ILLUMINATING THE ORIGINS OF MATERIAL STRENGTH

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Supported by: EPSRC

The highly conservative field of structural engineering is getting an injection of new ideas from the application of traditional scientific tools such as synchrotron radiation. White beam energy-dispersive diffraction on Station 16.3 at the SRS has been used to develop novel non-destructive means for the analysis of deformation and strength of important structural engineering materials. The capabilities of the new approach for accurate strain measurement and direct numerical model validation through *in situ* deformation testing are contributing to new thinking about efficient design against mechanical failure.

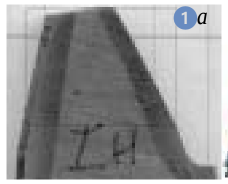
Structural engineers are responsible for safeguarding human life, so we like to think of them as a conservative bunch of people. Using the paradigm of proving the design through trial and error, full scale experimental testing can be extremely costly. However, it is very appealing because of its simplicity. An alternative idea is to conduct experiments on smaller laboratory test pieces and to scale up the results to the real structure. This way of thinking can be traced back to Galileo, and was developed into a branch of science by the great engineers of the 18th and 19th centuries.

Since then structural integrity has always been characterised by destructive means. This involves dozens of nominally identical test specimens being subjected to loading experiments conducted until failure occurs. Developments in materials science contributed to the methodology of sectioning the specimens or components to image their microstructure and to correlate it with strength. However, in the modern engineering climate of accelerated product development and get-it-right-first-time design requirements, even these traditional methods are proving to be too expensive and time consuming.

So is there a different, more modern view? Oxford University engineering scientist Alexander Korsunsky and his team are developing truly non-destructive approaches to characterising the strength and failure of structural materials and components using polychromatic synchrotron X-ray beams and energy dispersive detectors on the 6T Wiggler Station 16.3 at the SRS.

Most high strength engineering materials such as metallic alloys and ceramics consist of multitudes of tiny crystals, together forming a bulk solid. Stress and strain interactions take place inside these tiny grains (intragranular) and between different neighbouring crystals (intergranular). It is these stresses and strains that are responsible for the initiation of defects and ultimate failure. X-ray diffraction is a unique method of measuring grain-level deformation by interrogating the distances between elastic lattice planes that act as built-in strain gauges. However, a laboratory X-ray diffraction source lacks the penetration and flux to do a structural integrity experiment. The high energy, high flux beams and ample sample space afforded by SRS 16.3 allows test specimens, even entire engineering components, to be examined. From these measurements key measurable parameters can be identified that indicate the development of damage and the reduction of the remaining life of the component.

The change in crystal lattice spacing (and hence strain) can be measured either using a monochromatic beam and an X-ray detector scanning through a range of diffraction angles, or using a polychromatic beam and a fixed detector capturing photons over a whole range of energies. The option of holding the detector in a fixed position is highly attractive from the engineering scientist's viewpoint. Recent experiments at the SRS by the Oxford team proved that the white beam configuration is also highly efficient, with counting times as low as 10 s per point giving lattice spacing accuracy better than 50 parts per million even in transmission measurements through many millimetres of steel. The power and versatility of the technique was demonstrated in the study of an induction-hardened tooth from a large marine gear (Fig 1a). For the rectangular region indicated, a detailed spatially resolved residual stress map was compiled (Fig 1b).



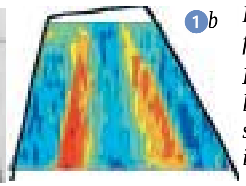


Fig 1a A tooth section from a large marine gear.

Fig 1b Map of the longitudinal residual stress for the region indicated in Fig 1a.

A compact 15 kN loading rig for *in situ* deformation studies was specially designed and constructed at Oxford to fit the beamline instrumentation (Fig 2). The rig is capable of performing tensile experiments under remote displacement and load control, and fully integrates with the PINCER data collection program. The response of different grain groups to plastic deformation was monitored in a sample of commercially important titanium alloy widely used in the aerospace industry. This experiment led to the discovery of intricate interactions between grains of different orientation during continuous loading (Fig 3). These processes are impossible to capture by any other method, as none can match the speed or accuracy of this technique. Several other UK research groups are involved in further development of the approach. The Oxford team collaborates closely with the groups of Professor P Withers at the Manchester Materials Science Centre and Professor P Webster based at Salford, and with the ESRF staff (A Kvick, A Fitch) in Grenoble. The emphasis of the present development in this area is firmly placed at the SRS Daresbury, with new funding for equipment and development initiatives being sought from the EPSRC. The results have also provided input into the design of the new dedicated Joint Engineering, Environment and Processing (JEEP) beamline on DIAMOND.

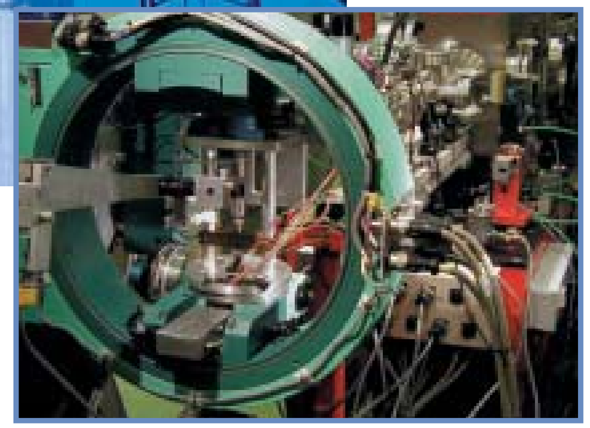


Fig 2 The specially-designed 15 kN loading rig mounted in the beam on Station 16.3 at the SRS.

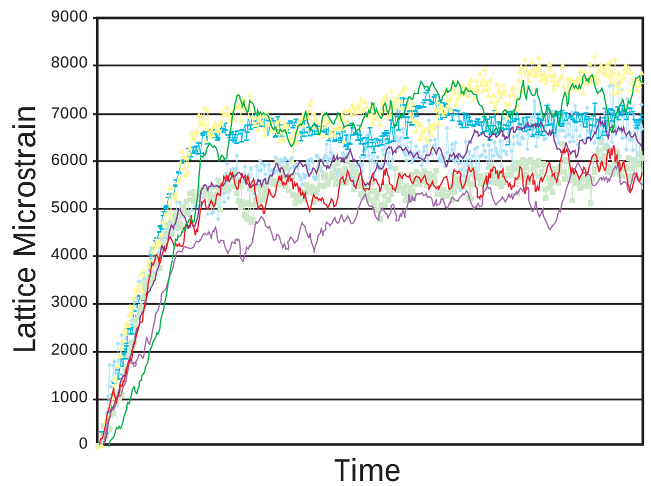


Fig 3 Time history of grain-level orientation specific strains in a titanium alloy.

GENERAL REFERENCE:

AM Korsunsky, SP Collins, RA Owen, MR Daymond, S Achtioui and KE James, (2002).
Fast Residual Stress Mapping Using Energy Dispersive Synchrotron X-ray Diffraction on Station 16.3 at the SRS.
J. Synchrotron Rad. Vol 9, pp 77-81.