Hot deformation and corrosion behaviour of low-cost α+β titanium alloys with aluminium, vanadium and iron additions

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Abstract

This thesis presents information on the development and processing of potentially low-cost α+β Ti-Al-V-Fe alloys. The major problem addressed in this research is the high cost of titanium and its alloys which have limited their widespread use since commercial production began in the 1950s. Two cost reducing research approaches: substitution of low-cost for expensive alloying elements, and the optimisation of hot working parameters were adopted in the development and processing of the low-cost Ti-Al-V-Fe alloys.

In the first approach, two sets of low-cost alloys were developed based on the composition of commercial grade Ti-6Al-4V, the most utilised titanium alloy. The first set of alloys were designed by partial and full substitution of expensive vanadium with iron, a low-cost beta stabiliser, producing Ti-6Al-3V-1Fe, Ti-6Al-2V-2Fe, Ti-6Al-1V-3Fe and Ti-6Al-4Fe alloys. The second set of alloys was designed by both partial replacement of vanadium with iron and the reduction of aluminium content from 6 to 4.5 wt%, producing: Ti-4.5Al-3V-1Fe, Ti-4.5Al-2V-2Fe and Ti-4.5Al-1V-3Fe alloys. The influence of varying composition on the microstructure, hardness and corrosion behaviour was evaluated.

Thermo-Calc software with the TTTi3 database was used to determine the phases present, their relative amounts and transformation temperatures under equilibrium conditions. The alloys were then produced by vacuum arc melting. The microstructure and hardness of as-cast samples and annealed samples of each alloy were evaluated. The results from the Thermo-Calc modelling showed that the beta transus temperature of the alloys reduced with increasing iron content while the volume fraction of the beta phase increased with increasing iron content. When compared to wrought Ti-6Al-4V alloy, the iron-containing alloys had a lower transus temperature but a higher volume fraction of beta phase. The annealed alloy showed a reduction in the volume fraction of beta phase since there was sufficient time for the beta-alpha transformation to take place during annealing.

The hardness of iron-containing alloys increased with increasing iron content in both as-cast and annealed conditions. The hardness of the wrought Ti-6Al-4V alloy was lower than all the iron-containing low-cost alloys except Ti-4.5Al-3V-1Fe. The annealed samples were harder than the as-cast alloys. The increase in hardness was attributed to the Fe content, reduction in lath thickness and oxygen contamination during casting and heat treatment.

The corrosion behaviour of the annealed iron-containing alloys were compared with the wrought Ti-6Al-4V alloy in solutions of sulphuric acid, sodium chloride and mixed sulphuric acid /sodium chloride. Open circuit potential and linear polarisation measurements were carried out. Ti-6Al-

1V-3Fe and Ti-4.5Al-1V-3Fe alloys had superior corrosion resistance to commercial Ti-6Al-4V in both sulphuric acid and sodium chloride solutions.

Cost analysis on the low-cost alloys showed that about 7% ($175.6/100 kg) lower cost savings can be achieved by replacing 3 wt% V with Fe in Ti-6Al-4V. The advantage of cost with the improved hardness and corrosion resistance was used as a basis for selecting Ti-6Al-1V-3Fe and Ti-4.5Al-1V-3Fe for further work, *i.e.* optimisation of hot working parameters as the second cost reducing approach.

In the second approach, the two selected experimental alloys were machined to rectangular samples and subjected to isothermal compression testing at varied temperatures (750 - 950°C) and strain rates (0.001 - 10 s^{-1}) on a Gleeble 3500 thermomechanical simulator. The analysis of stress-strain curve and processing maps were used to determine the optimum processing condition during hot working. The activation energy for hot working of the alloys was determined using the hyperbolic-sine constitutive equation. The commercial grade Ti-6Al-4V alloy with a complex initial microstructure was also investigated. The flow curves exhibited distinct features under different deformation conditions. This indicated that flow behaviour is dependent on process variables such as strain rate, deformation temperatures, total strain and initial microstructures.

Processing maps showed that the optimum processing conditions for the Ti-6Al-4V, Ti-4.5Al-1V-3Fe and Ti-6Al-1V-3Fe alloys were ~940°C/1 s^{-1}, ~900°C/0.1 s^{-1} and ~900°C/0.01 s^{-1} respectively. Microstructural analysis revealed that the dominant softening mechanisms at the identified optimum processing conditions in both Ti-6Al-1V-3Fe and Ti-4.5Al-1V-3Fe alloys were dynamic recrystallisation of the prior beta grains and dynamic globularisation of the alpha phase respectively. Dynamic globularisation occurred much faster and easier in the lower aluminium alloy Ti-4.5Al-1V-3Fe (0.1 s^{-1}) than in the Ti-6Al-1V-3Fe alloy (0.01 s^{-1}). The activation energy for hot working of the alloys was higher in Ti-6Al-4V and Ti-6Al-1V-3Fe than in Ti-4.5Al-1V-3Fe. Some of the regions of instability were identified as ≥ 935°C/0.05 - 0.1 s^{-1} for Ti-6Al-4V, 750 - 780°C/1.2 - 10 s^{-1} for Ti-4.5Al-1V-3Fe and 750 - 870°C/0.9 - 10 s^{-1}, Ti-6Al-1V-3Fe. The microstructures of the samples deformed in these regions revealed non-uniform deformation, voids and cracking as the unsafe softening mechanisms. These regions should be avoided when processing the alloys to save cost and prevent waste of materials.