Materials Letters 144 (2015) 58–61

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

Role of powder metallurgical processing and TiB reinforcement on mechanical response of Ti–TiB composites

M. Selvakumar [a], P. Chandrasekar [b], M. Mohanraj [c,*], B. Ravisankar [d], J.N. Balaraju [e]

[a] Department of Mechanical Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi 642003, India
[b] School of Engineering, Professional Educational Trust's Group of Institutions, Coimbatore 641662, India
[c] Department of Mechanical Engineering, Hindusthan College of Engineering and Technology, Coimbatore 641032, India
[d] Department of Metallurgical and Materials Engineering, National Institute of Technology, Trichy 620015, India
[e] Surface Engineering Division, National Aerospace Laboratories, Bangalore 560017, India

ARTICLE INFO

Article history:
Received 20 August 2014
Accepted 25 December 2014
Available online 3 January 2015

Keywords:
Composite materials
Sintering
Powder technology

ABSTRACT

In this work, titanium–titanium boride (Ti–TiB) composites were synthesized by three different powder metallurgical techniques, namely, spark plasma sintering (SPS), hot iso-static pressing (HIP) and vacuum sintering (VS). The mechanical properties of the composites were determined using the nanoindentation technique. The role of the material processing route and TiB reinforcement employed on the mechanical properties of the composites was investigated. The results revealed that the composites processed by SPS possessed improved mechanical properties relative to those of the composites prepared by the HIP and VS techniques. Furthermore, reinforcement of the composites with TiB enhanced the hardness, elastic modulus and contact stiffness, whereas it reduced the fracture toughness and indentation creep.

1. Introduction

Titanium-based composites are being developed to meet specific requirements for defense, automobile, aerospace, biomedical and allied engineering applications [1,2] because of their good resistance to corrosion and wear [3,4]. Ceramic reinforced titanium composites exhibit good mechanical properties and bonding strength [5,6]. TiB has been identified as one of the reinforcement materials that is most compatible with titanium, exhibiting good thermo-chemical stability and mechanical properties [7,8]. Titanium composites have generally been processed through combustion synthesis [4], solidification [5,6,9,10], casting [7] and direct laser cladding [8]. However, powder metallurgical techniques have received increasing attention due to their low level of material wastage and the near net shape achieved during processing. Such techniques overcome the drawbacks of conventional methods, such as the pollution of reinforcements, wettability between ceramic particles and their corresponding matrix and intricate processing steps [11–14]. A review of the available literature shows that there is no specific work reported on Ti–TiB composites processed by powder metallurgical techniques such as Hot Iso-static Pressing (HIP), Spark Plasma Sintering (SPS) and Vacuum Sintering (VS).

The mechanical properties estimated by conventional indenters require large force to produce the necessary cracks for analysis [15]. However, nanoindentation is a versatile technique that overcomes the limitations of conventional indentation and offers direct measurement of mechanical properties [16–18]. Limited studies have been reported on the estimation of mechanical properties of Ti–TiB composites by nano indentation technique. The main objectives of this work were to process Ti–TiB composites through SPS, HIP and VS techniques and characterize their mechanical properties through nanoindentation. Additionally, the effects of the processing route and reinforcement adopted on the mechanical properties of the composites were investigated.

2. Materials and methods

Commercially available titanium (Ti-325 mesh and 99.5%), titanium diboride (TiB_2-325 mesh) and ferromolybdenum (β stabilizer) powders were mixed together to prepare the composites. A β stabilizer was added to increase the β phase content of the composites, which is more ductile than the α phase. The two Ti–TiB composites composed of Ti-78%, TiB_2 -6% FeMo-16% and Ti-70%, TiB_2-15%, FeMo-15% were processed through three powder metallurgical techniques, SPS, HIP and VS.

To process composites by SPS, the milled powders were pressed uniaxially at 20 MPa and maintained at approximately 1100 °C. The powders were heated by spark discharge between the particles,

* Corresponding author.
E-mail address: mohanrajrac@yahoo.co.in (M. Mohanraj).

http://dx.doi.org/10.1016/j.matlet.2014.12.126
0167-577X/

which facilitates a high heating rate, thereby accelerating the sintering process and reducing the sintering time, which controls the grain structure. To prepare composites by the HIP process, the milled powders were packed in a container and heated to 1200 °C and maintained at 120 MPa to reduce shrinkage. During the process, the environment was maintained at approximately 10^{-6} m bar for a period of 5 h to eliminate internal voids and to improve the homogeneity and bonding strength. To prepare composites by the VS process, the powder mixtures were compressed in a 100 t capacity UTM at a load of 350 kN. Consolidation was carried out in a vacuum furnace maintained approximately at 1200 °C for 5 h. TiB_2 reacted with Ti and transformed into TiB during sintering.

The densities of the composites were determined by the water immersion method. It is an average value of three measurements taken for each sample. The microstructures were studied using X-ray diffractometry (XRD), scanning electron microscopy (SEM) and electron probe microanalysis (EPMA). The mechanical properties (hardness, elastic modulus and contact stiffness, fracture toughness and indentation creep) of the composites were measured through the nanoindentation technique. Among these properties, elastic modulus and hardness hardness of Ti–TiB composites are of great attention due to their higher modulus of TiB relative to titanium [15–18]. Two samples were tested for each composition. Four indentations were done on each sample and adequately spaced such that their behavior was not affected by nearby indentations. The values obtained in the observations were within ±2% deviations.

3. Results and discussion

Table 1 depicts the volume fraction of the TiB phases in the composites measured by an image analyzer. The XRD results (Fig. 1(a) and (b)) confirm the presence of both β and α Ti phases without intermediate phases (Ti_3B_4). The spectra clearly indicate that the composites sintered through the SPS process feature more dominant TiB and Ti phases than the composites processed through the other two techniques (HIP and vacuum sintering).The presence of few TiB_2 peaks in the VS and HIP composites indicate the slow diffusion of boron atoms in TiB, which is similar to the result reported in an earlier reported study [9]. Moreover, there is evidence of FeMo, with a small (310) peak in the VS composite containing 17.6 vol% TiB. The EPMA results (Fig. 2) confirm the presence of Ti (as lighter, gray

Table 1
Mechanical properties of Ti–TiB composites.

Powder (in weight percentage)			TiB reinforcement (in volume percentage)		Nomenclature	Mechanical properties						
Ti	TiB_2	Fe Mo	Target	Estimated		Density (g/cc)	Contact depth (nm)	Hardness (HV)	Elastic modulus (GPa)	Fracture toughness	Indentation creep (%) (MPa $m^{1/2}$)	Contact stiffness (N/m)
78	6	16	20	24	SPS	4.9	832.39	837	162.64	14.53	1.41	0.812
				20.6	HIP	4.92	897.09	819.29	169.51	14.22	1.54	0.801
				17.6	VS	4.2	928.42	600	141.76	12.91	2.03	0.809
70	15	15	40	38.5	SPS	4.75	819.27	992.73	190.46	12.26	1.04	0.819
				38.3	HIP	4.90	874.06	913.27	179.04	11.81	1.28	0.826
				37.9	VS	4.685	866.26	772.64	167.04	10.72	1.38	0.818

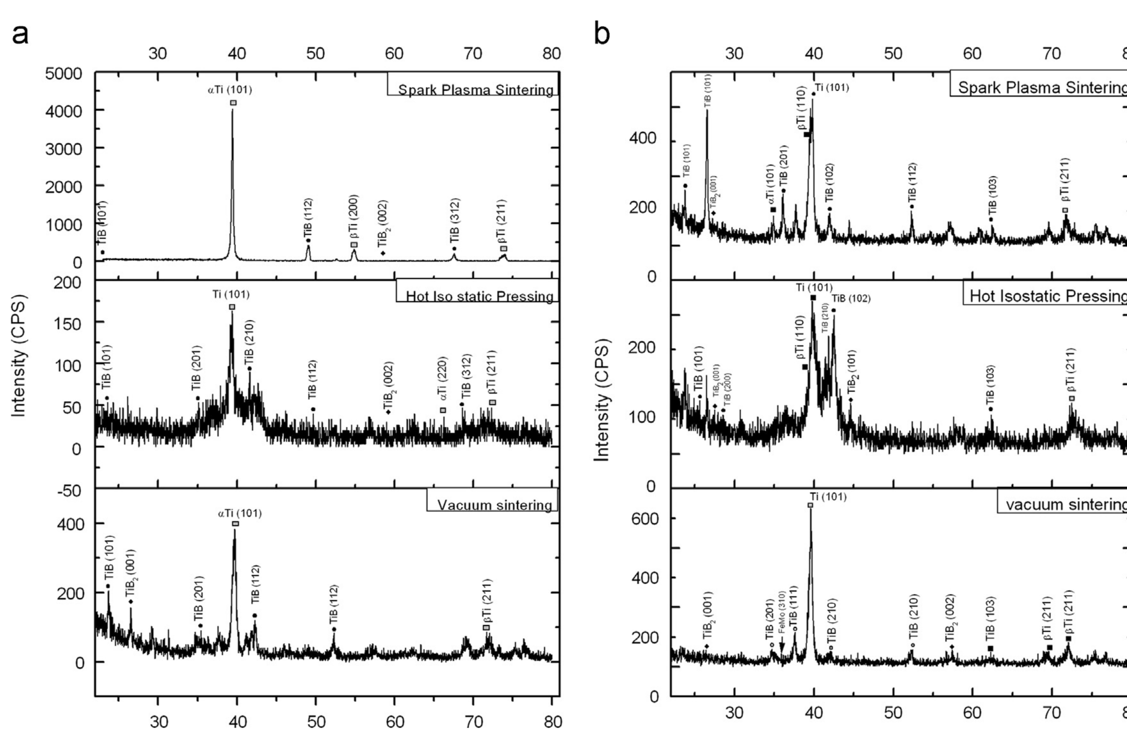

Fig. 1. XRD Patterns.(a) SPS (Ti–24% TiB), HIP (Ti–20.6% TiB), and VS (Ti–17.6% TiB) and (b) SPS (Ti–38.5% TiB), HIP (Ti–38.3% TiB), and VS (Ti–37.9% TiB).