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| ESRF | **Experiment title:**<br>Intergrannular Stress Development in Al during Dynamic Strain Aging | **Experiment number:**<br>ME360 |
| **Beamline:**<br>ID11 | **Date of experiment:**<br>from: 19 June 2002 to: 22 June 2002 | **Date of report:**<br>25 Jan 2003 |
| **Shifts:**<br>9 | **Local contact(s):** Gavin Vaughn | *Received at ESRF:* |

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## Report:

When the majority of alloys undergo tensile testing, an idealised stress-strain curve in is expected; an initial elastic loading is followed by a reduced gradient as plasticity occurs. During tensile testing of Al-Mg alloys (such as 6063) however, an unusual behaviour which is different again is observed. In this material, while the initial elastic loading is as one would expect, once plasticity has started to occur the loading response consists of elastic regimes interspersed with perfectly plastic regimes (Fig. 1). That is, while the loading response bears superficial similarities to that of conventional materials, there are distinct differences. Each of the steps where the load increases has an identical gradient to the initial elastic gradient. Each of the plateaus exhibits near perfect plasticity and, in a test carried out under load control, occurs rapidly (seconds). Further, the load increments required to initiate a new plastic straining 'event' are not equal, nor do they vary in an obvious systematic event as the load increases, but appear to be randomly distributed about some value.

This phenomenon is due to dynamic strain aging (DSA). During the elastic loading dislocations are arrested by the magnesium atoms in the aluminum lattice. The plastic relaxation occurs when the driving force for the dislocations becomes larger than a given threshold, and the dislocations can move past the magnesium atoms.

We have carried out a range of *in situ* loading studies on ID-11 to investigate this phenomena, studying the effect of loading rate, and the influence of running tests in strain or stress control. The Instron stress rig in hutch 2 was used, with a beam size of approximately 0.5 x 0.5mm. The beam was used in transmission, with the FreLoN camera used for data collection. The detector was placed ~2m from the sample obtaining reasonable peak resolution and the 220, 222, 400 and 311 reflections simultaneously (this range of peaks is optimum for comparison with models). At this distance the CCD records only part of the diffraction circle, thus it was necessary to carry out each experiment twice (with the camera moved for each), one to measure the axial strains, the other the transverse component.

The redistribution of intergranular strains (the relative load sharing between grain families contributing to different diffraction peaks) during elasto-plastic loading gives direct insight into the mechanisms of polycrystalline plasticity e.g.[1]. In analogy to composite load transfer, load transfer is from plastically soft directions to plastically hard directions. Thus typically in aluminium alloys, with its low elastic anisotropy, the 200 direcition has a low Schmidt (or Taylor) factor and therefore yields early in the deformation process, transferring load to the plastically harder directions such as the 111.

Figure 1 shows the stress-strain curve observed during one of the loading tests at ESRF with the characteristic plateau behaviour described above clearly visible. Three plateaus are shown in this data set, at around 250, 270 and 290MPa. The corresponding strains in the various diffraction peaks is shown in Fig. 2. The corresponding peak widths are shown in Fig. 3. In order to emphasise the effects observed, only the applied stresses corresponding to plastic deformation are shown. The early plasticity occurring prior to the DSA plateaus (220-250MPa) results in a slight divergence of the diffraction peak strains and an increase in the peak width. The signature of the large macroscopic plateaus is very clear in the diffraction peak strains, particularly the event at about 280MPa. However, what is evident for all three macroscopic steps observed is that the diffraction peaks are showing evidence of discontinuity *prior* to the actual macroscopic strain discontinuity. For example, a discontinuity is seen in the 400 peak at 242MPa, but the macrosopic strain increment actually occurs between 252 and 254MPa. Similarly the very clear redistribution of of strains occurring at 282MPa in all three diffraction peaks is not evidenced in the macroscopic strain until more than 290MPa is reached. Hence the *hkl* diffraction peak strains show evidence of a sudden redistribution of load between differently orientated grain families, and hence of plasticity, but this is occurring just prior to the macroscopic elongation. The changes in peak width are extremely interesting, with discontinuous increases occurring at the same stresses as the strain discontinuities. However, the increments in peak width are very strong in both the 220 and 400 peaks for all 3 of the macroscopic straining events even though the strain discontinuties are not clearly evidenced each time. It is likely that the sharp increases in peak width correlate to plasticity and increased dislocation density. The 222 peak however shows only moderate increase in peak width at each straining event. We interpret that this indicates that the 111 oriented grains are not exhibiting significant plasticity during the DSA discontinuities, and that the changes in the elastic strain seen in the 222 peak are due instead to load transfer occurring upon plasticity in other grain orientations. This is consistent with a Taylor model description, since the 111 grains have the highest Schmidt factor. As the loading rate is reduced (data not shown), the discontinuities in the grain family strains are reduced. However, the discontinuities in the peak widths are maintained, suggesting that the plastic deformation is still occurring but that relaxation mechanisms are operating to prevent strains building up on the various diffraction peaks.

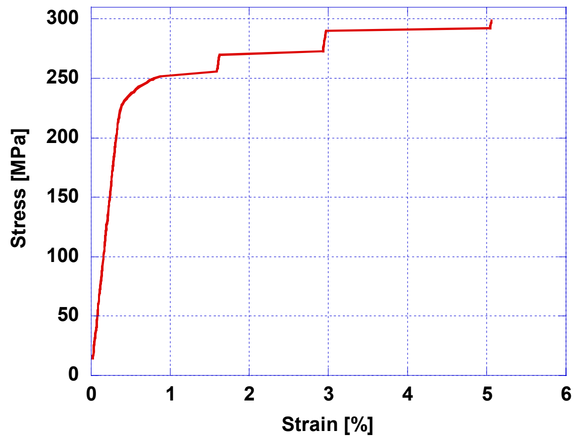

Fig. 1. The macroscopic stress strain curve obtained for a constant stress rate test of 1MPa/s.

[1] Daymond, M.R., Tomé, C.N and Bourke M.A.M, Acta mater, vol. 48, p553-564, (2000)

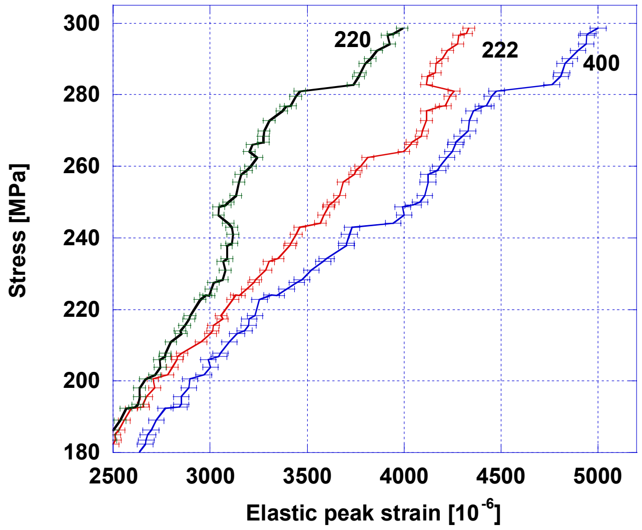

Fig. 2. The intergranular strain response for three of observed diffraction peaks.

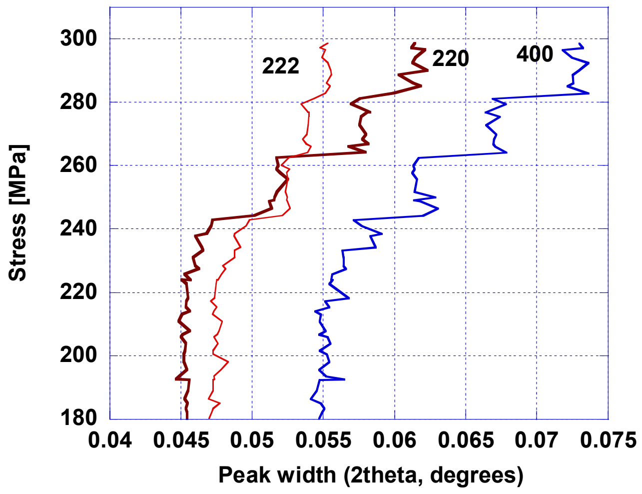

Fig. 3. The peak width for three *hkls*. A sharp increase in width is seen on the 220 and 400 planes, but not the 111 plane.