Journal of Alloys and Compounds 472 (2009) L1–L5

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

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

Letter

Microstructure of cermet coating prepared by plasma spraying of Fe–Ti–C powder using sucrose as carbonaceous precursor

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ARTICLE INFO

Article history:
Received 10 January 2008
Received in revised form 8 April 2008
Accepted 8 April 2008
Available online 19 May 2008

Keywords:
TiC/Fe composite coating
Reactive plasma spraying
Carbonaceous precursor
Sucrose

ABSTRACT

In this paper, a kind of Fe–Ti–C composite powder for reactive plasma spraying (RPS) was prepared by heating a mixture of ferrotitanium and sucrose as a carbonaceous precursor, with an intention of carbonizing the sucrose. The tiny ferrotitanium particles were bound by the carbon obtained from the carbonization of sucrose. The carbon was a reactive element as well as a binder in the composite powder. While the composite powder was sprayed to deposit TiC/Fe composite coating by RPS, it was proved that the reaction between Ti and C was performed completely to form TiC, without impurity or residual raw materials in the coating. The composite coating is mainly composed of layers in which a mass of TiC particles are uniformly distributed and enwrapped within the crystal grains of metallic matrix, and the TiC particles in these layers are spherical or near-spherical in submicron-scale or nano-scale sizes.

1. Introduction

Metal matrix coatings reinforced with ceramic particles, especially carbide particles, are widely used in many wear-resisting applications [1]. Titanium carbide (TiC) can offer the necessary toughness to the coating to operate under high loads and remain stable, up to 1100 °C, for high-temperature applications [2]. Low friction coefficient and density are other advantages of TiC to make it supposed to be an excellent reinforcement for the cermet coatings [3].

Plasma-sprayed TiC/Fe composite coatings are demonstrated to be potentially very useful for applications where high wear resistance is required [4]. So far, there are two ways to prepare TiC/Fe composite coatings by plasma spraying of powders.

One is to spray cermet powders, in which the TiC is included prior to the spraying process. The TiC particles are directly added into metallic binder to prepare cermet powders via Sintering [5]. The surface of added TiC particles is generally polluted. The interface between the reinforced particles and metallic binder is often a potential source of weakness. A later employed method of cermet powders production is self-propagating high-temperature synthesis (SHS), which utilizes the exothermic heats of reaction between raw powders to synthesize the cermet powders [6,7]. The TiC particles in the coatings are usually unevenly distributed and in sizes of more than 1 μm. Besides, stringent conditions are required to spray the SHS powders, such as high spraying temperature, high spraying speed, etc.

The other is to spray granular powders consisting of raw materials without TiC prior to the spraying process. The method consisting in the simultaneous synthesis and deposition of TiC/Fe composite coating by plasma spraying was proposed in the literature [4], which is called reactive plasma spraying (RPS). The TiC particles in situ synthesized during spraying have a clean interfacial structure with the metallic matrix. This is likely to produce a good bond between the hard phase and binder [8,9]. In addition, the exothermic reactions provide a supplemental heat, along with the heat of plasma, to deposit the cermet coatings. Thus the powders can be heated sufficiently to improve properties of the coatings.

Since the enthalpy of TiC formation is approximately $\triangledown H_f = 185$ kJ/mol, the RPS is recognized to be one of the best ways to prepare TiC reinforced composite coatings [10]. TiC-reinforced composite coatings are usually prepared by RPS using granular powders consisting of titanium, graphite, and other metallic elemental powders (Ni, Fe, etc.) [4]. However, the composite powders used for RPS have mostly being prepared by simple mechanical blend [11,12] or granulation adding a small amount of agglomerant into the raw materials [13–15]. Because of the low strength in the granular powders prepared by the methods above, the reactive raw materials are liable to incompletely react with each other during spraying so that some raw materials particles remain in coatings, or graphite is lost during spraying [16]. It

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doi:10.1016/j.jallcom.2008.04.028

Table 1
Chemical composition of ferrotitanium powders

Chemical composition (wt%)	
Powders	TiFe
Fe	Balance
Ti	47
Al	1.7
Mn	1.9
Si	0.2
C	0.2
P	0.1
S	0.02
Cu	0.1

results in an inhomogeneous microstructure of the coating with a small amount of TiC particles [17].

In this paper, in order to get abundant uniformly distributed TiC particles in the TiC/Fe composite coatings prepared by RPS, precursor carbonization process was performed to fabricate a kind of Fe–Ti–C composite powder, in which the carbon obtained from the carbonization of carbonaceous precursor was a reactive element as well as a binder. Sucrose and ferrotitanium powders were used as the precursor and raw materials, respectively. It is included three aspects to be the main features of the composite powder prepared by carbonization of sucrose. The first is that the sucrose can be carbonized easily at low temperature without impurity; the second is that the ferrotitanium particles are bound by the carbon tightly to avoid separation of Ti and C during spraying; the third, ferrotitanium powders as raw materials can be effortlessly milled into tiny particles so that the ferrotitanium particles have an extremely large amount of interface with the carbon, that is beneficial to the reaction between Ti and C. Ascribing to the special structure of the Fe–Ti–C composite powder, a type of metallic matrix composite coating reinforced with a great number of tiny in situ synthesized TiC particles had been deposited by RPS.

2. Experimental

In this experiment, the raw materials are ferrotitanium powder (its composition is shown in Table 1) and sucrose as carbonaceous precursor. 73.8 wt% ferrotitanium powder (5 μm average particle size) and rest sucrose were mixed with alcohol to be milled for 24 h in a miller. Then, the slurry was put in a drying cabinet for 12 h. The mixture was hold at 250 °C for 2 h and 350 °C for 1 h sequentially in the atmosphere of nitrogen to carbonize the sucrose completely. Finally, it was crushed on a centrifugal mill and sieved mechanically to get the Fe–Ti–C composite powder in the size range of 40–60 μm. The Ti and C made up 53 wt% of the composite powder with titanium to carbon atomic ratio of 1:1.

A plasma spraying facility (METCO-7M, USA) was used to deposit the TiC/Fe composite coating on substrates by plasma spraying of the Fe–Ti–C composite powder. Prior to spraying, the substrates were grit blasted on one side to clean and roughen the surfaces.

The phases presented in the composite powders and the TiC/Fe cermet coatings were identified using X-ray diffraction (XRD) with Cu Kα radiation. Leo-1450 scanning electron microscope (SEM) with energy dispersive X-ray spectrometer (EDS) and transmission electron microscope (TEM) were employed to analyze the microstructure of the composite powder and coating. The volume fraction of different regions in the TiC/Fe cermet coating was measured by LECO-IA32 Image Analysis System (LECO Corporation, USA).

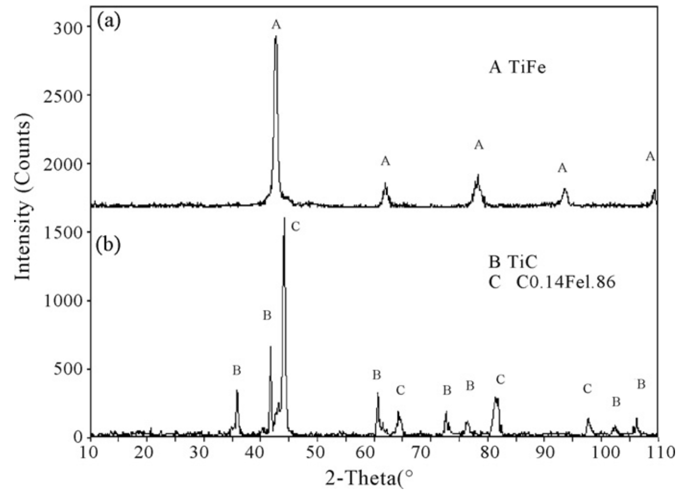

Fig. 1. XRD diffraction pattern of the Fe–Ti–C composite powder for RPS (a) and the TiC/Fe composite coating prepared by RPS (b).

3. Results and discussion

3.1. Special structure of the Fe–Ti–C composite powder prepared by carbonization of sucrose

Fig. 1(a) shows the XRD diffraction pattern of Fe–Ti–C composite powder for RPS prepared by carbonization of sucrose. Neither TiC nor impurity is produced within the Fe–Ti–C spraying powder during carbonizing the sucrose.

Fig. 2(a) presents that the Fe–Ti–C composite powder is uniformly granular in size range of 40–60 μm. The structure of the composite powder is revealed in Fig. 2(b), in which the white are ferrotitanium particles and the black surrounding is the carbon. The tiny ferrotitanium particles are bound by the carbon, which is a reactive element as well as a binder in the composite powder. Every single composite powder granule can be recognized as an independent reactive unit with this kind of special structure. The tight structure can effectively prevent the reactive elements from being separated to avoid incomplete reaction and residual raw materials. Furthermore, the ferrotitanium particles are about 5 μm. The interface between ferrotitanium particles and carbon increases so much in this special structure that the nucleation of TiC must be enhanced sharply during spraying.

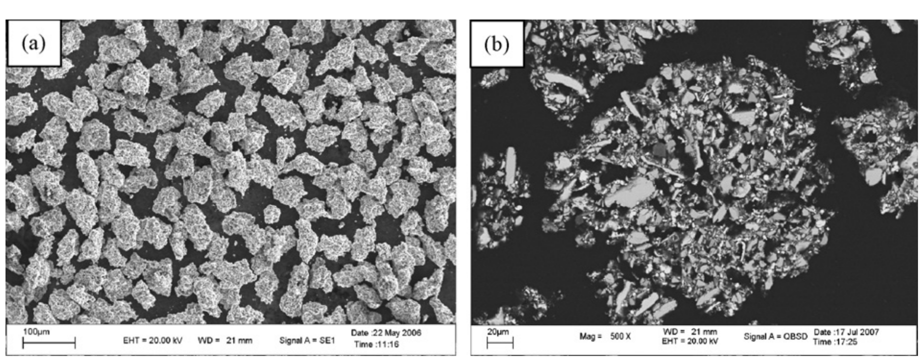

Fig. 2. Morphology (a) and cross-section (b) SEM micrograph of the Fe–Ti–C composite powder for RPS.