Effects of Cold Drawing Ratio on δ Phase Precipitation Behaviors of Alloy 718 Wire

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The δ phase precipitation behavior of cold drawn alloy 718 has been investigated at 1116 K as a function of cold drawn ratio and aging time. The planar markings formed by cold drawing were identified as deformation twins and developed more clearly as cold drawing ratio increases. The grain boundaries and twins were played as nucleation site of δ precipitation, therefore, cold drawing enhanced the precipitation of δ particles. As the cold drawing ratio and aging time increased the amount of round-shaped δ also increased. In a specimen which was 50% cold drawn and aged for 4 hrs, the finely dispersed δ phase precipitated throughout the material. As aging time increased, The round-shaped δ phase changed to plate-like morphology, and the morphology transformation time was increased with cold drawing ratio. With a 50% cold drawn specimen, the transformation time was 7 hrs. On the other hand, for the 50% cold drawn specimen aged for one hour at 1116 K, nucleation of the strain free grain was observed.

1. INTRODUCTION

Superalloy IN 718 has good creep resistance, LCF properties and microstructural stability up to 873K [1]. Not only the mechanical properties but also the weldability of the alloy is excellent. Therefore, it is used in gas turbine parts, atomic power plant and chemical industries which operate at elevated temperatures.

γ (Ni,Al), γ" (Ni,Nb), δ (Ni3Nb) and carbides are precipitated in γ matrix by aging and dissolved by solid solution treatment in γ matrix which has a fcc structure. The mechanical properties in superalloy IN 718 are influenced by the size and morphology of γ (fcc, L12 structure), γ" (bct, DO21 structure), δ (orthorhombic, D02 structure), carbides and grain size which can be controlled by fabrication or aging processing.

As a result of cold working, the material has strain energy which enhances recrystallization and precipitation during subsequent heat treatment.

Many studies have been done on the precipitation kinetics of γ, γ" and δ phases in alloy 718 [2,3]. However, studies on the morphology of the δ precipitates which can influence creep resistance and fatigue properties are lacking, and it has only recently been recognized that the existence of the δ phase having a plate-like morphology in Fe-Ni alloy has a detrimental effect on its mechanical properties [4]. This study investigate the effects of cold drawn ratio and aging time in a fully solution treated and in cold drawn conditions on the amount and morphology of δ precipitation during aging treatment at 1116°C, which is a part of the MERIK heat treatment [5].

2. EXPERIMENTAL PROCEDURES

2.1. Wire rod

The wire rod used in this study was produced by double melting processes (VIM and VAR), forged, hot drawn to a 10.3 mm diameter rod and solution heat treated followed by quenching. The solution anneal resulted in a single phase material with an average grain size of 30-40 μm. The chemical composition of the specimen is shown in Table 1.

2.2. Cold working and aging

The cold work was achieved by drawing at room temperature which provided a uniform working condition throughout the cross section of the rod. This 10.3 mm diameter rod was further cold drawn to 30% or 50% reduction in diameter. The Cold drawn specimens were subjected to aging at 1116 K in a conventional furnace for various time followed by air cooling.

2.3. Microstructural analysis

Microstructural changes during aging were observed...
Table 1. Chemical composition of specimen

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>S</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Fe</th>
<th>Cu</th>
<th>Nb+</th>
<th>Al</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification</td>
<td>Max. 0.08</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>53</td>
<td>19</td>
<td>3.0</td>
<td>Bal.</td>
<td>Max. 0.15</td>
<td>5.1</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Specimen</td>
<td>0.06</td>
<td>0.12</td>
<td>0.17</td>
<td>0.004</td>
<td>53.33</td>
<td>18.29</td>
<td>3.06</td>
<td>Bal.</td>
<td>0.02</td>
<td>5.17</td>
<td>0.58</td>
<td>0.95</td>
</tr>
</tbody>
</table>

in SEM and TEM. All the specimens for scanning electron microscopy were etched with Kalling’s reagent (5 g CuCl₂ + 100 ml HCl + 100 ml ethanol) in boiling condition. The specimens for transmission electron microscopy were jet-polished in a 70% ethanol +10% glycerin +20% perchloric acid solution at a current density of 120 mA at room temperature. Thin foil for TEM analysis was done on selected samples to observe the δ nucleation, growth, and stability during aging.

3. RESULTS AND DISCUSSIONS

3.1. Effects of cold working on the deformation characteristics

Fig. 1 shows the representative SEM microstructures of the solution-treated, 30% and 50% cold drawn specimens. Planar markings (marked by arrows) are observed within elongated grains in the 30% and 50% cold drawn specimens. For the 50% cold drawn specimen, the planar markings are more clearly developed than they are in 30%. Specimens in order to identify the planar markings, TEM analysis was carried out. Fig. 2(a) and (b) show the TEM images of the planar markings de-

Fig. 1. SEM microstructures of (a) solution treated (b) and (c) solution treated and subsequently cold drawn to 30% and 50% of alloy 718 wire, respectively.

Fig. 2. TEM microstructures and selected-area diffraction pattern of cold drawn (a) 30%, (b) 50% of alloy 718 wire and (c) SADP ([110] zone axis) of planar marking (marked by arrows in Fig. 1(b) and (c)).