Abstract

The influence of the amount of Cr and Ti on the microstructure, evolution of the phases, physical properties, and mechanical properties of a series of ternary Nb-Si-Cr and Nb-Si-Ti alloys have been examined. The concentrations of the third element have been varied in a way so as to achieve comparative assessment of structure-property relations of the nearly hypo-eutectic and hyper-eutectic ternary alloys. The alloys were prepared by arc-melting in vacuum and were homogenised by repeated melting. Studies on microstructures have been carried out using X-ray diffraction as well as optical, scanning, and transmission electron microscopy along with energy dispersive spectroscopy and image analysis. The lattice parameters and the elastic moduli of the investigated alloys were determined by X-ray and ultrasonic tests. The mechanical properties of the alloys including microhardness, hardness, fracture toughness, compressive strength at room temperature have been estimated by standard practices. Some limited efforts have been directed to examine the oxidation behaviour of these alloys.

The addition of Cr to Nb-Si alloys leads to the evolution of only Nb_5Si_3 type silicide phase, whereas Ti stabilizes $(Nb, Ti)_3Si$ phase in the as-cast microstructures at ambient temperature. The microstructures of as-cast Nb-Si-Cr alloys contain primary and or secondary $(Nb, Cr, Si)_{ss}$, $Nb(Cr, Si)_2$ and $Nb_5(Si, Cr)_3$ phases, whereas those of Nb-Si-Ti alloys contain primary or secondary $(Nb, Ti, Si)_{ss}$ and $(Nb, Ti)_3Si$. Both ternary and binary eutectic mixtures are found in as-cast Nb-Si-Cr alloys, while binary eutectic and eutectoid mixtures are observed in as-cast Nb-Si-Ti alloys. The eutectic domains exhibit degenerated, lamellar, non-lamellar or rod type morphology in these alloys. The evolution of the phases and the solidification paths have been proposed for these alloys from the nature of the primary dendrites and that of the phases existing at the interdendritic regimes. The sequence of formation and the amounts of the phases depend on the proportions of Nb, Si, and X (X= Cr or Ti) in the ternary Nb-Si-X alloys. These phenomena have been explained by considering Nb-Si, Nb-Cr and Nb-Ti binary equilibrium diagrams in the respective alloys. The lattice parameters of the $(Nb, Cr, Si)_{ss}$ and $(Nb, Ti, Si)_{ss}$ phase decrease with increasing Cr and Ti content respectively. The c_0/a_0 ratio of the $Nb_5(Si, Cr)_3$ phase first increases and then decreases with increasing Cr content, while the c_0/a_0 ratio of the $(Nb, Ti)_3Si$ phase increases with increasing Ti content.

The addition of Cr increases micorhardness of the Nb_{ss} by solid solution strengthening, whereas Ti addition decreases microhardness of the Nb_{ss} phase by solid solution softening. The addition of Cr as alloying element to Nb-Si system increases the bulk hardness of the system by promoting enhanced formation of $Nb(Cr, Si)_2$, whereas Ti addition apparently decreases the bulk hardness of Nb-Si system. Addition of Ti increases fracture toughness of the Nb-Si system in comparison to that obtained by Cr addition. The maximum compressive strength of ~ 1855 MPa is observed for Nb-17Si-6Ti alloy in Nb-Si-Ti system and that of ~ 1700 MPa for Nb-13Si-22Cr alloy in Nb-Si-Cr alloys. The compressive stress-strain curves of the Nb-Si-Ti alloys have shown higher amount of plastic deformation in comparison to that for Nb-Si-Cr alloys. Fractographic studies have revealed evidence of transgranular cleavage in the primary phases as well as interphase boundary failure. The extrinsic toughening mechanisms in these alloys are associated with bridging of the crack faces, crack deflection at interphase interfaces, microcracking inside the brittle phase and crack blunting by the ductile phase ahead of the main crack. Thermogravimetric analyses of the Nb-Si-Cr alloys have shown higher mass gain in comparision to Nb-Si-Ti alloys. A new phase $(Nb, Cr)_{89}Si_{11}$ has been detected in the Nb-Si-Cr alloys, while heat treating these in graphite crucibles.