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Influence of Mg content on quench sensitivity of Al–Zn–Mg–Cu aluminum alloys

Yun-lai Deng[a,b,*], Li Wan[a,b], Yun-ya Zhang[a,b], Xin-ming Zhang[a,b]

[a] School of Materials Science and Engineering, Central South University, Changsha 410083, China
[b] Key Laboratory of Nonferrous Materials Science and Engineering, Ministry of Education, Changsha 410083, China

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ABSTRACT

The influence of Mg content on quench sensitivity of Al–8.0Zn–x(=1.0–2.0)Mg–1.6Cu alloys was investigated by an end-quenching test method. The depths of age hardening layer referenced to hardness retention values (e.g., 90%) of the end-quenched samples were used to describe the quench sensitivity. The results showed that the depths of age hardening layer decreased with increase of Mg content. The amount of the equilibrium-state $MgZn_2$ (η) particles was the primary factor that determined the depths of age hardening layer. The η particles underwent two precipitation processes successively with decrease of cooling rate during quenching: precipitation on grain boundaries and precipitation inside the grains. The precipitation temperature peaks rose, and the ranges of the temperatures are extended with the increase of Mg content. A preliminary prediction has been made for the initial precipitation temperatures and the temperature peaks satisfying linear relation with Mg content (wt.%).

1. Introduction

Aeronautical and aerospace industries are developing rapidly, and the use of monolithic components could help in reducing component weights significantly as well as lower assembly costs. Accordingly, the fabrication of large monolithic components using 7*xxx* series Al alloys thick plates has attracted increasing attention because they have superior mechanical properties [1–3]. However, because of their relatively high quench sensitivity, there is a significant difference in the mechanical properties from the surface to the center after quenching-aging [4–8]. As a result, Alcoa Company developed the 7050 and 7150 alloys, in which quench sensitivities are lower than those of 7075 alloy, and used them in the Boeing 757, 767, and 777 aircrafts [9,10]. The quench sensitivities of various Al alloys and addition of trace elements (e.g., Cr, Zr) have been reported in many papers [4,11–14]. In 2003, Alcoa Company developed 7085 Al alloy, which has high strength and toughness and low quench sensitivity; this alloy has been used in the advanced aircrafts such as A380 [11]. However, it is well known that when the arithmetic mean of the limit of an Al alloying element in an original alloy is 1.0–2.0 (wt.%), the maximum difference is 0.20 (wt.%). If the component range is exceeded, the Al alloy should be registered as a new Al alloy [15]. In 7085 Al alloy, the Mg content is 1.2–1.8 (wt.%), this accordingly results in more than two types of Al alloys. Therefore, it is important to know the effect of Mg content on quench sensitivity of the 7085-type Al alloys, but few reports have covered this issue.

In present paper, an end-quenching test, which has been used to determine the quench sensitivity of Al alloys and to improve the parameters of water spraying-quench technique [16,17], was employed to identify the effect of Mg content on quench sensitivity of the 7085-type Al alloys. This study will be helpful to develop this type Al alloys.

2. Experimental

The investigated Al–8.0Zn–xMg–1.6Cu alloys were prepared in laboratory by an ingot metallurgical route. The raw materials were high purity Al (99.998%), Zn (99.98%), and Mg (99.98%) and Al–3%Zr, Al–30%Cu, and Al–5%Ti–B (wt.%). The alloys were melted in a graphite crucible heated using an electrical resistance furnace. The liquid metal was then poured into an iron mold to produce 40 mm × 80 mm × 120 mm ingots. The chemical compositions of the alloys are shown in Table 1. The ingots were homogenized at 400 °C for 12 h and then at 470 °C for 12 h. The total thick reduction of rolling deformation was approximately 70%. The initial rolling temperature was 420 °C. Cylinders with dimension of Φ10 mm × 140 mm were cut from the rolled plates as samples used in an end-quenching test. The schematic diagram of the end-quenching test and the water flux and pressure through nozzle used by present paper are shown in Fig. 1. After solution heat treatment at 475 °C for 4 h, the end-quenching tests were conducted, and the end-quenched samples were aged at 121 °C for 24 h. Hardness tests of the aged samples were conducted to obtain the hardness changes along the direction of the distance far from the end-quenched face.

An XJP-6A metalloscope was used to obtain the metallographes, and the corrosive solution was composed of 1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, and 95 ml distilled water. A JSM-6360LV scanning electron microscopy (SEM) and a TECNAIG^{2} 20 transmission electron microscopy (TEM) at an acceleration voltage of 200 kV were used to study the second phases. Furthermore, A Rigaku D/Max 2500 diffractometer was used for the X-ray diffraction (XRD) tests. A NET2SCH-200 F3 thermal analyzer was used for differential scanning calorimetry (DSC), with a temperature reduction rate

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* Corresponding author at: School of Materials Science and Engineering, Central South University, Yuelu Section, Changsha, Hunan 410083, China.
Fax: +86 731 88876913.
E-mail address: dengylcsu@126.com (Y.-l. Deng).

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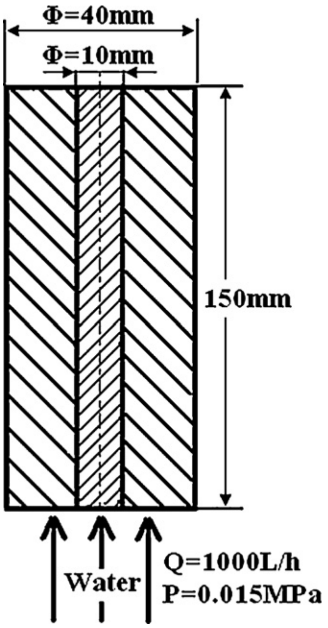

Fig. 1. Schematic diagram of the end-quenching test.

of 5 °C/min from 450 °C. An HV-5 tester was used to measure Vickers hardness (HV) under a load of 3 kg and a hold time of 15 s.

3. Results and analyses

3.1. Hardness curves

The hardness curves of the end-quenching-aging specimens of the 1#, 2#, 3# Al alloys in Table 1 are shown in Fig. 2. It can be seen in Fig. 2(a) that when Mg = 1.0% (1# alloy), $HV_{max} = 167$, when Mg = 1.4% (2# alloy), $HV_{max} = 173$, and when Mg = 2.0% (3# alloy), $HV_{max} = 197$. The reason is that the dominant strengthening particles in the present Al–Zn–Mg–Cu alloys are non-equilibrium η' phase particles, and the increased addition of Mg causes the amount of η' phase particles in the matrix to increase. However, the higher Mg content, the greater decrease of hardness along the direction of the distance far from the end-quenched face (d). This means that the quench sensitivity is influenced by the Mg content in present Al alloys, i.e., the higher Mg content, the more sensitive.

In order to quantitatively describe effect of Mg content on quench sensitivity, the curves of hardness retention value vs d are shown in Fig. 2(b). As mentioned above, the hardness retention value decreases with increase of the d. It is very interesting that the quench sensitivity could be simply described by the depth of age hardening layer, which is evaluated by the distance at where a certain hardness retention value is selected. Here, the selected hardness retention value is 90%, and then for Mg = 1.0, the entirely tested-distance of the specimen can achieve full hardening, and the depth of age hardening layer is more than 100 mm; when Mg = 1.4, the depth of age hardening layer is about 65 mm; when Mg = 2.0, the depth of age hardening layer decreases to about 40 mm. It is also worthy to notice that the deviation distances of the hardness retention values between the specimens of the three alloys become small with the increase of Mg addition, i.e., the deviation occurs at 50 mm between 1# and 2# alloys, whereas 3# alloy almost deviate from 1# and 2# alloys at the beginning. In short, the depths of age hardening layer of the alloys are very sensitive to Mg content.

Table 1
Nominal chemical composition of the investigated Al–Zn–Mg–Cu alloy (wt.%).

Alloy	Zn	Mg	Cu	Zr	Fe	Si	Cr	Mn	Ti	Al
1#	8.0	1.0	1.6	0.13	0.07	0.05	0.03	0.04	0.06	Bal.
2#	8.0	1.4	1.6	0.13	0.07	0.05	0.03	0.04	0.06	Bal.
3#	8.0	2.0	1.6	0.13	0.07	0.05	0.03	0.04	0.06	Bal.

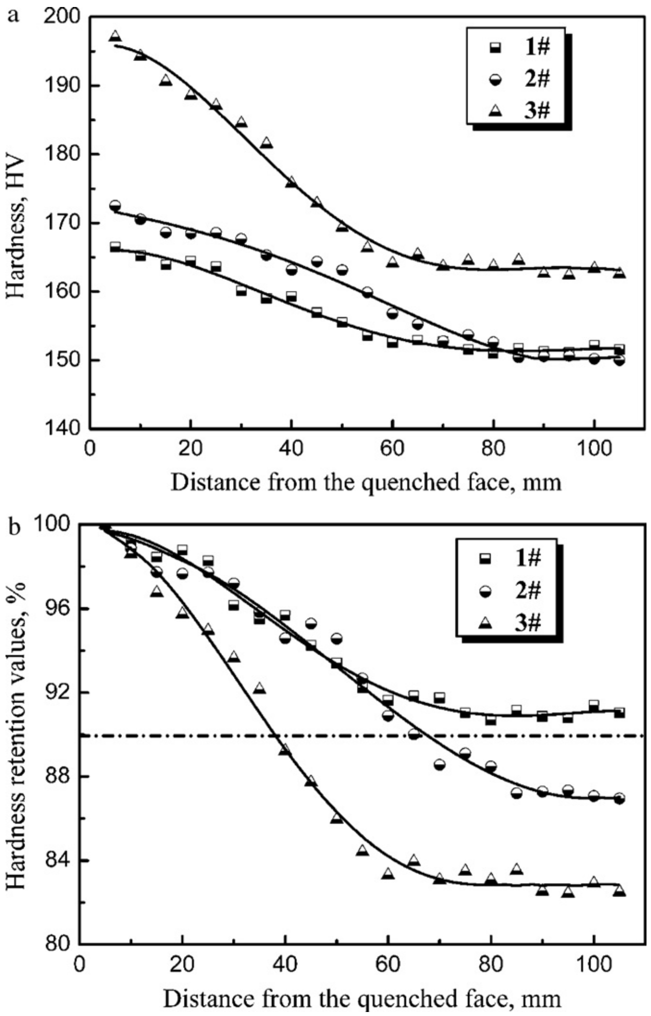

Fig. 2. Aging hardness and hardness retention values curves of the end-quenched samples.

3.2. Microstructures

Stereo metallographic images along the direction with the increasing d in the end-quenched sample of 3# alloy are shown in Fig. 3. It can be seen in Fig. 3(a) that no significant recrystallization occurred during solution heat treatment. The matrix microstructures in the specimen cut from $d \approx 5$ mm of the end-quenched sample still maintains the stripe-shaped grains extended along rolling direction. As the cooling rate of the quenching decreased with the increasing d of the end-quenched sample, significant recrystallization and non-recrystallization areas can be observed in the metallographic images of the specimens cut from $d \approx 40$ mm to $d \approx 80$ mm, respectively, as shown in Fig. 3(b) and (c), respectively. The bright areas are the recrystallization areas, and the dim areas represent the sub-grain structures with precipitations on the sub-grain boundaries.