Abstract

This thesis is a study of Nb-silicide based alloys for the intended application as a turbine blade within the high temperature, high pressure region of a gas turbine engine. Current turbine entry temperatures (TETs) are ≈ 1600 °C, above the Ni-based superalloy melting temperature (≈ 1350 °C), due to environmental and operational requirements the TET will increase towards ≈1900 °C and Ni-based superalloys will be inadequate for operation at these temperatures.

To investigate the viability of Nb-silicide alloys as a turbine material, the microstructures, isothermal oxidation properties (air) and nano hardness of the four alloys (at%) JN1 (Nb-18i-24Ti-5Cr-5Al-5Hf), JN2 (Nb-18Si-15Ti-10Cr-2Hf-5Mo-2W-2Sn), JN3 (Nb-18Si-15Ti-2Cr-2Hf-5Mo-2W-2Sn) and JN4 (Nb-20Si-20Ti-2Cr-2Hf-6Mo-5Sn) in their as-cast (AC) and heat treated (HT) conditions (1500 °C for 100 h) were studied. In addition, the fracture toughness of two cast alloys with nominal compositions (at%) Nb-24Ti-18Si-5Al-5Cr (KZ5 (JN)) and Nb-19Ti-18Si-4Al-4.5Cr-5Hf (JN5) were also studied.

The AC alloys displayed macrosegregation of Si which was increased with increasing Hf and Cr content and the addition of Sn. Hf, Ti, Al, Cr and Sn partitioned to the Nb_{ss}, with Hf, Al and Cr partitioning preferentially to areas with high Ti. This effect caused large amounts of microsegregation, particularly in JN1 and JN2, with this partitioning effect continuing after HT for JN1. Mo and W also displayed partitioning to the Nb_{ss}, though these elements showed an inverse relationship with regards to high concentrations of Ti.

During solidification the βNb_5Si_3 was the primary phase in all four alloys. The synergy of Hf with Al, Cr and Ti stabilised the βNb_5Si_3 in JN1-HT, and probably the hexagonal γNb_5Si_3. The synergy of Hf with Mo, W and Sn enhanced the transformation $\beta Nb_5Si_3 \rightarrow \alpha Nb_5Si_3$. The formation of the C14 $NbCr_2$ Laves phase depended on the presence and concentration of Hf in the alloy and on the concentration of Cr in the alloy. The Laves phase was stable only in the alloy JN2 and the Nb_3Sn phase was formed only in JN4-HT. The Nb_{ss} + Nb_5Si_3 eutectic formed in all four alloys but was not stable after HT in any of the alloys.

At 800 °C the alloys JN1, JN2 and JN3 suffered from pest oxidation and exhibited mixed oxidation kinetics, whilst JN4 did not pest and followed parabolic oxidation kinetics. All four alloys displayed cracking in the substrate parallel to the sample. In all four alloys a diffusion zone formed below the scale/substrate interface.

At 1200 °C the alloys JN1 and JN4 exhibited best oxidation with parabolic oxidation kinetics, whilst the alloys JN2 showed mixed kinetics and JN3 followed linear oxidation kinetics. There was spallation of the scale formed on the alloys JN1 and JN2, and the alloy JN3 formed "Maltese cross". Sn segregated below the scale/substrate interface during oxidation where it formed Nb_3Sn, this was thicker in and more continuous in JN4. Both Ti niobate and a mixed oxide rich in Nb and Si were found in the oxidised samples.

Nano-indentation showed that Ti, Hf, Al and Cr in JN1 "softened" the solid solution, Hafnium had a weak hardening effect in $(Nb,Ti,Hf,Cr)_5(Si,Al)_3$. The addition of Mo and W "softened" the 5-3 silicide whilst aalloying with Hf resulted in a reduced elastic modulus, Mo had a very strong effect on the elastic modulus of Nb_{ss} and Nb_5Si_3 and this effect was compromised by the synergy of Mo and W with Cr, Hf, Sn and Ti.

Fracture toughness testing showed the K_Q values of the alloys KZ5 (jn) and JN5 were $\geq$ 19.5 MPa$\sqrt{}$m. The Nb_{ss} provided effective crack blunting. The presence of lamellar Nb_{ss}/ Nb_5Si_3 eutectic microstructure contributed to the toughness of the alloys. Calculations of toughness for crack bridging by ductile Nb_{ss} grains suggested that the constraint operates positively into the Nb_{ss} phase.