Processing and microstructure of Ti$_3$SiC$_2$/M (M=Ni or Co) composites

H. Li$^{a,b,*}$, L.M. Peng$^b$, M. Gong$^b$, L.H. He$^b$, J.H. Zhao$^b$, Y.F. Zhang$^a$

$^a$Research Institute of Micro/Nano Science and Technology, Shanghai Jiao Tong University, Shanghai 200030, People’s Republic of China
$^b$CAS Key Laboratory of Materials Behavior and Design, Department of Mechanics and Mechanical Engineering, University of Science and Technology of China, Hefei 230026, Anhui, People’s Republic of China

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Abstract

Ti$_3$SiC$_2$/M (M=Ni or Co) composites were synthesized through powder metallurgy technology. It was found that the metal atoms tended to aggregate towards the sample surface. As a result, layered microstructures were formed. The outer layer was composed of exuded metal/alloy, wrapped Ti$_3$SiC$_2$ and TiC particles. The porous transition layers consisted of continuous metal nets and ceramic inclusions while loose Ti$_3$SiC$_2$ and TiC particles were located in the inner layers. The above microstructural features were attributed to the poor wettability between Ti$_3$SiC$_2$ and Ni or Co under the present processing conditions.

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1. Introduction

Ti$_3$SiC$_2$ has recently attracted extensive research attention due to its combination of the merits of both metals and ceramics. The uniqueness of its properties is considered to derive from the metallic bonding nature, the layered crystal structure, the mobility and multiplication of the basal plane dislocations [1,2]. Up to date, the research is mainly focused on the synthesis and mechanical properties of the pure bulk Ti$_3$SiC$_2$. Recent researches [3–5] have demonstrated that Ti$_3$SiC$_2$-based composites, such as Ti$_3$SiC$_2$/Al$_2$O$_3$ [3], Ti$_3$SiC$_2$/SiC [4] and Ti$_3$SiC$_2$/TiC [5] exhibit more excellent mechanical properties than the monolithic Ti$_3$SiC$_2$ matrices. Nevertheless, very little information has been available with respect to the processing and mechanical properties of Ti$_3$SiC$_2$/metal composites [6].

Accordingly, the present study attempts to synthesize Ti$_3$SiC$_2$/M (M=Ni or Co) composites through vacuum sintering since these two metals display high melting points, strength, hardness and wearing resistance. The microstructure and elemental composition of these two composites were examined by a scanning electronic microscope (SEM) and energy dispersive X-ray spectroscopy (EDX), respectively.

2. Experimental procedure

Ti$_3$SiC$_2$ powders containing 93 vol.% Ti$_3$SiC$_2$ and 7 vol.% TiC were synthesized previously from elemental powders of Ti, Si and C through vacuum sintering at 1450 °C for 180 min [7,8]. The Ti$_3$SiC$_2$ powders were blended with Ni (average particle size: 3 μm, >99% purity) or Co (average particle size: 3 μm, >99% purity) powders. The powder mixtures were then ball milled in ethanol at 100 rpm for 12 h. The milled slurries were dried at 80 °C in vacuum and then ground with 10 wt.% polyvinyl alcohol (C$_{2n}$H$_{4n}$O$_n$, PVA) solution in order to improve the compactability and finally uniaxially die-pressed under 100 MPa into platelets with dimensions of $8 \times 8 \times 35$ mm. The compacts were then heated slowly up to 400 °C in vacuum (~1 Pa) during 10 h to remove
PVA, moisture and absorbed gases. The green bodies were placed into a boron nitride powder-coated graphite crucible and sintering was conducted in vacuum (~0.1 Pa) at 1450 °C for 90 min for Ti₃SiC₂/Ni and 1480 °C for 90 min for Ti₃SiC₂/Co.

The microstructure was observed on a scanning electron microscope (SEM, XL30 ESEM) with an accelerating voltage of 20 kV. Energy dispersive X-ray spectroscopy (EDX) analysis was also conducted to detect the elemental composition.

3. Results and discussion

All the composites, containing different amount of Ni ranging from 10 to 40 wt.% were composed of two parts: the outer shell of silvery white metal and the inner black bodies of loose ceramic particles. This implied that Ni had migrated to the sample surface through diffusion and the wettability between Ni and Ti₃SiC₂ is quite poor. Fig. 1(a) and (b) showed the cross-section microstructures of the outer and inner parts of Ti₃SiC₂-10 wt.% Ni sample, respectively. It could be found that the cross-section was composed of outer layer, transition layer and inner layer, which are marked by O, T and I, respectively. The outer layer and the transition layer were composed of a continuous integrated metal coat without internal boundary but more pores and ceramic inclusions existed in the transition layer. As shown in Fig. 1(b), the inner area that mainly consisted of slightly sintered lamellar particles and isometric particles.

Similar to Ni, most of Co also migrated to the sample surface to form a silvery white surface coat. The cross-section microstructures of the Ti₃SiC₂-10 wt.% Co were shown in Fig. 2. Again, three distinct layers, denoted as O (outer layer), T (transition layer) and I (inner layer) were observed. The inner layer was also composed of loose particles, which produced low relative density and poor mechanical properties.

As demonstrated by the EDX spectra in Fig. 2, the chemical composition difference between the two layers lay mainly in the concentration of Co and Si. The atom fraction of Co in the outer layer was quite high but there was almost no Co in the inner layer. The content of Si decreased remarkably in the outer layer whereas that of C increased slightly. In general, it could be inferred that the material in the outer layer was mainly composed of Co or its alloy, and some Ti₃SiC₂ and TiC, while the inner layer contained Ti₃SiC₂, TiC and small amount of Co or Co-containing alloy.

4. Conclusion

Ti₃SiC₂/Ni and Ti₃SiC₂/Co composites were synthesized through vacuum sintering. In both composites, the metals aggregated towards the sample surfaces, resulting in layered microstructural features. The outer and the porous transition layers were composed of the exuded metal/alloy, wrapped Ti₃SiC₂ and TiC aggregates. The inner layer consisted of partially sintered Ti₃SiC₂ and TiC particles. Based on these preliminary results, it can be concluded that the wettability between Ti₃SiC₂ and Ni or Co are both poor and some adequate sintering additives should be added to improve the wetting performance and interface properties between Ti₃SiC₂ and metals to achieve homogeneous microstructures and excellent mechanical properties.

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Fig. 2. SEM micrograph and EDX spectra of \( \text{Ti}_3\text{SiC}_2\)-10 wt.% Co sample.

References