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Effect of compositions on the quenching sensitivity of 7050 and 7085 alloys

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ABSTRACT

The requirement for large aircraft components to have Al-Zn-Mg-Cu alloys with high strength and low quenching sensitivity has been increasing. The quenching sensitivity of 7085 and 7050 alloys used for thick plate applications was characterized via hardness tests and microstructure observation. A quenching precipitation model was established to predict the evolution of grain boundary and intragranular precipitates during air quenching process, and the effect of composition on the quenching precipitation behavior was investigated using this model. The quenching precipitation kinetic results show that the 7085 alloy has a low quenching sensitivity because the density of the precipitates in the Al_3Zr dispersoids and at the grain boundary is lower compared with that of the 7050 alloy. This result is in agreement with experimental results. Furthermore, the thermodynamic calculation results illustrate that the increase in the Zn/Mg ratio and the decrease in Cu element cause the α phase region to expand, thereby reducing the quenching sensitivity of the 7085 alloy.

1. Introduction

Improving the overall performance of Al-Zn-Mg-Cu alloys to meet the requirements of large aircraft components has gained increasing attention [1,2]. For large-scale products such as thick plates and bulk forgings, Quenching sensitivity of Al-Zn-Mg-Cu alloys is a critical factor that should be considered because an inadequate quench rate at the center of large-scale products results in poor mechanical properties [3]. Quenching sensitivity is essentially caused by the loss of solutes during the slow quenching process because heterogeneous precipitation occurs at the dispersoids and at the (sub)grain boundary [4–6]. Quenching precipitation and its effect on the mechanical properties of materials after aging have been widely investigated via interrupted quench [7–10] and Jominy end quench methods [11–13]. The quenching sensitivity of Al-Zn-Mg-Cu alloys has been evaluated using time-temperature-property (TTP) curves and the depth of the age-hardening layer. Godard [6] investigated the quenching precipitation sequences of the 7010 alloy via interrupted quench. However, little attention has been given on the quantitative description of quenching precipitation, whose heterogeneous nucleation may occur either at the grain boundary or at the dispersoids.

Chemical compositions significantly affect the quenching sensitivity of Al-Zn-Mg-Cu alloys. Quenching sensitivity increases when the total content of alloying elements (Zn+Mg+Cu) is increased because rapid decomposition occurs during slow quenching [11]. The increase in the amount of Mg and Cu elements leads to a high quenching sensitivity [11]. The 7050 alloy was designed by replacing Cr and Mn elements with Zr element to obtain a low quenching sensitivity [3,5]. The decrease in quenching sensitivity can be attributed to the high Zn/Mg ratio [14,15]. The 7085 alloy, which is a new generation of Al-Zn-Mg-Cu-Zr alloys with high strength and low quenching sensitivity, has been recently developed by increasing the Zn content and increasing the Zn/Mg ratio. This alloy has been used in advanced aircrafts such as A380 [16]. Thus far, few studies have investigated on the effect of alloy compositions on the quenching sensitivity based on quenching precipitation kinetics and thermodynamic calculations.

This paper focuses on 7050 and 7085 alloys that are used for thick plate applications. A comparative study was conducted to reveal the difference in the quenching precipitation behavior between the 7050 and 7085 alloys. A quenching precipitation model was established to predict the evolution of precipitates that nucleate at the grain boundary and in the Al_3Zr dispersoids during air quenching process. The effect of compositions on quenching

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sensitivity was analyzed based on thermodynamic calculations.

2. Experimental procedures

2.1. Materials and test

Two types of aluminum alloy ingots with nominal chemical compositions of 7050 and 7085 alloys were prepared. The compositions of these alloys are shown in Table 1. The ingots were homogenized by slow heating to 450 °C, held for 24 h, and then cooled in air. After pre-heating at 400 °C for 1 h, the homogenized ingots were rolled into sheets with multi-passes. The rolled sheets were cut into rectangular samples with a block size of 20 mm × 20 mm × 4 mm.

After solution heat treatment at 470 °C for 60 min, the samples were quenched in water at room temperature and in air, respectively. The specimens were then artificially aged at 120 °C for 24 h. The cooling curves during the quenching process were obtained using thermocouples that were soldered into the sample, and there was any air or water around the tip of the thermocouples. The detecting interval was 0.04 s Fig. 1 shows the cooling rate of the air-quenched sample was much lower than that of the water-quenched sample.

The Vickers hardness of the samples was tested on a HV-10A machine with a load of 3 kg. Six measurements were made on each sample to obtain an average value. The microstructure was observed using a JEOL JEM2100 transmission electron microscope operated at 200 kV. Samples with a diameter of 3 mm and a thickness of 80 μm were electropolished for TEM observation by using 30% HNO_3 + 70% CH_3OH solution below −20 °C.

2.2. Thermodynamic calculation

The thermodynamic calculation was based on the CALPHAD method (calculation of phase diagrams), which can be described by a thermodynamic model with the Gibbs energy of the entire system. The system reaches an equilibrium state when the Gibbs energy of the system reaches the minimum. The Gibbs energy of a phase in a multicomponent system can be expressed as follows [17]:

$$G_m = \sum_i x_i G_i^0 + RT\sum_i x_i \ln x_i + \sum_i \sum_{i>j} x_i x_j \sum_v \Omega_v (x_i - x_j)^v \quad (1)$$

where the first component is the Gibbs energy of the pure components, the second is the ideal entropy, and the third is the interaction term with interactive parameters; x_i and x_j are the mole fractions of the different alloying components; T is the temperature; R is the gas constant; Ω_ν is an interaction coefficient dependent on the value of ν.

Thermodynamic calculation of the equilibrium phase was carried out using the Thermo-Calc software and an aluminum database. The mole fractions of the equilibrium phase and the phase diagrams were calculated with the nominal chemical compositions of the 7050 and 7085 aluminum alloys.

Table 1
Nominal chemical compositions of the 7050 and 7085 aluminum alloys (mass fraction, %).

Alloys	Zn	Mg	Cu	Zr	Al
7050	6.2	2.25	2.3	0.115	Bal.
7085	7.5	1.5	1.65	0.115	Bal.

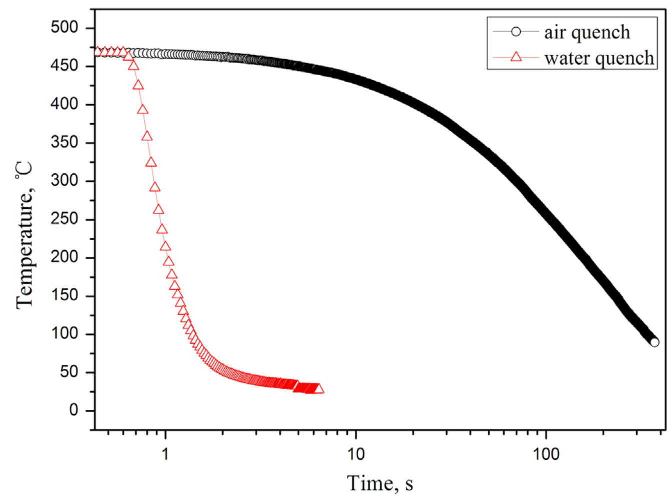

Fig. 1. Cooling curves during the water and air quenching processes.

3. Results and discussion

3.1. Characterization of quenching sensitivity

The aging curves of the 7050 and 7085 alloys after water and air quenching are shown in Fig. 2. The hardness values of both 7050 and 7085 alloys decrease as a result of air quenching. The Vickers hardness of the water-quenched 7050 alloy is 201 HV after the sample was heat treated at 470 °C for 60 min, followed by cold water quenching, and artificial aging at 120 °C for 24 h (Fig. 2a). The Vickers hardness value for the air-quenched and aged sample decreases to 182 HV, with a maximum hardness reduction of about 9.45%. The overall hardness of the 7085 alloy decreases by about 5.2%, which is much smaller than that of the 7050 alloy. This result indicates that the 7085 alloy has lower quenching sensitivity than the 7050 alloy.

For the water-quenched sample, no precipitates are observed at the grain boundary and in the Al_3Zr dispersoids located inside the grains for both 7050 and 7085 alloys (Figs. 3 and 4). When the alloys are quenched in air, quench-induced precipitates, which are identified as $MgZn_2$ (η) phases in the conferences 3 and 18, are observed at the grain boundary for both alloys (Fig. 5). Quench-induced precipitates inside the grains nucleate in the Al_3Zr dispersoids [3,18] after air quenching (Fig. 6). The quench-induced precipitate bands are observed inside the grain for the 7050 alloy because Al_3Zr dispersoids are heterogeneously distributed in long thin bands. The reasons for this distribution include the peritectic nature of the Zr element [19] and its very low diffusivity in aluminum [18]. The precipitation in the 7085 alloy is less than that of the 7050 alloy (Fig. 7), whereas no significant difference is observed between the size of the precipitates inside the grains and at the grain boundary. Thus, the 7085 alloy has a low quenching sensitivity because the precipitates have a low density during the slow quenching process.

3.2. Quenching precipitation kinetic analysis

Deschamps and co-workers have developed several models for precipitate evolution in 7xxx alloys under both isothermal [20] and non-isothermal conditions [21] based on classic kinetic theory and the Kampmann and Wagner numerical (KWN) framework. These models treat a single population of precipitates, and do not differentiate between the precipitates inside the grain and at the grain boundary. A model in the present work is to establish to descript the precipitate evolution during air quenching process. In