Residual stress analysis around foreign object damage using synchrotron diffraction

P. Frankel[1, 2], J. Ding[3], M. Preuss[1], P.J. Withers[1], J. Byrne[3]

[1]University of Manchester, Manchester, UK

[2]University of Birmingham, Birmingham, UK

[3]University of Portsmouth, Portsmouth, UK

The ingestion of small, hard particles during takeoff and landing of aircraft can cause significant damage to compressor blades in aero-engines. The size of these particles is typically in the millimetre regime, with impact velocities in the range of 200 ~ 350 m/s, depending on the blade speed of the engine. The effects of such damage have received increasing attention over recent years, particularly because of their influence on the high cycle fatigue (HCF) properties of aerofoil components. The combination of the geometric stress concentration introduced by FOD, the residual stress and the accumulation of an extreme number of fatigue cycles could act as significant limiting factors for component life.

On top of obvious safety worries associated with engine failures there is also a substantial financial cost. Issues associated with FOD cost the civil aerospace industry approximately €4 billion annually and the maintenance budgets for the UK and USA Air Forces run into many millions of euros each year.

Several experimental and computational studies into the interaction between FOD and fatigue strength, have demonstrated the importance of defining the residual stress field, the plastic damage distribution and the relaxation or redistribution of residual stresses upon subsequent cycling.

Previous studies have been mostly related to FOD induced high cycle fatigue (HCF) behaviour. In real flight conditions high-frequency minor cycles from blade vibrations are always superimposed on each major cycle (centrifugal and thermal stresses for each flight). Any fatigue integrity assessment must consider the behaviour of aero-engine materials in conjunction with a residual stress field induced during FOD under combined HCF and low cycle fatigue (LCF) loadings.

The present work compares predicted and measured residual stress maps around simulated FOD in fatigue specimen. Strain mapping was performed on the high-energy synchrotron x-ray beamline, ID15A, using a white beam and two detector setup at the ESRF in Grenoble, France. The high energy/high flux on ID15B together with a slit size of 100 x 100 μm provides the resolution needed to resolve the stress field around the FOD. Accurate alignment of the sample was achieved by measuring the surface of the samples using a co-ordinate measurement machine (CMM), and defining measurement points relative to a specific feature on each sample. A two-dimensional grid of measurements provided strain data around the impact area, allowing direct comparison with finite element predictions. Complimentary laboratory x-ray measurements were also performed to provide additional residual stress information.

The experimental data are compared with residual stress predictions undertaken in a finite element model developed in ABAQUS according to a plastic model with power-law dependence. The model is currently used to provide stress data for ongoing fatigue investigations.