Microsc. Microanal. 8 (Suppl. 2), 2002
DOI 10.1017.S1431927602107653
1444CD

The GP-Zone to β'' Transformation in the Al-Mg-Si System

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ABSTRACT

GP-zones and the β''-Mg_5Si_6 phase are essential strengthening phases of the Al-Mg-Si system. The GP-zones nucleate in a very high number during heat-treatments and transform into fewer and coarser β''-particles. We present the structure of GP-zones in the Al-Mg-Si system and relate it to that of β''. The GP-model was derived by analysis of exit wave images, comparison of inter-atomic distances and image simulations. It is a centred super-cell on the Al-lattice with $\vec{a}_{GP} = [3\bar{2}0] \cdot a_{Al}$ (14.60Å), $\vec{b}_{GP} = [001] \cdot a_{Al}$ (4.05 Å), $\vec{c}_{GP} = [130] \cdot a_{Al}$ (6.40 Å). Both phases have the same monoclinic space group (C2/m). The a- and c- parameters of β'' are 15.16 Å and 6.74 Å, respectively, corresponding therefore to a slightly expanded super-cell. We show that the structure of β" may be obtained from that of the GP-zone by a translation b/2 of the Mg (000) atoms.

EXPERIMENTAL

The 6082 type Al-alloy where GP zones were investigated contains 0.6 Mg, 0.9 Si, 0.5 Mn and 0.2 Fe (weight %). The variation in hardness at 150°C ageing is shown in Figure 1. Ageing was performed immediately after water-cooling from a solution temperature [1]. A Philips CM30UT/FEG electron microscope operating at 300kV was used in the investigation. Each exit wave was reconstructed from one through focus series of 16 HREM images with 3.2 nm focus increment. The reconstructions were done using a software package based on algorithms developed by Van Dyck and Coene [2].

RESULTS AND DISCUSSION

Ageing for 11 hours and 9 days optimises the number of GP-zones and β'' which corresponds to the hardness-peaks in Figure 1. The exit wave images in Figure 2 show typical precipitates of these conditions. They are needles parallel to the aluminium <100> directions. The fully coherent GP-zone in a) is hardly visible. The larger β''-phase in b) is usually only partly coherent. It clearly produces strain in the surrounding matrix. We count twice as many precipitates in the case with GP-zones (11 hrs), but they have a much lower hardening effect. The β"–phase and later the GP zone structures were recently solved by our group [3,4] and [1]. The structure of β'' is shown in Figure 2c). The structure of the GP zone is that of a real ordering of atoms on the Al-grid. Figure 2d) shows the atomic model of the GP precipitate compared to the structure of the β" phase. Analysis of inter-atomic distances in a large number of GP-zones leads to the conclusion that Al must be part of the

composition. Mg and Si replace Al during growth of the GP zones, increasing strain in the ordered solution, causing a hardness increase up to 11 hours. The transformation to the β''-phase opens the possibility for a partly coherent phase to form, which is more effective in obstructing dislocations. The essential geometrical difference between the two structures can be observed in Figure 2d). The heights of the central Mg-atoms are different. When Mg-atoms have replaced most of the Al-atoms in the GP structure, it is energetically favourable for β" to form. This is obtained by moving the central Mg-atoms half way in the *b*-direction, parallel to the needle length.

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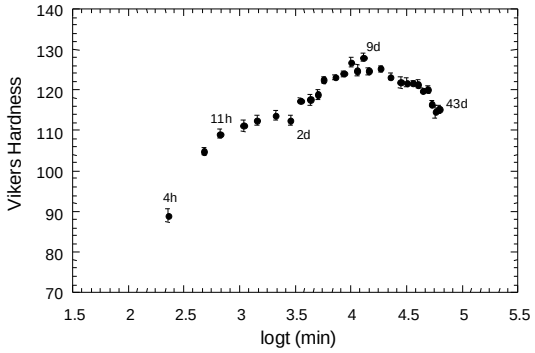

FIG. 1. Evolution of hardness as function of ageing at 150°C in a 6082 Al-Mg-Si alloy. Convex parts correspond to high density of GP-zones (11 hrs) and β'' (9 days).

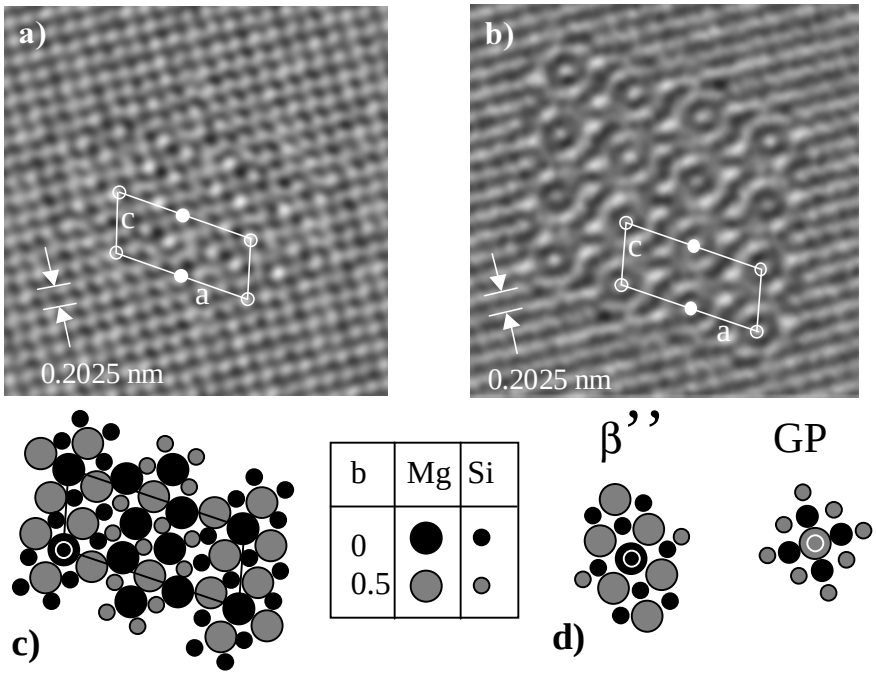

FIG. 2. a), b) Exit waves of precipitates in Al-matrix of 11h sample (GP-zone) and 9d sample (β"). c) Atomic structure of the β" precipitate; d) Comparison between the atomic structures of β"-phase and GP-zone. The Al-matrix is oriented in <100> zone axis.

https://doi.org/10.1017/S1431927602107653 Published online by Cambridge University Press