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Technical Report

Retrogression and re-aging treatment on short transverse tensile properties of 7010 aluminium alloy extrusions

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ABSTRACT

The influence of retrogression and re-aging treatment (RRA) on short transverse tensile properties of 7010 aluminium alloy extrusions was studied. The short transverse ductility of extrusions, which was much lower in the T6 condition, was improved to the optimum level after retrogression and re-aging treatment. It is found that short transverse ductility is influenced by the nature of precipitate particles located along the grain boundary. It is observed that coarsening of the grain boundary precipitates and its copper enrichment that occurs during RRA are found to be the factors responsible for improvement in stress corrosion cracking (SCC) resistance. The optimum retrogression and re-aging schedule is established that gives rise to the best combination of strength, ductility and SCC resistance.

1. Introduction

The overaged temper was introduced for 7xxx series alloys to improve stress corrosion cracking resistance (SCC) on thicker components, but resulted in 10–15% loss in strength in comparison to the peak-aged temper [1]. It spurred the development of retrogression and re-aging (RRA) treatment to raise the SCC resistance level to that for the overaged temper, while maintaining strength equal to that for the peak-aged temper [2].

Researchers are still divided so as to the reactions occurring during RRA [3,4] and the mechanism of improvement of SCC resistance. The microstructural features such as precipitate free zones (PFZ) adjacent to the grain boundaries, dispersion of precipitate particles along grain boundaries and solute concentration in the grain boundaries have been reported to increase the susceptibility to SCC.

In a corrosive medium, it is considered that either PFZ or the grain boundary precipitates will be anodic with respect to the grain interiors. In the 7xxx series alloys, the η phase formed along the grain boundaries is considered to be very active and anodic with respect to the grain interiors [7]. The copper enrichment of grain boundary precipitates reduces their anodic nature by increasing the electrode potential to a more noble value, which in turn leads to the reduced rate of corrosion reaction [7]. Puiggali et al. [6] attributed that grain boundary precipitates, which coarsen during overaging, act as hydrogen trapping sites [6] and thereby reduce the concentration of interstitial hydrogen ahead of the main crack. Talianker and Cina [8] postulated that dislocation density was reduced due to retrogression, which otherwise would enhance the hydrogen embrittlement by giving an easier diffusion path to hydrogen.

The 7010 aluminium alloy, chosen for the present study, was not widely used as extrusions and published reports on the effect of various temper conditions, such as RRA, T6 and T7451, on short transverse mechanical properties are not available. Aeronautical material specifications for 7050 aluminium alloy extrusions [9] and 7010 forgings [10] do not specify minimum guaranteed properties in short transverse direction for the overaged temper. Earlier, Robinson et al. [11] carried out extensive RRA studies on 7010 aluminium alloy forgings. In the present work, an attempt has been made to examine tensile properties in detail using 7010 aluminium alloy extrusions with an emphasis on RRA and T6 tempers.

2. Experimental procedure

Aeronautical grade 7010 aluminium alloy (Al-6.12Zn-1.71Cu-2.25Mg-0.12Zr-0.1Si-0.14Fe) extrusions in the form of slabs of size 2000 × 200 × 70 mm was chosen for the present study. The slabs were received in T7451 temper, i.e. solutionised at 480 °C for 4 h, control stretched and aged in two stages: 120 °C for 24 h followed by 170 °C for 18 h. Coupons of size 200 × 25 × 15 mm and 15 × 200 × 70 mm were cut from the slabs to study mechanical properties along longitudinal (L) and short transverse (ST) directions, respectively. These coupons were re-solutionised at 480 °C for 90 min followed by aging at 120 °C for 24 h (T6 temper). Retrogression of these coupons was carried out at 200 °C using a salt bath furnace for 5, 10, 20, 30, 40, 50, 60 and 70 min. This

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was followed by re-aging at 120 °C for 24 h. The hardness, electrical conductivity and tensile properties were evaluated for various tempers. The microstructure was characterized using a Philips CM20 transmission electron microscope operating at 200 kV.

3. Results and discussion

3.1. Role of RRA on short transverse tensile properties

The variations in hardness and electrical conductivity with retrogression time are plotted in Fig. 1. The variations in 0.2% YS and Elongation (%) with retrogression time for RRA200 (retrogression at 200 °C followed by re-aging) condition for extrusions in L and ST direction are plotted in Figs. 2 and 3 respectively, and also compared with that of T6 temper. The hardness and 0.2% YS in ST direction attains a peak after 10 min of retrogression and starts to decrease with a further increase in retrogression time. The maximum in 0.2% YS achieved for RRA200-10 (retrogression at 200 °C for 10 min followed by re-aging) is 15% more than that for T6, with ductility ~1% in both cases. Similar behavior is also observed in L direction during short retrogression times with a marginal reduction in ductility. This suggests that the material has not achieved its peak strength after T6 treatment. The dissolution of precipitates during retrogression and subsequent re-precipitation after RRA200-10 condition might have led to a higher concentration of η' and η particles than that of T6 condition [3]. However, the strength is decreased beyond 10 min of retrogression time due to the coarsening of the precipitates [3].

The role of RRA on ductility in ST direction is distinct (Fig. 3). The ductility remains almost unaffected even after RRA200-30 (Fig. 3). But, it increases after 30 min, goes up to 6% after 50 min of retrogression and begins to drop subsequently.

The TEM micrographs of the extruded 7010 aluminium alloy obtained for different tempers are examined. The microstructure of the alloy in the T6 condition as shown in Fig. 4 a has relatively coarse and closely spaced precipitates along the grain boundaries and fine precipitates within the grains. On the other hand, in RRA200-10 condition as shown in Fig. 4 b, the grain boundary precipitates are continuous and coarser than that of T6 condition due to the formation of additional grain boundary precipitates during the initial phase of retrogression. Due to the presence of elongated grains in extrusions, crack propagation is much easier in the short transverse orientation, affecting in the process the tensile properties, particularly ductility. In addition to this, the formation of precipitates as a continuous network along the grain boundary will adversely affect the ductility. This is the reason for obtaining lower ductility during initial retrogression cycle and in T6 condition.

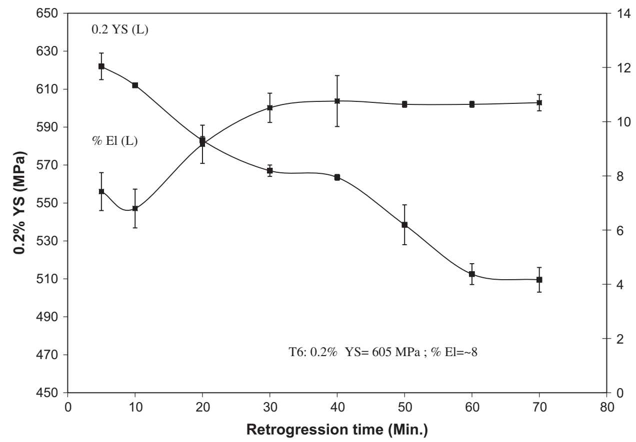

Fig. 2. Variations in 0.2% YS and % Elongation along L direction with retrogression time for 7010 extrusions retrogressed at 200 °C.

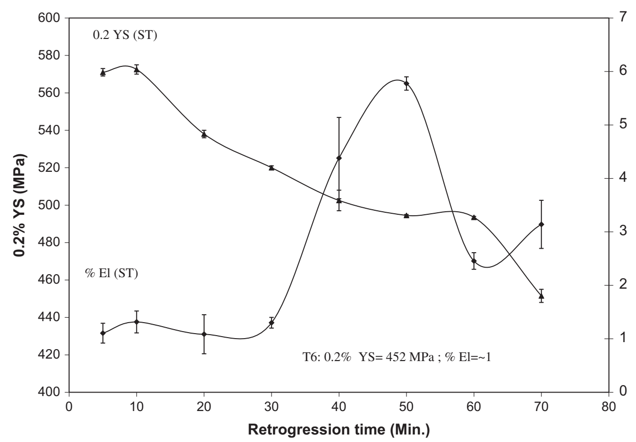

Fig. 3. Variations in 0.2% YS and % Elongation along ST direction with retrogression time for 7010 extrusions retrogressed at 200 °C.

The microstructure of the alloy in RRA200-40 condition, as shown in Fig. 4 c, shows coarse and widely spaced precipitates at the grain boundaries compared with RRA200-10 condition. It indicates that retrogression for a longer duration followed by re-aging breaks the network by causing coarsening of the precipitates, which, in turn, restores the ductility. However, a drop in ductility was noticed after prolonged retrogression. This may be related to the increased size of the grain boundary precipitate particles with increase in retrogression time as shown in Fig. 4 d for RRA200-70 condition. It was shown that [12] first aging at a higher temperature to the maximum hardness followed by aging at a lower temperature would result in slight coarsening of the precipitate in the matrix and a more pronounced coarsening of the big stable particles on the grain boundaries. A similar behavior was observed in the present work since retrogression too was carried out at a higher temperature followed by re-aging at a much lower temperature. It was deduced [12] that the reduction in ductility in Al–Zn–Mg alloy was due to weakening of the grain boundary by the growth of the big stable particles at the grain boundary. With respect to strain localization due to soft PFZ, it was also shown in the above work that ductility was increased with increase in width of the PFZ zone as stress relaxation could occur in the PFZ. The noticeable variation in short transverse ductility during RRA treatment

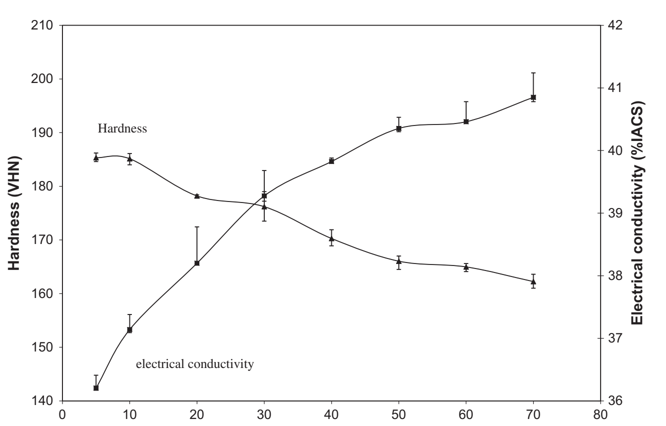

Fig. 1. Variations in hardness and electrical conductivity with retrogression time for 7010 extrusions retrogressed at 200 °C.