# 論文 / 著書情報
# Article / Book Information

| | |
|---|---|
| 題目(和文) | |
| Title(English) | Microstructure and mechanical properties of Al-Zn-Mg-Cu alloys and Al-Cu-Mg alloys after cold rolling and artificial ageing heat treatment |
| 著者(和文) | 李有眞 |
| Author(English) | Yujin Rhee |
| 出典(和文) | 学位:博士(工学),<br>学位授与機関:東京工業大学,<br>報告番号:甲第12865号,<br>授与年月日:2024年9月20日,<br>学位の種別:課程博士,<br>審査員:小林 郁夫,村石 信二,史 蹟,木村 好里,曽根 正人 |
| Citation(English) | Degree:Doctor (Engineering),<br>Conferring organization: Tokyo Institute of Technology,<br>Report number:甲第12865号,<br>Conferred date:2024/9/20,<br>Degree Type:Course doctor,<br>Examiner:,,,, |
| 学位種別(和文) | 博士論文 |
| Category(English) | Doctoral Thesis |
| 種別(和文) | 要約 |
| Type(English) | Outline |

# 論 文 要 約

THESIS OUTLINE

| | | | | |
|---|---|---|---|---|
| 系・コース：<br>Department of, Graduate major in | 材料<br>材料 | 系<br>コース | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of Philosophy （工学） |
| 学生氏名：<br>Student's Name | RHEE Yujin | | | |

要約

The present thesis mainly investigates the mechanical properties and precipitation evolutions of Al-Zn-Mg-Cu and Al-Cu-Mg alloys with different chemical compositions processed by plastic deformation followed by artificial aging treatment. Micro Vickers hardness measurement, tensile test, differential scanning calorimetry (DSC), scanning electron microscopy (SEM), transmission electron microscopy (TEM) were applied for mechanical properties measurement and microstructure characterization.

The detailed aims of the present investigation are as follows:

1. To investigate the effect of pre-deformation on the age-hardening behavior of an Al-Zn-Mg-Cu and Al-Mg-Cu alloys.
2. To understand precipitation sequences both in the Al matrix and along dislocations with respect to the cold rolling.
3. To reveal the structure evolutions of the disordered $\eta$ phase, Y phase in an Al-Zn-Mg Cu alloy and of various GPB, S-I, S-II and novel phase in an Al-Cu-Mg alloy during aging.
4. To study the age hardening response both in an Al-Zn-Mg-Cu and Al-Mg-Cu alloys and the aging behavior of deformed samples.
5. To achieve better understanding of precipitates evolution and mechanical properties by cold rolling and aging.

The research contents of this thesis consist of three parts: First chapter: The effect of pre-deformation on precipitation in Al-Zn-Mg-Cu alloy, Second chapter: The effect of pre-deformation on age-hardening behavior and precipitation in an Al-3.9Cu-1.5Mg wt.% alloy, Third chapter: Investigation on age hardening behaviors of Al-Zn-Mg-Cu alloy with various Zn contents

In the first chapter, the strengthening effects and evolution of precipitates in a pre-deformed Al-Zn-Mg-Cu alloy during ageing were investigated using Vickers hardness measurements, tensile tests, and high angle annular dark field scanning transmission electron microscopy (HAADF-STEM). It was found that all cold rolled conditions had higher mechanical strength than the non-deformed condition for all ageing times and that this effect increases at higher deformation ratios. It was also found that the non-deformed condition has a higher age hardening response than that of the cold rolled conditions. A homogeneous precipitate distribution was observed in the non-deformed condition, while the cold rolled conditions contained non-uniformly distributed precipitates due to the introduced dislocations. This led to larger precipitate sizes and a reduction in the precipitate number densities in the pre-deformed conditions. HAADF-STEM analysis revealed differences in the fraction of different precipitate types between the non-deformed and the cold rolled conditions. $\eta'$, $\eta_2$, and disordered $\eta$ phase were observed in the non-deformed condition, while $\eta'$, $\eta_2$ and the newly identified Y phase were observed in the cold rolled conditions. The disordered $\eta$ phase contained structural units of the $\eta_1$ phase and was associated with reducing the lattice misfit between this phase and the Al matrix. Formation of the Y phase was related to an accelerated nucleation rate in the regions of high dislocation density.

In the second chapter, the effect of 90% pre-deformation after solution heat treatment on precipitation during subsequent artificial ageing at 190°C in an Al-3.9Cu-1.5Mg wt.% alloy has been investigated by means of Vickers hardness measurements, differential scanning calorimetry (DSC) and high angle annular dark field scanning transmission electron microscopy (HAADF-STEM). It was found that the 90% pre-deformed samples had higher Vickers hardness than the non-deformed samples for all ageing times and that the non-deformed samples had a higher age hardening response than the pre-deformed samples. The main contributor to strength in the non-deformed material in underaged conditions was GPB$^1$ clusters homogeneously nucleated in the matrix, while at peak hardness a mix of GPB$^{(n)}$ nucleated homogeneously and S-phases nucleated heterogeneously on naturally occurring dislocations was found. Homogeneous precipitation of GPB$^1$ and GPB$^{(n)}$ was suppressed in the pre-deformed conditions. Here the main hardness contributors were the dislocations themselves and the S-phases heterogeneously nucleated on them. GPB$^1$ and GPB$^{(n)}$ were observed with low occurrence formed at the interfaces of S-phases in both non-deformed and pre-deformed samples during artificial ageing. A novel type of phase named here the "Y phase" was forming with low occurrence along dislocation lines together with the S phases in the pre-deformed sample. The Y phase is isostructural with a previously reported rectangular phase in a pre-deformed Al-Cu-Mg-Si alloy, and has structural similarities with the E phase observed in a pre-deformed Al-Mg-Si alloy. but has different composition because the alloy in this study is Si-free. The crystal structure of Y is proposed as monoclinic with the core composition of $Al_{12}Cu_5Mg_5$. The growth direction of its cross-section is along $<110>_{Al}$ which is different from those of the S-1 and S-II phases. The combination of deformation and ageing can significantly change the precipitation sequence and mechanical properties of the Al-Cu-Mg alloy by reducing the formation energy of precipitates and promoting solute atom diffusion along dislocation lines.

In the last chapter, strengthening effects and precipitation behavior of Al-Zn-Mg-Cu alloys with respect to Zn addition from 4.5% to 8.0% during artificial ageing at 120°C were investigated by means of Vickers hardness measurements, tensile

tests, high angle annular dark field scanning transmission electron microscopy (HAADF-STEM) and Scanning precession electron diffraction (SPED). It was found that initial hardness increases with increasing Zn contents due to the solid solution strengthening by increased total amount of solute Zn and Mg atoms as well as age hardening response increase with increasing Zn contents due to the promotion of η' phase formation by increasing Zn/Mg ratios. In DSC results, it was found that formation peaks of GPII zone is observed in 8.0Zn indicating that GPII zone regarded as precursors of η′-phase precipitates enhances the formation of η-phase precipitates compared to 4.5Zn and 5.5Zn samples resulting in higher densities of η' phase of 8.0Zn than other samples. Also, T′ phase formation appears in both 4.5Zn and 5.5Zn and remains unchanged suggesting that T′ phase forms at the early stage of ageing and acts as co-strengthening precipitates with η' phase both in 4.5Zn and 5.5Zn. A dense and homogeneously distributed η' phase, T' and disordered η phase was found for all there samples and precipitates size is decrease with increasing Zn contents, while number densities of η' phase was significantly increased by BF-TEM and HAADFSTM images. From the phase maps analysis, we clearly identified the existence of T phase and η' phase.

Overall, in this study, in-depth researches on the understanding of relationships among microstructure (at atomic- and nanoscale), mechanical properties, plastic deformation and alloying elements of aluminum alloys have been carried out.