ESRF	**Experiment title:** Relaxation of Residual Stresses In and Around Electromagnetically Installed Rivets During Fatigue Loading	**Experiment number**: ME-1036
Beamline: ID15a	**Date of experiment**: from: 10/7/06 to: 17/7/06	**Date of report**: 28/2/06
Shifts: 18	**Local contact(s)**: Thomas Buslaps	*Received at ESRF:*

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Report:

INTRODUCTION

Knowledge of the in-service performance of mechanical joints is important as part of design, servicing and lifetime criteria. As fatigue failure at fastened joints is a common problem in aircraft, it is important to understand how the beneficial residual stresses introduced by mechanical fastening relax during fatigue loading stages and if and when the improvement in fatigue behaviour around the joint is compromised. Four fatigue samples were used in the experiment. Each had been fatigued to a differing amount and contained cracks of different lengths. S0 was a control sample (no fatigue), S1 was fatigued but no visible crack was seen, S2 contained a small (approximately 3 mm surface crack) and S3 had a fatigue crack running to edge of the sample width. Each plate sample had been prepared with a Low Voltage Electromagnetic Riveter (as used on the Airbus A380 wing sections) using identical hole-drilling and riveting parameters. Aluminium alloy 7055 was used as a representative top skin with rivets similar in composition to AA2017 countersunk to a depth of 3.3 mm.

MEASUREMENTS

The samples were positioned so that, with the two-detector setup on ID15a, the x (parallel to the load) and y (transverse) strain directions could be measured simultaneously. A square aperture was used giving 500 mm lateral resolution. The use of a scattering angle of 5° produced an elongated gauge volume in the out-of-plane (z) direction of approximately 11 mm so that with the plate placed in the middle of the gauge volume the measurements represented a through-thickness average. The elongated nature of the gauge volume along the beam path combined with long path lengths meant that out-of-plane (z) measurements were not feasible. A plane-stress assumption was used to calculate the stresses within the samples.

After calculation of the stresses within the sample, it was noticed that the stresses along a planar line did not sum to zero over sample cross-sections. A 'stress-balance' correction was carried out where stress line profiles were extracted from the maps and the stress was integrated over the sample width. d_0 was then adjusted so that the resulting force along each cross-section was zero.

RESULTS

Maps of the residual stresses around the rivets were produced. Figure 1 shows line scans extracted from the maps to produce showing the hoop and radial stresses extending away from the rivet approximately 90° from the growth path of any cracks.

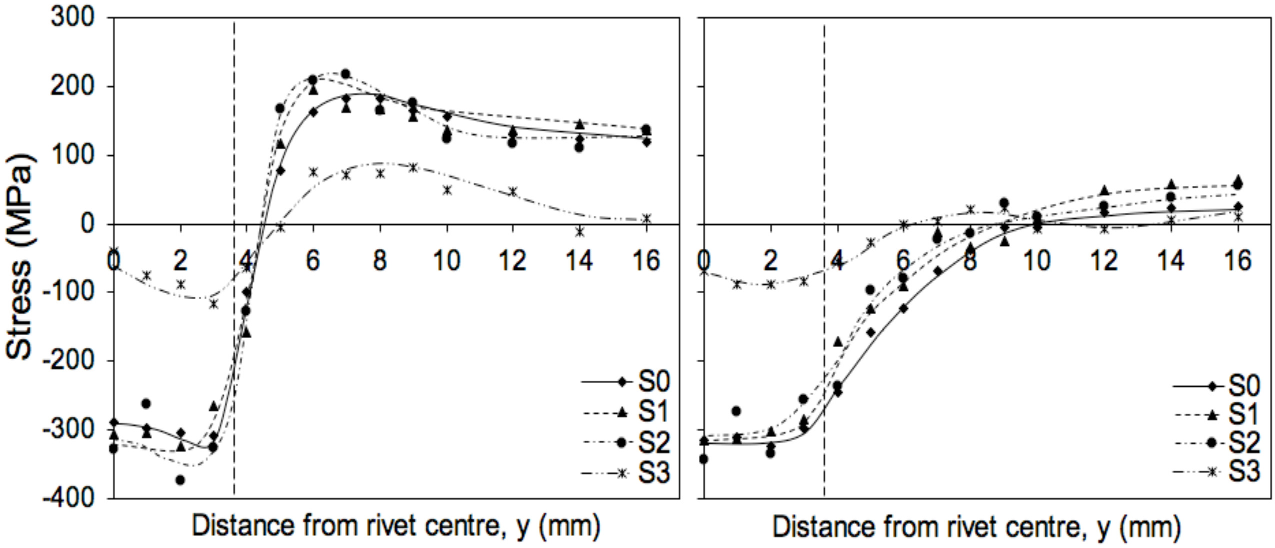

Figure 1 - (a) Hoop and (b) radial stresses along x-axis for samples fatigued to varying amounts. The vertical dashed line indicates the interface between the rivet and plate material.

Compressive hoop stresses are present at the hole edge and are balanced by tensile stresses peaking just below 200 MPa approximately 3 mm from the hole edge. They then tend to zero further away from the hole. The radial stresses are at a maximum compressive stress next to the hole and equilibrate to a value close to 0 MPa about 4 mm from the hole edge. It can be seen that that the distance over which the compressive hoop stress extends in the non-relaxed specimens is to a radius of approximately 4.5 mm – only a small amount of the plate is in compression. However, the general character of the stress profile and map is similar to that seen around cold expanded holes where the hoop stresses delay or resist fatigue crack growth [2,3].

There is little variation in the stress distribution between samples S0, S1 and S2. This indicates that the fatiguing without cracking and the growth of a small crack (which may have grown from a surface defect that provided an initiation site more likely to yield a crack than the fastener hole) has not cause much relaxtion of the residual stresses around the rivet hole. If crack growth were a result of the absence or reduction of compressive hoop stresses, the samples would have exhibited some amount of stress relaxation. However, the restraint provided to the plastically deformed zone by the bulk elastic material remains and thus the stress distribution is mainly unaffected. The absence of visible cracking in S1and the presence of a crack before stress relaxation occurs in S2 indicate that relaxation is a result of crack growth rather than the stresses relaxing before a crack is initiated. The lack of variation in the stress profiles for samples S0, S1 and S2 suggests that the full-field residual stress fields are unchanged by fatigue loading and the presence of small cracks.

It was observed, however, that when a crack is present in the sample which is known to extend through some thickness of the plate (as could be seen from the edge of S3), the stresses around the rivet do significantly relax. However the compressive-tensile hoop stress profile is still present although in a much reduced form. In this case the crack has become large enough for the rivet to elastically relax more freely within the fastener hole which has substantially reduced the magnitude of the residual stresses within the rivet itself. The crack has grown far beyond the elastic-plastic boundary in the plate and has thus provided new surface area for the relaxation of the elastic stresses in the bulk material.

CONCLUSION

The presence of a residual stress field similar to that seen around a cold expanded hole has been shown through the use of synchrotron diffraction. In a control sample, the typical compressive hoop stresses which act to resist fatigue crack growth have been seen as well as balancing tensile stresses in the bulk of the plate. After fatiguing of a single plate containing a rivet, when no crack existed within the specimen, there was no noticeable relaxation of the residual stresses around the rivet hole. However, once a crack which extends beyond the elastic-plastic boundary exists within the fatigue sample, relaxation of the residual stresses has been observed. It appears as though the presence of the crack allows the relaxation of the residual stresses rather than vice versa. Once this has occurred, crack growth rates will accelerate and fatigue failure will occur readily.

ACKNOWLEDGEMENTS

The assistance of the ID15a beamline scientist, Thomas Buslaps was greatly appreciated as well as that of Philipp Frankel and Yu-Chen Hung. We also acknowledge Matthew Peel (FaME38) for provision and assistance with the synchrotron analysis software. The authors thank David Colebourne of Airbus UK for providing the test samples and Gary Harrison (Manchester) and Peter Ledgard (Open University) for machining them. The fatigue testing was carried out at The Open University with excellent support from Stan Hiller and Lyndon Edwards.

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