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Towards the development of experimental ($\alpha+\beta$) Ti-Al-V-Fe alloys

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Abstract

The influence of partial substitution of vanadium with iron and the reduction of aluminium content on the microstructure and hardness of low-cost $\alpha+\beta$ titanium alloys was evaluated using Thermo-calc simulation, scanning electron microscopy and Vickers hardness testing. The results show that Thermo-calc predictions and microstructural analysis were in good agreement. The beta phase fraction increased with iron addition and no intermetallic phase was found in alloys having both iron and vanadium as beta stabilising elements. The hardness of the low-cost alloys increased with iron content but commercial Ti-6Al-4V alloy has superior hardness in comparison with the low-cost alloys containing 4.5 wt% aluminium and ≤2 wt% Fe.

Introduction

The hallmark of titanium alloys is their unique combination of properties which include excellent specific strength, excellent biocompatibility and very good corrosion resistance [1]. These properties make titanium and its alloys undeniably the first choice material for making aeroengine components in the aerospace industries and military applications [2]. Additionally, these unique attributes have made titanium alloys to be long-coveted in other niche applications that are strictly land-based [3], [4]. However, because titanium alloys are highly priced [5], [6], they hardly compete favourably with steel and aluminium alloys which are the most utilised metallic materials for land-based applications. For example, in the automotive sector where light metals are ordinarily demanded for fuel savings and reduction in green-house-gas emission, aluminium alloys are preferred over titanium alloys [5], [7].

Bearing this in mind, many researchers have explored different avenues to develop less-expensive titanium alloys [8], [9], [10]. One of the foremost researchers who worked on the development of low-cost titanium alloys considered the reduction of expensive alloying elements or their substitution with elements that could fulfil similar role in titanium as the first step towards reducing the cost of titanium alloys. For example, substitution of V, Mo, Ta, Nb which are expensive beta stabilisers with Fe, Cr, Cu, Ni which are cheaper alternatives [11].

In this paper, an experimental Ti-Al-V-Fe alloys which may potentially be used in a number of land-based applications were developed by partial substitution of expensive vanadium with iron, and the reduction of aluminium content in a typical Ti-6Al-4V system. The influence of these modifications on the microstructural evolution and hardness of the low-cost Ti-Al-V-Fe based alloys is presented. Aluminium content in the new alloys was lowered from 6 wt% to 4.5 wt% because it contributes to cost of titanium. Hot working of titanium alloys containing aluminium can be more challenging as it increases flow stress and causes damage to forging dies [8]. The choice of iron as an alternative beta stabilising element to vanadium is informed by its availability and low-cost compared to Ni, Cr and Cu [12].

The partial substitution approach was adopted because it was reported that using a combination of isomorphous beta stabilising element like V, Mo and Nb with eutectoid beta stabilising elements like Fe, Cr and Cu could help suppress the formation of intermetallic compounds which are the equilibrium phase that are obtained when eutectoid stabilisers are used in making titanium alloys [13]. These intermetallic compounds decrease the ductility and toughness of titanium alloys [14]. Both predictive and experimental approaches were used in obtaining information about the low-cost Ti-Al-V-Fe alloys with both Fe and V being used for stabilising the beta phase.

Section snippets

Thermo-Calc simulation

The targeted composition of the low-cost Ti-Al-V-Fe alloys is shown in Table 1. Thermo-Calc modelling was carried out to predict the possible equilibrium phases in the alloys, determine the amounts of the phases and transformation temperatures under equilibrium conditions. The targeted alloy compositions were inputted into the software and the simulation was performed on the titanium database (TTTi3). The Thermo-Calc code (.tcm) that was used in the simulation is shown in Fig. 1. Ti-6Al-4V and…

Thermo-Calc predictions

Table 2 lists the results obtained from Thermo-Calc simulation using the TTTi3 database and their corresponding transformation curves for the simulations are shown in Fig. 2. The estimated beta-transus temperature and the predicted volume fraction of the beta phase at 800 °C under equilibrium conditions are presented. The results show that the volume fraction of the beta phase increased with increasing iron content in the alloys. An inverse relationship exists between the beta-transus…

Conclusion

New experimental alloys that were proposed to be cheaper alternatives to Ti-6Al-4V for land-based applications were developed by partial substitution of vanadium with iron and reduction in aluminium

content. The influence of iron substitution on the microstructure and hardness was evaluated. The phase constituents and beta transus temperatures were predicted using Thermo-calc and were then confirmed experimentally using X-ray diffraction and scanning electron microscopy. The beta transus…

CRediT authorship contribution statement

Michael O. Bodunrin: Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Funding acquisition. **Lesley H. Chown:** Supervision, Writing - review & editing, Conceptualization, Methodology, Resources, Funding acquisition.…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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