# Experimental report

22/11/2016

**Proposal:** **1-02-195**

**Council:** 4/2016

**Title:** Following the reduction in residual strain and residual stress duringplastic deformation of the aluminium alloy 7449

**Research area:** Engineering

**This proposal is a new proposal**


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**Samples:** Al

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| SALSA | 5 | 5 | 16/11/2016 | 21/11/2016 |


## Abstract:

Rectilinear blocks of the very high strength aerospace aluminium alloy 7449 will be solution treated and cold water quenched. They will then be stress relieved immediately by cold compression. The amount of cold compression will be systematically varied from 0% to 0.5%. The amount of plastic strain being limited to well below the industrial norm of ~2%. The blocks will then receive a stabilising aging treatment. The residual stress distribution remaining in the blocks will then be characterised using neutron diffraction. This experiment will aim to track how the through thickness three dimensional residual strains and stresses change as cold compression progresses.

**Following the reduction in residual strain and residual stress during plastic deformation of the aluminium alloy 7449.**

**Experiment number 1-02-195 Date of report 22 November 2016**

Abstract

Rectilinear blocks of the very high strength aerospace aluminium alloy 7449 will be solution treated and cold water quenched. They will then be stress relieved immediately by cold compression. The amount of cold compression will be systematically varied from 0% to 0.3%. The amount of plastic strain being limited to well below the industrial norm of ~2%. The blocks will then receive a stabilising aging treatment. The residual stress distribution remaining in the blocks will then be characterised using neutron diffraction. This experiment will aim to track how the through thickness three dimensional residual strains and stresses change as cold compression progresses.

Introduction

This experiment will use a series of rectilinear sample blocks made from the very high strength aluminium alloy 7449. This alloy, like all 7000 series alloys relies on heat treatment to develop its high strength. The critical step during heat treatment is the rapid cooling from the solution heat treatment temperature. This quenching step introduces thermal gradients into the material and this non uniform cooling can induce plastic deformation which in turn develops residual stresses.[1] These residual stresses can be of very large magnitude and must be reduced prior to the material being used or subject to some subsequent machining process. The usual way of managing these residual stresses is to plastically deform the material by stretching or cold compression.[2] This technology is long established, but the detail of how plastic deformation actually modifies the residual stresses in a sample containing a complex three dimensional stress distribution has not been investigated.

This experiment will aim to follow how the residual strains and stresses change as cold compression progresses. This is of interest because current practice involves applying >2% plastic deformation and the evidence for this amount is purely empirical. While it is known that >2% is effective in reducing residual stresses, a disadvantage of this amount of plastic strain is the reduction in the strength of the material in the opposite direction (by ~5%) to that used to apply the plastic deformation, (Bauschinger effect). If it can be demonstrated that less than 2% plastic strain is just as effective, the consequences of the Bauschinger effect will be reduced. What is also not available in the literature is how the triaxial nature of the as quenched residual stress distribution changes with the application of uniaxial plastic deformation. There are theoretical explanations of this but these have not been subject to experimentation. This part of the experiment is ideally suited to the highly penetrating characteristics of neutron diffraction. [3-5]

The unique aspect of this experiment is the application of very small cold compression magnitudes (≤0.30%).

Sample preparation details

Eight rectilinear blocks (60ST x 81L x 155LT mm, 2.2kg) were extracted from a parent open die forging. These blocks were solution treated at 472°C and were cold water quenched to induce a large magnitude residual stress distribution. To track the change in residual stress as cold compression proceeds the blocks received 0(X2_4), 0.10(X2_5), 0.13(2 off, X2_6, X2_7), 0.19(X2_8) or 0.3 % (X2_1) plastic strain in the LT (155 mm) direction of the block. To achieve this required the manufacture of two 7449 sacrificial stop blocks (X2_9 and X2_10) that closely controlled the amount of cold compression. Two duplicate sacrificial blocks supplied strain free reference samples (X2_2(0.30%CC) and X2_3(no CC)). Cold compression was conducted on a 250-ton hydraulic press. To stabilise the microstructure, all blocks were aged for 6 hours at 120°C.

Neutron diffraction measurements

The measurement plan for each block was to measure the residual strains at the geometrical centre and then take further readings in each principal direction. The assumed principal strains, ε1, ε2, ε3 were measured so that the principal residual stresses could be determined. 800 counts was determined to be an acceptable criteria for good (311) peak resolution. The time to achieve this varied widely from 2 minutes/point to 12 minutes/point. This was due to the non-uniform microstructure and texture within the samples. A gauge volume of 2*2*2 mm3 was used for all measurements. Six blocks and two reference samples were measured successfully. The diffraction angle was 82°.

Results

When the strain free reference samples were measured on SALSA, the variation with condition (cold compressed or not) and orientation of the unstrained lattice parameter was found to be negligible. A single value of d0 was used for all strain calculations. Cursory examination of the strains suggests a predictable variation of strain with orientation. The bulk elastic modulus E for 7449 was assumed to be 70 GPa with Poisson's ratio ν = 0.3. Lattice spacings were converted to residual stresses using the standard three dimensional Hooke's law. Figure 1 displays the residual stresses in block X2_4 which had received no cold compression. It will be noted that the residual stresses are high magnitude both in the centre of the block >200 MPa tensile and close to outer surfaces >200 MPa compressive. The magnitudes are consistent with the many previous experiments conducted by the authors, and the surface measurements will be augmented by laboratory x-ray $\sin^2\psi$ measurements. Figure 2 illustrates the residual stresses in block X2_5. This block treated exactly the same as X2_4 but received 0.10 % cold compression in the LT direction prior to aging for 6 hours at 120°C. It can be seen that even a very small amount of cold compression has had a detectable influence on the residual stress. The change in the 155 mm LT dimension to account for this amount of plastic deformation was only 0.16 mm so the final height of the sample was 154.84 mm.

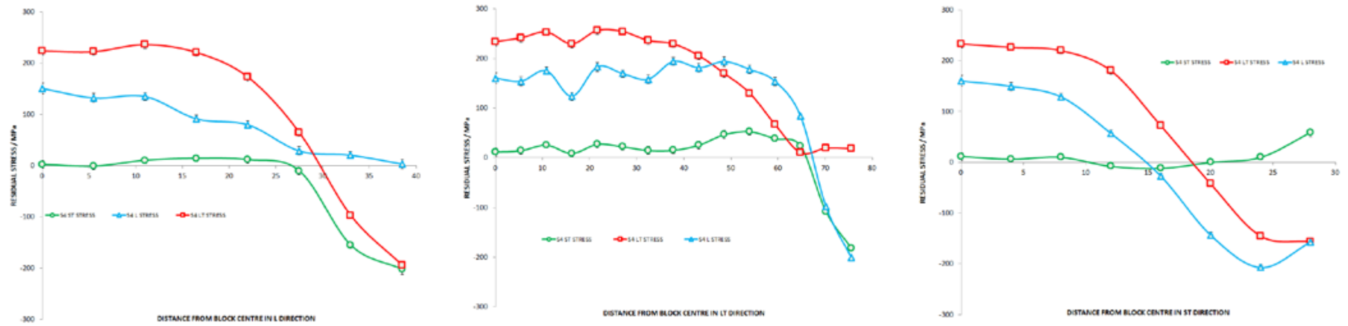


Figure 1. Residual stresses in block X2_4. This block was cold water quenched and aged for 6 hours at 120°C only

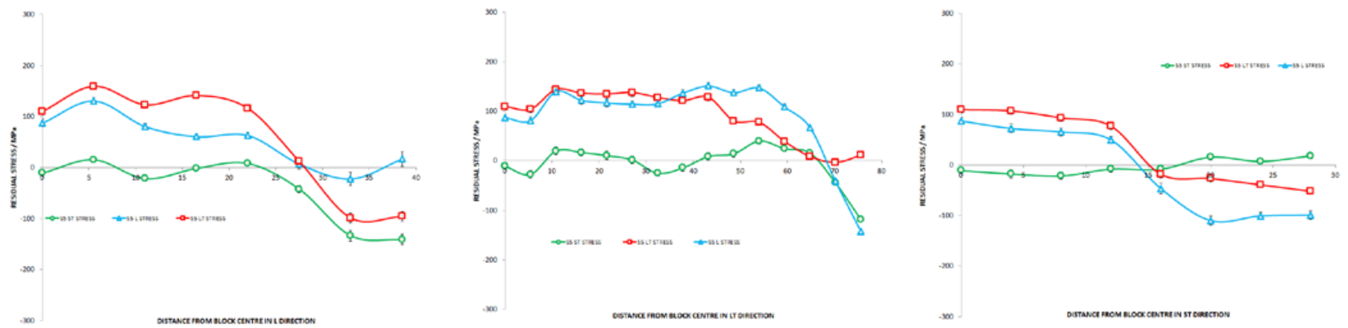


Figure 2. Residual stresses in block X2_5. This block was cold water quenched cold compressed 0.10% in the LT direction and aged for 6 hours at 120°C only

Subsequent increasing amounts of cold compression (X2_6/7/8/1) had a much smaller influence on the residual stress state within the blocks. It was found that the initial plastic strain had a proportionally larger influence. This is an observation that has not been reported before. It will be necessary to continue the investigation by systematically increasing the cold compression to approximately 1.4%. From a previous SALSA experiment on the cold compression of 7075 conducted in December 2012 (1-02-119) it is known that after 1.4 % cold compression the residual stresses have effectively disappeared.[2]

As only a single quadrant of each block was characterised in terms of residual stress it was felt necessary to assess the symmetry of the strains in the blocks. The was done by measuring the LT strain from surface to surface in all three orthogonal directions of block X2_4. It was found that strains were extremely symmetrical which reflects the relative uniformity of the heat transfer out the block surfaces during the cold-water quench.

## Conclusions

SALSA has proved once again it is more that capable of rapidly characterising complex three-dimensional residual stress states in blocks made from high strength, heat treated 7000 series alloys.

The residual stresses in the cold water quenched block are entirely consistent with other reported observations.

The effect of extremely small amount of cold compression are easily detectable using SALSA. The reduction in residual stress by the application of just 0.1% plastic strain in the LT direction is significant.

Subsequent increases in the plastic deformation have a much smaller influence but continue to lower the residual stress.

A continuation of the experiment is desirable to determine just how much plastic deformation is required to lower the residual stress into he range of the experimental uncertainty

## References

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[5] J.S. Robinson, D.J. Hughes, C.E. Truman, Confirmation of principal residual stress directions in rectilinear components by neutron diffraction., Strain, 47 (Suppl. 2) (2011) 36-42.