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Properties of (Ti,Nb)Al–$(Ti,Nb)_5Si_3$ eutectic composite

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ABSTRACT

Ti–40Al–5Si and Ti–39Al–5Si–2Nb (in at.%) alloys were studied as prospective high-temperature structural composites consisting of γ-(Ti,Nb)Al + α_2-$(Ti,Nb)_3Al$ matrix and Ti_5Si_3 reinforcement. The alloys were prepared by arc melting under helium. Oxidation resistance was studied at 900 °C in air. Thermal stability of alloys was investigated by measuring room temperature hardness and compressive strength after long-term annealing at 900 °C. To prepare oriented composites, directional crystallization at rates of 5–115 mm/h was carried out by the floating zone technique. It was observed that the addition of 2% Nb to the Ti–40Al–5Si alloy does not modify eutectic structure. Niobium is almost uniformly distributed in all present phases. Both alloys show excellent oxidation resistance at 900 °C in air. The Nb-addition causes significant improvement of oxidation resistance due to the doping effect and increase of Al activity in the scales. Room temperature hardness and compressive strength of both as-cast alloys are similar – about 500 HV and 1600 MPa, respectively. Room temperature mechanical properties do not reduce significantly after 300 h annealing at 900 °C, due to a high morphological stability of eutectic silicides. Directionally solidified alloys consist of columnar Ti–Al grains elongated in crystallization direction and silicides. Niobium refines both Ti–Al grains and Ti_5Si_3 silicides. As a consequence, orientation and elongation of silicides in the Nb-containing alloy are reduced. In the Ti–Al–Si alloy directionally crystallized at 5–115 mm/h, the silicide interparticle spacing λ (in mm) is related to the crystallization rate R (in mm/h) by a following expression: $\lambda^{1.33} \cdot R = 0.32$. In the Nb-containing alloy, silicide interparticle spacing does not depend on the crystallization rate.

1. Introduction

TiAl-based intermetallics show a large number of attractive properties, such as light weight, high-temperature oxidation resistance and creep resistance, making them of interest for production of components in aerospace and automotive industry. Binary Ti–Al intermetallics show rather poor strength, oxidation and creep resistance. For this reason, commercial materials also contain other additives, such as Nb, Cr, V, Si, and Ta improving these characteristics. In this work we focus our attention on additions of niobium and silicon. A lot of work has been reported on the high-temperature oxidation of Nb-containing Ti–Al intermetallics [1–6]. These investigations revealed that niobium strongly improves oxidation resistance which is generally explained in terms of the internal sub-structure of scales formed during oxidation process. In contrast to niobium, silicon shows much lower solubility in the Ti–Al phases, leading to the formation of Ti_5Si_3 silicide in microstructure. The Ti_5Si_3 silicide is extremely hard (above 1500 HV [7]), thermally stable (melting point of more than 2000 °C) and oxidation resistant. Therefore, its presence strongly modifies high-temperature properties of Ti–Al intermetallics.

In this work, our attention is devoted to eutectic alloys based on the Ti–Al–Si system. An alloy having a proper composition can be regarded as a eutectic composite consisting of γ-TiAl + α_2-Ti_3Al matrix and Ti_5Si_3 reinforcement. Both matrix and reinforcement are formed together by eutectic crystallization which facilitates formation of a strong adhesion between them. An advantage of eutectic composites is their good castability which is generally defined as a set of properties that enable to produce complex shape products by simple casting. Under proper conditions of unidirectional crystallization, a composite having aligned fiber-like morphology of reinforcement can be prepared [8]. Fiber-reinforced composites often show high modulus and strength in fiber direction, as well as good fatigue and thermal shock resistance [9]. Additionally, composites containing the Ti_5Si_3 phase are also resistant to high-temperature oxidation [8]. As stated before, niobium is a common additive in the Ti–Al intermetallics strongly affecting their high-temperature properties. For this reason, influence of a low Nb-addition on the

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structure and mainly on the high-temperature oxidation of the Ti–Al–Ti_5Si_3 composite is investigated in the presented work.

2. Experiment

Two alloys with nominal compositions (all concentrations are in at.%, unless otherwise specified) Ti–40Al–5Si and Ti–39Al–5Si–2Nb were investigated. The composition of the Ti–Al–Si alloy was selected according to the study on eutectic reactions in the Ti–Al–Si system [10]. Eutectic line in this system, representing Ti + Ti_5Si_3, Ti_3Al + Ti_5Si_3 and (Ti_3Al,TiAl) + Ti_5Si_3 eutectics is shown in Fig. 1a. The sequence of eutectics with increasing concentration of aluminium is in accordance with the Ti–Al phase diagram presented in Fig. 1b. Niobium was added in a relatively small amount of 2% to prevent any modification of phase composition.

The investigated alloys in amounts of about 200 g were prepared from pure elements (Ti 99.9%, Si 99.99%, Al 99.99% and Nb 99.8%) in an arc furnace in a copper crystallizer under helium atmosphere. The alloys were remelted seven times to ensure homogeneous composition. Mass reduction after melting due to evaporation of more volatile elements was less than 0.05%. Structures of the as-cast alloys are shown in Fig. 2. It is observed that both alloys are dominated by eutectic colonies grown in various directions depending on local heat flows. The morphology of Ti_5Si_3 eutectic phase (light) varies from fiber-like to lamellar. In the centre of each eutectic colony, the structure is refined and the eutectic phase has predominantly fiber-like morphology. As the eutectic colony grows, the recalescence leads to progressive coarsening of the fibers and to their transition into lamellae. Matrix consists of a typical lamellar mixture of γ-TiAl and α_2-Ti_3Al phases which was also proved by X-ray diffraction analysis (XRD). X-ray elemental map in Fig. 3 confirms our assumption that niobium is almost uniformly distributed in all present phases. The as-cast ingots were cut by spark-machining into rectangular samples having size of $10 \times 10 \times 10$ mm for structural examination, measurement of mechanical properties and for oxidation tests. Samples of $10 \times 10 \times 100$ mm were cut from the cast ingots for directional crystallization experiments.

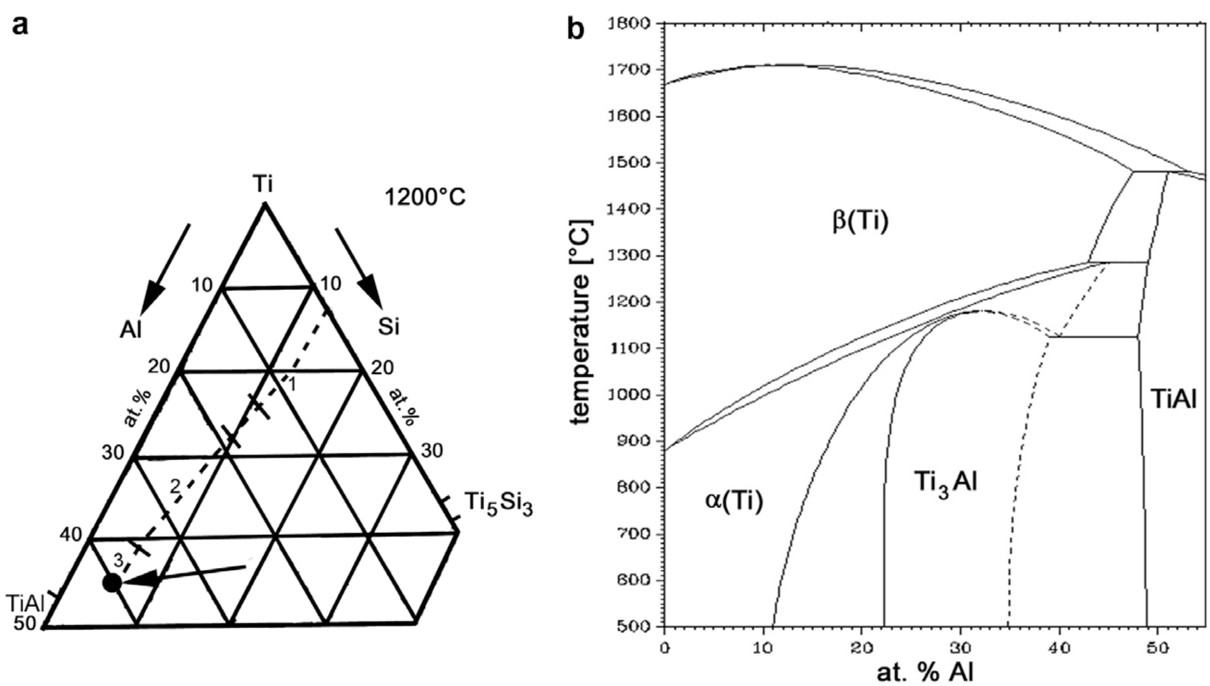

Fig. 1. (a) Isothermal section of the ternary Ti–Al–Si phase diagram showing the eutectic line (dotted line) [10]. The eutectic line is divided into three parts: (1) Ti + Ti_5Si_3 eutectic; (2) Ti_3Al + Ti_5Si_3 eutectic; and (3) (Ti_3Al,TiAl) + Ti_5Si_3 eutectic. The investigated Ti–Al–Si alloy (A) is marked by an arrow. (b) Ti–Al phase diagram [13].

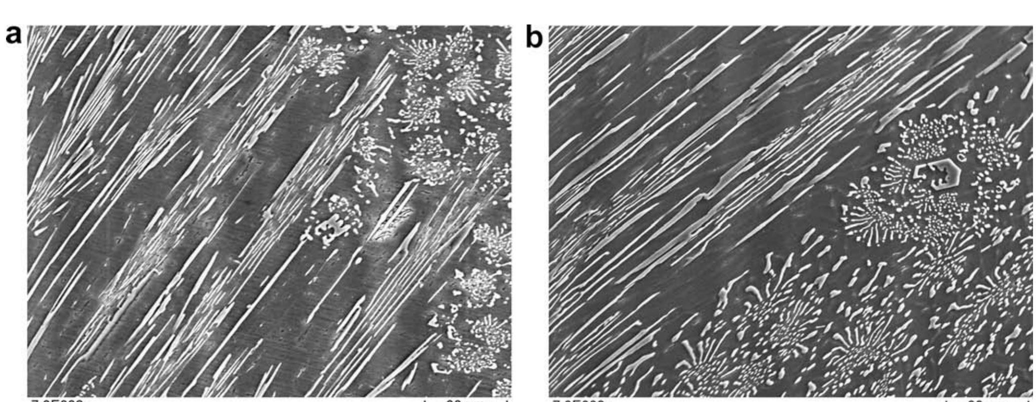

Fig. 2. SEM micrographs of the as-cast alloys: (a) Ti–Al–Si alloy and (b) Ti–Al–Si–Nb alloy.