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APT Characterisation of Solute Clustering in 6111 Al Alloy

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Introduction

There have been strong demands for development of light weight vehicles with better fuel efficiency and less environment impact over the last ten years. A6111 alloy as light weight materials are showing strong potentials for automobile applications especially as car body panel materials. It is known that the formation of clusters prior to the strengthening β" phase have a significant effect on the strength of the material after two-stage ageing treatment.

In this investigation, samples were heat treated for various ageing temperatures, ranging from room temperature to 180 , to obtain a similar yield strength of about 140-180 MPa. This is an initial study to understand how the microstructures change with ageing heat treatment to achieve similar yield strength. Atom probe characterisation has been performed to get quantitative information about cluster size and number density, and the chemistry of the clustered solute atoms.

Experimental

Wire samples of AA6111 (Al-0.9Mg-0.6Si-0.3Cu-0.1Fe-0.1Mn-0.003Ti (at.%)) were received in various heat treated conditions. These were divided into two groups, based on ageing temperature, as listed in Table 1.

Needle-like specimens were prepared for atom probe tomography (APT) by a standard two-stage electropolishing process. APT experiments were carried out on a Local Electrode Atom Probe (LEAP) using laser pulsed evaporation mode.

Cluster-finding analysis was performed using a 3D Markov Field algorithm developed at the University of Sydney.

Heat Treatment	RT yield stress (MPa)	Heat Treatment	RT yield Stress (MPa)
RT 1 week	139	RT 2h	76
90ºC 24h	151.4	RT 4D 5h	120
150ºC 20mins	145.2	RT 1 week	139
180ºC 4mins	137.6	RT 2 weeks	148

Table 1. Yield stress of samples treated by different ageing conditions (RT refers to room temperature)

3D Reconstruction

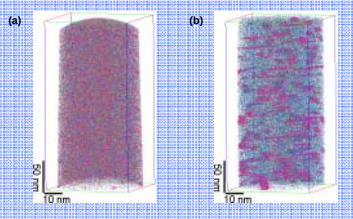

Fig .1 3D reconstruction of APT data of different samples (a) 180ºC 4mins (b) 180ºC

As ageing temperature increases, the needle shaped β" phase is observed (Fig. 1(b)). In this microstructure containing precipitates, the yield stress has increased significantly (up to 329 MPa) according to the mechanical testing results.

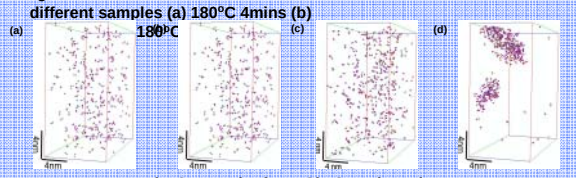

Fig. 2 growth of Mg-Si –Cu solute clusters (a) RT 2h (b) 150ºC 20mins (c) RT 4D 5h (d) 180º C 6h

Number Density of Clusters

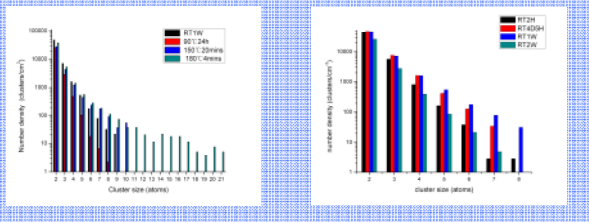

Fig.3 and Fig.4 – Change in number density of clusters divided into two groups, (natural ageing samples and iso-yield stress samples by different heat treatment conditions).

Heat Treatment	Number density Clusters/ cm^{-3}	Heat Treatment	Number density Clusters/ cm^{-3}
RT 1 week	5.77E+4	RT 2h	5.31E+4
90°C 24h	2.98E+4	RT 4D 5h	5.99E+4
150°C 20 mins	3.48E+4	RT 1 week	5.77E+4
180°C 4 mins	4.62E+4	RT 2 weeks	3.05E+4

Table.2 Number density of clusters of different samples

Cluster Chemistry

Heat Treatment	Mg:Cu ratio	
	Matrix	Cluster
RT 2h	3.66	3.87
RT 4D 5h	3.59	4.27
RT 1 week	3.22	3.36
RT 2 weeks	3.85	4.25

Heat Treatment	Mg:Cu ratio	
	Matrix	Cluster
RT 1 week	3.66	3.87
90ºC 24h	3.17	3.51
150ºC 20 mins	3.41	4.02
180ºC 4 mins	3.63	4.17

Table. 3 Comparison of Mg:Cu ratio between Matrix and Clusters

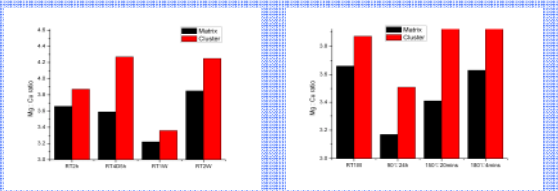

Fig. 5 Comparison of Mg:Cu ratio between Matrix and Clusters

Summary

- Yield stress of samples aged at room temperature increased gradually in respect with the increasing ageing time. Samples of different ageing conditions reached up to almost the same yield stress.
- The number density of clustered samples with higher yield strength is consistently higher than those with lower number density.
- The Mg:Cu ratio of clustered solute is higher than that of the matrix, and similar, for all samples.
- Further study includes cluster analysis using a different cluster-finding algorithm (Core-Linkage), with the aim to support the current results and further reveal the relationship between clustered microstructure and iso-yield strength phenomenon.

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