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Structure and properties of Ti–Al–Si-X alloys produced by SHS method

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ABSTRACT

This work aims to describe the effect of alloying by transition metals (Co, Cr, Cu, Fe, Ni, Mo) on the structure and properties of TiAl15Si15 alloy prepared by SHS technique. Results show that alloying elements do not form their own phases in detectable amounts, being dissolved in titanium silicide or aluminide. Co, Cu and Ni were determined mainly in aluminide, while iron was found predominantly in the silicide phase. Chromium and molybdenum dissolve in both aluminide and silicide in almost comparable amounts. All applied alloying elements increase the wear resistance and the oxidation resistance at 1000 °C, but reduce the room-temperature mechanical properties. Molybdenum-alloyed material exhibits the best oxidation resistance, followed by chromium-containing alloy. These alloys are also characterized by exceptional thermal stability.

1. Introduction

Titanium aluminides (Ti_3Al and TiAl) are promising materials for high-temperature applications. Due to unique combination of low density, good mechanical properties and oxidation resistance at high temperatures, these alloys have been already applied in jet engines of airplanes. The application limits of Ti_3Al phase are 760 °C in inert atmosphere (creep limit) and approximately 600 °C in air (oxidation limit) [1]. Application range of TiAl phase is higher – 750 °C in air and approx. 900 °C in inert atmosphere or vacuum [1]. It shows that the temperature range of application of all Ti–Al phases is strongly limited by their high-temperature oxidation. To improve the high-temperature oxidation behaviour of these materials, additions of various alloying elements were applied. Previously, it was reported that niobium and tantalum increase the high-temperature oxidation resistance [2] and creep behaviour [3,4] of Ti–Al alloys. It led to the development of new generation of Ti–Al alloys [5]. However, these heavy and expensive elements undesirably increase the density and cost. Other possibility how to improve high-temperature behaviour is alloying with silicon. Silicon forms with titanium stable Ti_5Si_3 silicide, which is used also in the surface treatment of titanium alloys against high-temperature oxidation [6].

When Ti–Al–Si alloys are produced by conventional melting metallurgy techniques, coarse randomly oriented sharp-edged particles of Ti_5Si_3 silicide are formed, having negative impact on mechanical properties such as ductility or fracture toughness. To minimize these undesirable effects, directional solidification was tested in order to produce in-situ composite formed by aluminide matrix reinforced by Ti_5Si_3 fibres [7]. This approach was found to be unsuccessful due to the initiation of cracks in silicide phase during solidification.

Simple production route leading to the fine structure is the powder metallurgy technique using SHS (Self-propagating High-temperature Synthesis). In our previous works [8,9], production route for Ti–Al–Si alloys with aluminium content between 8 and 20 wt.% and silicon in the range of 10–20 wt.% was developed and room-temperature properties were described [8]. In our previous work [10], the isothermal oxidation resistance and thermal stability of these alloys is investigated at a temperature of 1000 °C, i.e. above the air operating limit for TiAl. Oxidation behaviour was compared with the TiAl binary phase produced by conventional vacuum melting technique and highly positive effect of silicon was observed.

There are many papers dealing with the influence of various alloying elements on the structure and selected properties of Ti–Al and Ti–Si binary alloys. In addition to the effect of Nb and Ta, positive effect of chromium on the oxidation resistance of Ti–Al alloys was reported [11]. Copper [12] and iron [13] were found to improve the reactive sintering behaviour of Ti–Si alloys. Iron also reduces the grain size of titanium silicides produced by this process [13]. With the

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exception of the papers dealing with the niobium addition [14], there is a lack of information about the possibilities of the improvement of Ti–Al–Si alloys' properties by the addition of quaternary alloying element. This paper aims to describe the effect of selected transition metals (Co, Cr, Cu, Fe, Mo, Ni) on microstructure, phase composition, mechanical properties and high-temperature behaviour of Ti–Al–Si alloys prepared by reactive sintering. High-temperature behaviour was evaluated above the common applicability limit (at 1000 °C) as in our previous paper dealing with ternary Ti–Al–Si alloys [10].

2. Experimental

2.1. Preparation of Ti–Al–Si-X alloys

In this work, the effect of alloying elements (Fe, Ni, Cr, Mo, Co, Cu) on the structure, phase composition and properties of Ti–Al–Si alloys was studied. The alloys were produced by SHS reactions between titanium, silicon, AlSi30 alloy and alloying elements' powders according to the procedure developed for ternary Ti–Al–

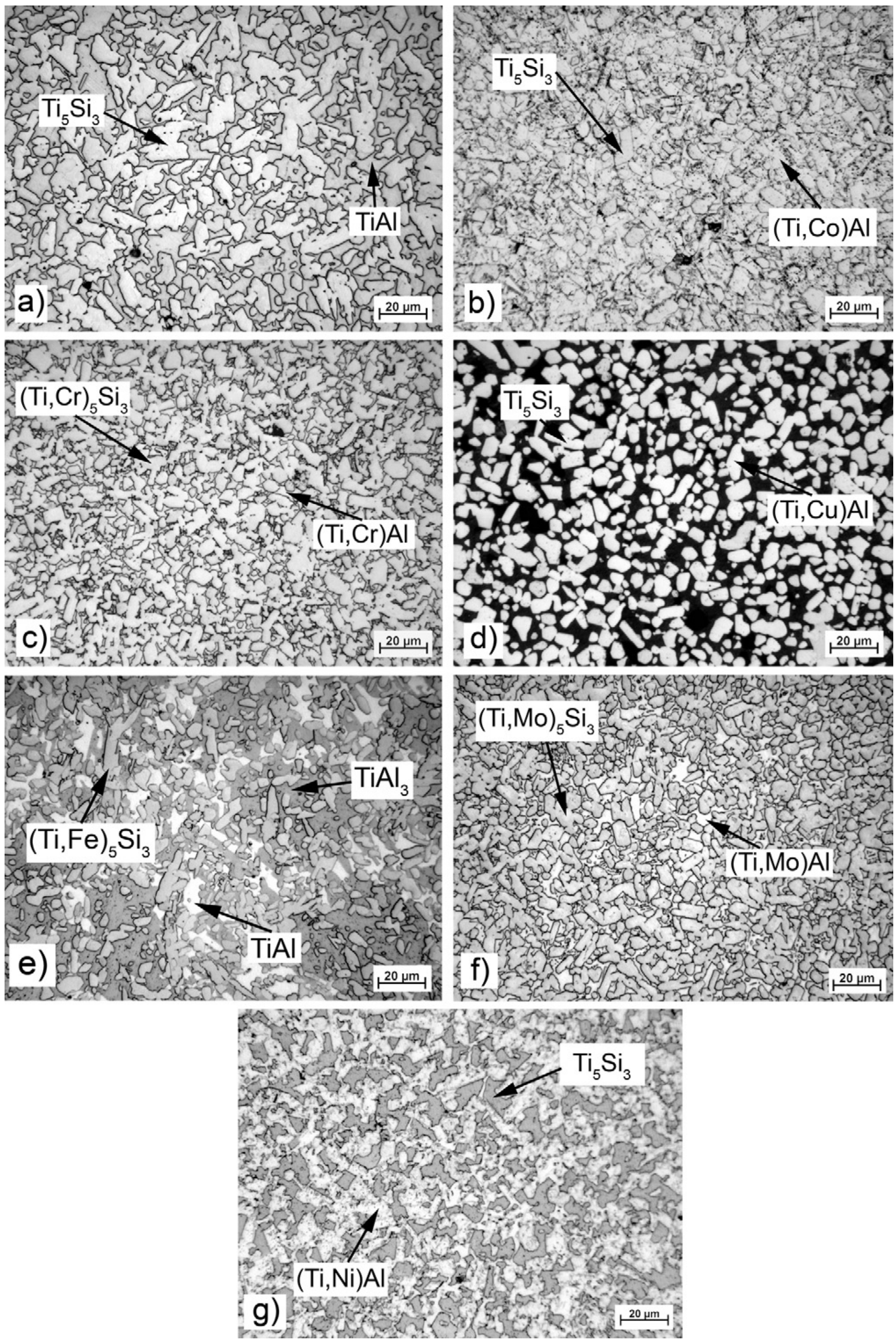

Fig. 1. Microstructure of a) TiAl15Si15, b) TiAl15Si15**Co15**, c) TiAl15Si15**Cr15,** d) TiAl15Si15**Cu15,** e) TiAl15Si15**Fe15,** f) TiAl15Si15**Mo15,** g) TiAl15Si15**Ni15** produced by reactive sintering at 900 °C for 30 min.