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The Use of Scanning Electron Beam-based Phase Classification as a Crucial Tool in Alloy Development for Gas Turbine Engine Applications

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The rapid alloy characterisation capabilities of scanning electron microscopy (SEM) techniques permit confident and precise insight into the roles of beneficial and deleterious microstructural constituents. In this work, simultaneous electron backscatter diffraction (EBSD) and energy dispersive X-ray spectroscopy (EDS) are used to fully understand the chemistry and structure of grain boundary precipitates in new Co/Ni-base superalloys.

Discovery of the $Co_3(Al,W)$ $L1_2$ ternary has stimulated the development of dual-phase γ/γ' Co-base superalloys for high temperature gas turbine engine applications. These alloys are thought to have a superior temperature capability ceiling than conventional Ni-base superalloys, due to the higher melting point of cobalt than nickel. Hotter operation brings improvement to aeroengine efficiency.

Development of polycrystalline Co/Ni-base superalloys pursues improvement in mechanical properties at high temperature, specifically fatigue and creep. Alloying additions of Mo are employed for solid solution strength of the matrix γ phase, with Ta included for optimisation of the γ' volume fraction. Additionally, Cr and Al are required for oxidation resistance [1]. These elements stabilise a variety of grain boundary precipitates. It is well known that boundary character and cohesion has a critical effect on mechanical behaviour. Tertiary creep (strain acceleration to failure at higher temperatures and modest stress) in polycrystalline alloys is thought to be dependent on grain boundary sliding [2]. Furthermore, intergranular cracking during fatigue is known to be exacerbated by precipitate oxidation. Whether and to what extent various boundary phases are desirable evidently requires precise characterisation of sample microstructures.

We have found with EBSD, and confirmed with simultaneous EDS, that too high a concentration of Al stabilises the undesirable B2 NiAl phase at grain boundaries. These precipitates appear to nucleate on MC carbides, in turn thought to form from refractory element rejection at growing dendrites during solidification. With EBSD alone, MC carbides are difficult to distinguish from the matrix due to their shared FCC crystal structure. However, their chemistries are distinctive, and EDS allows easy identification. $M_{23}C_6$ carbides and MB_2 borides share a chemical fingerprint but exhibit significant difference in crystallography, indexing with Fm3m and P/6mmm structures respectively. An example of this approach is presented in Figure 1. We show that the apparent boride solvus and behaviour is consistent with previous studies [3].

Combining EBSD and EDS thus permits us to separate all phases independently, where either technique individually would be insufficient. Leveraging the insight this approach provides allows further understanding of deformation mechanisms and mechanical behaviour, for example in Figure 2, and provides direction for us to design a new generation of high temperature aeroengine alloys [4].

References:

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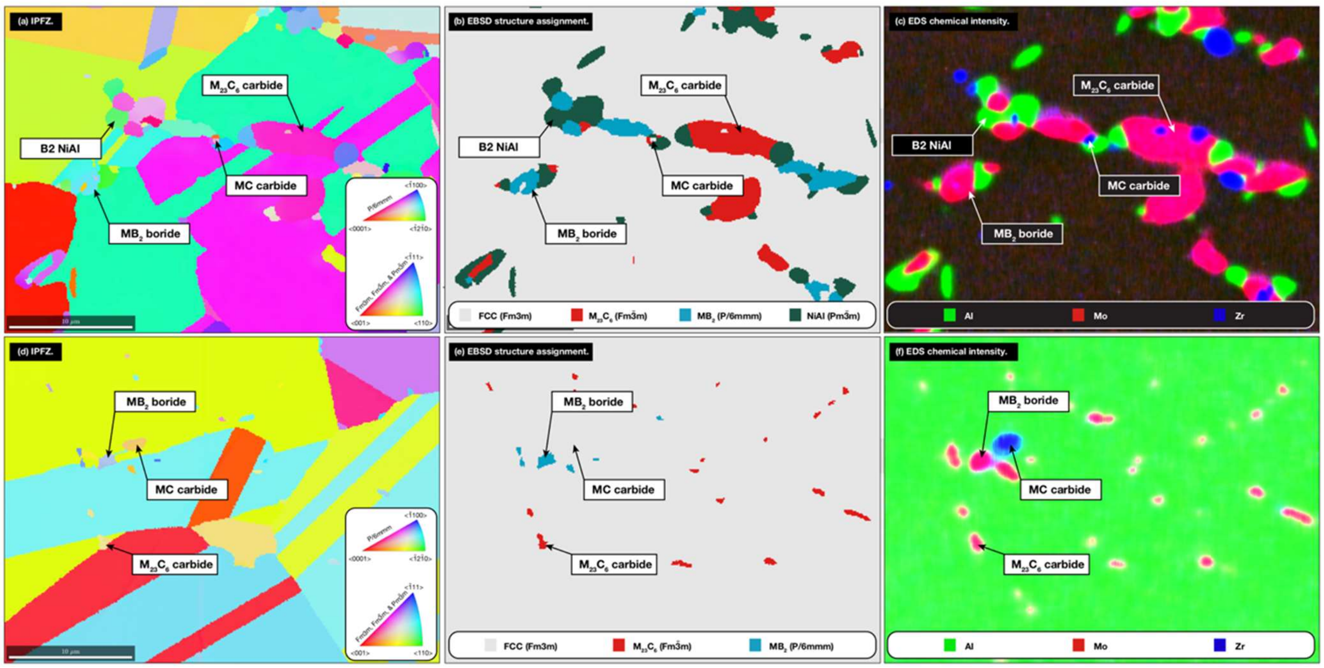

Figure 1. Phase classification based upon simultaneous EBSD (a-b & d-e), and EDS (c & f), with chemical gain optimised for contrast. Two example microstructures are presented: (a-c) and (d-e).

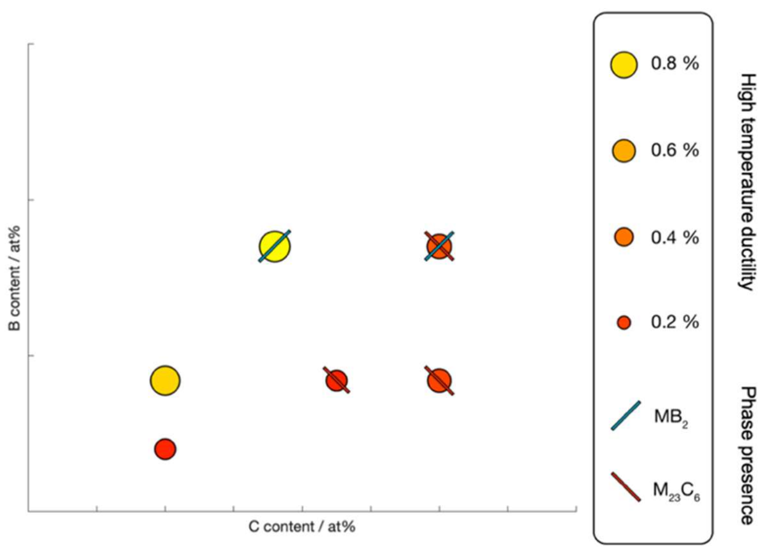

Figure 2. Variation in high temperature ductility with changes in dominant grain boundary precipitate(s).

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