MATEC Web of Conferences 67, 05020 (2016) DOI: 10.1051/matecconf/20166705020
SMAE 2016

Two-step Aging Treatment in Ultra-High-Strength Al-Zn-Mg-Cu Aluminum Alloy

Kun LIU*, Gang ZHAO, Ni TIAN

Key laboratory for Anisotropy and Texture of Materials; (Ministry of Education)
Northeastern University, Shenyang 110004, China;

Abstract. The parameters of duplex aging treatment of pre-stretched plates including both the temperature and the holding time of two aging stages have been systematically investigated by using electric conductivity and tensile properties tests, exfoliation corrosion experiments and TEM observations. The results show that both the first and the second age have effect on properties of plates after having been performed by different duplex aging treatments and the effect of the second age is much greater. It is found that such a duplex aging treatment is appropriate in which the temperature of the second age is 155℃ and the holding time of the first and the second age is 4-6 and 28-32 hours, respectively. The ultimate strength of specimens treated with the duplex aging treatment given above can achieve 540MPa while electric conductivity is 40.5-42 %IACS.

1 Introduction

The Al-Zn-Mg-Cu alloys are the foundation of high-strength aluminum alloys, whose strength is the highest in commercial aluminum alloys made in traditional way. Besides of the high strength, the Al-Zn-Mg-Cu alloys also have many attractive properties, such as low density, good ductility and so on. Due to these attractive properties, they are widely used in aeronautical industries as structural materials. However, alloys of Al-Zn-Mg-Cu series are sensitive to stress corrosion cracking (SCC) and exfoliation corrosion, which limits the applications in some special fields. Though the contradiction between strength and resistance of corrosion has already been settled abroad, it is still a puzzle in our country. So it is one of the vital study aspects to research the proper heat treatment including solution and aging treatment which can improve the resistance of corrosion at no or a little expense of the strength [1].

The key work of this study is to investigate the effect of different parameters of duplex aging on the materials through electric conductivity and tensile properties tests, exfoliation corrosion experiments and TEM observations. Then it is possible to establish the experimental base of new duplex aging treatment to improve the overall properties of alloys.

* Corresponding author:k.liu1350@hotmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (http://creativecommons.org/licenses/by/4.0/).

2 Experimental

The chemical compositions of the alloy studied in this work were shown in Table 1. The ingots were produced by using semi-continuous casting method. Specimens were homogenized, scalped, hot rolled to plates of 12 mm in thickness, solid solution treated at 470℃ for one and a half hours and then water quenched to the room temperature. To relieve the stress, the plates were pre-stretched by 2%. Then the specimens were aged at different temperatures (155°C and 165°C) for different holding time (2-8 hours for the first age and 20-32 hours for the second age).

Table 1 Chemical compositions of the alloy (mass fraction, %)

Zn	Mg	Cu	Mn	Cr	Zr	Ti	Fe	Si	Al
6.24	2.26	2.32	0.10	0.01	0.1	0.13	0.07	0.15	Bal.

The TEM observations were conducted on TECNAI $G^2$20 operated at 200kV while the tests of electric conductivity and tensile properties were performed using Sigma scope SMP10 and CMT5105-SANS, respectively.

3 Results and Discussion

3.1 Effect of the second aging temperature on properties

In order to study the effect of the second aging temperature, the specimens were treated with different duplex aging treatments in which only the temperature of the second age was different (155°C and 165°C). Table 2 shows the electric conductivity and tensile properties of the specimens. Comparing the values in Table 2, it can be concluded that when the second aging temperature is different, the properties are significantly distinct: the strength of the specimens treated at 155°C is much higher than that at 165°C while the electric conductivity is lower. This is mainly because that the duplex aging is an over-aging treatment, the peak age can be achieved in a short time and the time decreases with the increase of aging temperature [2]. So when the temperature of the second age is higher, the time to peak age is shorter. After achieving peak age, the size of the matrix precipitations (MPt) will become coarser which will reduce the strength during the over-age. Meanwhile, the electric conductivity will increase with the coarse and discontinuity of grain boundary precipitations (GBP), which will weaken the block function to the conduction electron [3, 4]. To obtain better combined properties, 155°C is proper to the second aging temperature.

Table 2 Electric conductivity and tensile properties

Aging treatment	$\sigma_{0.2}$\MPa	σ_b \MPa	ρ\%IACS
120°C×4hr+ 165°C×20hr	440.4	508.7	42.5
120°C×4hr+ 155°C×20hr	506.6	562.0	39.5
120°C×4hr+ 165°C×24hr	435.6	504.4	42.7
120°C×4hr+ 155°C×24hr	501.9	557.9	39.8
120°C×4hr+ 165°C×28hr	424.9	497.4	42.9
120°C×4hr+ 155°C×28hr	490.2	546.3	40.5
120°C×4hr+ 165°C×32hr	417.9	493.7	43.3
120°C×4hr+ 155°C×32hr	483.5	541.0	40.9

3.2 Effect of second aging holding time on properties

After having decided the second aging temperature, the effect of holding time cannot be ignored. Fig. 1 depicts the curves of electric conductivity and tensile properties of the specimen, whose second aging holding time is different.

From the curves, it is found that the trend of strength is decreasing with the prolonging of holding time while the electric conductivity increases. This phenomenon can be attributed to the over-aging treatment: During the over-age, the coarse of MPt leads to the reduce of strength while the coarse and discontinuity of GBP leads to the increase of electric conductivity [5] Considering the overall properties, we settle the holding time 28-32hours.

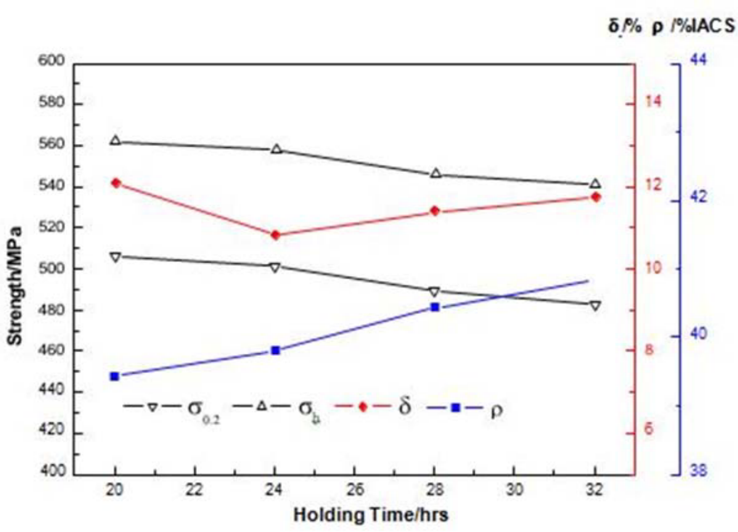
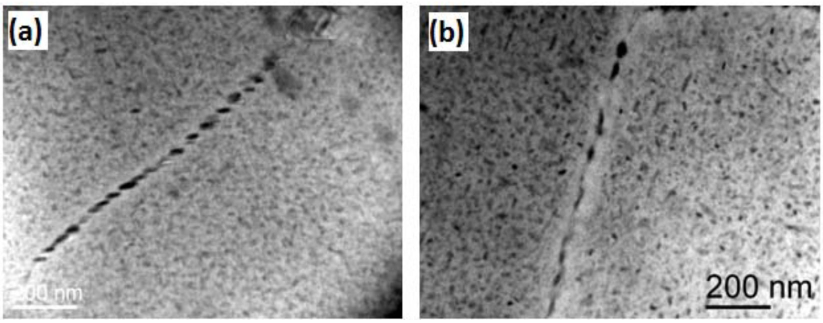


Fig.1. Curves of electric conductivity and tensile properties

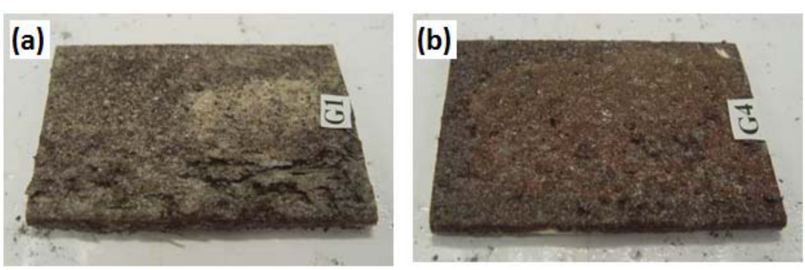
The SCC phenomenon of aluminum alloys has been extensively studied and now the category of anodic dissolution is widely used in 7XXX series alloys [6]. In anodic dissolution model, the potential of grain boundary precipitation is lower than matrix, acting as the anode in the corrosion. So the grain boundary will be firstly dissolved when the corrosion occurs. When GBP are fine and continuous, it is easy to form the cracks and the resistance is lower; To the contrary, when the particles become discontinuous and the size is greater, it is easier to form the corrosion pits than cracks and then the resistance improves [7]. So to improve the combined properties, it is feasible to gain such microstructures in which MPt is fine while GBP is coarse and discontinuous. TEM and exfoliation corrosion pictures of specimens for different second aging holding time are shown in Fig. 2 and Fig. 3.



(a) holding time is 2 hours (b) holding time is 28 hours

Fig.2. TEM pictures of specimens under different holding time

In Fig.2, the size of MPT is similar fine and (b) is a little coarser than (a), so the tensile properties descends a little with the increase of holding time. But the size and space between GBP are significantly distinct: when the holding time was 2 hours (Fig.2 (a)), GBP are fine and continuous while they are coarse and discontinuous for 28 hours (Fig.2 (b)), so the resistance of SCC increases. The results also can be confirmed by the exfoliation corrosion pictures of Fig.3. From Fig.3, it is found that the degree of exfoliation corrosion decreases with the increase of holding time: when holding time is 2 hours, the grade of exfoliation corrosion (Fig.3 (a)) is E_C and is much heavier than that for 28 hours (Fig.3 (b)), the grade of which is E_A+1/2. So the second aging holding time of 28-32hours is proper.



(a) holding time is 2 hours (b) holding time is 28 hours

Fig.3. Exfoliation corrosion pictures of specimens under different holding time

3.3 Effect of the first aging holding time on properties

Though many researchers had studied the effect of different ways of altering between the first and second age, such as water quenched, air cooled and so on [8]. The author still thought that the first aging holding time will make effect on the properties, so the effect of first aging holding time of was one part of the work. Fig.4 shows the curves of electric conductivity and tensile properties of specimens for different first aging holding time.

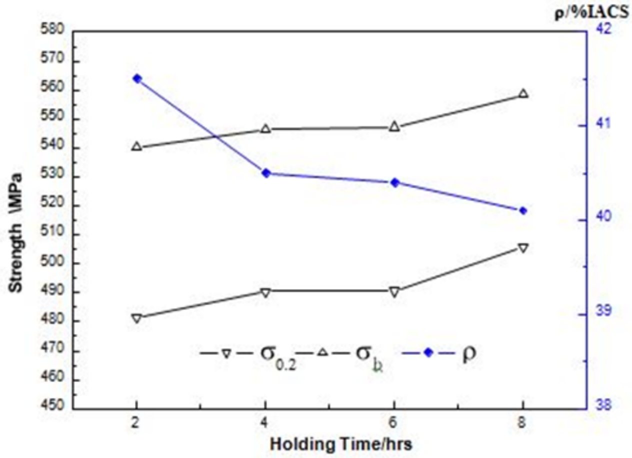


Fig.4. Curves of electric conductivity and tensile properties

Contrast with Fig.2, the trend of electric conductivity and strength in Fig.4 is reversed. This may be resulted from that the first age is the high temperature pre-nucleate stage, the core of nucleation will multiple with the increase of holding time, and then more strengthing phases will form during the second age, which leads to the increase of strength. On the other hand, the dispersity of MPT will augment with the increase of holding time, which leads the improvement of the block function to conduction electron, then electric conductivity decreases. Comparing with the electric conductivity and strength under different conditions, we make the conclusion that when the holding time of the first age is 4-6 hours, the properties will be better.

4 Conclusions

1. While the second aging temperature is different, the properties are significantly distinct: the extent of strength increases is much higher than that of electric conductivity decreases and when the temperature is 155℃, the overall properties will be better than that when it is 165℃.
2. Since duplex age is over-aging treatment, the tensile properties decreases with the second aging holding time while electric conductivity increases. However, as the first age is a high temperature pre-nucleate stage, the trend is different from the second age, that is, the tensile properties increases while electric conductivity decreases with the prolonging of the first aging holding time.
3. Treated with such a duplex aging treatment in which the temperature of the second age is 155℃ and the holding time of the first and the second age is 4 and 28-32 hours, respectively, the overall properties of plates will meet the required standards.

5 Acknowledgement

This project is supported by Postdoctoral Science Foundation of China (2014M551108)

References

1. N.U. Deshpande, A.M. Gokhale, D. K. Denzer, Relationship Betweeen Fracture Toughness, Fracure Path, and Microstructure of 7050 Aluminum Alloy, Metallurgical and Materials Transactions A. 29 (1998) 1191-1201.
2. Z. H. Li, B. Q. Xiong, Y. A. Zhang, B. H. Zhu, F. Wang, H. W. Liu, Effects of the two-step ageing treatment on the microstructure and properties of 7B04 alloy pre-stretched thick plates, Rare Metals. 26 (2007) 193-199.
3. Z. Zhang, K. H. Chen, Effect of solution heat-treating on electrical conductivity of Al-Zn-Mg-Cu aluminum alloy, P/M MS&E, 2004, 9(1):82-83.
4. Thakur, R. Raman, S. N. Malhotra, Effect of natural aging on the resistivity evolution during artificial aging of the Al-Zn-Mg-Zr alloy. Materials Processong Technology, 194 (2007) 184-486.
5. X. G. Fan, D. M. Jiang, Effect of Aging on Microstructure and Properties of 7150 Aluminum Alloy, Material & Heat Treatment. 35 (2006) 22-25.
6. J. C. Lin, H. L. Liao, W. D. Jehng, C. H. Chang, S. L. Lee, Effect of heat treatments on the tensile strengh and SCC-resistance of AA7050 in an alkaline saline solution, Corrosion Science. 48 (2006) 3139-3156.
7. L.P. Huang, K.H. Chen. Influence of high-temperature pre-precipitation on local corrosion behaviors of Al-Zn-Mg alloy. Scripta Materialia. 56 (2007) 305-308.
8. F. Q. Tian, J. Z. Cui, Effect of duplex aging on microstructure and properties of 7050 aluminum alloy, The Chinese Journal of Nonferrous Metals. 16 (2006) 958-963.