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Study on microstructure, mechanical properties and corrosion behavior of spray formed 7075 alloy

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ABSTRACT

Microstructure and properties of the spray formed 7075 alloy with various heat treatments were studied by using tensile tester, transmission electron microscope and scanning electron microscope. The results show that the tiny precipitates distributed homogeneously in matrix can increase the ultimate tensile strength (UTS). The disconnected precipitates at grain boundary and wide precipitate free zones can improve the corrosion resistance of the alloy. Both strength and corrosion resistance of the alloy can be improved by retrogression and re-aging (RRA) processes. Especially, the U–RRA–H process can increase the UTS up to 791 MPa, which is higher than that after T6, T73 and conventional RRA treatments.

1. Introduction

The 7075 (Al–Zn–Mg–Cu) alloy has been widely used in the aerospace industry due to its desirable mechanical properties [1,2] with general acceptable tensile strengths between 510 and 530 MPa [3,4]. In order to further improve the mechanical properties, the spray formed method was used and the strength over 730 MPa [5,6] was obtained for 7075 alloy. With the development of manufacturing process on 7075 alloy, the corrosion resistance of the alloy has been much accounted.

Papers have reported the effects of heat treatments on 7075 alloy, i.e., strength were improved in 7075 alloys after T6 treatment [7,8], the loss of strength of about 10–15% after T73, T74 or T76 treatment due to looking for fine corrosion resistance [9–11]. To solve the contradiction between strength and corrosion resistance, Cina [12] presented a three-stage treatment (retrogression and re-aging, RRA). In next researches, it was found that the strength maintains at T6 level by RRA treatment and the stress corrosion resistance is close to that at T7 at the same time [13,14]. Soon afterwards, Su et al. [15,16] reported the RRA treatment also can improve the intergranular corrosion (IGC) and exfoliation corrosion (EXCO) sensibility of a spray formed 7075 alloy.

RRA treatment is consisted of pre-aging, retrogression and re-aging. Ohnishi and co-workers [17,18] considered the peak aging is the best pre-aging in RRA treatment process. And this type of pre-aging has been used until now. In recent years, scholar [19] mentioned the peak aging is not perfect. With regard to pre-aging in RRA treatment, there are some arguments on the type and reason of pre-aging was not reported. The usual retrogression always treats at high temperature for a short time, which is only dozens of seconds even several seconds. Such short times could not fit for industrial production.

To optimize aging treatments on spray formed 7075 alloy and references for next step research, this paper studied several aging treatments on microstructure and properties of spray formed 7075 alloy.

2. Experimental

The 7075 aluminum alloy with alloying elements of 5.48 wt.% Zn, 2.21 wt.% Mg, 1.48 wt.% Cu, 0.189 wt.% Cr, 0.371 wt.% Fe and 0.121 wt.% Si was sprayed with atomization gas of nitrogen (N_2), spray distance of 370–380 mm, substrate eccentricity of 60–65 mm, conduit bore of 3.6 mm, incidence angle of 37–39°, spray temperature of 770–780 °C, crucible temperature of 735–745 °C, horizontal velocity of 0.15 mm/s, and vertical velocity of 0.18 mm/s. Then resulting bar was extruded at temperature of 400 °C, ratios of 30:1 and feeding rate of 1.5 mm/s.

The test samples were cut from the as-extruded bar for the two-stage solid solution, i.e., 450 °C for 1 h and 475 °C for 2 h, respectively, after which the samples were water quenched to room temperature. The details of aging treatments are listed in Table 1. Especially, U–RRA–L and U–RRA–H are new type RRA treatments, which are pre-aged at 120 °C for 16 h, retrogressed at 160 °C for 2 h

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Table 1
Aging treatment conditions.

Aging treatments	Conditions
T6	120 °C, 24 h
T73	(120 °C, 8 h) + (160 °C, 16 h)
RRA	(120 °C, 24 h) + (200 °C, 10 min) + (120 °C, 24 h)
U–RRA–L	(120 °C, 16 h) + (160 °C, 2 h) + (120 °C, 24 h)
U–RRA–H	(120 °C, 16 h) + (200 °C, 8 min) + (120 °C, 24 h)

and 200 °C for 10 min, respectively, and then re-aged at 120 °C for 24 h.

According to ASTM G34-2001 [20], the EXCO solution contains NaCl, KNO_3 and HNO_3 with concentration of 4.0 mol/L, 0.5 mol/L and 0.1 mol/L, respectively, in the distilled water. The temperature and time for the specimens immersed in the solution are 25 ± 1 °C and 48 h, respectively. The ratings for the EXCO were established according to the standard photographs N (No appreciable attack, surface can be disrobed or superficially etched), P (Pitting; discrete pits, sometimes with a tendency for undercutting and slight lifting of metal at the pit edges), and EA to ED (Exfoliation; EA to ED represent the EXCO becoming more and more seriously).

The standard of ASTM G110-1992 [21] is referred to evaluate the IGC resistance of heat treatable aluminum alloys by immersion in a solution with 57 g of sodium chloride and 10 mL of hydrogen peroxide, respectively, in a 1 L distilled water. The specimen in the solution was maintained at temperature of 35 ± 2 °C for 6 h. The un-etched polished surfaces were examined by a scanning electron microscope (SEM) with 500 magnifications.

The microstructures for the sample after different aging treatment were observed by transmission electron microscope (TEM). The tensile samples with gauge length of 25 mm and diameter of 5 mm were tested by using a universal tensile tester.

3. Results and discussion

3.1. Effects of spray forming and hot extrusion on 7075 alloy

Fig. 1a shows SEM microstructure of the center of spray formed 7075 alloy. From Fig. 1a, it can be seen that spray formed 7075 alloy is composed of equiaxed grains and some fine secondary phases close to the grain boundaries. In addition, segregation above the limit of solubility led to secondary phase formation at the grain boundaries during solidification. The equiaxed grains are about 30–50 μm in size. The presence of the equiaxed grain morphology is attributed to the high cooling rate, associated with the spray forming. Fig. 1b shows the micrographs after extrusion process. The porosity presented in the as spray formed alloy can be described as the summation of gas porosity, interstitial porosity, and porosity resulting from the solidification shrinkage. Gas porosity forms due to the spray parameters, such as melt flow rate, gas-to-metal ratio, flight distance, and so on [22]. And after extrusion, the grains of the alloy are broken and fine due to performance improvement. The grain sizes are less than 30 μm. After extrusion, the tensile strength, yield strength and elongation of the alloy is 555 MPa, 522 MPa and 6.4%, respectively.

3.2. Effects of aging treatments on EXCO of the alloy

Fig. 2 shows the EXCO morphologies of spray formed 7075 alloy under different aging treatments. It can be seen form Fig. 2a that the corrosive causes much great penetration depth for the sample after T6 treatment. According to standard test [20], the EXCO rating of the alloy after T6 treatment is ED. However, only sporadic pits appear on the surface for the sample after T73 treatment as indicated in Fig. 2b and the EXCO rating is P. For the RRA treated sample, many discrete pits with a tendency of protruding at the pit edges can be observed on the surface as shown in Fig. 2c, and the EXCO rating is EA. Fig. 2d shows the surface with notable layering and blisters for the sample after U–RRA–L treatment and the EXCO rating is EB. From Fig. 2e, it can be found that thin slivers and flakes with slight separation appear on the surface for the sample after U–RRA–H treatment, and the EXCO rating is EA.

3.3. Effects of aging treatments on IGC of the alloy

Fig. 3 shows the cross-sections for samples after different aging treatment to reveal the IGC resistance of spray formed 7075 alloy. For T6 treatment sample, the surface is rough and uneven as shown in Fig. 3a, which indicates that the corrosive has penetrated to a great distance of about 131.4 μm into the alloy and the IGC is serious in such case. It can be seen from Fig. 3b that only sporadic pits appear on surface of the sample and the IGC depth is about 2.0 μm. Therefore the alloy presents a favorable IGC resistance after T73 treatment. However, the IGC depth is further reduced to 16.8 μm for the sample underwent RRA treatment, and only sporadic pits on surface were observed as indicated in Fig. 3c. The U–RRA–L treatment can improve the IGC resistance. It can be found from Fig. 3d that the pits on surface of sample decrease and become shallow after U–RRA–L treatment, and the IGC depth is reduced to 71.6 μm. Fig. 3e shows some pits on surface of sample after U–RRA–H treatment. The corrosive can infiltrated into the matrix under the help of some pits and the IGC depth reaches 29.8 μm. Corrosion stability of alloy is observably enhanced for the alloy after RRA, U–RRA–L and U–RRA–H treatment comparable to those after T73 treatment. According to experiments, the EXCO and IGC for spray formed 7075 alloy after various aging treatments are shown in Table 2.

3.4. Effects of aging treatments on mechanical properties of the alloy

The ultimate tensile strength (UTS), yield strength (YS) and elongation are listed in Table 2. The UTS and the elongation are 760 MPa and 4.8%, respectively, for the samples underwent T6 treatment. The UTS is reduced to 676 MPa and the elongation increased to 8.4% for the T73 treatment samples. RRA treatments can further improve the UTS of tested samples. It can be found that the UTS and the elongation for U–RRA–L and U–RRA–H treated samples are all greater than those for T6 and T73 treated samples. Especially, the UTS, YS and elongation of the alloy is 791 MPa, 736 MPa and 8.5%, respectively, after U–RRA–H. And U–RRA–L can get the similar properties but not as good as those after U–RRA–H.

From the above-mentioned microstructure and properties of the spray formed 7075 alloy, as listed in Table 2, the UTS and YS of the spray formed 7075 alloy are better than those of the alloy prepared with forging and rolling [23], semi-solid rheocasting [24], direct chill (DC) casting [25], low frequency electromagnetic casting (LFEC) [25] or cryomilling [26], which are shown in Table 3.

4. Discussion

The usual precipitation sequence of 7xxx series aluminum alloys can be summarized as SSS (super-saturated solid solution) → GP zones → metastable η' → stable η [27,28]. GP zones are metastable, coherent solute clusters of Zn, Mg and Cu. The metastable η' phases, Al, Cu and Mg components based on a solid solution of $MgZn_2$, $Mg(ZnCuAl)_2$ appear as discrete platelet particles that are semi-coherent with the matrix, which is known to populate within the grains, and η is pseudostable, non-coherent of the same phase appearing as rods or plates, which is known to populate the grain boundary.