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Microstructural and mechanical characterisation of a Ti6Al4V/TiC/10p composite processed by the BE-CHIP method

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Abstract

Room and high temperature behaviour as well as the microstructural characteristics of a Ti6Al4V/TiC/10p composite produced by the blended-elemental cold and hot isostatic pressing method (BE-CHIP) were investigated. It was shown that the damage mechanisms of both tensile and fracture toughness specimens of the composite material were strongly influenced by the poor distribution of the reinforcement (particle clustering and large particulate size). The composite fracture surfaces were investigated using a scanning electron microscope (SEM) and an optical microscope (OM) showing that the failure of the composite was controlled by fracture of the reinforcement followed by ductile failure of the titanium matrix.

Keywords: E: Isostatic pressing; A: Particle-reinforced composites; B: Mechanical properties; B: Microstructure; D: Fractography

1. Introduction

Nowadays, there is considerably interest in the development of particulate-reinforced titanium matrix composites (TMCs) due to its isotropic characteristics and excellent combination of strength-to-weight ratio and high-temperature properties as well as its low cost compared to the continuously reinforced TMCs. Blended-elemental cold and hot isostatic pressing method (BE-CHIP) has been used to produce composites with superior properties showing higher elasticity modulus and yield strength than the unreinforced alloys (especially at high temperatures), good fracture toughness properties, high wear resistance and excellent creep properties [1–10], see Table 1 for comparison between BE-CHIP processed composite and different monolithic alloys processed by BE methods. Furthermore, the titanium-based composites reinforced with TiC particles present important advantages over the aluminium-based MMCs and titanium monolithic alloys especially at high temperatures retaining good mechanical properties, provided that detrimental reactions do not occur between matrix and ceramic at high temperatures. A comparison between the tensile strength of an aluminium-based MMC (Al–10Si–3Cu–1.25Ni–1Mg–0.3Fe–0.2Ti/SiC/10p) with a titanium-based MMC (Ti6Al4V/TiC/10p) at similar temperatures (371 and 400 °C, respectively) shows a difference of almost 450 °C (55 MPa for the aluminium-based MMC and 518 MPa for the titanium-based MMC) [11,12].

Recent advances in solid-state joining, e.g., friction welding and diffusion bonding, have opened new opportunities of using such material in a wide range of applications especially in the automotive and aerospace fields where the successful application of particulate TMCs depends on the their weldability aspects and proven welding techniques that can produce high performance and high quality joints [13–16].

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Table 1
Mechanical properties comparison of the composite (Ti6Al4V/TiC/10p) and similar materials

	$R_{p0,2}$ (MPa)	R_m (MPa)	Elongation (%)	K_{IC} (MPa $m^{1/2}$)
Ti6Al4V/TiC/10p [8]	965	999	–	44
Ti6Al4V BE press/sinter [9]	827	896	12	–
Ti6Al4V BE press/sinter/HIP [9]	806	875	9	41
Ti6Al4V BE CIP/sinter/HIP [9]	827	916	13	–
Ti6Al4V (annealed) [10]	830–924	900–993	14	32[a]

[a] $\alpha - \beta$ rolled + mill annealed.

In the present article, recent results are shown on the room and high-temperature mechanical behaviour, microstructural characterisation as well as damage mechanisms of the Ti6Al4V/TiC/10p titanium matrix composite.

2. Materials and experimental procedure

The material used in this investigation was the Ti6Al4V matrix reinforced with 10 wt% of TiC particles supplied by Dynamet Technology, Inc. (50 mm diameter bars) produced by the BE-CHIP method which consists of blending Ti6Al4V powders (generally, particulate diameter less than 150 μm) and 10 wt% TiC_p (generally less than 10 μm) to obtain a uniform distribution of the particulates. The blended powders were CIPped, followed by vacuum sintering. Finally, the as-sintered P/M preform was HIPped in a protective atmosphere (argon) for 2 h under a combination of pressure and temperature to obtain a full density and was then furnace cooled [1–3].

Fracture toughness tests have been conducted in 18 specimens using SEN(B) samples [17,18] with 6 mm thickness and 12 mm width (a/W of 0.5) using a servo-hydraulical test machine (Schenck Hydropuls PSA −40 kN load cell) for fatigue precracking and a screw-driven Zwick 1484 test machine (200 kN load capacity) for monotonic loading with a displacement rate of 0.1 mm/min. Room temperature tensile tests were carried out for the composite in five specimens using round specimens (6 mm diameter and 30 mm gauge length [19]) in the Zwick 1484 testing machine with a displacement rate of 0.2 mm/min. High temperature tensile tests were performed at 200 and 375 °C for five specimens in each temperature in a Schenk Trebel RM100 test machine (100 kN load capacity) with a displacement rate of 0.2 mm/min. The standard Rockwell C-scale test was used to characterize the hardness of the composite [20].

SEM was used to investigate the microstructural features of the composite material. Samples have been prepared according to standard metallographic procedures and etched using Kroll's reagent (2%HF + 8%HNO_3 and water balance). The particle characteristics of the composite such as the shape factor, mean Ferret diameter and the nearest neighbour distance (NND, i.e., the frequency distribution of the interparticle spacing) have been determined with the aid of an image analyser (Leica Qwin) and an OM using a magnification of 200 times comprising a total area field of approximately 0.77 mm^2 (for each of the 10 micrograph analysed).

3. Results and discussion

3.1. Microstructural characterisation

Fig. 1 shows the microstructure of the Ti6Al4V/TiC/10p alloy which consists of platelike elongated (P in Fig. 1(a)) and equiaxed (E in Fig. 1(a)) α grains as well as intergranular β (I in Fig. 1(a)) with TiC particles randomly distributed in the matrix. The microstructure is typical from α + β titanium-base alloys that have been furnace cooled from above the β transus temperature since the last step of the process (HIP) allowed slow cooling rates. Indeed, the composite is formed during the sintering process by diffusion-driven solid-state alloying, typically at temperatures less than 250 °C above β transus temperature (approximately 1230 °C for Ti6Al4V). It is also possible to observe from Fig. 1a that in some regions the composite matrix contains not-elongated α grains suggesting that the growth of this phase from the β crystals occurs in a different way with respect to the other regions. Very likely, the presence of the TiC particles (which means the appearance of matrix/TiC interfaces) hinders the growth of α crystals parallel to specific crystallographic planes and, as a consequence, the formation of elongated crystals [12]. It can be observed from Fig. 1b an inhomogeneous distribution with some regions having fewer particles than others showing some degree of TiC clustering throughout sample (located mainly in the prior β grain boundaries). Porosities could be observed in some areas, particularly in between TiC particulates indicating that full density has not been achieved; however, the presence of such defects can result from problems occurred during metallographic preparation, when TiC parts were knocked off as a result of excessive force during polishing and/or grinding. Indeed, Ranganath [21] has affirmed that particle clustering and porosity in CHIP-processed composites have proved to be problematic.