Industry Case Study

Siemens Energy

Analysis of environmentally assisted crack propagation in turbine blade superalloy

BACKGROUND

Siemens Energy, a leading global energy technology company, operates a state-of-the-art manufacturing facility in Lincoln, UK and are a member of the Bridge, they specialise in the design and production of cutting-edge gas turbines renowned for their exceptional performance.

Siemens Energy turbine blades are meticulously crafted from advanced single-crystal nickel-based superalloys like CMSX-4. This cutting-edge material boasts exceptional high-temperature strength, exceptional creep resistance, and a resistance to high temperature oxidation and hot corrosion – critical attributes for withstanding the rigorous demands of continuous operation.

Siemens Energy gas turbines are designed to operate 24/7, 365 days a year, providing reliable power generation. These turbines operate in extremely demanding environments characterised by high temperatures, intense mechanical stresses, and elevated pressures, while simultaneously enduring exposure to a variety of chemical agents used as fuels, all in the presence of oxygen.

Understanding the potential degradation mechanisms within this challenging environment is paramount. By meticulously analysing these factors, Siemens Energy can continually innovate and extend the lifespan of their turbines, minimising costly downtime and ensuring maximum value for their customers.

APPROACH

Siemens Energy have used the advanced microscopy facilities at the Bridge, including focussed ion beam milling and the FEG-SEM, and high-resolution scanning/transmission electron microscopy (S/TEM) with EDX elemental analysis to further understand how microcracks grow in CMSX-4 test samples thermally exposed to environmentally assisted crack test conditions.

OUTCOMES

The SCIOS FIB-SEM at the Bridge was used to identify a crack tip of interest and extract a section for analysis using in-plane lift out. Figure 1 shows the location of the crack in a polished section of aged CMSX-4, and the extracted chunk before ion beam milling.

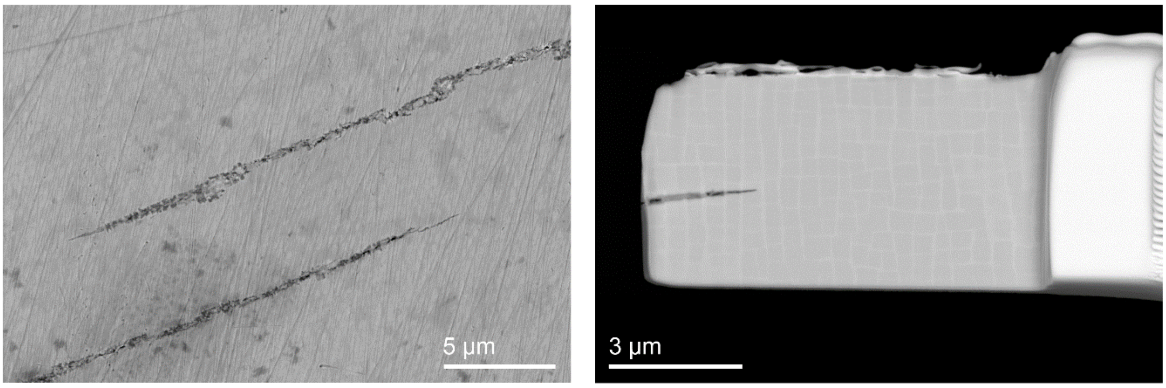

Figure 1 *Left: An SEM image of a polished section of a post thermally exposed CMSX-4 test sample showing two microcracks. The lower crack penetrating from the left was chosen for further analysis. Right: SEM image of the planar lift-out extracted chunk welded to a TEM grid before thinning and polishing showing the crack tip.*

As can be seen in Figure 1, it was possible to successfully isolate and extract a section of the superalloy sample containing the tip of a propagating crack. This was further analysed on the Talos S/TEM for imaging and elemental analysis with EDX mapping.

Using the TALOS TEM, it was possible to observe not just the crack tip, but many microcracks originating and spreading from the larger crack. The mechanism of crack creation is not fully known, but a previous publication (1), suggested it may involve sulphur, so the chemistry in these microcracks was probed using the EDX elemental mapping capability of the S/TEM.

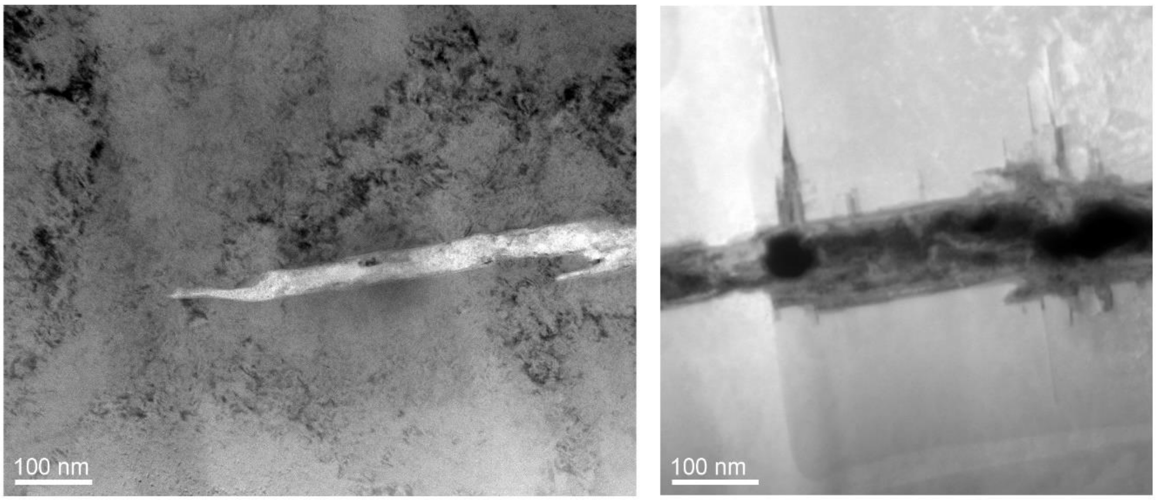

Figure 2: *Left: A TEM brightfield image of the crack tip in the CMSX-4 test sample. Right: A STEM HAADF image showing small microcracks leading off at 90° to the axis of the main crack in the same sample.*

The images in Figure 2 show several features of interest, including multiple crack tips, light coloured material (non-metallics) within the crack, and the aforementioned microcracks, which are seen to propagate mostly perpendicular to the main crack axis.

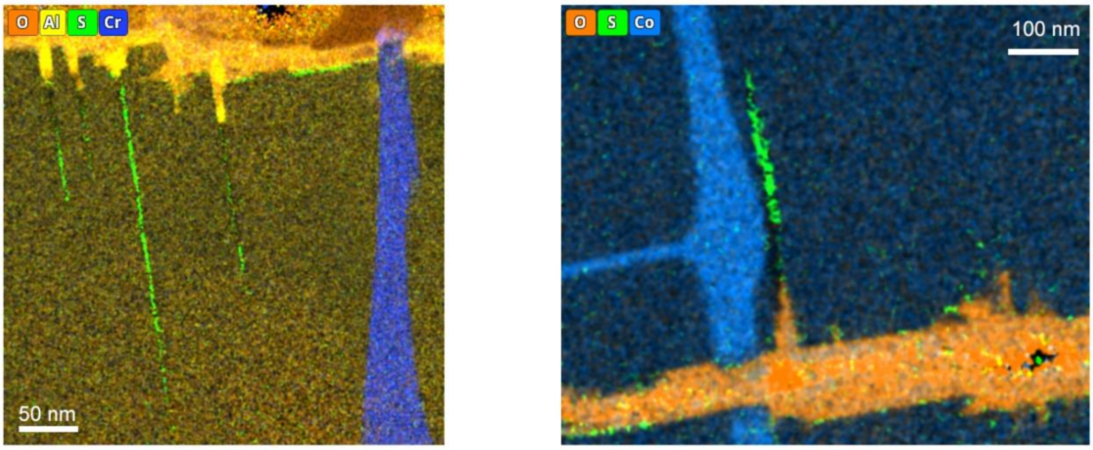

Figure 3. *STEM-EDX mapping result on the CMSX-4 test sample. Left: An area showing multiple microcracks extending from the main crack. Right: another area, showing the growing microcrack tip rich in sulphur.*

Figure 3 shows some results from chemical mapping with the EDX-STEM mode, the main crack consists mainly of oxide, while the microcracks contain mostly sulphur. In addition, the surface of the main crack is rich in sulphur.

SUMMARY

The combination of FIB-SEM and EDX-STEM is shown to be a very powerful technique to aid characterisation of degradation mechanisms in metals such as this superalloy. It allows the extraction of samples for ultra-high resolution analysis at exactly the desired location on a specimen. Using the combination of S/TEM with EDX allows us to detect and locate tiny amounts of a wide range of elements, helping to elucidate the diffusion paths of corrosive elements. The data obtained here supports the suggested mechanism of sulphur-induced environmentally assisted cracking. Knowledge of the mechanism allows Siemens Energy to improve products, and understand operating conditions which can potentially affect turbine blade lifetime – for example, using sulphur-rich fuels.

REFERENCE

(1) Stress Corrosion Testing of CMSX-4, CM247LC DS and IN6203DS Ni-Base Superalloys, Chapman, N. et al., Oxid Met 95, 85–104 (2021).