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Mechanical Properties and Recovery of AA 2618 Aluminum Alloy

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Abstract. The effects of addition of lanthanides and zirconium on mechanical properties and recovery behavior of AA 2618 aluminum alloy have been studied. The apparent activation energies of recovery process of the alloys, obtained from the change in micro-hardness were in the range 31.34 to 46.15 kJ mol^{-1}. Lanthanides have caused the decrease in recovery rate and the increase in creep resistance of examined alloys.

Keywords. 2618 aluminum alloy, mechanical properties, recovery.

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1 Introduction

The most successful commercial high temperature metals are known to be complicated alloys because they have better over-all properties for the use at elevated temperatures than do pure metals. The RR 58 (AA 2618) alloy faces the challenges of modern development of the aerospace industry. This alloy used for the Concorde supersonic air plane at temperatures up to 448 K was originally an early engine material for compressor blades and impellers.

Most of well-known hardening methods are applicable to creep-resistant alloys. These include solid-solution hardening, precipitation hardening and hardening by cold working. However, these hardening mechanisms are unstable relative to a rise in temperature. Their application for the purpose of increasing the creep resistance is therefore limited to the temperature ranges that alloys are fully stable [1].

In order to develop higher creep-resistant alloys it is necessary to increase the resistance of both the grains and the grain boundaries to flow, while the recovery of softening effects should be minimized. Many investigators have reported that the addition of transition metals with relatively low solid solubility (manganese, chromium, zirconium) as well as lanthanides to the 2618 alloy causes the precipitation of fine dispersed particles [2–6]. The designing of complex chemical composition could be used for improving mechanical properties by making recovery and recrystallization inhibition of the alloy better. The purpose of this work focuses on the effects of addition of lanthanides and zirconium on mechanical properties, particularly creep resistance, of aluminum 2618 alloy after cold deformation, quenching and aging treatments.

2 Experimental

Aluminum alloys with nominal composition given in Table 1 were prepared by melting AA 2618 (RR 58) alloy, Al-Zr_5 pre-alloy and lanthanides in the form of so called misch metal (50 % Ce and 50% other elements) in a resistance-heated furnace with the graphite crucible. The resulting ingots were subjected to the homogenizing heat treatment at 783 to 788 K for 22 hours and furnace cooled. The homogenized ingots were then hot forged and cold rolled resulting in a final thickness of 0.5–0.6 mm. The specimens cut from the final plate were solution treated at 798 K for 12 h and then quenched in water at 305 to 308 K. The quenching procedure was followed by aging at 473 K for 12 h.

In order to study the recovery process that may appear during annealing of the alloy specimes, the cold rolled specimens at temperatures from 423 to 623 K for times up to 320 min. Deformed, quenched and aged specimens were subjected to tensile testing at room temperature using the 1195 Instron machine. As-cast micro-structure was examined by energy dispersive spectroscopy of X-rays. The micro-hardness values of samples deformed and annealed at temperatures from 423 to 623 K for times up to 320 min were measured using a 20 g load on a MT 3 system in an optical microscope.

Alloy	Cu	Fe	Ni	Mg	Si	Zr	Lanthanides
Alloy 1	2.10	0.96	1.21	1.28	0.30	–	–
Alloy 2	2.12	0.94	1.21	1.24	0.29	–	0.15
Alloy 3	2.13	0.93	1.19	1.26	0.27	–	0.25
Alloy 4	2.10	0.90	1.20	1.23	0.28	0.14	0.15

Table 1. Chemical composition of alloys (in mass %).

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3 Results and Discussion

Microstructural analysis of cast alloys revealed heterogeneous phase distribution. Dark phase containing silicon, magnesium and aluminum is observed in all specimens presently examined. Since aluminum could arise from matrix, the observed phase is believed to be Mg_2Si. Beside dark phase, two phases are observed in alloy 1 (Figure 1(a)). Fe-Ni based phase that is almost white is present in regular form (Al_9FeNi), while extended Ni-Cu phase is found light grey (Al_6Cu_3Ni). The redistribution of solute atoms within solid solution lattice is obvious. The degree in supersaturation decreases because of the copper enrichment in the phases. In alloy 3 containing lanthanides (Figure 1(b)), in addition to Mg-Si (dark phase) and Fe-Ni, arrangement of the phases containing lanthanides is observed. Skeleton microstructure was formed. However, the observed phases are found to contain nickel, copper and lanthanides. The morphology of Fe-Ni based phase is similar to that of the Fe-Ni based phase revealed in alloy 1.

Mechanical properties of the alloys after cold deformation, quenching and aging are presented in Figure 2. The results show that the addition of lanthanides contributes to the hardening by cold work. The additions of 0.15 % and 0.25 % of lanthanides to AA 2618 alloy clearly indicate the increase in yield strength $Rp_{0.2}$ about 9.78 % and 11.38 %, respectively. The increase in $Rp_{0.2}$ about 10.58 % is found when adding 0.15% of lanthanides and 0.14 % of zirconium. It may be worthy of note that our previous investigation [7] shows the increase in zirconium content up to 0.24 % in AA 2618 alloy due to the increase in $Rp_{0.2}$ about 11.32 %.

Quenching procedure has caused the significant difference in ultimate strength R_m and $Rp_{0.2}$ values in all examined alloys (Figure 2). In solid-solution hardening, the temperature rise increases the diffusion rates of solute atoms in the dislocation atmosphere and at the same time this process tends to disperse solute atoms of the atmosphere. Both effects make the movement of dislocation easier. Small non-coherent particles of secondary phases in aluminum matrix caused the decreasing of $R_m/Rp_{0.2}$ ratio.

The effect of precipitation on mechanical properties is greatly accelerated by reheating the quenched specimens to 473 K. The structural changes occurring at the elevated temperatures are reflected in the characteristics in mechanical properties. The increase in yield strength is more pronounced than the increase in tensile strength (Figure 2). The addition of lanthanides to AA 2618 alloy increases the response of alloys to artificial aging. The zirconium and lanthanides addition also improves the effect of precipitation hardening.

In the recovery stage of annealing, the physical and mechanical properties that suffered changes as a result of cold working tend to recover their original values. Very complex quantitative determining the time and temperature dependence of recovery rate could be simplified by monitoring some physical or mechanical properties during annealing of cold deformed alloy. In this work the change in micro-hardness of specimens was examined in order to monitor the recovery process (Figure 3). The change in micro-hardness of specimens in the recovery process during the isothermal annealing from 423 to 623 K decreases with increas-

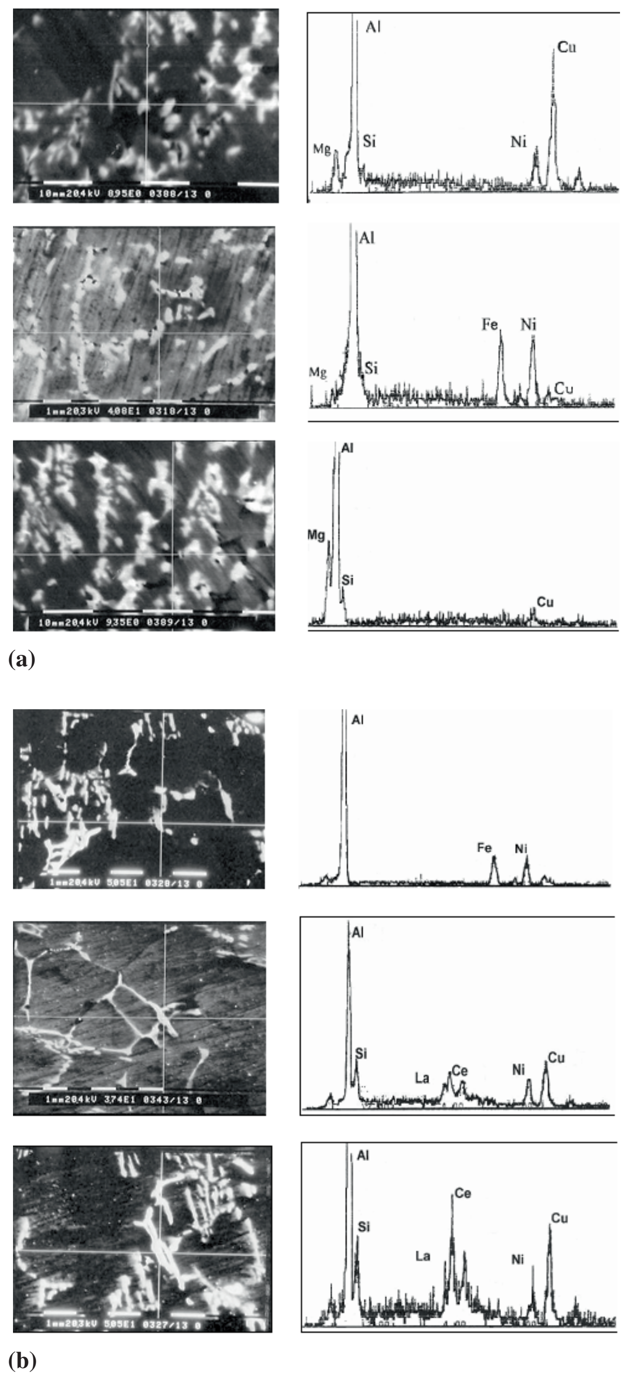

Figure 1. EDS spectra of phases in alloy 1 (a) and alloy 3 (b).

Activation energy [kJ mol^{-1}]	Alloy 1	Alloy 2	Alloy 3	Alloy 4
	31.34	32.67	33.65	46.15

Table 2. Activation energies obtained from micro-hardness measurements.

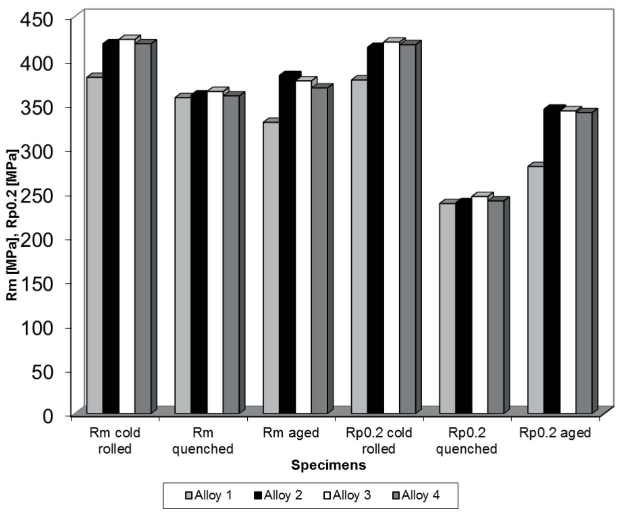

Figure 2. Ultimate strength (Rm) and $Rp_{0.2}$ (yield strength) of cold rolled, quenched and aged specimens of the alloys.

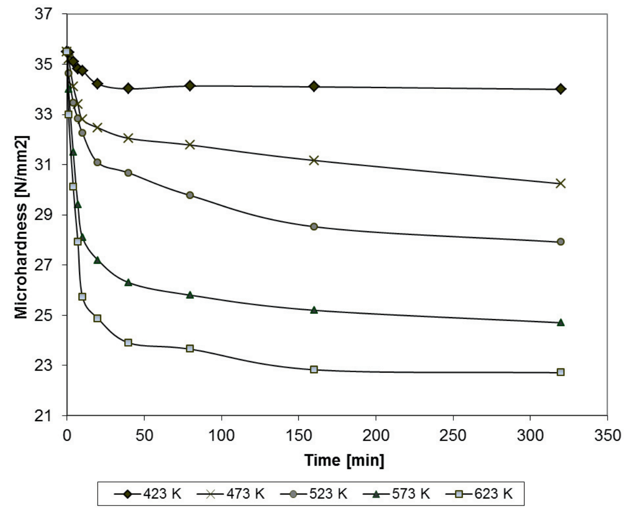

Figure 3. Diagram showing the influence of annealing time and temperature on the microhardness of the alloy 4.

ing time. It changes rapidly in a short period less that 20 min and rather gradual change is detected in a longer time. Recovery was very slow in specimens annealed at 423 K. The recovery rate increases with the increase in temperature. The rate of recovery is much faster at 523 K than it is at 473 K. The fastest recovery process is occurred at 623 K. During annealing the fastest recovery process was observed in matrix alloy. The change in micro-hardness during annealing decreases with increasing lanthanides content. Recovery and recrystallization can completely remove the effects of cold working and thereby increase the creep rate at a given stress and temperature. Since the addition of zirconium and lanthanides contributes to a raise in recrystallization temperature of the matrix, these elements cause the decrease in the recovery rate and the increase in creep resistance of the alloys presently examined.

The apparent activation energies of recovery process were determined on the base of isothermal-anneal curves. Modern software tools for tabular and graphical presentation of experimental and computing data were used as a program package for the statistical analysis. The exponential form of dependence of microhardness on annealing time has been recognized. In order to achieve the higher quality of the data processing each of the experimental curves was interpolated. EViews3 program package, for data processing, statistical analysis, graphic representation, estimation, prediction and simulation, was used for interpolation of the data through the average squared error minimization. This procedure has been described in detail in our previous investigation of 2618 alloy contained different amounts of zirconium [8]. The obtained activation energies of recovery process are presented in Table 2. Lanthanides slightly increase the apparent activation energy of recovery process. The highest activation energy value was obtained for alloy 4 containing zirconium and lanthanides, but it is lower than those (47.43 to 75.72 kJ mol^{-1}) reported for recovery process in 2618 alloy in which zirconium was added in its amount up to 0.25% [8]. However, our previous paper [9] shows that 2618 alloy containing lanthanides exhibits higher recovery resistance at temperature annealed between 573 and 623 K when comparing with the alloy containing zirconium, but lower recovery resistance during annealing at 423–523 K. While at low annealing temperatures this may be associated with elimination of vacancies, at higher temperatures the climb of dislocations is considered dominant process. Hence, the dislocation climb was strongly obstructed by lanthanides. This implies that the addition of lanthanides caused the increasing in recovery resistance and creep resistance at high temperatures.

4 Conclusions

1. Secondary phase containing magnesium, silicon, iron and nickel as well as phase containing lanthanides and zirconium were observed in as cast alloys.
2. Addition of lanthanides contributed to the hardening by cold work. The increase in $Rp_{0.2}$ about 11.38 % is

caused by addition of 0.25% of lanthanides, while the increase about 10.58 % was observed in alloy containing 0.15 % of lanthanides and 0.14 % of zirconium.

3. Quenching procedure has caused the significant difference in R_m and $Rp_{0.2}$ values in all examined alloys. The addition of lanthanides to AA 2618 alloy increased the response of the alloys to artificial aging. The zirconium and lanthanides addition improved the effects of precipitation hardening too.

4. The apparent activation energies for recovery process of the alloys, obtained from the change in microhardness were in the range 31.34 to 46.15 kJ mol^{-1}.

5. The addition of lanthanides caused the increasing in recovery resistance and creep resistance at high temperatures.

References

[1] R. E. Reed-Hill and R. Abbaschian, *Physical Metallurgy Principles*, 3rd edition, PWS Publishing Company, Boston (1994).

[2] K. P. Rao and K. Sivaram, Deformation behavior and microstructure-mechanical-property correlations for RR 58 aluminum alloy, *J. Mater. Process. Techn.*, Vol. 29 (1992), 91–101.

[3] S. C. Bergsma, X. Li and M. E. Kassner, Effects of thermal processing and copper additions on mechanical properties of aluminum alloy ingot AA 2618, *J. Mater. Eng. and Perform.*, **5**, No. 1 (1996), 100–102.

[4] K. Yu, S. R. Li and W. X. Li, Recrystallization behavior in an Al-Cu-Mg-Fe-Ni alloy with trace scandium and zirconium, *Mater. Trans, JIM*, **2** (2000), 358–361.

[5] J. H. Wang, D. Q. Yi and B. Wang, Microstructure and properties of alloy 2618-Ti heat resistant aluminum alloy, *Trans. Nonferrous Met. Soc., China*, **3** (2003), 90–95.

[6] Y. H. Wang and D. Q. Yi, Microstructure and properties of alloy 2618 reinforced by submicron AlN particles, *J. Mater. Eng. Perform.*, **5** (2006), 596–600.

[7] N. Jaukovic, *The Influence of Zirconium and Lanthanides on Structure and Properties of Wrought heat-resisting alloys*, PhD Thesis, University of Montenegro (1998).

[8] N. Jaukovic and D. Perovic, ISIJ International, Influence of zirconium on the recovery process in heat-resistant Al alloys, **44**, No. 7 (2004), 1238–124.

[9] N. Jaukovic and M. Lalovic, Effect of zirconium and lanthanides on the recovery in 2618 base aluminum alloys, *ISIJ International*, **45**, No. 3 (2005), 405–407.