Factors Affecting Longitudinal Tensile Strength of SiC/Ti-Al-V Composites Manufactured by Plasma Spraying

Kyeong Ho Baik[a]

Department of Nanomaterials Engineering, Chungnam National University,
220 Gung-dong, Yuseong, Daejeon, 305-764, Korea
[a]khbaik@cnu.ac.kr

Abstract

In this study, multi-ply SiC fiber reinforced Ti-6Al-4V composites have been manufactured by plasma spraying and subsequent vacuum hot pressing. Two different sizes of Ti-6Al-4V feedstock powders were used for plasma spraying to form matrix. A considerable amount of oxygen was incorporated into as-sprayed Ti matrix during plasma spraying, and consequently caused matrix embrittlement. The use of coarse-sized feedstock powder reduced oxygen contamination, but tended to increase fiber spacing irregularity and fiber strength degradation. Longitudinal tensile strength and ductility of the composites were mainly affected by the matrix oxygen content.

Keywords : Plasma spraying, Ti Composites, Tensile strength, Embrittlement

1. Introduction

Titanium matrix composites (TMCs) are candidates for structural applications in the aerospace industry primarily because of their high specific strength and modulus, good dimensional stability, and good strength retention at elevated temperatures. A concurrent fiber winding and plasma spraying process has been developed for manufacturing multi-ply fibers reinforced composite rings in a single spraying operation [1]. Controlling the combination of fiber winding and spraying motion can produce locally reinforced composite rings. The process employs plasma spraying which offers rapid solidification benefits including fine matrix microstructure and limited interfacial reaction between fiber and matrix [2].

This paper describes the longitudinal tensile properties of SiC fiber reinforced Ti-6Al-4V composites manufactured by plasma spraying route and subsequent vacuum hot pressing.

2. Experimental and Results

Two different sizes of commercial Ti-6Al-4V powder were used in plasma spraying to form matrix: <90μm (CP) and <63μm (FP). Four-layer SiC fiber reinforced Ti-6Al-4V composite preforms were manufactured by a concurrent fiber winding and plasma spraying technique. Details of this technique are described elsewhere [1]. Plasma spraying was carried out using a Sulzer Metco A2000 low pressure plasma spray unit (LPPS). As-sprayed composite preforms were subsequently consolidated using uniaxial vacuum hot pressing (VHP).

The microstructures of as-sprayed LPPS TMC preforms are shown in Fig. 1 (a) and (b) for FP (<63μm) and CP (<90μm) respectively. The as-sprayed CP-TMC had a poorly controlled fiber distribution, containing several touching fibers, and a high fraction of porosity of ~8%. Both of these microstructural characteristics are a result of the relatively high surface roughness of the as-sprayed matrix deposit. A rough surface resulted in a locally too narrow or too wide fiber spacing [1]. When smaller average particles were used, a larger fraction of the feedstock powder was melted in the plasma flame, and there was a greater fraction of liquid droplets at deposition. Therefore, deposit surface roughness was reduced and fibers were accurately placed in winding operation, as shown in Fig. 1(a). The reduced surface roughness of matrix deposit was also benefical in low porosity by generating small-sized cavities under the fibers. Subsequent VHP consolidation of the as-sprayed LPPS TMCs resulted in full density. The FP TMC had a better controlled fiber distribution than the CP TMC.

As-sprayed LPPS Ti-6Al-4V matrix suffered from oxygen contamination, as shown in Table 1. Because of the great affinity of Ti alloys for oxygen, the spray chamber pressure of ~10^{-2}mbar prior to Ar backfill and the use of commercial Ar gas still provided sufficient oxygen for substantial contamination. Oxygen contamination was greater for the FP spraying because of the larger surface area to volume ratio of feedstock powder. A considerable amount of oxygen still remained in the VHP TMCs, 0.45wt% for the FP and 0.31wt% for the CP.

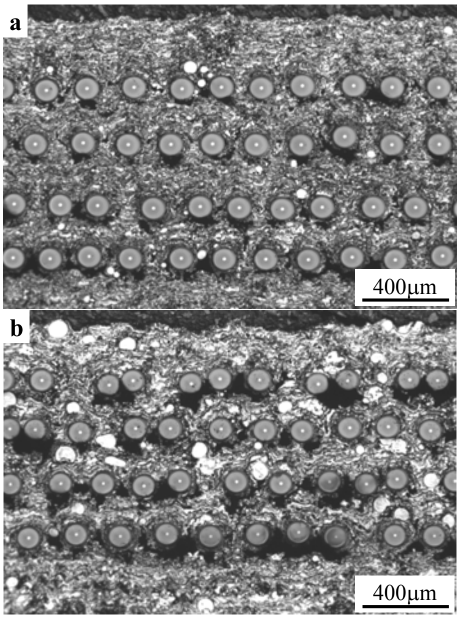

Fig. 1. Microstructures of as-sprayed LPPS SiC/Ti-6Al-4V composites manufactured by (a) FP (<63μm) and (b) CP (<90μm).

Table 1. Oxygen contents in powder and TMCs

(wt%)	Powder	LPPS TMCs	VHP TMCs
FP	0.18	0.48	0.45
CP	0.11	0.35	0.31

In order to quantify any fiber damage from the LPPS and VHP processing, the tensile strength of SiC fibers was evaluated after fiber extraction from the TMCs. Fig. 2 shows a Weibull plot of fiber strength for as-received and extracted SiC fibers. Both sets of the extracted SiC fibers showed a decrease in fiber strength and a large spread of measured strengths. The CP-LPPS/VHP TMC contained a higher population of very low strength fibers. The physical impact of large, poorly melted particles during LPPS and the localized stress concentration on the fibers during VHP were possible damage mechanisms [3].

Longitudinal tensile properties for the LPPS/VHP TMCs are given in Table 2. The CP-LPPS/VHP TMCs in general had a higher tensile strength and ductility than the FP-LPPS/VHP TMCs. This result was unexpected because the CP-LPPS/VHP TMCs have been shown to suffer from poorer fiber distribution and more severe fiber strength degradation. The only advantage for the CP-LPPS/VHP TMCs was low oxygen ingress during plasma spraying. The higher failure strain of the CP-TMCs (1.3-1.4%), compared with the typical SiC fibre failure strain of 0.8%, was evidence that the matrix did not fail immediately when the fibers failed. The fractography studies suggested that the lower tensile strength of the LPPS/VHP TMCs was associated with matrix embrittlement by oxygen.

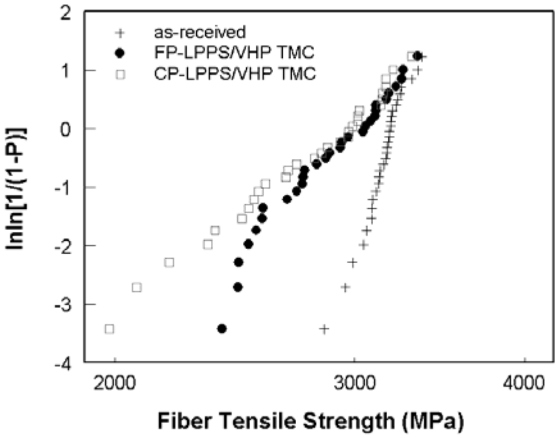

Fig. 2. Weibull plot of SiC fiber strength extracted from TMCs.

Table 2. Longtudinal tensile strength and ductility of TMCs

	UTS (MPa)	Ductility (%)
FP-LPPS/VHP	1165±74	~0.9
CP-LPPS/VHP	1237±67	~1.3

3. Summary

Plasma spraying of the coarse feedstock powder increased composite porosity and fiber spacing irregularity because of a higher surface roughness of as-sprayed matrix. However, oxygen incorporation into the Ti matrix was more severe when the smaller feedstock powder was used. Strength degradation of SiC fibers was much significant in the CP-LPPS/VHP TMC. The longitudinal tensile properties of LPPS/VHP TMCs were mainly affected by the matrix oxygen content. The CP-LPPS/VHP TMCs have been shown to suffer from poorer fibre distribution and more severe fiber strength degradation, but a low oxygen ingress allowed a sufficient matrix plastic deformation to provide load transfer from failed fiber to adjacent intact fibers.

4. References

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