論文 / 著書情報
Article / Book Information

題目(和文)	
Title(English)	Evolution and Thermal Stability of Nanoclusters in Al-Mg-Si Alloys: Insights from Interatomic Structure of Clusters Formed at Low Temperature and Two-step Aging
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出典(和文)	学位:博士(工学), 学位授与機関:東京工業大学, 報告番号:甲第12548号, 授与年月日:2023年9月22日, 学位の種別:課程博士, 審査員:小林 郁夫,史 蹟,藤居 俊之,多田 英司,村石 信二
Citation(English)	Degree:Doctor (Engineering), Conferring organization: Tokyo Institute of Technology, Report number:甲第12548号, Conferred date:2023/9/22, Degree Type:Course doctor, Examiner:,,,,
学位種別(和文)	博士論文
Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	Materials Science and Engineering IGP(C)	系 コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of	(Engineering)
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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

With the rapid emergence of environmental issues caused by recent climate change, there has been a growing global interest in achieving carbon neutrality. The crash tests such as frontal and small overlap crash tests become more stringent. The automotive industry faces the challenge of meeting those inevitable requirements. The Al-Mg-Si alloys is widely used in automotive industry because of its excellent age-hardening properties. The Al panel is produced by the two-step aging process exposed to room temperature (i.e. natural aging (NA)) before artificial aging at about 170 ℃ (i.e. bake-hardening). Since nanoclusters are formed during NA, their formation is inevitable during Al panel fabrication. Obtaining the uniformly distributed fine metastable precipitates with high number density is the key factor in making high-strength Al-Mg-Si alloys. The nanoclusters formed at the early stage of phase decomposition influence on the formation of metastable precipitates during subsequent two-step aging. Therefore, it is important to understand the clustering behavior. However, the clustering behavior of nanoclusters in Al-Mg-Si alloys is not well understood due to the controversial issues related to the clustering evolution and thermal stability of the nanoclusters. Here, main issues related to those issues are introduced.

i. There is currently no established consensus on the optimal method for characterizing clusters using cluster identification algorithm in atom probe tomography.
ii. No attempt has been made to investigate the transition behavior of nanoclusters at the elevated temperature than natural aging under considering diffusion rate of solute atoms.
iii. The main factor of determining the thermal stability of nanoclusters is not clear.
iv. The reason for the different clustering evolution with different temperatures has not been fully understood yet.
v. The atomic-scale microstructure evolution during the initial stage of two-step aging has not been understood well.

The research work of the present thesis, titled ″Evolution and Thermal Stability of Nanoclusters in Al-Mg-Si Alloys: Insights from Interatomic Structure of Clusters Formed at Low Temperature and Two-step Aging″, is divided into five chapters to address the aforementioned issues. The major results and findings obtained from Chapter 2 to Chapter 6 are summarized as follows.

In the Chapter 2, the optimization of user-defined parameters in cluster identification algorithm were attempted. The four types of unphysical clusters were confirmed: large size having alloy composition, string-like, fragmented and connected clusters. It was confirmed that the combination of the parameters that minimized those unphysical clusters was in good agreement with the volume render and isoconcentration surface. A proposal was successfully made for optimizing user-defined parameters in the DBSCAN algorithm to perform cluster analysis on Al-Mg-Si-Cu alloy.

In the Chapter 3, the transition behavior of the nanoclusters at 50 ℃ considering the diffusion rate of solute atoms was investigated. Despite the expectation that Cluster (2) should be sufficiently formed based on the normalized aging time, the results of DSC, hardness, and electrical resistivity experiments indicated the formation of the thermally unstable Cluster (1). From these results, it was concluded that the temperature increased from room temperature accelerated the Mg-enrichment of the clusters, but it did not facilitate the transition from Cluster (1) to Cluster (2).

In the Chapter 4, the relationship between interatomic structure and thermal stability of the nanoclusters were discussed via concentration profile that provide the atomic arrangement inside clusters. The clusters formed at 50 ℃ for the same aging time were found to be more thermally unstable than the clusters formed during NA. Those clusters formed at different temperatures were indistinguishable based on atomic arrangement-independent characteristics such as size, composition

and atomic density. On the other hand, it was observed that the clusters formed during 50 ℃ had a Mg-rich core-shell structure, which was different from the clusters formed during NA.

In the Chapter 5, the reason for the complex clustering evolution with different temperatures were investigated by newly proposed approaches. Two distinct clustering evolutions were observed, determined by the transition temperature between 40 and 70 ℃. The clusters capable/incapable of continuous evolution were found to have low/high solute atom concentration cores, respectively.

In the Chapter 6, the change in microstructure due to the simultaneous contribution of nanocluster dissolution and nucleation of precipitate was investigated. During the two-step aging after natural aging for 2419.2 ks, until the hardness reached a minimum and increased again, nanocluster dissolution and formation of β'' nucleus were predominantly observed, respectively. The partial dissolution of clusters was observed during the initial stage of two-step aging. It was found that the clusters with high atomic density can serve as nuclei for precipitation, in contrast to clusters of similar size formed during natural aging.

Those findings introduced above allow us for better understanding of the complex two-step aging behavior in Al-Mg-Si alloys. Those research achievements contribute to design the alloy and heat-treatment history to control the microstructure of Al-Mg-Si panels manufactured by two-step aging process.