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SIMULTANEOUS INFLUENCE OF ROLLING TEMPERATURE AND SOLUBILIZATION QUENCHING CONDITIONS ON STRUCTURE AND PROPERTIES OF A ZICRAL TYPE ALUMINUM ALLOY (CLASS 7075)

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This study investigates the influence of solubilization quenching behavior of 7075 aluminium alloy, regarding the different stage of heat temperatures, the microstructural and mechanical properties. The samples were heated at three different temperatures (450°C, 475°C and 500°C) and sudden quenching in water. The samples were microstructurally investigated by optical microscopy and by 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 the increase of solution heat treatment temperature influences the mechanical behavior.

Keywords: Zicral, hot rolling, solubilization quenching, mechanical properties.

1. Introduction

Introduced by Alcoa in 1943, alloy 7075 has been the standard workhorse 7XXX series within the aerospace industry ever since. It was the first successful Al-Zn-Mg-Cu high strength alloy using the beneficial effects of the alloying addition of chromium to develop good stress-corrosion cracking resistance in sheet products. Although other 7XXX alloys have since been developed with improved specific properties, alloy 7075 remains the baseline with a good balance of properties required for aerospace applications. [1].

Alloy 7075 contains zinc as its main alloying element. 7075 is one of the strongest Aluminum alloys available, making it valuable in high-stress situations [2]. Its high yield strength and its low density make the material a fit for applications such as aircraft parts or parts subject to heavy wear.

The addition of magnesium to the aluminum-zinc alloys develops the strength potential of this alloy system, especially in the range of 3 to 7.5% Zn. Magnesium and zinc form $MgZn_2$, which produces a far greater response to heat treatment than occurs in the system.

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The addition of Copper to the Aluminum-Zinc-Magnesium system, together with small but important amounts of Chromium and Manganese, results in the highest-strength Aluminum-base alloys commercially available. In this alloy system, Zinc and Magnesium control the aging process. The effect of Copper is to increase the aging rate by increasing the degree of supersaturation and perhaps through nucleation of the $CuMgAl_2$ phase. Copper also increases quench sensitivity upon heat treatment. In general, Copper reduces the resistance to general corrosion of Aluminum-Zinc-Magnesium alloys, but increases the resistance to stress corrosion. The minor alloy additions, such as Chromium and Zirconium, have a marked effect on mechanical properties and corrosion resistance [3,4,5].

Some major applications of 7075 aluminum alloy include: aircraft fittings, gears and shafts, missile parts, regulating valve parts, worm gears, aerospace/defense applications [6,7] .

Many heat treatments and heat-treating practices are available to develop optimum strength, toughness and other desirable characteristics for proper application of alloy 7075 [8].

Heat treatment operations such as annealing, quenching, aging, can be used and they all have the capacity to induce changes in the microstructure of the alloy and, therefore, changes in the mechanical behavior of the alloy [9].

2. Experiments

The objective of this experiment was to have a better understanding of how the solubilization quenching influences the microstructure and the mechanical properties of the 7075 alloy; to use various investigation techniques, such us optical microscopy for microstructural properties, tensile and resilience testing for mechanical characteristics. For this target to be achieve, samples were cut 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:

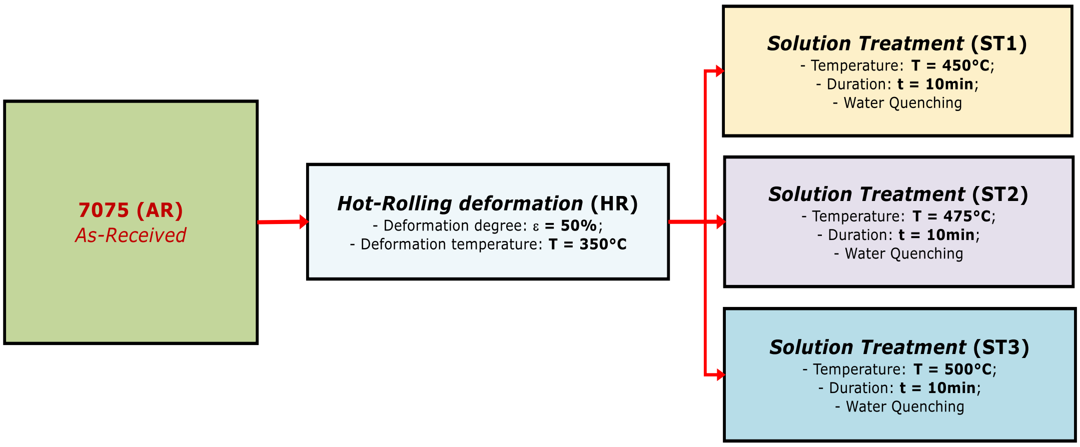
Table 1

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

Legend: Zn – Zinc, Mg – Magnesium, Cu – Copper, Fe – Iron, Cr – Chromium, Si – Silicon, Mn – Manganese, Ti – Titanium, V – Vanadium, Al – Aluminium.

The basic element in the chemical composition of this alloy is Zinc (5.57%), followed by Magnesium (2.38%), Copper (1.38%) and less than one percent are: Iron, Chromium, Silicon, Manganese, Titanium and Vanadium.

An experimental program was realized on alloy 7075:



Legend: AR – As Received; HR – Hot Rolling deformation at 350°C; ST1 – Solution Treatment at 450°C; ST2 – Solution Treatment at 475°C; ST3– Solution Treatment at 500°C. .

Fig.1 Thermomechanical processing scheme applied to 7075 alloy.

The samples was hot deformation (HD) by rolling at the 350°C , using a duo rolling mill ∅180 x 150 mm, with a maximum reduction of 50%. The thickness of the hot-formed samples decreased during deformation, from 12 mm to 6 mm.

After the rolling, the samples were heated at three different temperatures 450°C–ST1; 475°C–ST2; 500°C–ST3) and quenched in water. The duration of soaking time was 10 minutes for each sample.

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.

Microstructure tests were performed on an Olympus BX53M optical microscope and Stream Essentials 2.1 images 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 by 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: the optical microstructural analysis of all the processed samples, the discovery of the phases/compounds in the 7075 alloy (Zicral) analyzed by X-ray diffraction and the analysis of the results obtained in the mechanical properties of all processed samples.

The 7075 alloy in hot plastic state (Hot Rolling - HR) at 375°C (structural status - HR) and subjected to solubilization quenching at 3 different stages of temperatures: 450°C (structural status - ST1), 475°C (structural status - ST2) and 500°C (structural status – ST3) was characterized from a microstructural point of view. Microstructural characterization was performed using optical microscopy (OM).

Fig. 2 is represented by an evolutionary scheme of optical microscopy after hot plastic deformation at the temperature of 350°C with a deformation degree of 50%, solubilization quenching at three different temperatures (450°C; 475°C ; 500°C).

It can be seen that in the base mass (the Al phase) a number of secondary phases and compounds are present dispersed. As the solution heat temperature increases, the phases and compounds in the base mass of alloy 7075 change their shape, size and dispersion.

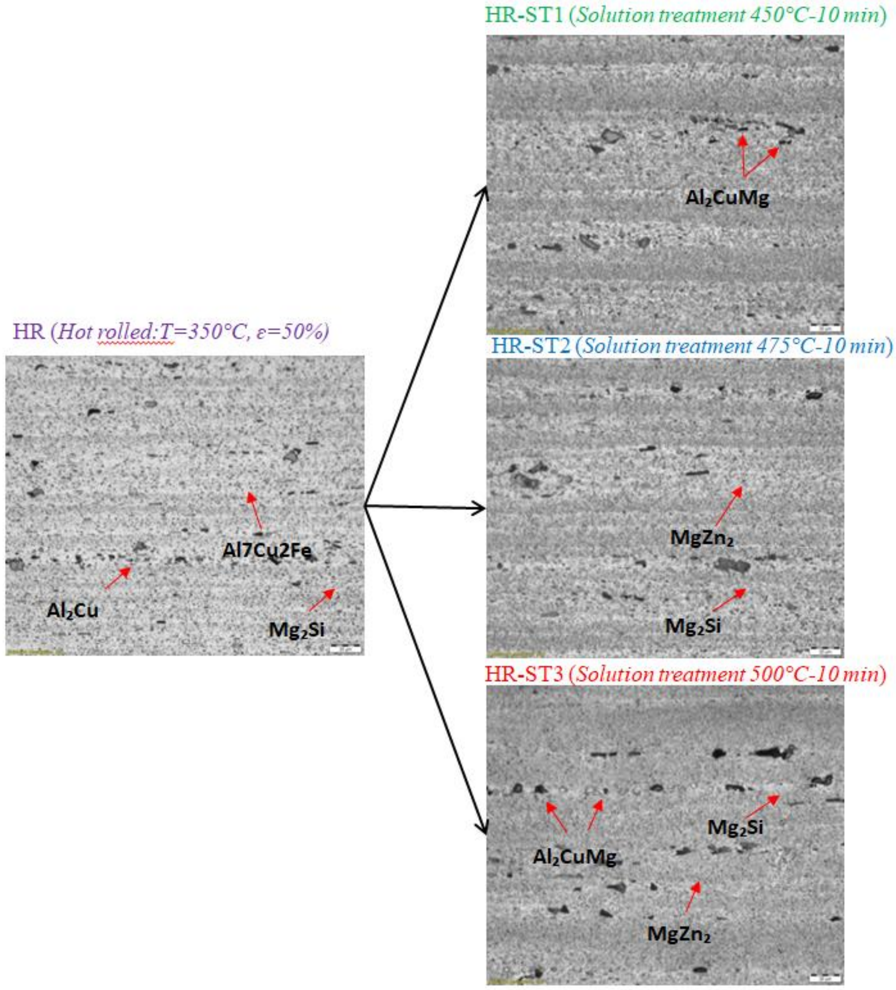


Fig.2 Optical microstructure of sample HR, HR-ST1, HR-ST2, HR-ST3. 500X raises

The Figs. show the optical microstructure at 500 times raises of the hot rolled at 350°C (HR), solubilization quenching at 450°C (HR-ST1), solubilization quenching at 475°C (HR-ST2) and solubilization quenching at 500°C (HR-ST3).

It can be seen that the phases Mg_2Si, Al_7Cu_2Fe, $MgZn_2$ and Al_2CuMg are uniformly distributed at the grain boundary. Mg_2Si and Al_7Cu_2Fe are shattered and elongated, $MgZn_2$ and Al_2CuMg are smaller particles. After heated to different temperatures the Mg_2Si, Al_7Cu_2Fe, $MgZn_2$ and Al_2CuMg phases are broken, rounded and uniformly distributed through all the mass of the analyzed samples.

With regards to the alloy structure, the results show that after hot rolling deformation the grain sizes are elongated in the rolling direction.

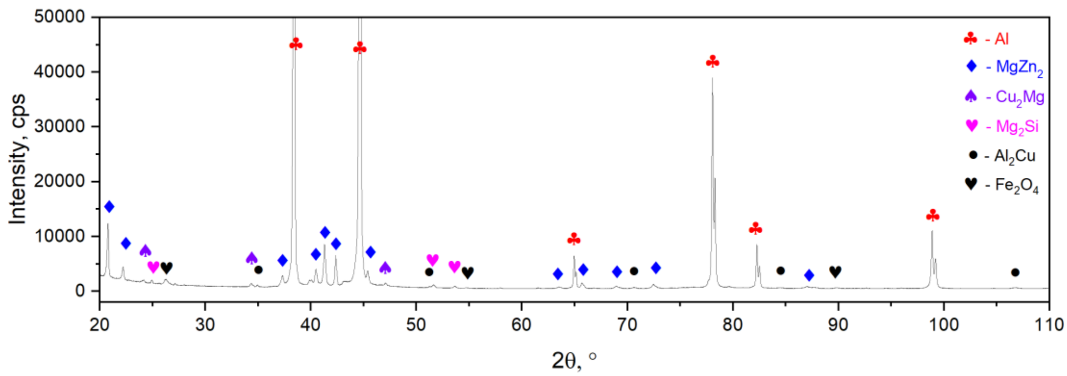


Fig.3 XRD spectra of as-received (AR) 7075 alloy

Through the XRD analysis (see Fig.3), the microstructure of alloy 7075 was identified, which consists of the following phases/compounds: Al, $MgZn_2$, Cu_2Mg, Mg_2Si, Al_2Cu, Fe_2O_4. It is observed that the majority phase remains the basic Al phase.

Results:

Nr	Sample ID	Rm MPa	Rp 0.2 MPa	$A_{50\,mm}$ %	Thickness a0 mm	Width b0 mm	L0 mm
1	2.6.1	256	196	11.0	4.99	9.85	30.00
2	2.6.2	258	197	11.5	4.98	9.94	30.00

Series graph:

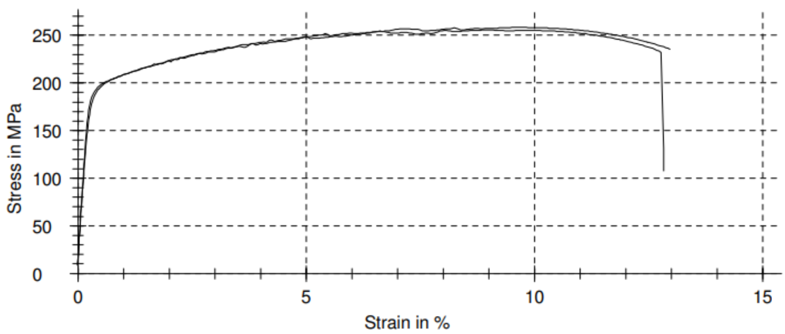


Fig.4. Strain-stress curve for the HR-ST2 sample

Fig. 4 shows the appearance of the resulting typical stress-strain curves. It is observed that the 7075 alloy in hot rolling (HR) has a high ductility, the elongation at break having a value between 12-14%. It is also observed that the ultimate strength limit exceeds the value/threshold of 250 MPa.

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 2, the obtained results for mechanical properties are presented centralized:

Table 2

Mechanical Properties

Sample name	Mechanical properties				
	Tensile testing			*Charpy impact testing*	
	Rm [MPa]	**$Rp_{0.2}$** [MPa]	**A_{50}** [%]	**E** [J]	**KCV** [j/cm^2]
Hot-rolled: T=350°C;ε=50% (HR)	261.0	206.5	10.0	6.0	15.5
Solution treated: T=450°C-10 min -WQ (HR-ST1)	260.5	203.5	10.8	7.6	19.0
Solution treated: T=475°C-10 min -WQ (HR-ST2)	257.0	196.5	11.3	8.2	20.5
Solution treated: T=500°C-10 min -WQ (HR-ST3)	245.5	188.0	9.8	9.2	22.5

Regarding the analyzed samples, it is confirmed that for each tested sample, one more sample was additionally tested, and table 2 contains the obtained values from the arithmetic mean of the results of the two samples. This double testing was done for better data accuracy.
The numerical results obtained were represented in graphic form for the visual synthesis of the differences obtained in the experimental program.

Mechanical properties evolution graphs are presented as follows.
In the graphs made for the mechanical tests of the experimental program, the increasing or decreasing trends of the results can be identified depending on the imposed thermomechanical processing, as well as the highlighting of the differences between the highest value and the other smaller ones with cylinder-type data markers in different colors.

Starting with the *mechanical tensile strength test* (Fig. a), values in the range of 245.5-361 MPa were obtained, the most advantageous value being obtained for the hot plastic deformed sample at a temperature of 350°C (HR). From the presented graph, it can be seen that the mechanical strength properties decreased considerably with the increase of solubilization quenching temperature.

When testing the *yield strength* (Fig. b), values in the range of 188-206.5 MPa were obtained, the most advantageous value being obtained for the hot plastic deformed sample at a temperature of 350°C (HR).

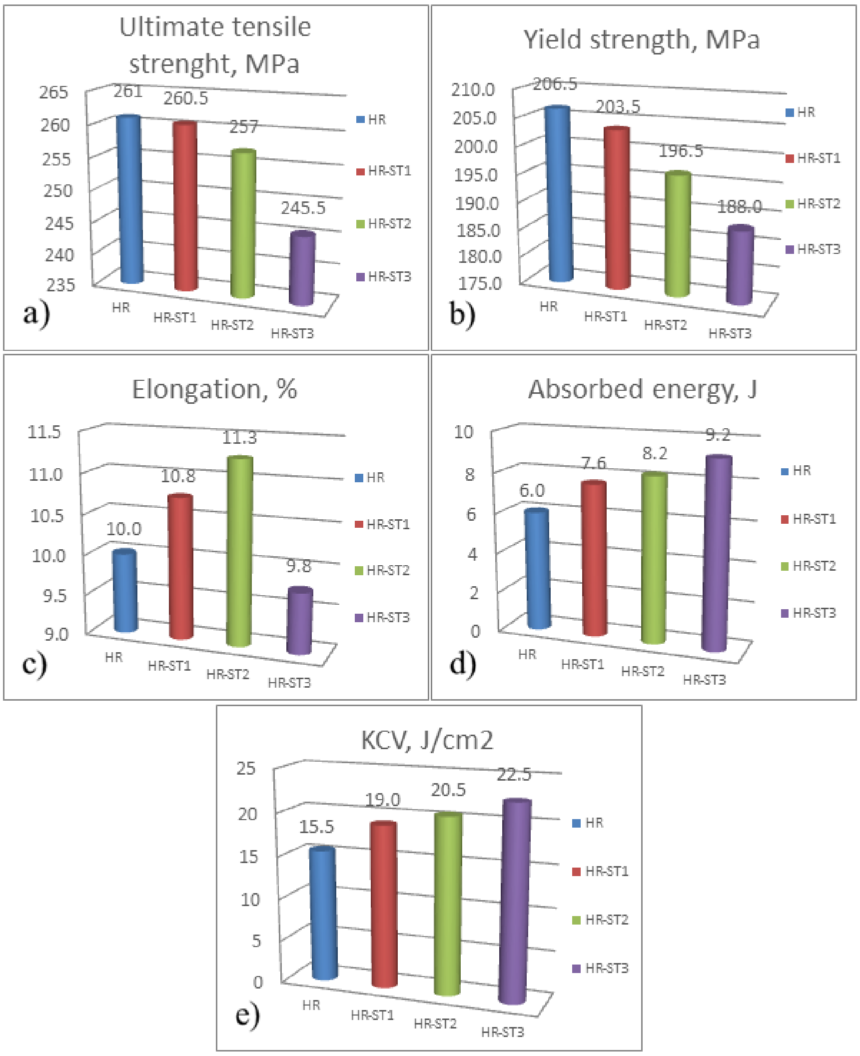


Fig.5. The evolution graphs of the mechanical properties are separately analyzed as follows: a) Ultimate tensile strenght (Mpa); b) Yield strenght (Mpa); c) Elongation (%); d) Absorbed energy (J); e) KCV (J/cm²)

Analyzing the obtained values, it is found that the hot plastic deformation increases the properties of the yield point, and after solubilization quenching a decrease in the values is observed as the treatment temperature increases.

In the *elongation* test (Fig. c), values in the range of 9.8-11.3% were obtained, the most advantageous value being obtained in the sample HR-ST2 (solubilization qunching treatment at 475°C). For elongation, it is observed that the best treatment is at 475°C, and after this temperature the value starts to decrease. For the *absorbed energy* test (Fig. d), values in the range of 6.0-9.2 (J) were obtained, the most advantageous value being obtained for the sample HR-ST3 (solubilization quenching at 500°C). The analysis shows that when increase the solubilization quenching temperature, the properties improve considerably. When testing resilience, for the *elasticity test* (Fig.e) were obtained values in the range of 15.5-22.5 J/cm^2, the most advantageous value being obtained for the sample HR-ST3 (solubilization quenching at 500°C). With the increase the temperature of solubilization quenching, the elasticity values improve. It can be concluded that an important factor for improving the resilience of the material is to increase the solubilization quenching temperature.

4. Conclusions

Following conclusions are drawn from the present investigation:

- The microstructure of 7075 alloy consists of the following phases/compounds: Al, $MgZn_2$, Cu_2Mg, Mg_2Si, Al_2Cu, Fe_2O_4;
- Increasing the temperature, from 450°C (ST1) to 500°C (ST3), leads to dissolution of different secondary phases / compounds, influencing the mechanical behaviour; the weight fraction of the constituent phases / compounds playing the most important role in the mechanical behaviour;
- As the solubilization quenching increases, the phases and compounds in the base mass of alloy 7075 change their shape, size and dispersion.
- The most advantageous values have been obtained for ultimate tensile strenght /RM = 261 MPa, for the sample HR (Hot-rolled: T = 350°C;ε = 50%);
- The most advantageous values have been obtained for yield strength /$Rp_{0.2}$ = 206.5 MPa, for the sample HR (Hot-rolled: T = 350°C; ε = 50%);
- The most advantageous values have been obtained for elongation/ A50 = 11.3%, for the sample HR-ST2 (solubilization quenching: T=475°C-10 min – WQ); increasing the temperature for solubilization quenching to 475°C, increases the ductility of the material ;
- The most advantageous values have been obtained for absorbed energy/ E = 9.2 J, for the sample HR-ST3 (solubilization quenching: T=500°C-10 min – WQ);
- The most advantageous values have been obtained for Elasticity/ KCV = 22.5 J/cm^2 for the sample HR-ST3 (solubilization quenching: T=500°C-10 min – WQ);

- Increasing the temperature for solubilization quenching the resilience properties improve considerably.

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R E F E R E N C E S

[1]. The Aluminum Association, Standards and Data.
[2]. J.R. Davis, Alloying: Understanding the Basics, 2001 ASM International;
[3]. Aluminum Alloys – Effects of Alloying Elements, Total materia, 2002.
[4]. J. Gilbert Kaufman, Introduction to Aluminum Alloys and Tempers, 2000 ASM International;
[5]. MIL-H-6088, Heat Treatment of Aluminum Alloys.
[6]. E.Cazimirovici, M.V.Suciu, “Laminarea materialelor metalice speciale”, Editura Bren București, 2000.
[7]. Rui Lin, Bo Liu, Junjie Zhang, Shengen Zhang; Microstructure evolution and properties of 7075 aluminum alloy recycled from scrap aircraft aluminum alloys; Journal of Materials Research and Technology, Volume 19, July–August 2022, Pages 354-367.
[8]. Lockheed L-1011 Tristar Statistics, Aviation- Safety.net, July 9. 2020.
[9]. W. Huo, Simultaneously enhanced mechanical strength and inter-granular corrosion resistance in high strength 7075 Al alloy, J. Alloy. Compd.(2019).