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論 文 要 旨

THESIS SUMMARY

専攻： Department of	材料工学	専攻	
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

The Al-Mg-Si alloys have been widely used for automobile body panels due to the attractive advantages such as excellent formability, high corrosion resistance. Especially, they can be strengthened by age-hardening during paint baking at 443K for 1.2 ks in practical processes. However, unavoidable natural aging at an ambient temperature due to shipping and storage deteriorates the age-hardening response. It is called as negative effect of two-step aging. In order to avoid this phenomenon, the nanoclusters formed by aging should be clarified because some of them act as a precursor of β" which is strengthening phase. In the present thesis, the nature of nanoclusters and its dependence on alloy composition and aging conditions are examined by three-dimensional atom probe (3DAP), differential scanning calorimetry (DSC) and hardness measurements. The correlation between nanocluster characteristics investigated by the 3DAP analysis and two-step aging behavior is also discussed. Finally, the more detailed model for two-step aging behavior and optimum nanocluster control conditions are proposed.

DSC is greatly useful technique to identify nanocluster formation. Therefore, the formation behavior of nanoclusters in the Al-Mg-Si alloys with different Mg and Si compositions is investigated using DSC analysis. Two overlapped exothermic peaks indicating Cluster (1) and Cluster (2) formation are clearly detected using DSC analysis in all examined alloys and separated using a Gaussian function method. The peak area was obtained by each separated exothermic peaks and it corresponds to volume fraction of the formed nanoclusters. As a results, the most favorable Mg/Si ratio of the alloys was 1.0 in terms of the Cluster (1) and Cluster (2) formation, which is lower than that of equilibrium β-(Mg_2Si).

3DAP is powerful technique to directly observe and characterize the nanoclusters. Therefore, the nature of nanoclusters and its dependence on alloy composition, aging temperature and time can be investigated using 3DAP analysis. It was found that the internal composition of nanoclusters is closely dependent on alloy compositions. Namely, the high Mg containing alloy produces more Mg-rich clusters. As a new finding, Cluster (1) and Cluster (2) were composed of the Mg-rich clusters, Mg-Si clusters and Si-rich clusters regardless of the alloy compositions. In addition, the fraction of three types of nanoclusters was different depending on the aging temperature and time.

In the previous approach, Cluster (1) is formed by natural aging at room temperature and leads to retarding of age-hardening response during artificial aging at 44K, while Cluster (2) formed by pre-aging at around 373K increase hardness promptly. However, new approach applying for the new categorization obtained by the 3DAP analysis is needed. Based on the results of two-step aging behavior, the Mg/Si ratio of alloys greatly affects to the two-step aging, especially, the negative effect caused by natural aging becomes larger in high Si containing alloys. It was also found that the two-step aging behavior is determined by the fraction of the Mg-Si clusters and Si-rich clusters regardless of aging temperature.

The quenched-in excess vacancies are also significant factor to help the nanocluster formation in

initial stage of aging. The Al-Zn-Mg alloy was considered as a comparison target of Al-Mg-Si alloy because they have a different quench sensitivity and two-step aging behavior. In the Al-Mg-Si alloy, it is likely to form the Si-vacancy complex after step-quenching (SQ). However, in the Al-Zn-Mg alloy, it is likely to form the dislocation loops and/or vacancy aggregation by absence of Si atoms. This dislocation loop acts as the annihilation point of vacancies as well as the source of vacancy supply into the matrix.

In practical field, the bake-hardening (BH) treatment was generally performed at 433K for 1.2 ks. The natural aging before the BH treatment leads to the insufficient the BH response. Also, as prolonged natural aging time, the BH response was greatly reduced by reversion of pre-formed clusters. It was found that the reversion phenomenon is only observed after long-term natural aging in high Si containing alloy, which has a lot of unstable Mg-Si clusters.

In conclusion, this is the first challenge in the field of the Al-Mg-Si alloy that the cluster categorization based on the 3DAP results. It allows us for better understanding a correlation between the cluster fraction and two-step aging behavior. In addition, the dependence of alloy compositions and aging conditions on the nanocluster formation was clarified. Based on these results, the more detailed model for the two-step aging behavior and optimum nanocluster control conditions were proposed. These research achievements contribute to the practical fields by the precise nanocluster and two-step aging control.