An investigation into the microstructure of Inconel 718 after machining

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Inconel 718 is a nickel-iron based superalloy with properties that include high strength and corrosion resistance [1]. Machining however can lead to the formation of a so-called "white layer" on the surface – *white* because of its appearance in the optical microscope – and such a layer may shorten a component's fatigue life [2]. This transmission electron microscopy (TEM) study forms part of an investigation into the effects of different high speed turning conditions – cutting speed, feed rate, tool wear, the use of coolant – on the microstructure at the machined surface [3].

TEM samples were prepared by focussed ion beam (FIB) milling on an FEI Nova Nanolab 600. Compared to conventional electropolishing, FIB milling can readily produce cross sections at specific points of a machined surface. It can also extract surface regions down to a depth of tens of µm, ensuring that the transition region between white layer and underlying layers is included. TEM was performed on the Lund JEM-3000F operating at 300kV. Figure 1 is a low magnification TEM image of a FIB lamella that has white layer (above the added line) and severely deformed zone (below the white line).

Inconel 718 has an fcc matrix (a = 0.36nm) and, in the material studied, the matrix has grain size ~23µm and the main strengthening component is a dispersion of coherent γ'' Ni_3Nb precipitates. γ'' has the DO_{22} structure (body centred tetragonal, a = 0.36nm, c = 0.74nm). The diffraction pattern in figure 2 confirmed the presence of γ'' (observed here in a mild deformation zone well below the surface) as also done in other studies [eg 4]. The elongation of spots along 010 arises from the small thickness of precipitate discs. The disc width ranged in size from around 15 – 20nm.

The grain size and texture in the white layer are of interest and various imaging methods were tried that would reveal the grains most clearly. Bright/dark field TEM via "high contrast" apertures (which lie outside the objective lens back focal plane) results in restricted image areas; *e.g.* ~2µm across for the 20µm aperture (semiangle 4.5mrad, resolution ~0.4nm). Scanning transmission electron microscopy was therefore pursued since areas of up to ~8µm across can be scanned. Different imaging conditions produce contrast that is more or less useful as shown in fig. 3. Fig 3a) used a convergent probe of 15mrad semiangle and small inner detector angle of ~20mrad. This "standard" annular dark field (ADF) leads to a satisfactory imaging of the grains. Fig 3b) is also ADF but with a less convergent probe of 4.5mrad. As expected, there is stronger diffraction contrast; but the imaging of the grains is less clear. Fig 3c) is "standard" high angle annular dark field (HAADF) with inner detector angle around 55mrad and 15mrad probe; contrast due to the thickness variation dominates, diffraction contrast is much lessened, and the grains are hard to see.

The figure 3 sample had been machined *with* coolant and *worn* tool. The white layer had grain sizes in the 50-150nm range, and studies continue into the relationship between grains in the white layer and in the severely deformed zone. Concerning the γ'' precipitates, preliminary indications are that they are not found in the white layer but are retained in the severely deformed zone [5].

References

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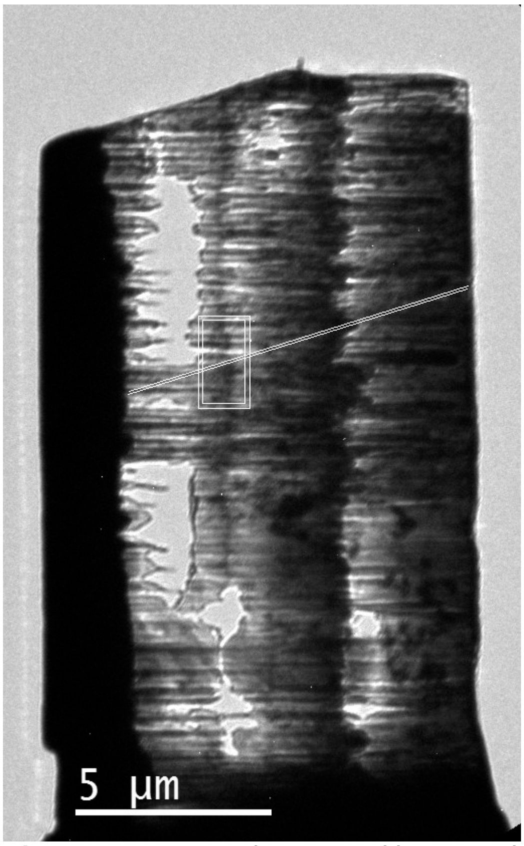

Figure 1. *TEM sample prepared by FIB. The white layer lies above the line, the box indicates the approximate region of fig. 3.*

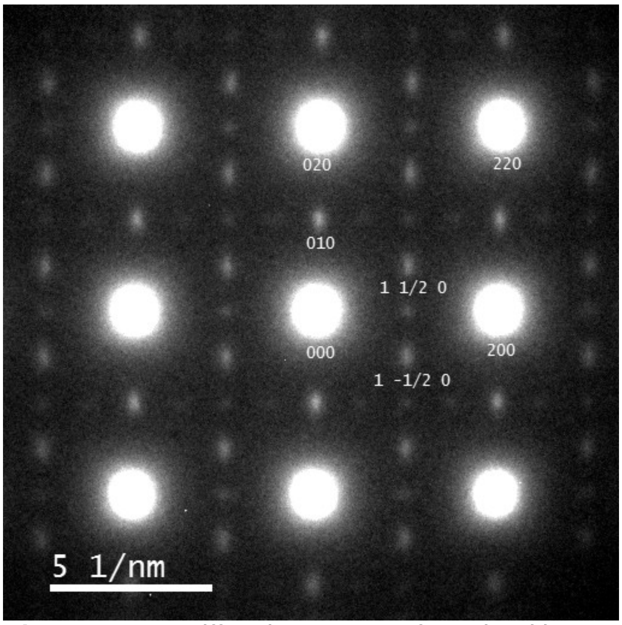

Figure 2. *001 Diffraction pattern of matrix with γ'' precipitates, indexed according to fcc matrix. One set of γ'' precipitates appear stronger and three reflections are labelled (010, 1½0 1-½0).*

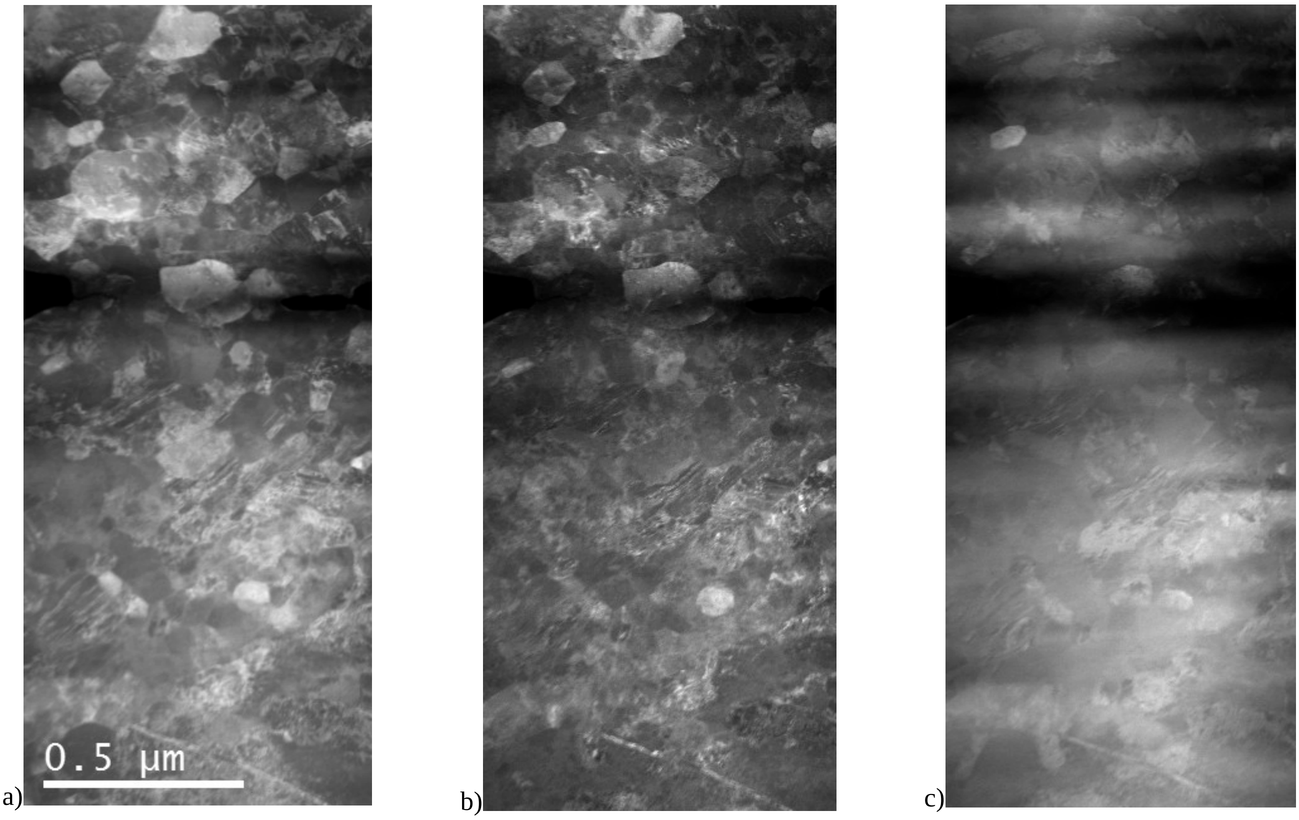

Figure 3. *Dark field STEM images of boundary region between white layer and severely deformed layer. a) ADF with convergent probe b) ADF with less convergent probe c) High angle ADF with convergent probe.*