Alloys and Intermetallics

MS.6.P180
Cu and Zn atomic columns of precipitates in Al-Mg-Si alloys investigated by aberration-corrected scanning transmission electron microscopy

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Keywords: Al-Mg-Si alloys, precipitates, aberration-corrected scanning electron microscopy

Al-Mg-Si alloys are important structural materials characterized by formation of high number density of nano-sized precipitates. Strength of the alloys is achieved by precipitates which prevent dislocation movement. There are several types of metastable precipitates in the alloy, depending on their structure. β" precipitates are the most important for strength evolution, since they are fully coherent to the aluminium matrix [1, 2]. All metastable precipitates are structurally connected via a hexagonal network of Si atomic columns projected in the precipitate needle growth direction [1, 3]. Effects of different alloying elements on the Al-Mg-Si alloys are of key interest to understand the precipitation, e.g. the change in structure of the precipitates and the consequence for mechanical properties. In this study, the effects of Cu or Zn additions on precipitate structures in the Al-Mg-Si alloy system are investigated by aberration-corrected scanning transmission electron microscopy (STEM). High angle annular dark field STEM (HAADF-STEM) enables us to achieve atomic number contrast intensity, in particular it is possible to distinguish Cu and Zn atomic columns from Al, Mg and Si columns in the precipitates.

Two Al-Mg-Si alloys were studied; one added 0.1 wt% Cu and the other added 1 wt% Zn. The alloys were solution heat treated, subsequently kept at room temperature and isothermally heat treated ~190°C. Based on the hardness curves, the peak hardness conditions from the isothermal heat treatment were used for further studies. STEM specimens were prepared by electropolishing. The electrolyte consisted of 1/3 HNO_3 in methanol, and the solution was kept at a temperature between -20°C and -35°C. All specimens were gently ion milled and plasma cleaned before HAADF-STEM imaging in order to reduce the effect of contamination. A probe corrected JEOL ARM200F was used to acquire the HAADF-STEM images, operating at 200 kV.

Low Cu additions to the Al-Mg-Si alloys made the β" precipitate partially disordered in the same precipitate needle [4], as shown in Figure 1. The disordered part of the precipitates still contains the Si hexagonal atomic columns. It is suggested that the Cu atomic columns need a particular coordination surrounded by Mg and Si atoms which is not present in the perfect β" precipitates. However, perfect β" precipitates were also observed. Here Cu atoms partially segregated at the interface of the β" precipitates. Furthermore, the position of these Cu atoms were replaced at Si positions in the interface of the β" precipitates, see Figure 2. Additions of Zn to the Al-Mg-Si alloys lead to formation of Zn atomic columns in the β" precipitates as well as disordered precipitates, although Zn atoms were likely to be segregated along grain boundaries. These observations suggest that additions of Cu or Zn to the Al-Mg-Si alloys affect the structure of the precipitate and make particular atomic columns with their own atomic environments in the precipitates. In other words, Cu or Zn is incorporated when forming the precipitate.

1. We are grateful to Drs. F.J.H. Ehlers and R. Bjørge, Norwegian University of Science and Technology, for helpful comments and further discussions. This research is supported by Hydro Aluminum and the Research Council of Norway through the bilateral KMB project: 193619 "The Norwegian-Japanese Al-Mg-Si Alloy Precipitation Project".
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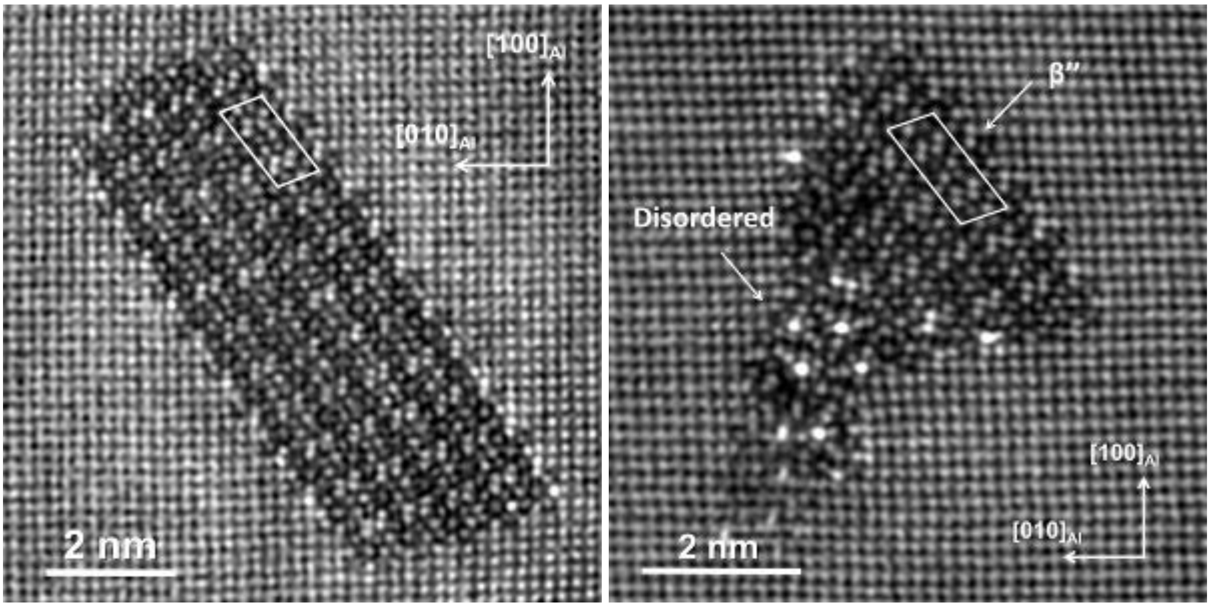

Figure 1. HAADF-STEM images from <100>Al direction for (left) Cu-containing β" precipitate and (right) Cu-containing β"/disordered precipitates. In these images, periodicity shorter than 1.5Å are filtered out with a circular band pass mask.

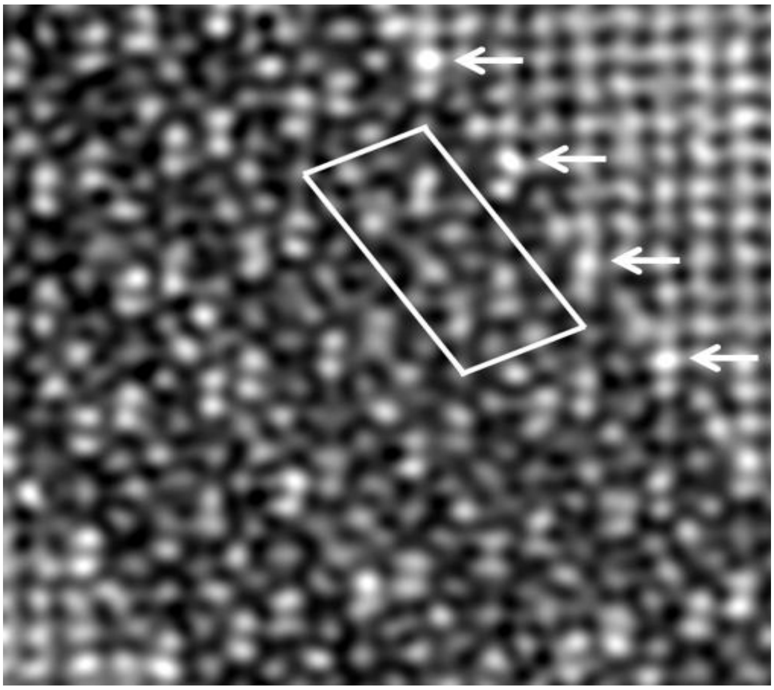

Figure 2. Enlarged part of the left image in Figure 1. Arrows indicate possible replacements of Cu atoms at Si positions in the interface of the β" precipitate, which was determined due to the atomic number contrast. The β" unit cell is drawn in the figure.