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Multi-scale Characterisation of Heat Treatment in Single Crystal Nickel-based Superalloys

Victoria C. I. Strutt[1], Michael P. Moody[1], David Rugg[2], Anna Radecka[2], Matthew Appleton[2], Jane Woolrich[2] and Paul A. J. Bagot[1]

[1.] Department of Materials, University of Oxford, Oxford, United Kingdom.
[2.] Rolls-Royce PLC, Derby, United Kingdom.
*Corresponding author: victoria.strutt@st-annes.ox.ac.uk

Nickel-based superalloys are the material of choice for gas turbine blades due to their excellent material properties, at high temperature, including strength and environmental-damage resistance[1]. Continual development of these alloys through chemistry and processing has enabled these desirable properties to match the increasingly harsh environments driven by the demands of improving engine efficiencies and operation in non-benign regions.

Changes in chemistry have seen alterations including an increase in the amount of refractory elements such as Re, Ta and W [2]. The complex nature of these alloys, with multiple alloying elements used, coupled with variations in heat treatments results in solute partitioning on both the micro-scale (between the dendrite cores (DC) and interdendritic areas (IDR)) and additionally on the nano-scale (between the gamma (γ) and gamma prime (γ') precipitates). This dual partitioning across multiple length-scales is particularly pronounced for the heavier refractory elements [3]. Deviation in mechanical properties has been observed on the macroscale, which is explained through variation in local composition and solute distribution [4]. These changes in composition have further been studied on the micron-scale, however to date they have been complemented with very few studies focusing on the nanoscale.

CMSX-4 and RR3010 are 2nd and 3rd generation Nickel-based superalloys currently used in gas turbine engines. These alloys exhibit dendritic microstructures with different bulk compositions. Such differences in bulk composition, which affects details such as the gamma prime volume fraction, can account for some of the dissimilarities in dendritic structures observed between these two alloys. However it is also apparent that these microstructures are strongly influenced by the exact heat treatment path chosen, which is also reflected in differences in bulk mechanical properties. Understanding and characterising the effects of chemistry and heat treatments on these individual alloys will optimize future alloy design and ensure the stability of these materials at the extreme conditions they are utilised under.

A combination of atom probe tomography, scanning electron microscopy and energy dispersive X-ray spectroscopy was used to characterise changes, induced by heat treatment and also model environmental exposures, across a range of length scales. The results showed a variation in γ' volume fraction and solute partitioning between heat treatments and for both alloys. Changes in solute partitioning were observed between DCs and IDRs and additionally between the γ and γ' precipitates. The high-resolution capabilities of atom probe tomography enabled the characterisation of γ and γ' interfaces and nanoscale precipitates within gamma channels. Both interfaces and nanoscale precipitates were affected by heat treatments, displaying variation in excess atoms and distributions respectively.

This talk presents results which will demonstrate the marked extent to which heat treatments and subsequent exposures play in the microstructural and consequent mechanical properties of both CMSX4 and RR3010. Mapping elemental behaviour with iterative heat treatments on the nano-scale and correlating these results with those on the micron-scale is imperative to ensuring the stability and safety of these and future alloys.

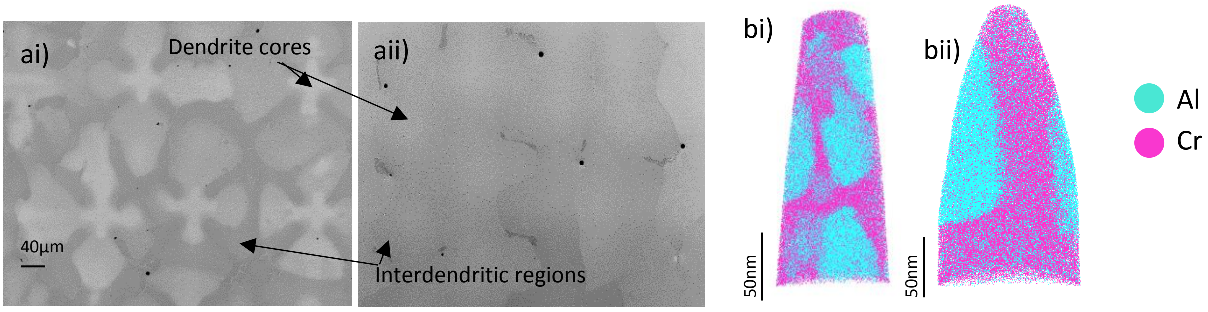

Figure 1. (a) SEM micrograph (400x) of RR3010 showing dendritic microstructure in i) as cast and ii) heat treated (b) Atom maps from RR3010 dendrite cores showing distribution of Al (blue) and Cr (pink) dendrite core (DC) in i) as cast and ii) heat treated states

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