuMg); phase - T ($Al_2Mg_3Zn_3$); phase - θ (Al_2Cu_3) and intermetallic compounds of the Al-Mn-Cr-Fe type. It is also observed that the secondary phases η ($MgZn_2$) and T ($Al_2Mg_3Zn_3$) show a spheroidal morphology and submicron size, while the phases S (Al_2CuMg), θ

(Al_2Cu_3) and Al-Mn-Cr-Fe type intermetallic compounds show a spheroidal/elongate morphology and micron size.

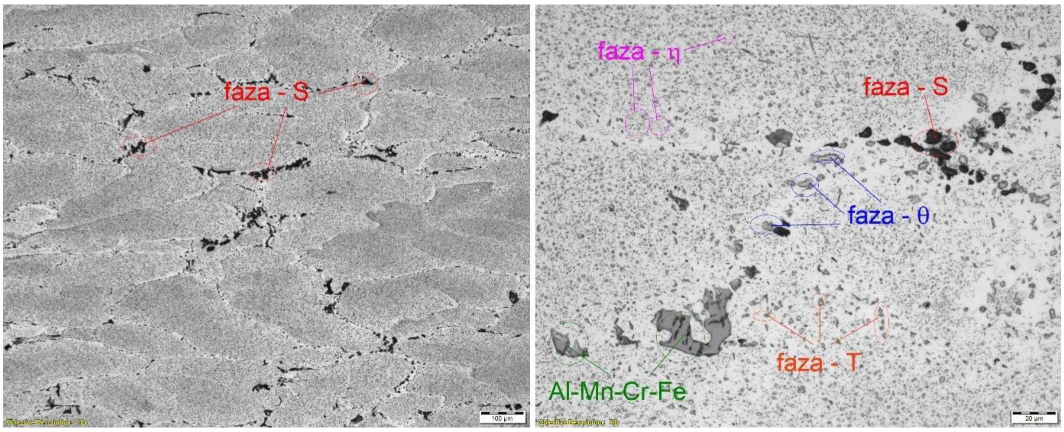
In Fig. 3-b it can be seen the EDS analysis of the dispersion maps who also indicates the presence of main constituent phases tinted with different colors: Al (coloured in blue), Zn (coloured in green), Mg (coloured in turquoise), Cu (coloured in red), Si (coloured in yellow) and Fe (coloured in pink).



a) b)

Fig.3. SEM image of the microstructure of alloy 7075 in the initial state (AR) – a ; dispersion of the main alloying elements in the base mass – b.

Analysis of the microstructure on the alloy 7075 in the initial state (AR) using optical microscopy (fig. 4) confirms the observations resulting from XRD analysis and SEM electron microscopy. Also, in this case it is observed that in the grains of the base mass (the α-Al phase) the phases η ($MgZn_2$) and T ($Al_2Mg_3Zn_3$) are present dispersed, while at the grain boundary the phases S (Al_2CuMg), θ (Al_2Cu_3) and intermetallic compounds of the Al-Mn-Cr-Fe type are present. Optical microscopy also confirms that the secondary phases η ($MgZn_2$) and T ($Al_2Mg_3Zn_3$) show a spheroidal morphology and submicron size, while the phases S (Al_2CuMg), θ (Al_2Cu_3) and Al-Mn-Cr-Fe type intermetallic compounds show a chunky/elongated morphology and micron size.



a) b)

Fig.4. Optical microscopy image for the microstructure of alloy 7075 in the initial state (AR); a: X100 ; b: X500.

3.2. Microstructural characterization for HR (Hot rolling) samples

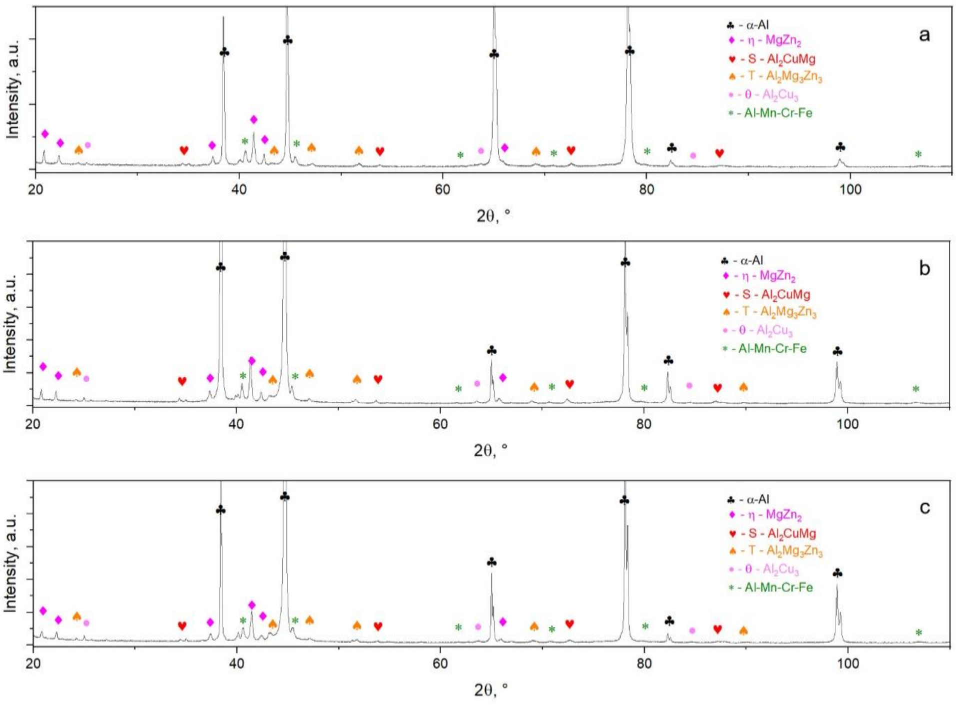


Fig.5. XRD spectra related to alloy 7075 plastically deformed at temperatures of 225°C (HR1) - a, 350°C (HR2) - b and 475°C (HR3) - c.

The XRD analysis on the 7075 alloy in a deformed state at different temperatures: 225°C (HR1) - a, 350°C (HR2) - b, and 475°C (HR3) - c. (Fig. 4.5), showed that in the following phases and compounds are present in its microstructure: α-Al, phase - η ($MgZn_2$); phase - S (Al_2CuMg); phase - T ($Al_2Mg_3Zn_3$); phase - θ (Al_2Cu_3) and intermetallic compounds of the Al-Mn-Cr-Fe type: Al_6(Fe,Mn), Al_5Si_2(Fe,Mn), Al_3(Fe,Mn,Cr), etc.. Also, the XRD analysis shows that the majority phase present is constituted by the basic phase α-Al.

Table 2

Crystal parameter / Structural condition	HR1	HR2	HR3
Crystal lattice parameter α-Al; a [Å]	4,0539(8)	4,0547(3)	4,055(2)
Mean size coherent crystalline domain α-Al, A [Å]	506(49)	840(27)	917(28)
Residual strain elementary cell α-Al, ε [%]	0,069(4)	0,06(2)	0,060(3)

The crystallographic parameters of the basic α-Al phase related to the hot plastic deformed alloy 7075 at the temperature of 225°C (HR1), 350°C (HR2) and 475°C (HR3) were established according to table 2.

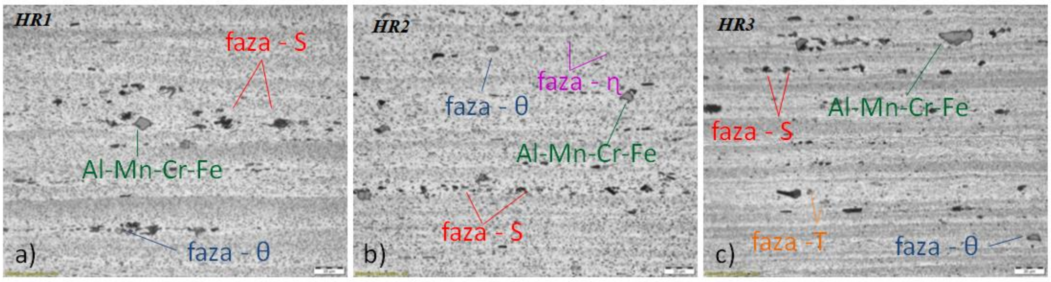


Fig.6. Optical microscopy images for microstructure of alloy 7075 in the deformed state at different temperatures: 225°C – HR1 (a), 350°C – HR2 (b) și 475°C – HR3 (c).

Fig. 6 shows the optical microstructure at 500 times raises of the primary sample (AR-As received), hot rolled at 225°C (HR1), hot rolled at 350°C (HR2) and hot rolled at 475°C (HR3).

It can be seen that the phases S (Al2CuMg), θ (Al2Cu3) and intermetallic compounds of the Al-Mn-Cr-Fe type are present and uniformly distributed at the grain boundary. At the HR3 sample, a greater deformation of the texture of the grain colonies can be observed along the rolling direction compared to the case of hot deformation HR1 and HR2.

With regards to the alloy structure, the results show, after hot rolling deformation the grain size are elongated.

3.3 Mechanical characterization for AR and HR (Hot rolling) samples.

Regarding the analyzed samples, it is confirmed that for each sample tested, one more sample was additionally tested, the table 3 containing the values obtained from the arithmetic mean of the results of the two samples. This double testing was done for better data accuracy.

By designing the strain-stress curve obtained from tensile tests for the case of the initial thermomechanically processed sample, the following mechanical properties were determined: ultimate tensile strength (Rm), yield strength ($Rp_{0.2}$), elongation(A_{50}), Charpy impact testing (J and KVC).

In table 3, the obtained results for mechanical properties are presented centralized:

Table 3

Sample name	**Mechanical properties**				
	Tensile testing			***Charpy impact testing***	
	Ultimate tensile strenght, Rm [MPa]	Yield strenght, $Rp_{0.2}$ [MPa]	Elongation, A_{50} [%]	Absorbed energy, E [J]	Elasticity, KCV [j/cm^2]
AR	261	144,5	17,2	6,6	16
HR1	295	249	6,5	5,9	15
HR2	261	207	10	6	16
HR3	344	215	16	6.5	17

Fig. 7 shows the appearance of the resulting typical stress-strain curves. It is observed that the 7075 alloy in as- received state (AR) and hot rolling state (HR) has a high ductility, the elongation at break having a high value (15-20)%. It is also observed that the ultimate strength limit exceeds the value/threshold of 300MPa.

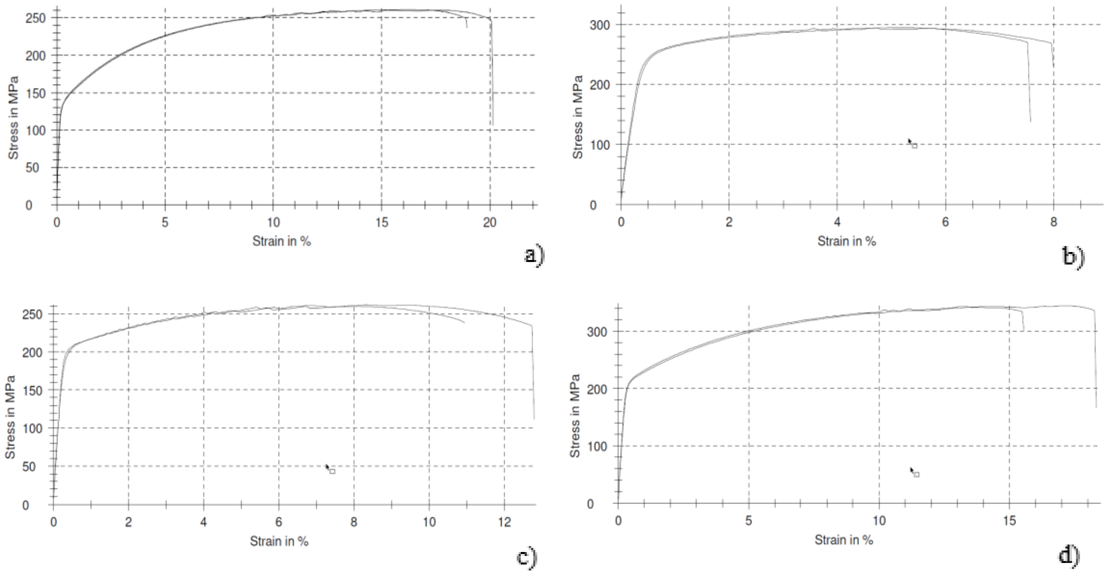


Fig.7. Typical strain-stress curves for alloy 7075 in the initial state – AR (a) and deformed by rolling at 225°C – HR1 (b), 350°C – HR2 (c) and 475°C – HR3 (d).

The numerical results obtained were represented in graphic form for the visual synthesis of the differences obtained in the experimental program.

Mechanical properties evolution graph are presented in fig.8 as it follows. Starting with the mechanical tensile strength test (Fig.8a), values in the range of 261-344 MPa were obtained, the most advantageous value being obtained for the hot plastic deformed sample at the temperature of 475°C (HR3). From the graph presented, it can be seen that the mechanical strength properties increased considerably with the increase of the rolling temperature.

When testing the yield strength (Fig. b), values in the range of 144.5-249 MPa were obtained, the most advantageous value being obtained for the hot plastic deformed sample at a temperature of 225°C (HR1). Analyzing the values obtained, it is found that the hot plastic deformation increases the properties of the yield point, the low rolling temperatures being clearly favorable to the increase of the yield point. In the elongation test (Fig.8c), values in the range of 6.5-17.2% were obtained, the most advantageous value being obtained in the AR (As-received) sample.

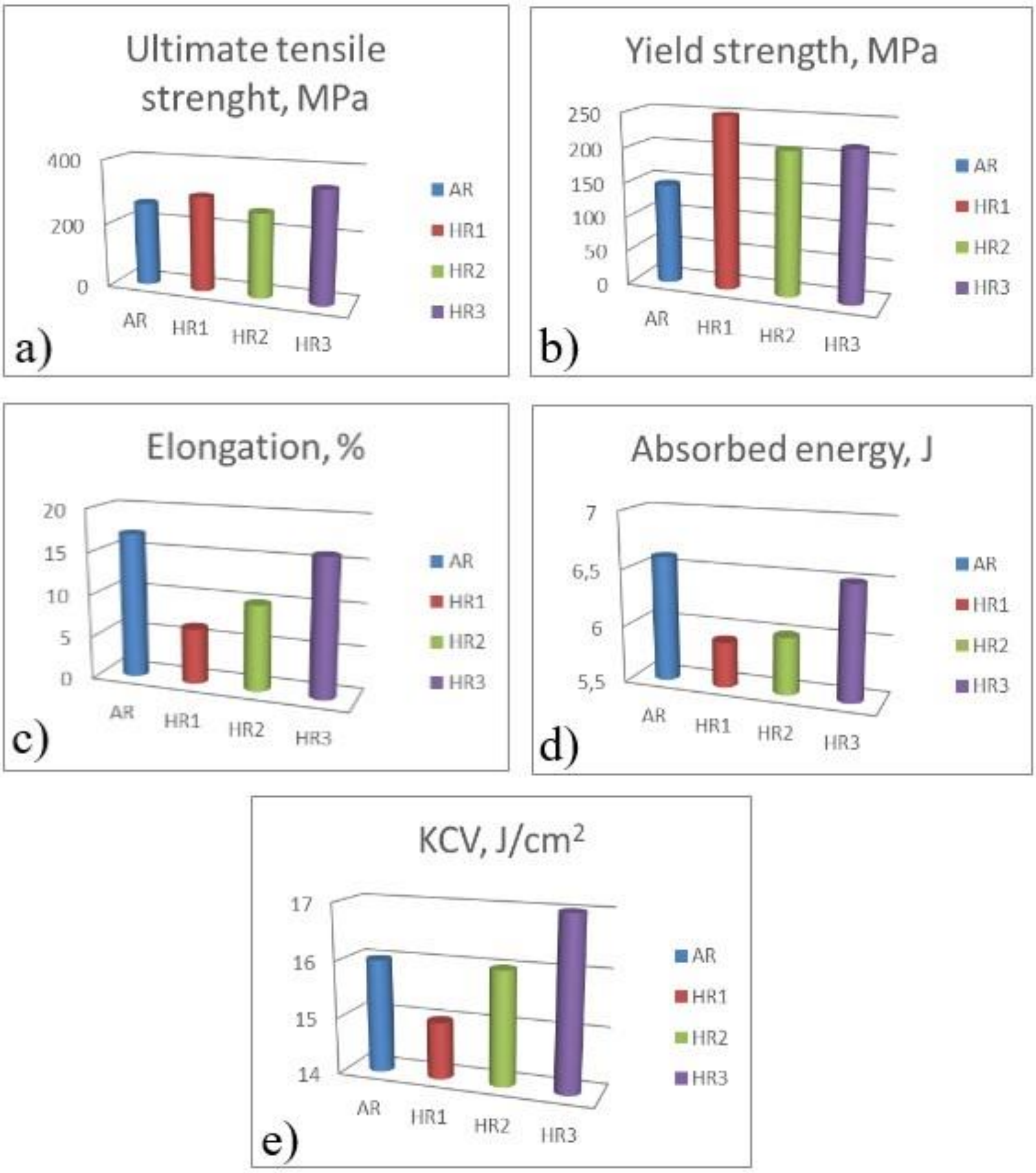


Fig.8. The evolution graphs of the mechanical properties are analyzed separately as follows: a) Ultimate tensile strenght (MPa); b) Yield strenght (MPa); c) Elongation (%); d) Absorbed energy (J); e) KCV (J/cm²).

The analysis shows that the sample without thermomechanical process has a higher value. With the increase of the hot plastic deformation temperature, the elongation values improve, therefore it can be concluded that an important factor for the improvement of the plasticity of the material is the increase the temperature of hot plastic deformation.

For the *absorbed energy* test (Fig.8d), values in the range of 5.9-6.6 (J) were obtained, the most advantageous value being obtained for the AR (As-received) sample. The analysis shows that the sample without thermomechanical process (sample in initial state - AR) has a higher value and in the immediate vicinity with a very close value is the sample thermomechanically processed at higher temperatures (HR3). With the increase of temperature during hot plastic deformation, the values for absorbed energy improve. When testing resilience, for the *elasticity test* (Fig.e) close values were obtained in the range of 15-17 J/cm², the most advantageous value being obtained for the hot plastic deformed sample at a temperature of 475°C (HR3). With the increase in the temperature of hot plastic deformation, the elasticity values improve. It can be concluded that an important factor for improving the resilience of the material is the increase of the hot plastic deformation temperature.

4. Conclusions

Following conclusions are drawn from the present investigation:

- The analysis of the optical microstructure of the 7075 alloy in the hot plastically deformed state (HR) confirms the observations resulting from the XRD analysis and SEM electron microscopy, the following secondary phases in the grains of the base mass (the α-Al phase) being observed in this case as well: the phase - η (MgZn2); phase - S (Al2CuMg); phase - T (Al2Mg3Zn3); phase - θ (Al2Cu3) and intermetallic compounds of the Al-Mn-Cr-Fe type;
- As the hot plastic deformation temperature increases, the phases and compounds in the 7075 alloy base mass change their shape, size and dispersion.
- After analyzing the stress-strain curves, it is found that the 7075 alloy in the as-received (AR) state and hot rolling (HR) state has a high ductility, the elongation at break having a high value (15-20)%, it is also observed that the maximum strength limit exceeds the value/threshold of 300Mpa;
- The microstructure of 7075 alloy consists of the following phases/compounds: Al, $MgZn_2$, Cu_2Mg, Mg_2Si, Al_2Cu, Fe_2O_4;
- The most advantageous values have been obtained for ultimate tensile strenght /RM = 344 MPa, for the sample HR3 (Hot-rolled: T = 475°C;ε = 50%);

- The most advantageous values have been obtained for yield strength /$Rp_{0.2}$ = 249 MPa, for the sample HR1 (Hot-rolled: T = 225°C; ε = 50%);
- The most advantageous values have been obtained for elongation/ A50 = 17%, for the sample AR;
- The most advantageous values have been obtained for absorbed energy/ E = 6.6 J, for the sample AR;
- The most advantageous values have been obtained for Elasticity/ KCV = 17 J/cm^2 for the sample HR3 (Hot-rolled: T = 475°C; ε = 50%);
- As it can be seen from the analyzed results, with the increase temperature in the hot deformation, the results of the mechanical tests improved considerably.

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R E F E R E N C E S

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