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The Heat Treatment Behavior of Super-High Strength Aluminum Alloys by Spray Forming

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ABSTRACT

In order to understand the stress corrosion behavior of super-high strength aluminum alloys by spray forming, different aluminum alloys by different heat treatment was made. The results showed that the alloy with peak aging has the most sensitive stress corrosion cracking, the crack can even be seen using eyes; the alloys with two step aging were better than one step aging alloys, the alloys has not been found stress corrosion cracking.

Keywords: Super-High Aluminum Alloys; Spray Forming; Stress Corrosion Crack

1. Introduction

Aluminum alloys especially super-high aluminum alloys often restrict to use as structural materials because of stress corrosion cracking. But their properties can be improved by appropriate heat treatment such as two step aging and retrogression and reaging (RRA). And some other attempts such as composition modification and use new processing methods were made to further increase the properties of the alloys.

Spray forming as a promising method was used to manufacture high properties aluminum alloys such as 7000 series aluminum alloys. Spray forming processing, which combines the advantages of rapid solidification, homogeneous microstructure containing fine grains and avoiding the macro segregation, and high solute content, has already been applied to improve the properties of many alloys. Thus, it is possible to enhance the tensile strength values of the Al-Zn-Mg-Cu series alloys by spray forming technique. The addition of Mg, with low cost and low density, has been used together with Zn to form the phases of η ($MgZn_2$), which can enhance the strength [5-7]. Furthermore, the content of the Zr, Mn, Ni between 0.1% and 0.9% is acceptable for increasing mechanical properties [8]. However, the stress corrosion cracking properties limited the alloys to further application.

In this paper, the stress corrosion cracking properties of the alloys by spray forming were researched. And the microstructure and mechanical properties of the alloys were introduced.

2. Experiment Procedures

The nitrogen was used of the spray forming equipment as atomizer gas. The spray pressure was between 0.4 - 0.7 MPa, the atomizer scan frequency was between 20 - 25 Hz, the collector round frequency was between 3 - 5 Hz and the deposited distance was 650 - 750 mm. The median frequency induction furnace was used as the melting furnace. The nominal chemical composition of the Al alloy was given in **Table 1**. The N_2 gas was used as refiner and the spray temperature was 830˚C - 850˚C. Al-Cu master, pure Mg and Zn were used in this experiment. Billets of spray forming were shown in **Figure 1**. The billets size were between (ϕ220 - ϕ280)* (300 - 350) mm. 2000 t reverse extruding machine was used to extrude the billets. Microstructure and mechanical properties of the alloy were investigated by S3400-N scanning electron microscopy and Instron Model 5585 respectively.

3. Results and Discussion

Table 2 was the tensile strength and elongations of the alloys by spray forming with different heat treatment. We can see that the tensile strength was 810 MPa and the elongation was 4% of the alloy with peak aging. The tensile strength was 710 MPa and the elongation was 8% of the alloy with two step aging. And the tensile strength was 800 MPa and the elongation was 6% of the alloy with retrogression and reaging. **Figure 2** was the microstructure of the alloys with different heat treatment.

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Table 1. The main chemical composition of tested alloy.

Elements	Zn	Mg	Cu	Zr	Mn, Ni	Al
Content(%)	11 - 13	2.2 - 2.6	1.0 - 1.3	0.1 - 0.3	0.2 - 0.6	Bal.

Table 2. The mechanical properties of the alloys with different heat treatment.

Heat treatment	Peak aging	Two step aging	RRA
Rm/MPa	810	710	800
A/%	4	8	6

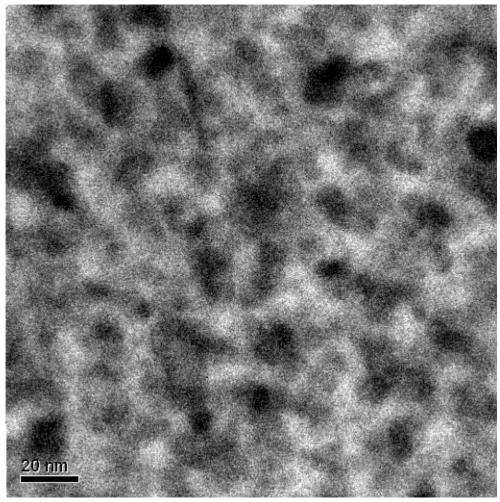
Figure 1. Billets of Al alloy by spray forming.

We can see that the main precipitate phases were G.P zones at peak aging and retrogression and reaging. While the main precipitate phases were $MgZn_2$ at two step aging. The G.P zones are coherence with the matrix, so the strength of the alloys were enhanced in big extent, but the $MgZn_2$ phases were coarsen and did not coherence with the matrix, so the tensile strength decreased in big extent.

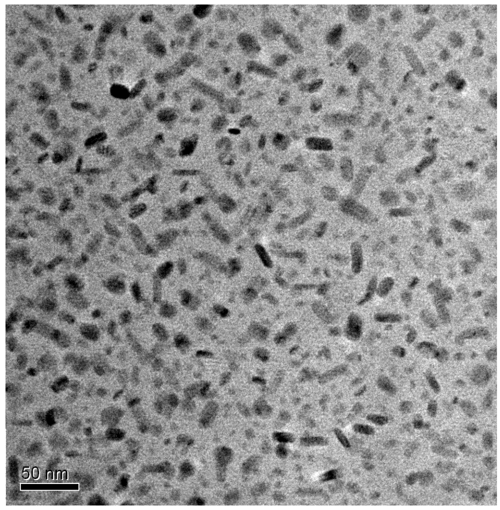
The alloys were put at air condition for 12 months. And we found that the alloy with peak aging was cracked. **Figure 3** was the crack of the alloy with peak aging.

From the photos we can see that the crack was intergranular, and the crack pattern like river. It's typical stress corrosion cracking. And the other two alloys didn't found crack even in scanning electron microscopy. So the peak aging heat treatment can not use for high strength aluminum alloys.

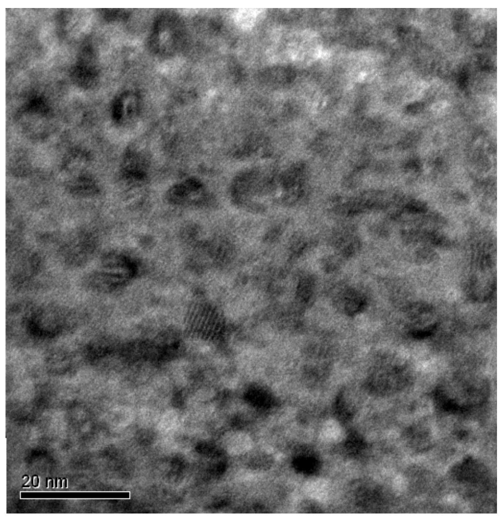
According to the theory of Mg-H composite, the interactional of Mg-H lead to the increase of H concentration at grain boundary, the segregation of H at grain boundary would decrease the binding energy of grain boundary, so the crack would spread quicker. So the interaction of Mg-H composite maybe the reason of stress corrosion cracking. In order to improve the stress corrosion cracking resistance of 7000 series alloys, appropriate heat



(a)



(b)



(c)

Figure 2. the microstructure of the alloys by spray forming with different heat treatment; (a) Peak aging; (b) Two step aging; (c) Retrogression and reaging.

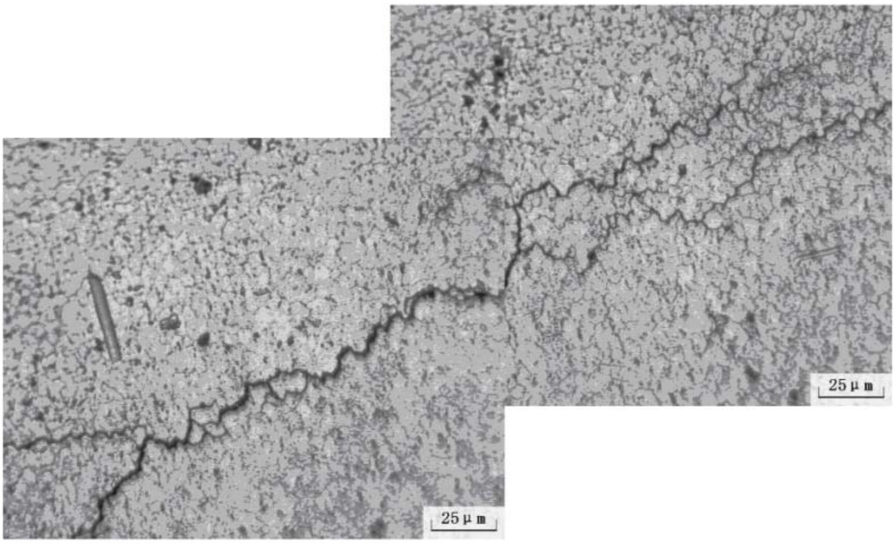


Figure 3. The crack of the alloy with peak aging.

treatment was needed to avoid the segregation of high concentration Mg. For example, two step aging which increases the second aging temperature can improve the stress corrosion cracking resistance of the alloy. That means the sensitivity of stress corrosion cracking was low at the second peak aging, this is because the concentration of Mg at the grain boundary was reduced with the second aging treatment. In addition, the precipitates phases in the alloy would change, that means α (supersaturation solid solution) → G. Pzone → η′ ($MgZn_2$, metastable) → η ($MgZn_2$). The fraction of η′ ($MgZn_2$) phases would increase all the time with the phases change going, so the free Mg in the grain would deplete, so the poor Mg zone would form. On the other side, the free Mg at the grain boundary would change little, so the rich-Mg formed. Because of the concentration difference, the free Mg at the grain boundary would diffuse to the inner of the grain by vacancies, so new η′ ($MgZn_2$) phases at the poor Mg zone would form, at last the free Mg at the grain boundary would decrease. At the same time, the η′ ($MgZn_2$) phases would form at the grain boundary, so the free Mg at the grain boundary decreased further. So there's three results: 1) η′ ($MgZn_2$) phase was the trap of free H, so the concentration of H at the grain boundary was reduced which improve the stress corrosion cracking resistance; 2) the stress of grain boundary fracture and the binding energy of grain boundary were increased because of the reduce of Mg segregation, so the Mg brittle at grain boundary was decreased; 3) because of the decrease of free Mg, the interaction of Mg-H was reduced, so the segregation of H at the grain boundary was reduced, so the hydrogen brittleness was reduced.

When the second aging temperature was increased, like two step aging and retrogression and reaging, the activation energy of the atom diffuse was decreased, so the hydrogen and Mg composite were interacting more intensity. So the stress corrosion cracking of the alloys were improved. So the two step aging and RRA technics would be used to use the high strength aluminum alloys.

4. Conclusions

1) The tensile strength and elongations were 810 MPa, 4%; 710 MPa, 8%; 800 MPa, 6% respectively at peak aging, two step aging and retrogression and reaging.

2) The main precipitate phases were G.P zones at peak aging and retrogression and reaging. While the main precipitate phases were $MgZn_2$ at two step aging.

3) The alloy with peak aging was appeared stress corrosion cracking while the other two alloys did not appear stress corrosion cracking.

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