A precipitate phase in AA2124

YAN JIN, CHUNZHI LI, MINGGAO YAN
Institute of Aeronautical Materials, Beijing, 100095, and Laboratory of Solid Atomic Images, Institute of Metals, Academic Sinica, Shenyang, People’s Republic of China

A new precipitate phase (designated X phase) other than the S(Al2CuMg) precipitate phase has been discovered in the 2124 aluminium alloy. Using selected-area electron diffraction analysis, dynamical diffraction simulation, energy dispersion analysis of X-rays and high-resolution electron microscopy, it is suggested that the X phase has an orthorhombic crystal structure with a = 0.492nm, b = 0.852nm and c = 0.701nm. The space group of the phase is Cmmm. There are 10 atoms in a cell with Al : Cu : Mg = 2 : 4 : 4. The orientation relationship between the X phase and the matrix is determined as (1 - 10)m\[ (01 0)x, [- 1 - 1 - 1]m\[ [001]x. 

1. Introduction
The 2124 aluminium alloy is one of the most commonly used age-hardening Al-Cu-Mg alloys. Therefore, research on the precipitate phases in the alloy is quite important. Until now, most researchers [1-5] believed that only S(Al2CuMg) precipitate existed in AA2124. The S phase has an orthorhombic crystal structure with a = 0.400nm, b = 0.923nm and c = 0.714 nm [4, 5]. The orientation relationship between the matrix and S phase is (100)m∥(100)s, [012]m∥[001]s, where m and s indicate matrix and S phase, respectively. The S' phase is the metastable phase of S phase. The orientation relationship between the matrix and S' phase is similar to that of S phase. The ageing sequence of S phase can be written as GP zone ~ S' phase ~ S phase.

In the present work, we observed another kind of orthorhombic precipitate phase with lattice parameters and atomic composition which are different from those of S precipitate phase. The ageing process of the phase has also been studied.

2. Experimental procedure
The alloys studied were laboratory melt-made to the specification of AA2124. The chemical composition of the experimental 2124 aluminium alloy was 4.9 wt % Cu, 1.8 wt % Mg, 0.9 wt % Mn, 0.3 wt % Fe and 0.2 wt % Si. The size of heat-treated specimens was 20 mm × 20 mm × 40 mm. The specimens were solution-treated at 495°C for 90 min, water-quenched, then aged at different ageing temperatures shown in Table I.

The samples for observation were prepared with a conventional jet-polishing technique. The electrolyte contained one part of HNO3 and three parts of CH3OH (by volume). Observations by conventional transmission electron microscopy (TEM) was performed using an H-800 transmission electron microscope, and high-resolution electron microscopy (HREM) was performed using a JEM-200CX transmission electron microscope. The accelerating voltage was 200 kV in all cases. The orientation relationship between the matrix and precipitate phase was calculated using the method suggested by Li et al. [6]. The software for simulation of lattice images and dynamical diffraction patterns was provided by the Beijing Laboratory of Electron Microscopy.

3. Results and discussion
For convenience, we have called the new precipitate phase, X phase.

3.1. Lattice structure of X phase
Fig. 1 is the bright-field image of X phase in specimen A along the [00 1]m direction. The X phase appears as a bulk-like precipitate with different sizes. The selected-area electron diffraction (SAD) patterns of X phase along [00 1]m, [0 1 1]m and [1 1 2]m directions are shown in Fig. 2. The corresponding parameters of the two-dimensional unit cell were measured and are listed in Table II, where R1 and R2 represent the lengths of the shortest and second-shortest reciprocal lattice vectors respectively, θ is the angle between them, and D1 is the measured plane-spacing corresponding to R1.

Through computer calculation, it was found that there were three possible lattice structures: (a) orthorhombic lattice, C-centred cell, a = 0.492 nm, b = 0.852 nm and c = 0.701 nm, (b) monoclinic lattice, primitive cell, a = b = 0.492 nm, c = 0.701 nm, γ = 120°, (c) Hexagonal lattice, primitive cell, a = 0.492 nm, c = 0.701 nm. The corresponding calculated parameters are listed in Table III.

<table>
<thead>
<tr>
<th>No.</th>
<th>Ageing-treatment</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>420°C/2 h</td>
</tr>
<tr>
<td>B</td>
<td>190°C/12 h</td>
</tr>
<tr>
<td>C</td>
<td>220°C/12 h</td>
</tr>
</tbody>
</table>
Figure 1 Bright-field image of X phase in specimen A along the [001]$_m$ direction.

Figure 2 SAD patterns of X phase along (a) [001]$_m$, (b) [011]$_m$ and (c) [112]$_m$ directions.

The relationship between the three possible lattice cells is schematically illustrated in Fig. 3. Obviously, these three lattices have quite similar lattice structures and could hardly be distinguished using SAD analysis. Therefore, a further study using high-resolution electron microscopy (HREM) is necessary.

3.2. Crystal structure of X phase
Fig. 4 shows the EDAX analysis of the atomic composition of X phase in specimen A. The corresponding data are shown in Table IV. It was found that the X phase contains mainly Al, Cu and Mg. A small amount of Mn and Fe may also be present. From the experimental results, the ratio between Cu and Mg atoms in the X phase was calculated as 1:0.891. Owing to the influence of the Al matrix, the atomic composition of Al in the phase could not be determined. Because the average ratio between Cu and Mg atoms in the studied alloy is 1:0.978, the most probable atomic composition of X phase would be Al$_x$CuMg.

Fig. 5 shows the lattice image of X phase in specimen A along the [112]$_m$ direction. If the X phase has the orthorhombic crystal structure, the corresponding direction of X phase would be [102]$_m$.

Considering the possibility of the orthorhombic crystal structure, observed along the [001]$_m$ matrix...