ESRF	**Experiment title:** "Engineering residual stress distributions by laser peening process control"	**Experiment number**: MA 1308
Beamline: ID31	**Date of experiment**: from: 25/08/2011 to: 29/08/2011	**Date of report**: 24/02/2012
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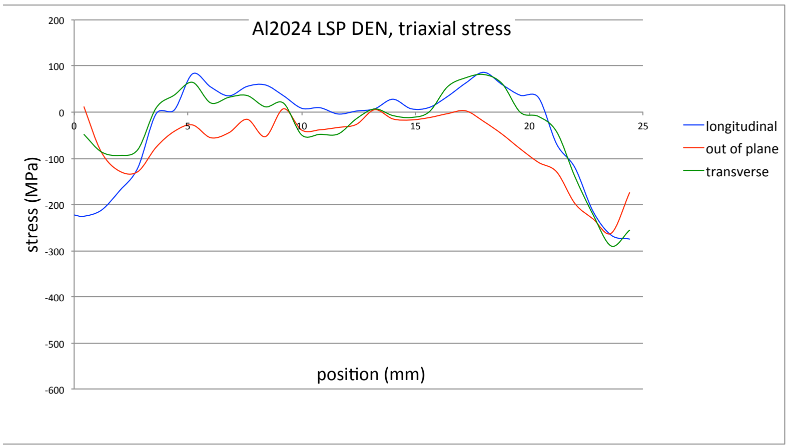
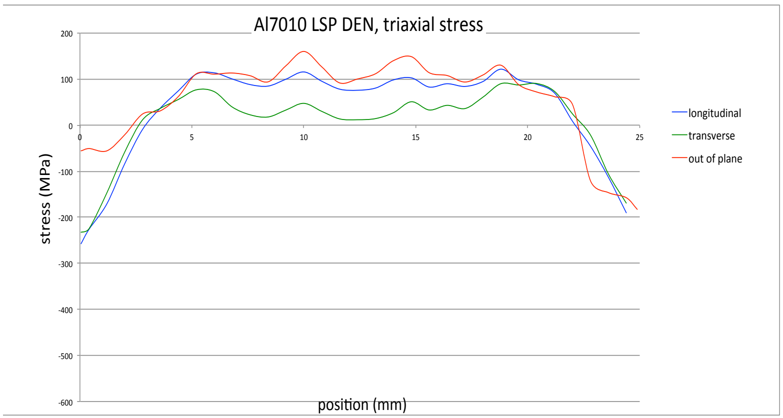
Introduction:
Laser shock peening (LSP) is capable of introducing life enhancing compressive residual stresses to ten times the depth of conventional shot peening (~2mm) [1]. Indeed recent results on stainless steel suggest that even greater depths (5-10mm) can be achieved with process optimisation. Remarkable improvements in foreign object damage (FOD) tolerance and fretting fatigue have been observed. However, significant improvements in life are not always achieved. In real components, sub-surface initiation can be enhanced, due to compensatory tension, the location of which can be very different for thick, thin, and irregular geometries. The purpose of this experiment was to form one part of an investigation into laser shock peening residual stresses as a function of fatigue. The experimental samples comprised two laser peened and two shot peened double edge notch (DEN) samples, in the latter case containing surfaces produced with differing laser irradience and spot size conditions. The materials studied are Al7010 and Al2024. The specimens were laser shock peened around all the surfaces in area of the centre of the sample, including the notches.

Residual elastic strains were mapped through the 25mm thicknesses of each of the samples at the midpoint of the notches. A monochromatic synchrotron x-ray beam was used (62keV, 0.1996Å) on ID31. One line scan on each sample was performed 3 directions; the in-plane longitudinal, in-plane transverse, and the out-of-plane strains were measured at each point along the line scanned. Step sizes of 0.1mm from the peened surface up to 2.5mm depth were used, 0.5mm step sizes from 2.5mm to 3.5mm depth, 1mm steps from 3.5mm up to 5mm depth, 2mm steps from 6mm up to 8mm and 5mm steps were applied thereafter up to the back face of the sample. The 311 plane of reflection was chosen for these experiments, at a diffraction angle (2θ) of ~ 9.3°. Data analysis was performed using the Large array manipulation program (LAMP).

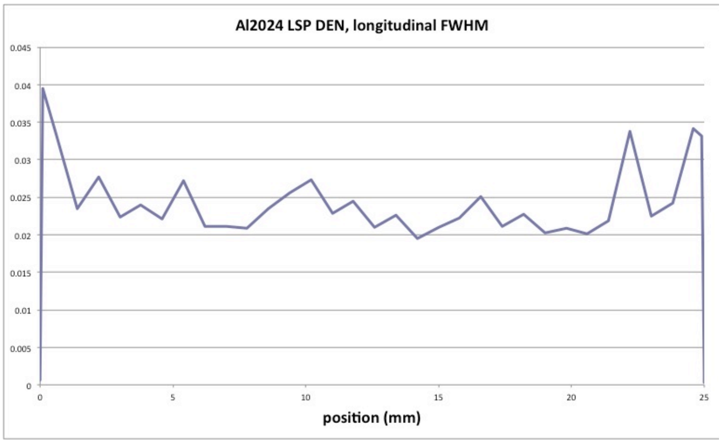
Experimental results:
The following figures represent strain results from part of an investigation into how LSP parameters affect the distribution of residual stresses in the two different aluminium alloys with similar, double-edeged notch (DEN) geometries.
Figures 1 & 2 show the calculated residual stresses in all three (in-plane longitudinal, out-of-plane, and in-plane transverse) directions. Here, the laser irradience settings are 3 (irradience in $GWcm^{-2}$)-18 (duration in ns)-3 (number of LSP layers applied over the same area). The sizes of the LSP spots individually are 5 x 5mm.
The graphs shown in figures 1 & 2 reveal larger maximum residual stresses in the Al7010 sample by a factor of approximately ⅔. A particular point of interest is that the the distribution of stresses in the Al2024 sample is such that maximums were located at positions 5 and 20mm from the (same) edge, and the stresses located

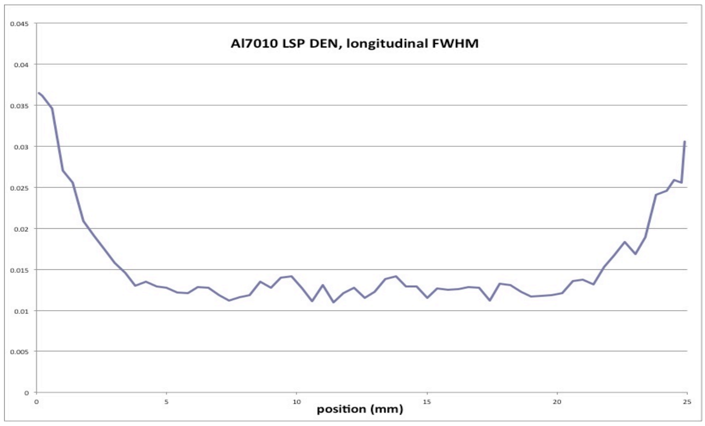
mid-wall are close to zero. This is not the case in the Al7010 sample, where stresses are seen to be approximately uniform and distributed over a central 15mm region. This difference between the two alloys suggests a sensitivity to microstructure of the effects of LSP on residual stress distributions.
As expected, the full-width half maximums (figures 3 & 4) demonstrated that the maximum stresses are located half-way between the sample walls and the middle of the sample Similarly, the maximum cold work has occurred at the areas nearest to the peened regions.





Figures 1 & 2:. The calculated stresses in the three orthogonal directions.





Figures 3 & 4: The corresponding full-width-half-maximum values, measured in the in-plane longitudinal direction.

Implications of the results:

These results will be compared against predicted data from finite element modelling performed by Oxford university. Ultimately, this will enable models capable of predicting compressive and tensile stresses and their locations for complex test pieces as a function of laser process parameters to be made available. This data will also be used as a basis for the interpretation of fatigue crack growth measurements made by the Swansea team on fatigue cycled samples. Further work will also include microstructural studies of LSP'd material to better understand the effect on the material on a (sub-)granular level under LSP.

References:

[1] King, A., Steuwer, A., Withers, P. J. (2006).: "Effects of fatigue and fretting in residual stresses introduced by laser shock peening." Materials science and engineering **435-6:** 12-18.
[2] Akita, K., Kuroda, M, Evans, A. D., Withers, P. J. (2006): "Dynamic finite element analysis and synchrotron X-ray measurements of residual stresses inducted by laser peening." Residual stresses vii **524-5**: 135-140.

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