JOURNAL OF MATERIALS SCIENCE 27 (1992) 5113–5140

Review
Synthesis, properties and applications of titanium aluminides

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Attractive elevated-temperature properties and low density make the titanium aluminides very interesting for both engine and airframe applications, particularly in the aerospace industry. The challenge to the materials scientist is to maintain these characteristics while building-in "forgiveness". The basic phase diagram and crystal structure of both the Ti_3Al and TiAl phases are reviewed, followed by a consideration of chemistry–processing–microstructure–deformation/fracture–mechanical property relationships in monolithic material. Conventional and innovative synthesis methods are presented, including use of hydrogen as a temporary alloying element. Composite concepts as a method to enhance not only "forgiveness" but also elevated-temperature behaviour are discussed. Environmental effects are evaluated prior to consideration of present and projected applications of both monolithic and composite material. It is concluded that while the titanium aluminides in monolithic form can be used now in non-demanding applications, much further research and development is required before this material class can be used in critical applications, especially in composite concepts.

1. Introduction

Advanced materials are key to technological advancement [1, 2], and enhanced structural materials are particularly vital to aerospace system improvements where the extremely demanding conditions require that the new materials are "stronger, stiffer, hotter and lighter". These advanced materials will often be "tailored" or "engineered" to exhibit the properties required for a given application by use of composite concepts [3–17]. Cost can be a major concern, but an integrated design, manufacturing and use approach can lead to cost-effective application, where these new materials are considered as structures rather than in the same way as traditional materials such as metals.

An attractive class of "advanced materials" are the intermetallic compounds [18] which can be simply defined as an ordered alloy phase formed between two metallic elements [19], where an alloy phase is ordered if two or more sublattices are required to describe its atomic structure [20, 21]. The ordered structure exhibits attractive elevated-temperature properties (strength, stiffness, environmental resistance, etc.) because of the long-range ordered superlattice which reduces dislocation mobility and diffusion processes at elevated temperatures [22–25]. However, this reduced dislocation motion also results in generally extremely low ambient-temperature fracture-related properties including ductility and fracture toughness. Recent research has focused on understanding and controlling this brittleness while maintaining the attractive elevated-temperature characteristics.

Because of their low density the ordered intermetallic titanium aluminides, based on Ti_xAl ($x = 1$ or 3), are particularly attractive candidates for applications in advanced aerospace engine and airframe components, in both monolithic and composite concepts [26–33]. A comparison of the characteristics of the monolithic titanium aluminides with other aluminides is shown in Table I [34] and with conventional titanium alloys in the creep curves shown in Fig. 1 [9]. The present materials mix in an advanced jet engine is shown in Fig. 2 [34] and a possible material mix in a 2010 engine in Table II [34]. A

TABLE I Melting points and densities for aluminides [34]

Aluminide	Melting point (°C)	Density ($g\,cm^{-3}$)
Ti_3Al	1600	4.2
TiAl	1460	3.9
Fe_3Al	1540	6.7
FeAl	1330	5.6
Ni_3Al	1390	7.5
NiAl	1640	5.9
Superalloys (typical)	1325–1400	9

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0022–2461

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