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The Effect of Retrogression and Reaging Treatments on Residual Stress in AA7075

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Abstract

Aging aircraft is a significant problem to the Australian Defence Force and aircraft fleets world wide - in particular corrosion of peak aged 7xxx series aluminium alloys. It is well documented that Retrogression and Reaging (RRA) has the ability to improve the poor stress corrosion cracking (SCC) resistance associated with 7xxx-T6 alloys, at little expense to the strength. However, as nearly all structural components contain beneficial residual stresses (cold worked holes and interference fit fasteners), an understanding of the interaction between residual stress and RRA treatment is required. This paper examines the effect on residual stress of Retrogression and Reaging treatments on aluminium alloy 7075. Fatigue tests were conducted using specimens with cold worked and non-cold worked fastener holes, in both the as-received T6 and the RRA condition. Both the fatigue crack growth rates and crack fractography were analysed. Changes in the residual stress magnitude and profile were determined by X-ray diffraction (XRD), for specimens containing cold worked fastener holes in the T6 and RRA condition.

1. Introduction

A number of the current fleet of Australian Defence Force (ADF) aircraft were built during the 60's and 70's. These aircraft while initially designed with service lives of 20 years are now looking at 40 and 50 year service lives. This has meant that many of the high strength peak-aged 7xxx series alloys used in these aircraft are suffering extensive corrosion damage, in particular exfoliation and intergranular corrosion. This sort of corrosion can have a significant effect on residual strength and thus the basis for certification. To ensure the aircraft complies with certification the corrosion damage is initially ground out. However if this grind out goes beyond damage tolerance limits the component needs to be repaired or replaced. Even replacing the component is problematic as generally the same material in the same condition (or can be worse for forgings) is used, leading to more problems in the future.

In the 1970's Cina [1] developed a process called Retrogression and Reaging (RRA) as a method of improving the corrosion resistance of high strength 7xxx series aluminium alloys with little reduction in strength. Cina's RRA process involved a short heat treatment of 7075-T6 in the range of 200-280ºC (Retrogression), followed by reaging using the original T6 temper conditions, 120ºC for 24 hours. This treatment resulted in a combination of improved SCC resistance (similar to that of a T73 temper) and T6 strength, however due to the high retrogression temperatures, the retrogression times of a few seconds would not be suitable for material other than thin sheet. This issue was addressed by Wallace *et al.* [2] with the use of lower retrogression temperatures down to 160ºC. At lower temperatures (160-180ºC) the kinetics of the reaction occurring during retrogression are retarded, allowing longer times and hence thicker sections to be treated.

During retrogression the hardness decreases rapidly to a minimum before increasing to a secondary maximum, and then decreasing with increasing time (overaging). After reaging following short retrogression times, the hardness can be restored and increased above the original T6 level, while at longer times the reaging response decreases (Figure 1).

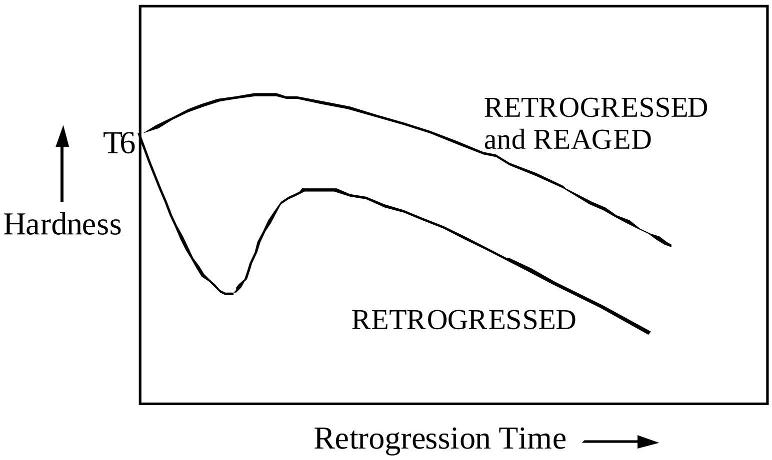

Figure 1: Schematic representation of hardness changes during retrogression and reaging.

However hardness is not the only mechanical property to change during the RRA process, electrical conductivity increases with increasing retrogression time. Wallace *et al.* [2] and Kaneko [3] both concluded electrical conductivity of 7075-T6 to be proportional to SCC resistance, when aged to or beyond the T6 condition.

Current RRA treatments aim to increase the materials conductivity and hence SCC resistance to that of the T73 temper (38-42%IACS), while retaining the base hardness of the T6 temper (83.5-94 HRB) [4]. In the present work, conductivity increases from the as received value of 32.5±0.5%IACS to 38.1±0.2%IACS, while hardness decreases from 92±1 HRB to 89±1 HRB (still well above the minimum T6 value of 83.5 HRB). Similar changes in conductivity and hardness were reported by Peeler [5].

While there have been many investigations into the effect RRA has on both alloy microstructure and mechanical properties (best summarised by Wu *et al.* [6]), the effect on residual stress has been somewhat overlooked, with only the effect of RRA on relieving quench stresses being investigated [7]. The presence of beneficial residual stresses (cold worked holes and interference fit fasteners) in nearly all aircraft structural components, means that an understanding is required before treatment of such components is possible.

Some initial work by the University of Dayton Research Institute [5] indicated that RRA had very little effect on residual stresses, however these tests were conducted in corrosive environments and may not give a true indication. The aim of the present work was to investigate the effect retrogression and reaging treatments have on specimens containing beneficial residual stresses under a laboratory environment, as this is the base condition for certification of the material and aircraft.

2. Experimental Procedure

The AA7075 was supplied in the T6511 temper condition, in the form of a 19mm x 101mm (3/4 inch x 4 inch) extruded bar. All specimens were machined from the as received bar prior to RRA heat treatment. The RRA treatments were performed using an air-circulating furnace, with specimens retrogressed at 195±1ºC for 55 minutes followed by water quenching, then reaged at 120±1ºC for 24 hours, before air cooling. The performance of the RRA heat treatment was assessed by changes in hardness and electrical conductivity measurements.

Constant amplitude (CA) fatigue testing was performed using a 100kN servo-hydraulic MTS, at a series of stresses using an R-value of 0.1. The CA sequence used marker bands to assist in crack growth measurements, this method has less than a 1% effect on life but greatly improves the fractography. Tests were conducted on the material in four different conditions (Table 1).

Table 1: Codes defining the test condition of fatigue specimens.

Code	Test Condition
AM	As Machined
AM/RRA	As Machined then RRA
AM/CW	As Machined then Cold Worked
AM/CW/RRA	As Machined then Cold Worked then RRA

Specimens were in the form of high Kt dogbones, 32mm wide, 10mm thick and with a 6.35mm (1/4 inch) reamed hole in the centre. The cold worked (CW) dogbones were initially reamed to 5.9mm, then cold worked before being reamed to 6.35mm. Crack growth rates were determined by optical microscopy of cycle marker bands, optical microscopy was also used for fractography.

The residual stress was measured by X-ray diffraction, using CrKα radiation and the aluminium (311) peak at about 139º 2θ. The d vs $\sin^2\Psi$ technique [8-9] was used to determine the triaxial stress state, with nine Ψ tilts over the range ±40 degrees and an additional ±3 degrees oscillation at each tilt used. The x-ray beam was collimated down to a spot focus 1mm in diameter, which was positioned adjacent to the 6.35mm cold worked hole (same specimens as used for fatigue). To develop an accurate residual stress depth profile a Leica Ultramil was used to machine the surface. This machine is a high speed cutter, but is able to remove the surface in 1μm steps, thus reducing the surface residual stress due to machining.

3. Results and Discussion

The fatigue life results (Figure 2) indicate RRA has the effect of greatly reducing the fatigue life. In all instances the fatigue life of specimens in the RRA condition (AM/RRA & AM/CW/RRA) were far shorter then those in the as received T6 condition, a similar reduction was reported by Kaneko [3].

This decrease in fatigue life indicates a reduction and possible redistribution of residual stresses, during RRA. The fact that all RRA specimens have a similar life at the same stress irrespective of pre-processing is evidence the process is relieving both internal and surface stresses. The preliminary residual stress measurements (Figure 3) clearly show this decrease in the cold worked compressive stress after the RRA process.

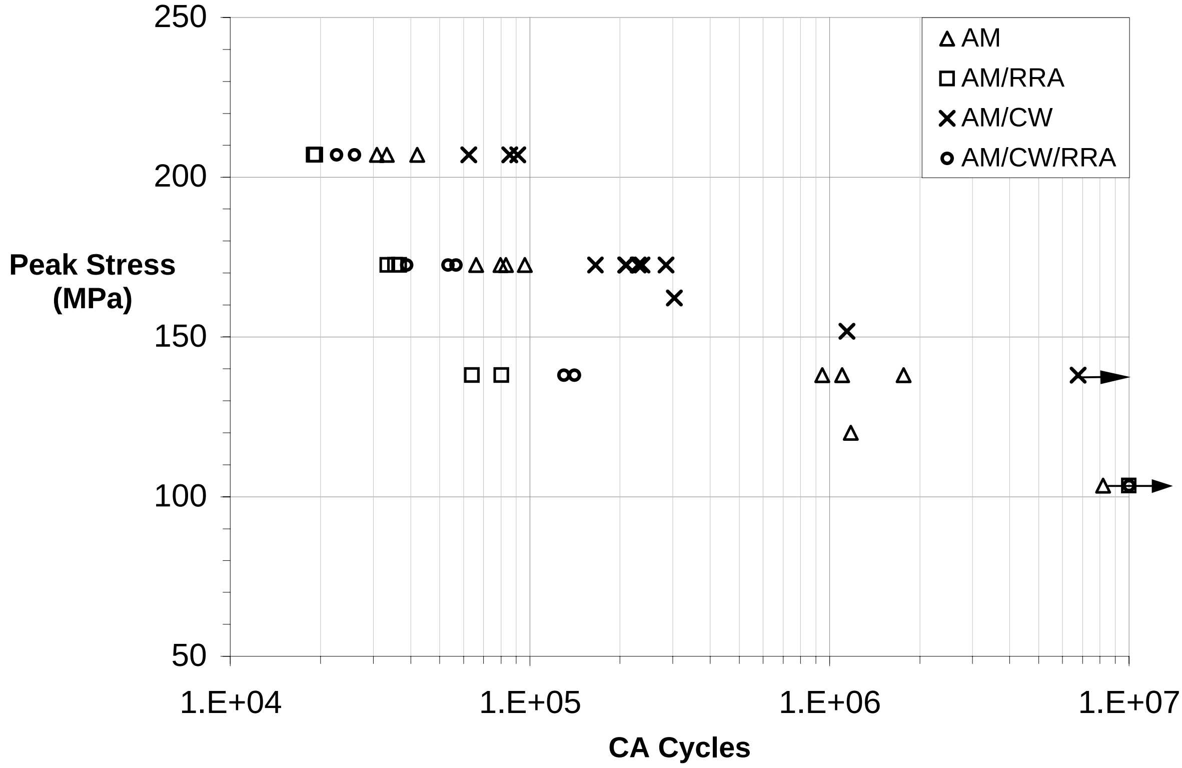

Figure 2: Fatigue life of constant amplitude tests (R = 0.1).

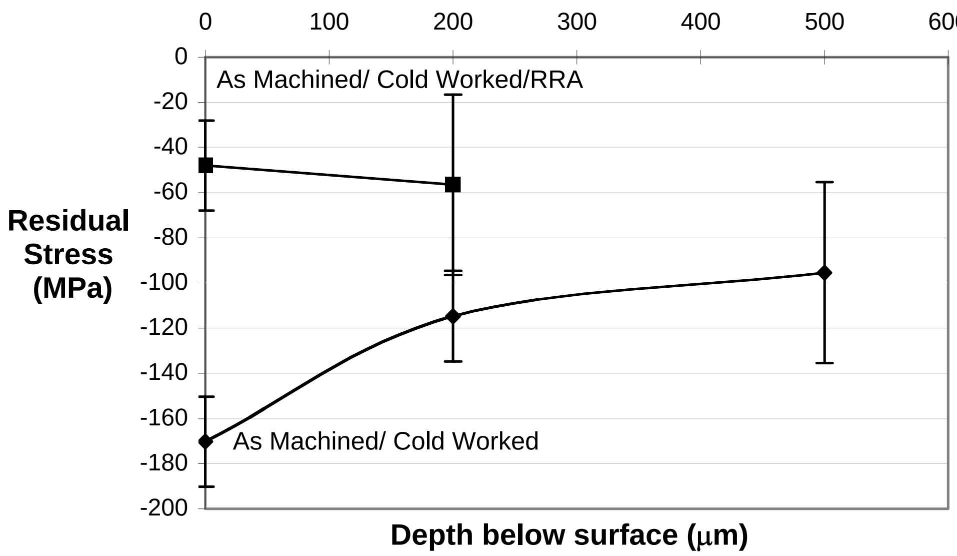

Figure 3: Radial compressive residual stress surrounding a 6.35mm (1/4 inch) cold worked fastener hole before and after undergoing a RRA treatment.

It would seem that for the As Machined specimens (AM/RRA), RRA relieves the small but beneficial compressive stresses created during machining. For the cold worked specimens (AM/CW/RRA), not only are the machining stresses relieved, the beneficial compressive stresses surrounding the hole are also relieved resulting in a fatigue life less than that of a non-cold worked specimen (AM).

The stress relieving effect of RRA is further supported by the crack fractography with a change in the number of crack initiation sites, from one (Figure 4a) to multiple (Figure 4b) after RRA.

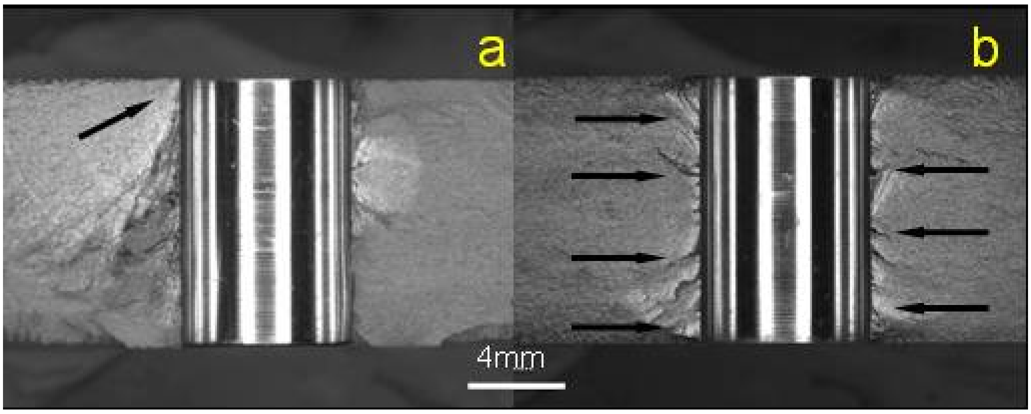

Figure 4: Fatigue fracture surface showing (a) single crack initiation site, indicated by the arrow and (b) multiple crack initiation sites indicated by the arrows after undergoing a RRA treatment.

The presence of even small residual compressive stresses (like those created during machining), are enough to retard crack initiation from stress concentrators like scratches. With cracks preferring to initiate from much higher stress concentration regions, such as that at the edge of the hole, usually resulting in a single crack initiation site. When the residual stresses are reduced or removed the initiation ability of these stress concentrators is no longer suppressed, allowing each to act as an initiation site, greatly decreasing the fatigue life.

The fatigue crack growth rate at a peak stress of 172.5 MPa (Figure 5) indicates RRA has a stress relieving effect, with the plateau in crack growth of the cold worked specimen (AM/CW) not seen in the cold worked RRA specimen (AM/CW/RRA). Both RRA specimens (AM/RRA & AM/CW/RRA) display similar rates to that of the non-cold worked specimen (AM).

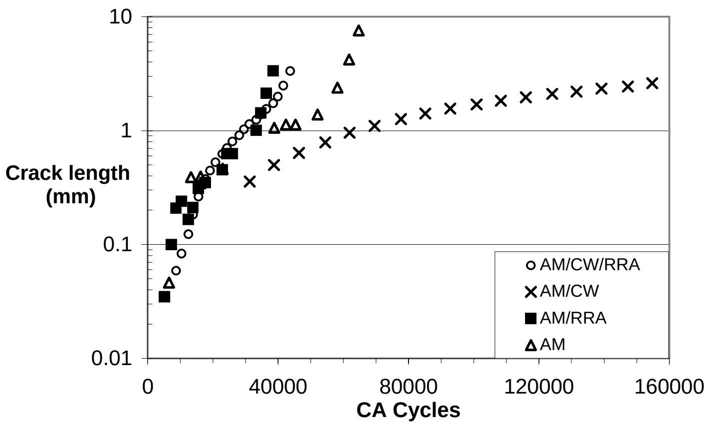

Figure 5: Fatigue crack growth rates at a peak stress of 172.5 MPa.

It is clear from the results presented that RRA has a stress relieving effect. Although all the RRA specimens retained T6 hardness and hence yield strength, there seems to be no correlation between this value and fatigue performance. If structural components are to undergo RRA, it would be desirable to perform any hole drilling and/or cold working after the RRA process.

4. Conclusions

1. RRA causes a reduction in the beneficial residual stresses induced by cold working.
2. RRA increases the number of crack initiation sites around a fastener hole.
3. RRA has little effect on the fatigue crack growth rate.
4. For this process to be certified for use on aircraft, the preferred approach would be to perform the RRA treatment prior to cold working and installation of fasteners.

Acknowledgment

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References

[1] B. Cina, U.S Patent 3856584, December 24, 1974.
[2] W. Wallace, J. J. Beddoes and M. C. deMalherbe, Canadian Aeronautics &. Space Journal, 27, 222-232, 1981.
[3] R. S. Kaneko, Metals Progress 118, 41-43, 1980.
[4] Boeing BAC 5946.
[5] Private Communication by D. Peeler to DSTO, 2001.
[6] X. J. Wu, M. D. Raizenne, R. T. Holt, C. Poon and W. Wallace, Canadian Aeronautics &. Space Journal, 47, 131-138, 2001.
[7] J. S. Robinson and D. A. Tanner, Materials Science and Technology, 19, 512-518, 2003.
[8] J. B. Cohen and I. C. Noyan, Residual stress: measurements by diffraction and interpretation, Springer-Verlag, New York, 117-144, 1987.
[9] Handbook of measurement of residual stress, edited by J. Lu, Fairmont Press, Lilburn, 71-131, 1996.