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Investigation of quench sensitivity and transformation kinetics during isothermal treatment in 6082 aluminum alloy

B.C. Shang [a], Z.M. Yin [a,*], G. Wang [a], B. Liu [a], Z.Q. Huang [a,b]

[a] School of Materials Science and Engineering, Central South University, Changsha 410083, China
[b] Foshan Sanshui Fenglv Aluminium Co. Ltd., Foshan 528133, China

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The quench sensitivity of 6082 aluminum alloy was investigated by time–temperature–property (TTP) curves. The sensitive temperature of quenching ranges from 250 °C to 440 °C in 6082 Al-alloy, and the nose temperature is about 360 °C. During isothermal treatment process, the Mg_2Si particles precipitate from the supersaturated solid solution, and the precipitation rate is the highest at the nose temperature. A number of rod-shaped β′ and β particles precipitate in the early stage of isothermal treatment at 360 °C. Prolonging the holding time leads to more and coarser β particles in the matrix. Both the precipitation of β′ and β particles results in loss of solute and decreasing of the subsequent age hardening effect. Also, the important coefficients k_2–k_5 and critical cooling rate for 6082 Al-alloy are identified, and the properties after different rates of cooling were predicted using quench factor analysis.

1. Introduction

6000 series alloys are widely used because of their benefits such as medium strength, formability, weldability, corrosion resistance and low cost. And these Al–Mg–Si alloys are mostly used in extruded aluminum products in Western Europe, as well as for construction and automotive purposes [1,2]. For the heat treatable alloys which can be heat treated to produce precipitation to various degrees, such as 6082 alloy, a proper process of heat treatment is important.

When the alloy is given a solution heat treatment and then quenched to a temperature lower or equal to room temperature, it will be supersaturated with respect to the dissolved elements. Consequently, a precipitation reaction occurs during slow cooling. As mentioned above, a rapid quench from the solution heat treatment temperature is required to achieve optimal mechanical properties. But in industrial production, the quench rates should be controlled at a low level to reduce the residual stress and warping. An ideal quench will minimize residual stresses while maximizing the mechanical properties of the alloy. To achieve these, the quench sensitivity of heat treatable alloys should be studied carefully.

Time–temperature-property (TTP) and time–temperature–transformation (TTT) curves are both effective approach to evaluate quench sensitivity. Much work about quench sensitivity of aluminum alloys has been done in the present investigation. Dolan et al. [3,4] investigated the quench sensitivity of some typical alloys using TTP curves which were obtained by an interrupted quench technique, the coefficients k_2–k_5 for three kinds of alloys are identified. Liu et al. [5–7] mainly investigated the quench sensitivity of high strength Al–Zn–Mg–Cu alloys by TTP diagrams, and the influence of quenching rate on the drop in the properties was studied by quench factor analysis method. And also many properties of alloy, such as hardness, strength, fracture toughness and corrosion resistance, were investigated using quench factor analysis method [8–10].

It is generally accepted that the TTP curves can be described mathematically as $t_c(T)$ shown in Eq. (1). $t_c(T)$ function with the following form is used to determine the incubation time for alloy of interest [11].

$$t_c(T) = -k_1 k_2 \exp\left[\frac{k_3 k_4^2}{RT(k_4 - T)^2}\right]\exp\left(\frac{k_5}{RT}\right) \qquad (1)$$

where $t_c(T)$ is the critical time for precipitation of a constant amount of solute, k_1 is the natural logarithm of the untransformed fraction during quenching, k_2 is the constant related to the reciprocal of the number of nucleation sites, k_3 is the constant related to the energy required to form a nucleus, k_4 is the constant related to the solvus temperature, k_5 is the constant related to the activation energy for diffusion, R is the universal gas constant, and T is the absolute temperature (K).

With TTP curves, the effect of quenching rate on properties can be predicted by quench factor analysis method. Quench factors can be calculated according to the equation [11]:

$$\tau = \int_{t_0}^{t_f} \frac{1}{t_c(T)} dt \qquad (2)$$

* Corresponding author. Tel./fax: +86 731 88830262.
E-mail addresses: shangbaochuan@163.com (B.C. Shang), zmyin@163.com, yin-grp@csu.edu.cn (Z.M. Yin).

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