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Effect of Mo coating on the interface and mechanical properties of SiC fiber reinforced Ti6Al4V composites

Xian Luo*, Yanqing Yang, Yingjuan Yu, Xingrui Wang, Bin Huang, Yan Chen

State Key Lab of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, China

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ABSTRACT

Ti6Al4V-matrix composites reinforced by continuous SiC fibers with Mo coating as interfacial modification layers were prepared by foil–fiber–foil method. Tensile strength of the as-prepared composites was tested, and thermal exposure of the composites in vacuum was carried out at 700 or 800 °C for different duration in order to investigate the thermal stability of Mo interlayer. Interfacial microstructure of the as-prepared and thermal-exposed composites was studied detailedly with the help of scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and transaction electron microscopy (TEM). The results show that, on the one hand, the original Mo coating becomes three layers: the residual Mo layer, a very thin layer of TiC (about 200 nm) and a mixed layer of Mo + β-Ti. In addition, there are two layers of the matrix that affected by the dissolution of Mo atoms between Mo + β-Ti layer and the normal matrix, which are identified to be β-Ti and a mixture of β-Ti with strip-like α-Ti, respectively. On the other hand, the tensile strength of the composites is significantly improved as the Mo coating can effectively hinder the fiber/matrix interfacial reaction, and the thermal exposure analysis indicates that Mo coating has excellent thermal stability when temperature is blow 700 °C.

1. Introduction

Due to their excellent mechanical properties, especially their tensile strength can be greatly improved, SiC fiber reinforced titanium matrix composites have become a new type of lightweight and high-strength structural materials for aerospace vehicle in many countries [1–3]. However, serious chemical reaction would take place between Ti matrix and SiC fiber during preparation of the composites at high temperature, which results in an interfacial reaction zone formed and leads to decrease in mechanical properties of the composites. Therefore, it has been focused on how to improve the interface compatibility of titanium matrix composites, and many coatings have been attempted, such as Al_2O_3, TiB_x, TiC, TiN, and ZrO_2, except for the basic carbon coating [4–8], but these ceramic coatings are feasible to crack and are a bit complex to prepare. Majumdar has given four main interface/coating design considerations [9], including: (1) the coating should protect fiber strength, (2) the coating should possess some degree of elongation to compensate for higher interface toughness, (3) the coating should allow for some degree of debonding, (4) it is desirable that the coating be under residual compressive stress. However, it is hard to find out such a perfect coating.

It is well known that Mo is an important alloying element of titanium alloys, and the addition of Mo can reduce the activity of titanium and slow down the interfacial reaction [10,11]. Meanwhile, if metal Mo is used as interlayers, it does not only have good elongation itself, but it also can make the matrix nearby become β phase (Mo is a β-stabilizer of titanium alloys) to have better ductility. More importantly, Mo has excellent stability with C or SiC according to the study of SiC particle reinforced $MoSi_2$ matrix composites [12] and Schwarz's study on C/Mo/Cu interface [13]. Therefore, in this study Mo coating was used as interfacial modification layer of SiC/Ti6Al4V composite, and its influence on the microstructure of the interfacial zone and on the mechanical property of the composites was studied, especially the thermal stability of the Mo coating in the interface was investigated through vacuum thermal exposure processing.

2. Experimental

The matrix material is Ti6Al4V alloy foil with about 60 μm thickness; the reinforcement is continuous SiC fiber with a diameter of about 100 μm made in China, which consists of a tungsten core (10–12 μm in diameter) coated with a layer of β-SiC about 45 μm thick. The longitudinal tensile strength of Ti6Al4V foil is about 900 MPa, and the tensile strength of SiC fiber is between 2000 and 3000 MPa.

* Corresponding author. Tel.: +86 29 88460536; fax: +86 29 88460499.
E-mail address: luo_shenfan@hotmail.com (X. Luo).

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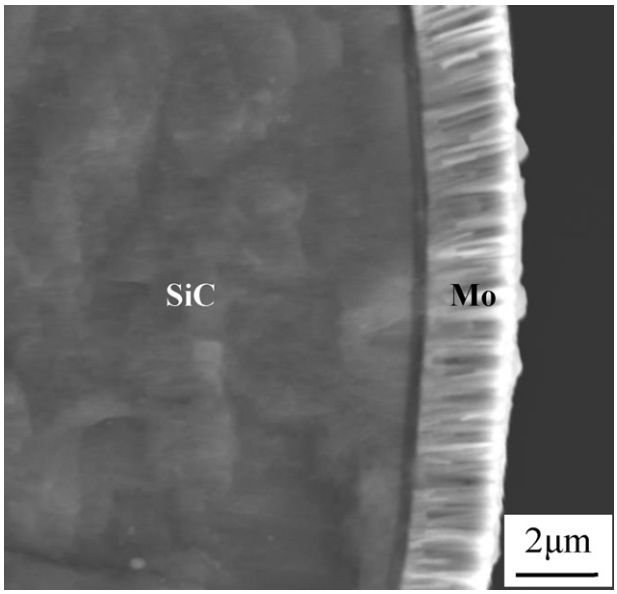

Fig. 1. The Mo coating on the surface of SiC fiber before hot pressing.

Pure Mo (>99.9 wt% in purity) was deposited onto the surface of SiC fiber by magnetron sputtering method. The thickness of Mo coating was controlled to be about 2 μm, as shown in Fig. 1. Unidirectionally aligned Mo-coated SiC fiber-reinforced Ti6Al4V composites were prepared by foil–fiber–foil (FFF) method plus vacuum hot pressing technique. The hot pressing parameters are: pressure 40 MPa, temperature 890 °C and duration 1 h. After hot pressing, the furnace chamber cooled naturally to room temperature in vacuum environment. The fiber volume fraction of the composites was about 25%.

In order to investigate the effect of Mo coating on the tensile strength of the composites, the composites were machined into dog-bone-type plate tensile specimens for tensile test. The thickness of the samples is about 1.2 mm. In order to study the thermal stability of Mo coating, some specimens were thermally exposed in vacuum at 700 °C for up to 200 h and 800 °C for up to 50 h, respectively. The microstructure and element distribution characteristics in the fiber/matrix interfacial zone of the as-prepared and thermal-exposed composites were analyzed by a SUPRA 55 field emission scanning electron microscope equipped with an Oxford INCA energy-dispersive spectrometer as well as a FEI's Tecnai F30 transmission electron microscope.

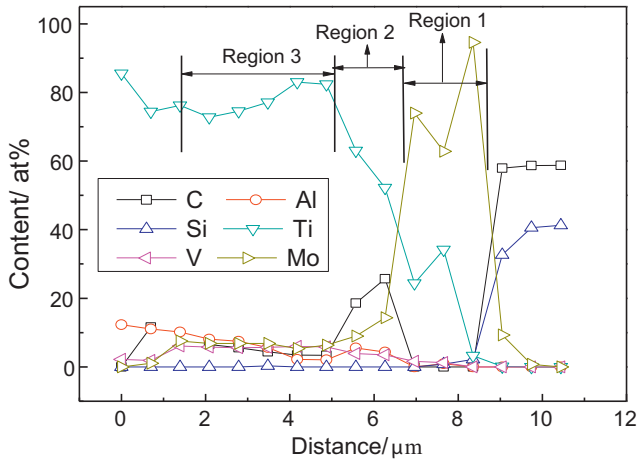

Fig. 3. The element line distribution along the SiC/Mo/Ti6Al4V interfacial zone (corresponding to Fig. 2b).

3. Results and discussion

3.1. The interface of as-prepared composite

3.1.1. SEM and EDS analysis

Fig. 2a shows a transverse metallograph of the as-prepared SiC/Ti6Al4V composite with Mo coating as an interfacial modification layer (hereafter denoted as SiC/Mo/Ti6Al4V composite). It can be seen that the combination between fiber and matrix is excellent, no obvious cracks or cavities can be found. However, the fiber distribution is not very uniform, as the common FFF method for fabricating the composites is generally difficult to control fiber distribution. In addition, it can be seen that each fiber is surrounded by a layer of white substance, which should be mainly Mo coating according to the back scattered electron image observation.

In order to further study the SiC/Mo/Ti6Al4V interface state, a higher magnification image of the interface zone of the as-prepared composite is presented in Fig. 2b, and corresponding element distribution curves along the interface are shown in Fig. 3. From Fig. 2b one can see that the interface zone has obvious stratification phenomenon. The interface zone might be divided into three regions roughly, which are marked as 1, 2 and 3. The average thickness of regions 1–3 is 2.2, 1.8 and 3.5 μm, respectively.

Region 1 shows columnar crystal characteristics of typical sputtering state, and the composition analysis in Fig. 3 also shows that this region mainly contains Mo, so region 1 should be mainly residual Mo coating, and a few Ti atoms have diffused into the Mo coating

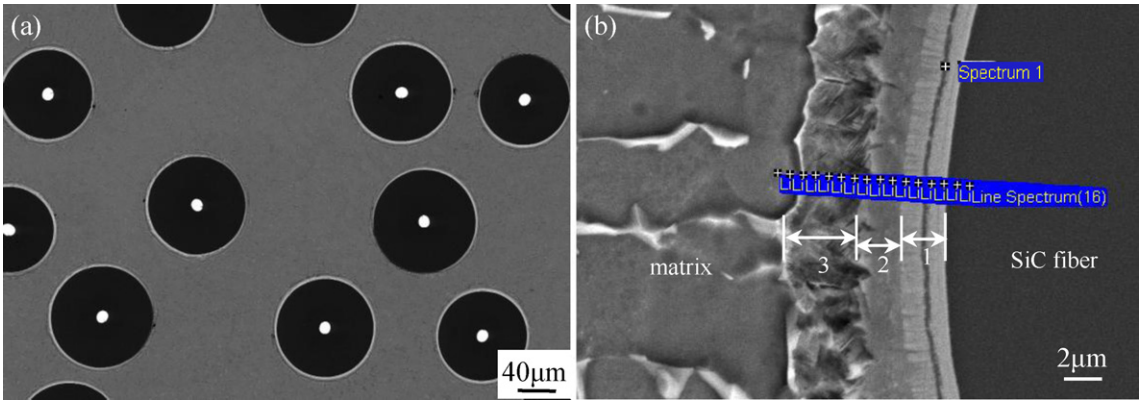

Fig. 2. Cross-sectional SEM image of the SiC/Mo/Ti6Al4V composite: (a) a lower magnification of back scattered electron image showing the whole impression of the composite; (b) a higher magnification image (secondary electron image) showing the SiC/Mo/Ti6Al4V interface zone.