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EFFECT OF THERMO-MECHANICAL TREATMENTS ON THE HOT DEFORMATION BEHAVIOR OF ALUMINUM ALLOY 2024

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Abstract: *In this paper different thermo-mechanical treatments were performed on the commercial aluminum alloy 2024-T3, in order to improve deformation characteristics. These treatments include the solution heat treatments of precipitates that have been performed at the temperature of 500°C for 4, 6 and 8 hours followed by a quenching in water, hot and cold rolling, recrystallization. By applying the hot tension tests was investigated the hot deformation behavior of the processed alloy. The tensile tests have been carried out at temperature of 460°C with the strain rates of 0.001* s^{-1}*and 0.01* s^{-1}*. The results show that, the increase of solubilization treatment time leads to a decrease of the tensile strength and to an increase of the fracture strain in all strain rates. The maximum ductility has been achieved on the solution treated specimen at the temperature of 500°C for 8 hours and tensile deformed at 460°C with strain rate of 0.001*s^{-1}*.*
Key words: *2024 aluminum alloy, thermo-mechanical treatment, solution heat treatment, hot tension tests, hot ductility.*

1. INTRODUCTION

Aluminum alloy 2024 is one of the best known high-strength aluminum alloys attributed to its high strength and excellent resistance to fatigue. With such properties and characteristics, it is extensively and commonly used for aircraft structures, truck wheels, screw machine products, parts for the transportation industry [1].

This alloy shows a relatively low ductility at room temperature and is generally heat treated in various conditions to suit particular applications.

It is known that precipitation heat treatments are important because directly affects the mechanical properties of the material. An important step of such treatments is solubilization, where the main objective consist in maintain the maximum amount of solute phases in solid solution [2].

In recent years, interest in thermo-mechanical treatments has increased, as important techniques for improving the properties of metallic materials, especially for intermediate thermo-mechanical treatment which focuses on grain morphologies refining, as-cast microstructures modification and depleting component segregation [3]. Since heat treating before hot deformation affects the properties of secondary phase particles, static and dynamic growth during deformation or just after that, will be affected [4].

To improve the hot workability, a solution heat treatment of precipitates can be applied on these alloys, so that by heating to a suitable temperature, soaking at that temperature for sufficient time to induce the constituents to enter into solid solution and then by cooling rapidly enough to keep these constituents in solution. The heat treatment of solution and hardening gives the aluminum alloys an increased ductility for a short period of time, less than 5 hours [4].

In this paper, the effects of different thermo-mechanical treatments (soaking time of 4, 6 and 8 hours) on the hot deformation behavior of a commercial aluminum alloy 2024 have been examined through the hot tensile tests.

2. EXPERIMENTAL RESEARCH

The experiments were conducted using a commercial aluminum alloy 2024-T3 received in the extruded rectangular shape bar with 40 mm width and 20 mm thickness, produced by S.C. ALPROM S.A. Slatina, Romania. Chemical composition (in wt%) is: 4.954 Cu; 1.663 Mg; 0.519 Mn; 0.496 Fe; 0.279 Si; 0.096 Zn; 0.029 Cr; 0.022 Sb; 0.006 Ni; 0.007 Sn; 0.020 Pb; Al-balance.

This bar was heat treated to T3 temper, which means that the extruded bar has been solution heat treated, cold deformed and then naturally aged up to stable condition.

Because the ductility of aluminum alloy 2024 as received is small, the material was processed thermo-mechanical (this is one methods to increase the ductility through grain refinement).

The specimens from a received material with a width 40 mm, thickness of 20 mm and a length of 45 mm, were solution heat treated at temperature of 500ºC for 4, 6 and 8 hours followed by a quenching in water. Hot rolling was performed at temperatures between 440÷480ºC with a total reduction of 65%, until a thickness of 7 mm and water quenched. Then the specimens were cold rolled to 3 mm thickness with a total reduction of 57%. After the rolled specimens were recrystallized by fast heating to 480ºC, soaked for 15 minutes and fast cooling in water, to obtain a fine grain structure and soaked at 350^0C for 30 minutes, in order to make fine-grained structure stable.

Tensile specimens were prepared with a gauge length of 25 mm, 6.6 mm width and thickness of 3 mm. All the samples were machined with the tensile stress direction parallel to the rolling direction.

The hot tensile tests were carried out at 460ºC with constant strain rates of 0.001 s^{-1} and 0.01 s^{-1}, using an experimental setup that was interfaced with a computer to provide complete control of strain rate.

After each test, the specimens were quenched in cold water to maintain the resulting structure during the test.

The as-received and as-solution treated and cooling in cold water specimens were cut in the longitudinale direction, polydol mounted, and mechanically polished. Keller's reagent was used to reveal microstructure in this material. The obtained microstructures were examined through optical microscopy using a optical microscope type Olimpus GX51.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the microstructure of alloy in the form of extruded bar in the T3 temper, characterized by a structure consisting in saturated solid solution in Cu and Mg, with two types of precipitates, soluble (Al_2Cu (θ) and Al_2CuMg (S)) and non-soluble precipitate which include the compounds based on Fe, Mn, Si. Here it identifies grains of solid solution elongated in the direction of the deformation axis, with fine precipitations inside the grains.

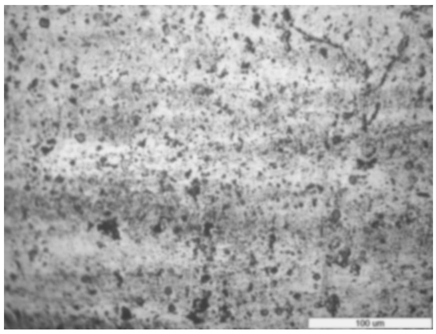
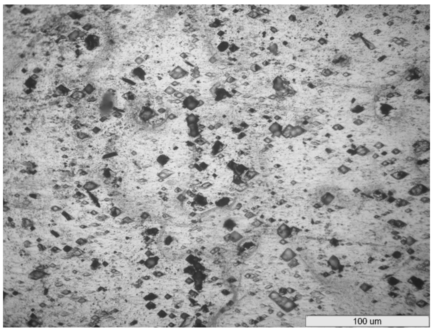


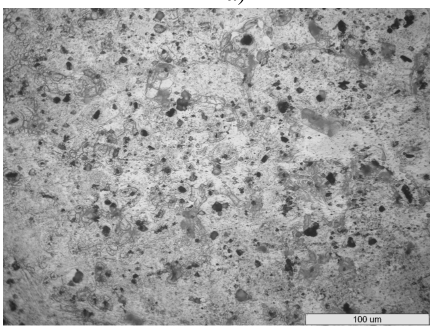
Fig.1. The initial microstructure of the aluminum alloy 2024.

The specimens were treated for heat solution at 500ºC with keeping at this temperature for 4, 6 and 8 hours. The microstructure of the specimens after solution heat treatment is shown in figure 2. This heat treatment led to the dissolution by diffusion of the phases Al_2Cu (θ) și $CuMgAl_2$ (S), that were present in the initial state at the heat treatment temperature. It is noted that, with increasing the soaking time, the size of the precipitates decreases by diffusion of the alloying elements into the solid solution, which becomes supersaturated (on the diffusion distance). The solution treated specimen for 8 hours at a temperature of 500°C shows the lowest segregation, having a relatively uniform structure with smaller particles of intermetallic phases.

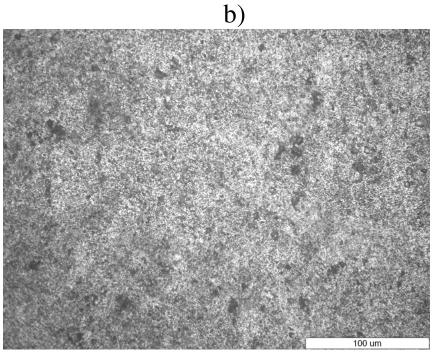
With the progressive increase of time to 4, 6 and 8 hours, the solubility of the precipitates in the matrix increased, the volume fraction decreased and the particle distribution became homogeneous. Applying this type of heat treatment leads to a decrease in the amount of precipitation and to the increase in the amount of solid solution, which cause an increase of the alloy plasticity.



a)



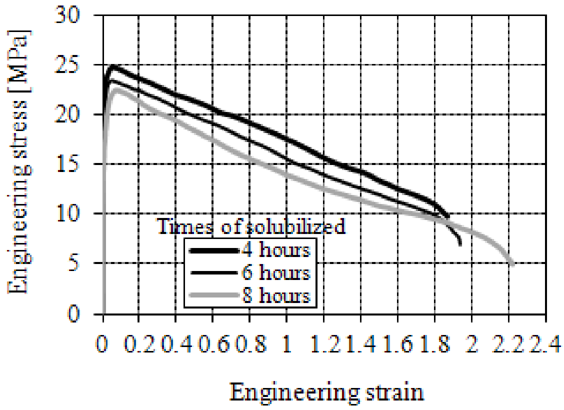
b)



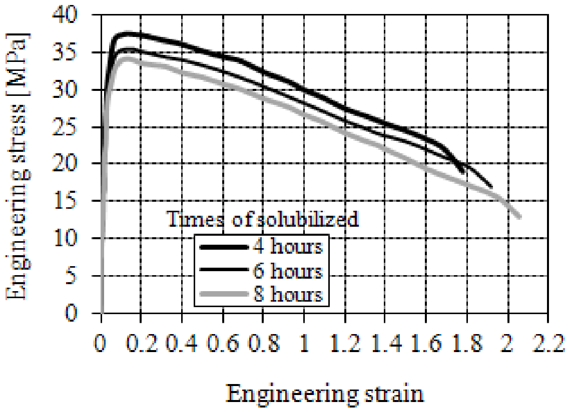
c)

Fig. 2. The optical micrographies of aluminum alloy 2024 with different times of solubilized at 500°C: a) 4 hours; b) 6 hours; c) 8 hours.

Figure 3 a-b shows the engineering stress-strain curves of thermo-mechanical processed specimens from aluminum alloy 2024 after tensile tests at temperature of 460°C with constant strain rates of 0.001 $s^{-1}$and 0.01 s^{-1}. The curves exhibit a stress maximum at strains less than 15%, a regime of stable flow during which a diffuse neck develops and the load drops gradually and a period at rapid load drop and failure occurs.



a)



b)

Fig. 3. The engineering stress-strain curves of the solution heat treated specimens for 4, 6, 8 hours at 500°C and tensile deformed at temperature of 460°C with strain rates of: a) 0.001 s^{-1}; b) 0.01 s^{-1}.

By decreasing the strain rate from 0.01 s^{-1} to 0.001 s^{-1}, the level of tensile strength decreases, due to the ease of the dislocation motions. The 8 hours solution treated specimen shows the lowest level of strength when she was tensile tested at temperature of 460°C and the lowest strain rate of 0.001 s^{-1}. Also, it is obvious that the increase of solution treated time leads to the decrease of the tensile strength for both strain rates.

The effect of strain rate on the fracture strain for different times of solution is shown in figure 4. It is obvious that, the increase of solubilization treatment time leads to the increase of the fracture strain for both strain rates. As is observed, the ductility increased in all the specimens as the strain rate is reduced from $0.01 s^{-1}$ to $0.001 s^{-1}$.

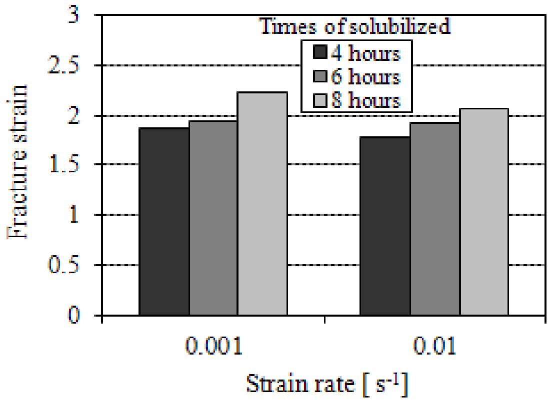


Fig. 4. The effect of strain rate and solubilization treatment time on fracture strain.

It is to be mentioned that the maximum ductility was realized for sample which was solution treated for 8 hours and tensile deformed at 460°C with strain rate of $0.001 s^{-1}$ and the lowest ductility occurred in the solution treated specimen at 500°C for 4 hours and tensile deformed at 460°C with strain rate of $0.01 s^{-1}$.

4. CONCLUSIONS

- Applying the solution heat treatment leads to a decrease in the amount of precipitation and to the increase in the amount of solid solution, which cause an increase of the alloy plasticity.
- The solubility of the precipitates in the matrix increases with increasing solution treated time, thereby increasing the degree of matrix supersaturation.
- The increase of solution treated time leads to a decrease of the tensile strength and to an increase of the fracture strain in all strain rates.
- The 8 hours solution treated specimen shows the lowest level of tensile strength and maximum ductility when she was tensile tested at temperature of 460°C and the lowest strain rate of $0.001 s^{-1}$.
- By decreasing the strain rate the level of tensile strength decreases.

5. REFERENCES

[1] *****ASM Specialty Handbook, Aluminum and Aluminum Alloys*, Edited by J.R. Davis', Davis & Associates, ASM International, The Materials Information Society, ISBN 978-0-87170-496-2, 1993.

[2] A.J. Ardell, *Precipitation Hardening,* Metallurgical Transactions A, Volume 16, Issue 12, pp. 2131-2165, Online ISSN 1543-1940, Print ISSN 1073-5623, 1985.

[3] C.G. Garay-Reyes, L. González-Rodelas, I. Estrada-Guel and R. Martínez-Sánchez, *Effect of Solubilization Temperature, Zn Addition and Thermo-Mechanical Treatments in the Microstructure of the Aluminum 2024 Alloy,* Microscopy and Microanalysis, 20 (Suppl 3), pp. 1478-1479, Journal of Microscopy Society of America, Online ISSN 1435-8115, 2014.

[4] G.R. Ebrahimi, A. Zarei-Hanzaki, M. Haghshenas, H. Arabshahi, *The Effect of Heat Treatment on Hot Deformation Behaviour of Al 2024*, Journal of Materials Processing Technology, Volume 206, pp. 25-29, ISSN 0924-0136,2008

Efectul tratamentelor termo-mecanice asupra comportării la deformare la cald a aliajului de aluminiu 2024

În această lucrare s-au efectuat diferite tratamente termo-mecanice pe aliajul de aluminiu comercial 2024-T3, pentru a îmbunătăți caracteristicile de deformare. Aceste tratamente includ tratamente de de punere în soluție a precipitatelor la temperatura de 500°C, pentru 4, 6 şi 8 ore urmate de răcire în apă, laminare la cald şi la rece, recristalizare. Prin aplicarea testelor de tracțiune la cald a fost investigată comportarea la deformare la cald a aliajului procesat. Testele de tracțiune au fost efectuate la temperatura de 460ºC cu viteze de deformare de $0.001 s^{-1}$ şi $0.01 s^{-1}$. Rezultatele arată că, creşterea timpului tratamentului de solubilizare conduce la o micşorare a rezistenței la rupere şi la o creştere a deformației la rupere pentru toate vitezele de deformare. Ductilitatea maximă a fost obținută pe proba tratată prin punere în soluție a precipitatelor la temperatura de 500°C timp de 8 ore şi deformată prin întindere la 460ºC cu viteza de deformare de $0,001 s^{-1}$.

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