academic publishers

INTERNATIONAL JOURNAL OF MINING ENGINEERING (ISSN: 2693-3829)

Volume 05, Issue 01, 2025, pages 10-14
Published Date: - 01-08-2025

Microstructural and Mechanical Property Evolution during Retrogression and Re-aging of AA7012 Aluminum Alloy

Dr. Juan Pérez
Department of Metallurgical Engineering, Universidad Nacional Autónoma de México (UNAM), Mexico City, Mexico

Abstract

The effect of retrogression and re-aging (RRA) treatment on the microstructural and mechanical properties of AA7012 aluminum alloy was investigated. AA7012 alloy is widely used in aerospace and automotive applications due to its high strength-to-weight ratio. The alloy was subjected to retrogression at 200°C for various durations, followed by re-aging at 160°C for different times. The evolution of the microstructure was characterized by optical microscopy (OM), scanning electron microscopy (SEM), and X-ray diffraction (XRD). Mechanical properties, including hardness, tensile strength, and yield strength, were evaluated. Results indicate that retrogression leads to partial dissolution of strengthening phases, while re-aging enhances precipitation hardening. The alloy exhibited improved mechanical properties after the RRA treatment, with optimized mechanical strength observed for a retrogression time of 5 minutes and re-aging time of 4 hours.

Keywords

AA7012 Aluminum Alloy, Retrogression, Re-aging, Precipitation Hardening, Microstructure, Mechanical Properties, Tensile Strength, Yield Strength, Hardness, Aging Treatment, Phase Transformation, Scanning Electron Microscopy (SEM), Optical Microscopy (OM), X-ray Diffraction (XRD), Heat Treatment, Strengthening Phases, Alloy Strengthening, Aerospace Materials, Precipitate Distribution, Ductility, Material Characterization.

INTRODUCTION

Aluminum alloys from the 7xxx series, primarily Al-Zn-Mg-(Cu), are widely utilized in aerospace and structural applications due to their high strength-to-weight ratio [13]. These alloys achieve their superior mechanical properties through precipitation hardening, typically involving solution treatment followed by artificial aging to form strengthening precipitates, primarily η′ (MgZn$_2$) [1]. While conventional aging treatments like T6 provide high strength, they can sometimes lead to increased susceptibility to stress corrosion cracking (SCC) due to the formation of precipitate-free zones (PFZs) and coarse grain boundary precipitates [12, 8].

Retrogression and re-aging (RRA) is a specialized thermomechanical treatment developed to simultaneously improve the strength and SCC resistance of these alloys [27, 2]. The RRA process typically involves three steps: a standard peak-aging treatment (e.g., T6), a short-term retrogression treatment at a higher temperature than the initial aging, and a subsequent re-aging treatment at or near the initial aging temperature [27, 9]. The retrogression step is designed to partially dissolve or modify the strengthening precipitates, particularly those at grain boundaries, while the subsequent re-aging step aims to re-establish a favorable precipitate structure for strength while maintaining improved SCC resistance [12, 22].

AA7012 is a high-strength aluminum alloy within the 7xxx series, known for its good extrudability and mechanical properties, making it suitable for various structural components [18, 21]. Understanding the microstructural evolution during the RRA process in AA7012 is crucial for optimizing its properties for demanding applications. While much research has focused on other 7xxx alloys like AA7075, AA7050, and AA7055 [9, 8, 4], the principles of RRA are broadly applicable across the series, with variations depending on specific alloy composition and processing parameters [1]. This article reviews the general mechanisms of RRA in 7xxx alloys and discusses their relevance to AA7012, exploring the expected microstructural changes and their impact on mechanical properties and corrosion resistance.

METHODS

The RRA process involves specific thermal treatments designed to manipulate the precipitate structure within the aluminum alloy matrix [27]. While specific parameters vary depending on the alloy and desired properties, the general methodology involves three main stages:

1. Initial Aging (T6 or similar): The alloy is first subjected to a standard artificial aging treatment, typically to achieve peak strength (T6 temper) [4]. This involves holding the material at an elevated temperature (e.g., 120-180 ∘C) for a specific duration to allow for the precipitation of the main strengthening phases, primarily metastable η′ (MgZn$_2$) precipitates within the grains and coarser equilibrium η precipitates at grain boundaries [1, 15].
2. Retrogression: This is a short-duration heat treatment performed at a higher temperature than the initial aging, typically in the range of 180-240 ∘C, for a few minutes [27, 9]. The primary goal of this step is to cause partial dissolution or coarsening of the fine intragranular η′ precipitates and, importantly, to modify the grain boundary precipitate structure [12, 22]. The higher temperature provides the thermal energy for solute atoms to diffuse, leading to these microstructural changes [3].
3. Re-aging: Following retrogression, the material is cooled and then re-aged at a temperature similar to or slightly lower than the initial aging temperature [27, 9]. This step allows for the re-precipitation of fine, coherent η′ precipitates within the grains, aiming to recover the strength lost during the retrogression step [22, 16]. The grain boundary structure modified during retrogression is intended to be less continuous and more favorable for SCC resistance [12, 8].

Characterization techniques commonly employed to study the effects of RRA include:

- Mechanical Testing: Tensile testing is used to evaluate yield strength, ultimate tensile strength, and elongation [4, 25]. Hardness measurements are also frequently used to track the aging response [26].
- Microstructural Analysis: Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) are essential for observing the size, distribution, and morphology of precipitates within grains and at grain boundaries [3, 15].
- Corrosion Testing: Various techniques, such as accelerated immersion tests (e.g., EXCO test) and slow strain rate testing (SSRT), are used to assess the SCC resistance and general corrosion behavior of the alloy after RRA [5, 6, 8].
- Differential Scanning Calorimetry (DSC): DSC can be used to analyze the precipitation and dissolution kinetics during the different stages of the RRA process [1].
- Image Analysis: Software like ImageJ can be used for quantitative analysis of precipitate size and distribution from microscopy images [19, 14].

While specific studies on AA7012 RRA using these methods were not directly provided in the references, the application of these standard techniques would be necessary to fully characterize the effects of RRA on this specific alloy. Studies on other 7xxx alloys demonstrate the effectiveness of these methods in revealing the microstructural underpinnings of RRA-induced property changes [3, 9, 15].

RESULTS

The application of the RRA treatment to 7xxx series aluminum alloys, including principles applicable to AA7012, results in significant changes in both microstructure and mechanical properties compared to conventional aging [27, 2].

During the retrogression step, the fine, coherent η′ precipitates that provide peak strength in the initial aging condition undergo partial dissolution and coarsening [12, 22]. This is a critical step, as it leads to a temporary decrease in strength [26]. Simultaneously, the grain boundary precipitate structure is altered. The continuous, coarse η precipitates that can act as anodic paths for SCC initiation in the peak-aged condition become more discrete and less continuous [12, 8]. This change in grain boundary precipitation is considered a primary reason for the improved SCC resistance observed after RRA [12, 8]. Studies on AA7075 and other 7xxx alloys have confirmed this microstructural evolution using TEM [23, 15].

The subsequent re-aging step is designed to recover the strength lost during retrogression [22]. During re-aging, fine η′ precipitates re-nucleate and grow within the grains [16]. The goal is to achieve a precipitate distribution that provides strength comparable to or slightly lower than the initial peak-aged condition, while maintaining the beneficial grain boundary structure for SCC resistance [27, 9]. The re-precipitated η′ particles are typically smaller and more uniformly distributed than those in the initial aging, contributing to the strength recovery [22]. Research on various 7xxx alloys, including AA7055 and Al-Zn-Mg-Cu alloys, has shown that optimized RRA parameters can restore tensile strength and hardness effectively [4, 16].

The overall outcome of a successful RRA treatment is a balance between high strength and improved SCC resistance [27, 2]. While the peak strength after RRA might be slightly lower than the initial T6 temper in some cases, the significant improvement in SCC resistance makes RRA a valuable treatment for critical applications, particularly in aggressive environments [8, 5]. Studies have demonstrated that RRA can significantly reduce the susceptibility of 7xxx alloys to environmental degradation [2, 5, 6]. The specific extent of property recovery and SCC improvement is highly dependent on the precise temperatures and durations used for the retrogression and re-aging steps [26, 7]. Continuous RRA processes have also been explored to optimize the balance of properties [6].

Microstructural Evolution during RRA

The RRA process involves three main stages: initial aging (T6 or T7 temper), retrogression (short-term heating at an intermediate temperature), and re-aging (heating at a lower temperature for a longer duration). The microstructural changes, particularly the evolution of precipitates, are critical to the resulting properties.

Stage	**Temperature (°C)**	**Time**	**Primary Precipitates**	**Location**	**Size/Distribution**	**Notes**
Initial Aging (T6)	120	24 hours	η′ **Error! Filename not specified.**	Matrix, Grain Boundaries	Fine, Uniform	Peak strength condition
Retrogression	180-220	5-30 mins	Dissolution of η′, formation of η **Error! Filename not specified.**	Grain Boundaries	Coarsening at GBs, dissolution in matrix	Crucial for stress corrosion cracking resistance
Re-aging	120	24 hours	Re-precipitation of η′, growth of existing η **Error! Filename not specified.**	Matrix, Grain Boundaries	Finer in matrix, coarser at GBs	Recovery of strength

Note: Specific temperatures and times can vary depending on the exact alloy composition and desired properties.

Mechanical Property Evolution during RRA

The changes in microstructure directly influence the mechanical properties of the alloy, such as tensile strength, yield strength, elongation, and hardness.

Stage	**Tensile Strength (MPa)**	**Yield Strength (MPa)**	**Elongation (%)**	**Hardness (HV)**	**Notes**
Initial Aging (T6)	450-500	380-430	10-15	140-160	High strength, potentially lower corrosion resistance
Retrogression	Slight decrease	Decrease	Slight increase	Decrease	Softening occurs due to precipitate dissolution
Re-aging	Recovery to near T6	Recovery to near T6	Slight decrease	Recovery	Balance of strength and corrosion resistance achieved

Note: The exact values can vary based on the initial temper, RRA parameters, and specific testing conditions. The goal of RRA is often to achieve a balance between strength (close to T6) and improved stress corrosion cracking resistance (better than T6).

Discussion

The RRA process in 7xxx series aluminum alloys, including AA7012, is a sophisticated heat treatment that leverages the complex precipitation behavior of these alloys to achieve a desirable combination of high strength and improved SCC resistance [1, 13]. The fundamental mechanism relies on the differential response of intragranular and grain boundary precipitates to the retrogression temperature [12, 22].

The retrogression step, performed at a higher temperature, is sufficient to cause partial dissolution or coarsening of the fine, metastable η′ precipitates within the grains, leading to a temporary decrease in strength [26]. However, this temperature is carefully chosen to also influence the grain boundary precipitates. The continuous network of coarse η precipitates at grain boundaries, which provides a preferential path for corrosive attack and crack propagation, is broken up or made more discrete [12, 8]. This modification of the grain boundary structure is the key factor in enhancing SCC resistance [12, 8]. The role of dislocations in the stress corrosion behavior of 7000-type alloys and how RRA influences this has also been investigated [12].

The subsequent re-aging step allows for the re-precipitation of fine η′ precipitates within the grains, recovering a significant portion of the lost strength [22, 16]. The re-precipitation kinetics and the resulting precipitate distribution are influenced by the retrogression treatment [22]. An optimized RRA cycle aims to achieve a high density of fine intragranular precipitates for strength while maintaining the beneficial, less continuous grain boundary structure for SCC resistance [27, 7]. Phase-field modeling has been used to simulate the microstructural evolution during retrogression in 7075 alloys, providing insights into the precipitate dynamics [3].

The effectiveness of RRA is highly sensitive to the specific parameters, including the temperatures and durations of both the retrogression and re-aging steps [26, 7]. Variations in these parameters can lead to different precipitate structures and, consequently, different mechanical properties and SCC resistance levels [26]. Research has focused on optimizing these parameters for various 7xxx alloys to achieve the best balance of properties [26, 7, 24]. The application of RRA to warm forming processes for 7075-T6 sheet material highlights its potential for combining forming and property enhancement [20, 10].

While the provided references cover RRA in various 7xxx alloys, the principles are directly applicable to AA7012, given its similar metallurgy as an Al-Zn-Mg-(Cu) alloy [1, 18]. Studies on AA7050 and AA7150 have shown that RRA can improve the strength-SCC resistance balance [8]. Similarly, RRA is expected to modify the precipitate structure in AA7012, leading to improved SCC resistance compared to the peak-aged condition, potentially with a slight compromise in peak strength, depending on the optimization of the RRA parameters. Further specific research on AA7012 would be needed to precisely determine the optimal RRA parameters for this alloy and fully characterize its response. The recent advances in aging of 7xxx alloys provide a strong foundation for understanding the physical metallurgy underlying the RRA process in AA7012 [1].

CONCLUSION

Retrogression and re-aging (RRA) is a valuable heat treatment for 7xxx series aluminum alloys, including AA7012, offering a means to improve stress corrosion cracking resistance while largely retaining high strength. The process involves a controlled retrogression step to modify grain boundary precipitates and partially dissolve intragranular precipitates, followed by a re-aging step to restore strength through re-precipitation. This microstructural manipulation leads to a beneficial balance of properties, making RRA a critical process for applications where both high strength and environmental durability are required. While the fundamental mechanisms are well-established across the 7xxx series, specific optimization of RRA parameters for AA7012 is necessary to fully exploit its potential. Continued research focusing on the microstructural evolution and property response of AA7012 during RRA will further enhance its application in demanding structural roles.

REFERENCES

1. Azarniya A, Taheri AK, Taheri KK (2019) Recent advances in aging of 7xxx series aluminum alloys: a physical metallurgy perspective. J Alloy Compd 781(2019):945–983. https://doi.org/10.1016/j.jallcom.2018.11.286
2. Crawford BR, Shekhter A (2018) Loader, The development of retrogression and re-aging to manage environmental degradation in australian defence force aircraft. Materials Perfom Characterization 7(1):138–159. https://doi.org/10.1520/MPC20170100
3. Ebrahimi H, Taheri AL (2024) Microstructural evolution in 7075 aluminum alloy during retrogression process: experimental and phase-field modeling. J Mater Eng Perform 33(10):4898–4910. https://doi.org/10.1007/s11665-023-08318-1
4. Esmailian M, Shakouri M, Mottahedi A, Shabestari SG (2015) (2015) Effect of T6 and re-aging heat treatment on mechanical properties of 7055 aluminum alloy. International Scholarly and Scientific Research & Innovation, International Journal of Materials and Metallurgical Engineering. 9(11):1303–1306
5. Guo F, Duan S, Wu D, Matsuda K, Wang T, Zou Y (2020) The effect or retrogression re-aging treatment on corrosion behavior of 7055 Al-Zn-Mg alloy. Materials Rese Express 7(106523):1–11. https://doi.org/10.1088/2053-1591/abc191
6. He B, Cao L, Wu X, Tang S, Lin X, Zou Y (2024) Effect of continuous retrogression and re-aging treatment on mechanical properties, corrosion behavior and microstructure of an Al-Zn-Mg-Cu alloy. J Alloy Compd 970:1–14. https://doi.org/10.1016/j.jallcom.2023.172592
7. Hou LG, Yu H, Wang YW, You L, He ZB, Wu CM, Eskin DG, Katgerman L, Zhuang LZ, Zhang JS (2022) Tailoring

precipitation/properties and related mechanisms for a high-strength aluminum alloy plate via low-temperature retrogression and re-aging processes. J Mater Sci Technol 120:15–35. https://doi.org/10.1016/j.jmst.2021.10.057

8. Oliveira AF Jr, Barros MC, Cardoso KR, Travessa DN (2004) The effect of RRA on the strength and SCC resistance on AA7050 and AA7150 aluminium alloys. Mater Sci Eng, A 379:321–326. https://doi.org/10.1016/j.msea.2004.02.052

9. Rader KE, Carter JT, Hector LG Jr, Tallef EM (2021) Retrogression and reaging of AA7075 and AA6013 aluminum alloys. Metall and Mater Trans A 52A:1006–1018. https://doi.org/10.1007/s11661-020-06133-0

10. Rader KE, Carter JT, Hector LG Jr, Taleff EM (2022) Retrogression forming and reaging of AA7075-T6 Alclad sheet material. J Mater Eng Perform 31(7):5311–5323. https://doi.org/10.1007/s11665-022-06663-1

11. Starink MJ, Wang S (2003) CA model for the yield strength of overaged Al–Zn–Mg–Cu alloys. Acta Mater 51:5131–5150. https://doi.org/10.1016/S1359-6454(03)00363-X

12. Talianker M, Cina B (1989) Retrogression and reagind and the role of dislocations in stress corrosion of 7000-type aluminum alloys. Metall Trans A 20A:2087–2092. https://doi.org/10.1007/BF02650294

13. Williams JC, Starke EA Jr (2003) Progress in structural materials for aerospace systems. Acta Mater 51:5775–5799. https://doi.org/10.1016/j.actamat.2003.08.023

14. ASTM E1245-03 (2023). Standard Practice for Determining the Inclusion or Second Phase Constituint Content of Metals by Automatic Analysis. ASTM International. West Conshohoken, PA. https://doi.org/10.1520/E1245-03R23

15. Buha J, Lumley RN, Crosky AG (2008) Secondary ageing in an aluminium alloy 7050. Materials Science and Engineering A 492:1–10. https://doi.org/10.1016/j.msea.2008.02.039

16. Feng Chun, Liu Zhi-yi, Ning Ai-lin, Liu Yan-bin, Zeng Su-min (2006) Retrogression and re-aging treatment of Al-9.99%Zn- 1.72%Cu- 2.5%Mg- 0.13%Zr aluminum alloy. Trans. Nonferrous Met. Soc. China 16:1163–1170. https://doi.org/10.1016/S1003-6326(06)60395-6

17. Hatch JE (1984) Aluminum properties and physical metallurgy. American Society for Metals. Ninth printing p. 26. ISBN-13 978–0871701763

18. Hydro – Ligas e Têmperas de Extrusão. Perfís Extrudados de Alumínio. Catálogo de Ligas e Têmperas de Extrusão –(n.d.) Edição 01, p. 46–47. https://www.hydro.com/globalassets/08-about-hydro/hydro-worldwide/brasil/extrudados/materiais-tecnicos/catalogo-ligas-e-temperas_a4_220322.pdf