Microstructure and properties of laser beam and gas tungsten arc welded zirconium-2.5 niobium

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Zirconium-2.5niobium (Zr-2.5Nb) alloy is the preferred material for manufacturing pressure tubes for the Russian (RBMK) and Canadian (CANDU) nuclear reactors. The service performance of the pressure tubes is largely dependent on the as-fabricated microstructure and texture. Welding pressure tubes during the fabrication of the nuclear reactor cause microstructural changes which can result in unfavourable changes of properties.

Zr-2.5Nb alloy exhibits two equilibrium phases at room temperature namely alpha (Φ#177;$_{\text{Zr}}$) phase with hexagonal close-packed (hcp) crystal structure and niobium-rich body centred cubic (bcc) beta phase (β_{Nb}). At temperatures above about 860 ˚C, a beta ($\beta_{\text{Zr, Nb}}$) phase with bcc structure exists. The phase transformation of beta to alpha during thermal treatment results in either Widmanstätten or a martensitic structure. A Widmanstätten structure can further manifest itself into two morphologies called parallel plates or basket-weave (Holt, 1969).

Autogenous welding was conducted using laser beam welding (LBW) and gas tungsten arc welding (GTAW). The aim of this study was to characterise and compare the complex microstructure that results from welding. In addition to welding, dilatometry was performed by varying the cooling rate from 1050°C holding temperature. Metallography samples were prepared by chemical polishing using 10HF - 45HNO_3 - 45H_2O_2 (vol. %) solution after grinding to 1200 grit. The microstructures were characterised at the Laboratory for Microscopy and Microanalysis using the scanning electron microscope (Zeiss Ultru-PLUS FEG SEM). Figures 1 are images of microstructures observed. In addition tensile and micro-Vickers hardness tests were done.

Dilatometry samples showed that at a cooling rate of 50°C/s and below, the transformation product was a mixture of basket-weave and parallel plate. At a cooling rate of 150°C/s and higher, martensite was the dominant transformation product. The GTAW and LBW morphologies were very similar. The heat affected zone (HAZ) and weld metal of both processes were characterised by equiaxed grains, and as the heat input increased, the equiaxed grains transitioned to columnar grains towards the centre. The microstructures of GTAW exhibited a basket weave structure in both HAZ and weld metal, with retained beta phase observed in HAZ of some welds. The LBW welds consisted of a mixture of martensite, retained beta and widmanstätten microstructure in the HAZ with a fully martensitic weld metal.

There was good agreement between dilatometry and the weld microstructure constituents. Increased heat input resulted in slower cooling rate and consequently a decrease in tensile strength and hardness.

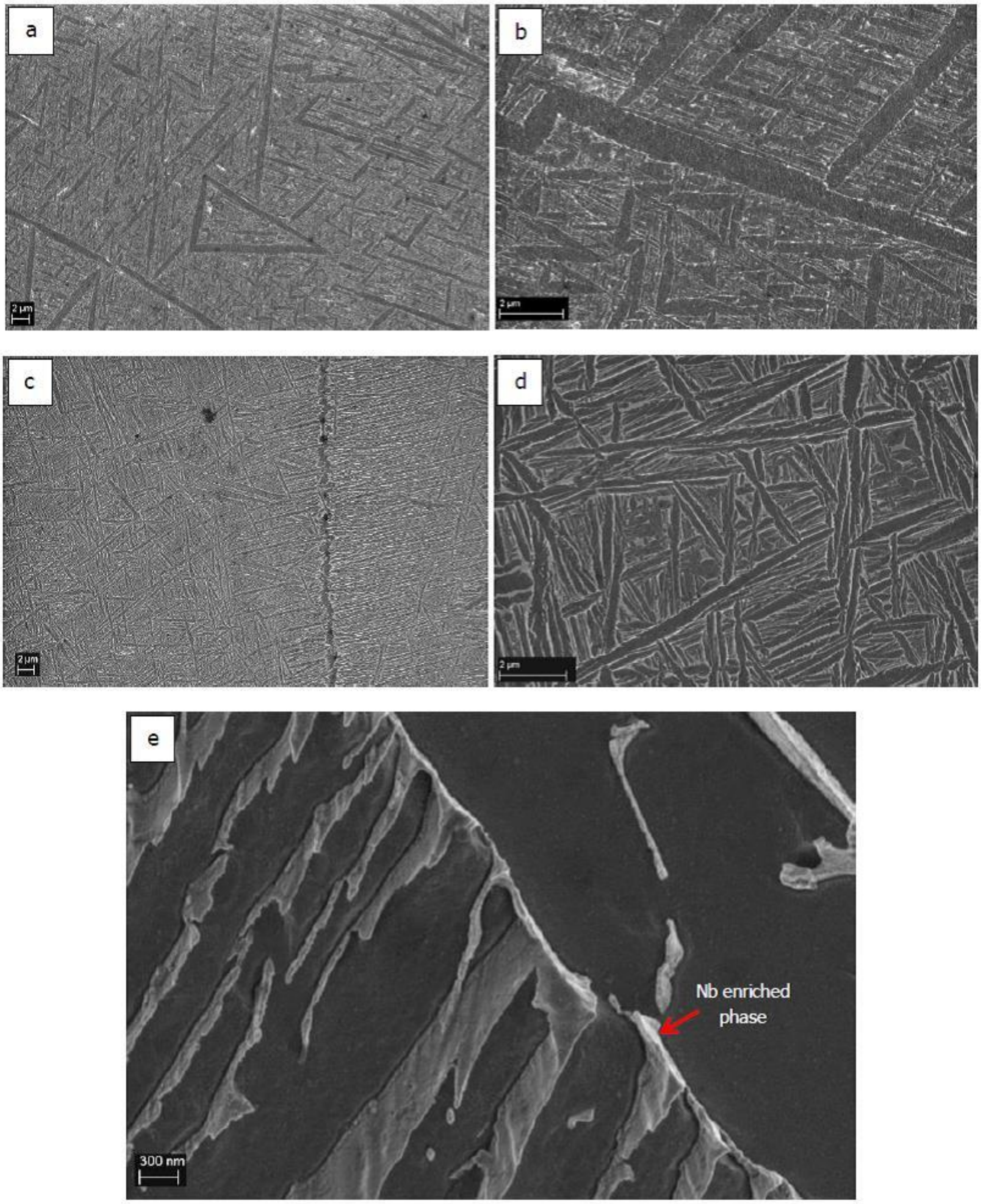

Figure 1: Secondary electron micrographs (Zeiss Ultru PLUS 55 FEG SEM), taken using inLens detector at 1kV.

(a) and (b) are images of a dilatometry sample cooled at 600°C/s showing acicular martensite.
(c) Widmänstatten microstructure consisting of basket-weave structure and parallel plates taken from GTAW weld metal.
(d) and (e) is the basket-weave structure at higher magnification. A niobium rich phase is observed between the alpha plates.