Densification mechanism of Ti–6Al–4V–TiN–TiCN powders during spark plasma sintering process

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Highlights

- SPS of Ti–6Al–4V reinforced nano–sized TiN/TiCN was successfully consolidated
- Temperature and time have influence on the microstructure which has been studied.
- A significantly improvement of titanium through addition of nanoceramic was achieved.

Abstract

Densification mechanism of Ti–6Al–4V–TiN–TiCN powders was processed using spark plasma sintering route. The powder consolidation was carried out at the temperatures of 1000 °C to 1100 °C and constant pressure of 50 MPa with different holding time of 10 and 20 mins. The relative density of the sintered sample reaches 99%, which was as a function of the SPS conditions. Results indicates that with rising in sintering temperatures, relative densities of the composites were found to be increasing, while the microstructure shows some level of rapid growth and provided the optimal combination of dense microstructure. The fractography of the sintered samples at different temperatures and holding time was observed to investigate the sintering mechanism as well.

1. Introduction

Spark plasma sintering is a novel and emerging sintering technique which has recently become widespread in use and has attracted considerable attention for powder metallurgy with characteristics due to its heating mechanism, such as short sintering time, cooling time, rapid temperature rise and uniform heating condition for sintered materials and which has been applied in the fabrication of metals, nanocomposites, ceramics and cermets compared to that used in conventional sintering technique [1, 2]. Titanium matrix composites (TMCs) has been reinforced with various types of materials and have proof to be promising alternative to increase the strength and Young's modulus of titanium alloys [3, 4]. Metal-Matrix Composites (MMCs) are a class of materials that seek to combine the high strength and stiffness of a ceramic with the damage tolerance and toughness provided by a metal matrix [5]. Sung et al. (2008) and Abkowitz et al. (2004) reported that addition of ceramics particles into titanium alloy matrix can enhanced its mechanical properties and also improved high temperature capability [6, 7].

2. Methods

Titanium nitride (TiN) and Titanium carbonitride ($TiC_{0.7}N_{0.3}$) powders (97%, 20 nm; 97%, 80nm respectively supplied by Nanostructured & Amorphous Material Inc., Texas, USA) were used as reinforcement phase materials. Commercially pure Ti-6Al-4V powder (99.9%, 25 µm by TLS-Technik, Germany) was used as the main metal matrix. A composite mixture of Ti-6Al-4V was added to TiN and TiCN while, the powders were mechanically blended by a turbula mixer for 8 h at a speed of 49 rpm was dry mixed with varying reinforcement ratios. Ti-6Al-4V-TiN-TiCN materials were produced by powder metallurgy (PM) process, namely spark plasma sintering (SPS) (HHPD–25 FCT Systeme GmbH). Sintering was performed in a vacuum at 1000 and 1100 °C under an applied pressure of 50 MPa. The relative density was calculated according to the theoretical density of the starting powders which was based on the rule of mixtures. Microstructural analysis of the sintered samples was done using field emission scanning electronic microscope.

3. Results and discussion

The densities of composites sintered at 1000 and 1100 ºC for 10 and 20 min respectively resulted in sintered densities ranging from 96 to 99% upon addition of TiN and TiCN. The distribution of grains was homogeneous and all composites have dense structures. Addition of nanoceramic phase impeded the diffusion of atoms and therefore causes decrease in the sintering rate of the materials during sintering [8]. Hence, the presence of a less compacted phase assists the diffusion which consequently promotes the grain growth. It was observed that with increasing both sintering temperature and holding time, α and β phases layer grow together. The presence of intergranular and trans-granular fracture pattern with fine dimples features are observed in the titanium matrix composites.

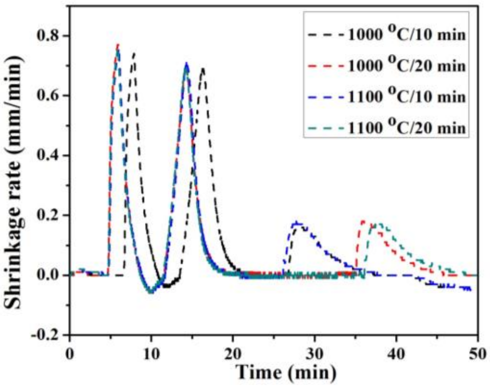

Figure 1: Shrinkage rate and time plots of the sintered compacts

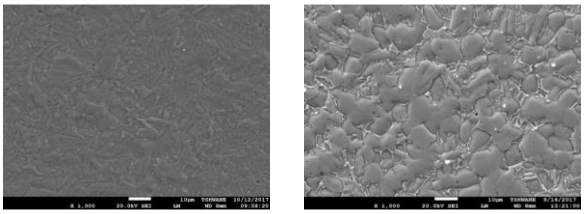

Figure 2: SEM image of sintered Ti-6Al-4V-TiN-TiCN

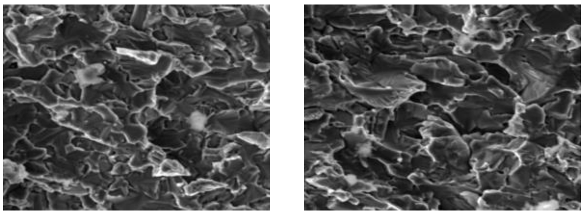

Figure 3: Fractographs of sintered Ti-6Al-4V-TiN-TiCN

4. Conclusion

Ti-6Al-4V-TiN-TiCN composites were produced by spark plasma sintering at 1000 ºC and 1100 ºC under a constant pressure of 50 MPa with holding time of 10-20 mins. The results of this study showed that fully dense Ti-based composites with a relative density of more than 99 % were obtained. Relative density of the composite and the interface cohesion between the TiN/TiCN and titanium matrix. The fractographs of the sintered samples exhibited both brittle-ductile cleavage fracture mechanism. The morphology of Ti-6Al-4V-TiN-TiCN matrix composite prepared using SPS method was determined.

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Keywords

Densification; Spark plasma sintering (SPS); Titanium alloys; Particle-reinforcement