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ARTICLE

Interface Optimization and Mechanical Properties of Cu-coated Carbon Fiber Cloth/Titanium Alloy Composite

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Abstract: Using Cu-coated carbon fiber cloth (CFC) as reinforcement and Ti-6Al-4V (TC4) as matrix, the Cu-coated CFC/TC4 composite was fabricated by spark plasma sintering. The interface morphology, phase microstructure, phase distribution and mechanical properties of CFC/TC4 were characterized. Results show that carbon fibers are uniformly distributed in Cu-coated CFC/TC4. CuTi, Cu and trace TiC are distributed along the interface between fibers and matrix. The Cu-coated CFC/TC4 possesses slightly better plasticity than TC4, and the yield strength and compressive strength are obviously enhanced. The electroplated Cu plays important roles: (1) markedly decreasing the sintering temperature of Cu-coated CFC/TC4; (2) significantly improving the wettability and interfacial bonding between carbon fibers and TC4 matrix, thus increasing mechanical properties of Cu-coated CFC/TC4; (3) effectively inhibits the excessiving generation of brittle TiC compared with uncoated CFC/TC4 composite, thus maintaining good plasticity of Cu-coated CFC/TC4.

Key words: metal-matrix composites (MMCS); interface; sintering; mechanical properties; microstructure

Carbon fiber reinforced materials have been widely developed in metal matrix composites (MMCs) in the last decades, since they can endow MMCs good performance of thermostability, wear resistance and fatigue resistance[1-7]. Recent research has shown that continuous carbon fiber possesses its unique advantages compared with short carbon fiber. Advanced continuous fibers have produced a revolution in the field of structural materials and composites in the last few decades because of their high specific strength, specific modulus, stiffness, and continuity, which meant processing and alignment are economically feasible[8]. Daoud reported that the incorporation of continuous carbon fibers into 2014 Al alloy significantly improved the wear resistance and the composite exhibited a higher seizure resistance compared with the unreinforced alloy[9].

Continuous carbon fiber reinforced composites have aroused lots of attentions[10-13], but most of them are about resin matrix and based on wear performance[9,14-17]. In recent years, research on continuous carbon fiber reinforced MMCs is relatively less mainly due to the following difficulties in the process of preparing composites[18-27]: (1) Carbon fibers are difficult to be wetted by molten metals, and thus the interfacial bonding between fibers and matrix is weak; (2) Carbon fibers tend to react with metal matrix at high temperature to produce excessive brittle intermetallic compounds in the interface, making the interface a weak link; (3) Carbon fibers are easily oxidized, largely decreasing mechanical properties. In order to solve above problems, and to give full play to the unique advantages of long carbon fiber and to obtain long carbon fiber reinforced MMCs with much more excellent mechanical properties, a large amount of work concerning interfacial optimization have been carried out.

In terms of interface optimization, excessive interfacial

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reaction leads to the vast generation of brittle intermetallic compounds in the interface between fibers and metal matrix while non-reaction results in bad interfacial bonding. Therefore, the design parameters of interphases depend on the reactivity between the matrix and the reinforcements[28]. It is reasonable to reduce the interfacial reactions for highly reactive systems by coating[9,19,27,29,30] and modify the surface chemistry of the reinforcement or change the matrix chemistry for non-reactive systems[28,31,32] in order to achieve the desired interfacial bonding properties.

In recent years, carbon fiber reinforced titanium composites were reported to improve the mechanical properties of titanium[3,33-35]. But these reports were mostly on carbon nanotubes or short (chopped) carbon fibers in order to improve the wear resistance or static strength, and the preparation methods were normally casting and powder metallurgy. At present, there are few studies about controlling the generation of intermetallic compounds, and the problem of wettability between carbon fibers and titanium also has not been fundamentally solved. If the interfacial problems like poor wettability and serious carbonization of matrix can be solved in long carbon fiber reinforced titanium alloy, continuous carbon fibers would fully play the advantages of high elastic modulus, high tensile strength, high shear strength and low density to further enhance the mechanical properties of titanium alloy, which is an important development trend for lightweight structural material in the future.

In the present paper, aiming to control the carbonization degree of Ti-6Al-4V (TC4) at high temperature and to improve the wettability between carbon fibers and TC4 matrix, carbon fiber cloth (CFC) was coated with Cu by electroplating. Considering the lower sintering temperature, shorter sintering time and moderate uniaxial pressure[36-39] of spark plasma sintering (SPS), we chose SPS to prepare CFC/TC4 composites. The static and dynamic mechanical properties of CFC/TC4 composites were investigated.

1 Experiment

PAN-based CFC (T300) was selected as raw material. Each bundle consists of 1200 single filaments with a diameter of 6 μm. Thousands of single filaments cohere together and compose CFC by the adhesive force of binder. The glue membrane and some other grease infectants on the surface of carbon fibers are both bad for electroplating. In order to obtain uniform coating on individual fiber, CFC must be modified to improve the interfacial bonding between fibers and coating[40]. In this paper, the surface treatment of CFC before electroplating included two steps. The first step was carried out by thermal debinding at 400°C for 30 min in muffle furnace to burn out the organic binder on the surface of fibers. In the following step, the CFC was immerged in a 50% aqueous solution of nitric acid for 12 h to improve surface activity of fibers. After acid etching treatment, the CFC was cleaned for several times using deionized water.

After the pretreatments above, Cu was electroplated on the CFC to inhibit the carbonization of TC4 matrix and to improve the wettability between fibers and matrix. A plating aqueous solution with content of 150 g/L $CuSO_4$ and 50 g/L H_2SO_4 was applied to electroplate Cu on the surface of CFC. The CFC acting as cathode was placed between two Cu anode plates in the bath, and then pulse current with duty cycle of 80% was imposed on Cu and CFC for 2 h. The current density was 3 A/dm^2 and the electroplating temperature was 24 °C. After that, the Cu-coated CFC was washed in distilled water for several times and lastly dried in a vacuum drying oven at 100 °C. Images of CFC before and after electroplating of Cu are shown in Fig. 1.

TC4 was selected to be the matrix and Cu-coated CFC/TC4 composite was prepared by SPS. For comparison, uncoated CFC/TC4 composite was also fabricated. The images of uncoated and Cu-coated CFC and original TC4 material are shown in Fig. 2. With a diameter of 40 mm, CFC and TC4 sheets were put into a cylindrical graphite die with an inner diameter of 40 mm. Fig.3 shows the schematic of the procedure to fabricate CFC/TC4 composites. In order to prevent TC4 sheets from reacting with the graphite die or punches, graphite foil was used. After several times of process optimization, the specimens were subjected to SPS using the following parameters: (1) heated from room temperature to 1050 °C (for Cu-coated CFC/TC4 composite) or 1500 °C (for uncoated CFC/TC4 composite) with a heating rate of 100 °C/min; (2) pressed by a uniaxial pressure of 50 MPa; (3) held at 1050 °C (for Cu-coated CFC/TC4 composite) or 1500 °C (for uncoated CFC/TC4 composite) for 15 min. The obtained Cu-coated CFC/TC4 composite is shown in Fig.4.

Microscopic images, elemental composition and phase distribution of composites were obtained by field emission scanning electron microscopy (FESEM, S-4800), energy dispersive spectroscopy (EDS, FEI Tecnai G2F20) and transmission electron microscopy (TEM, JEM-2100). Phase identification was carried out using an X-ray diffraction (XRD, D8 ADVANCE).

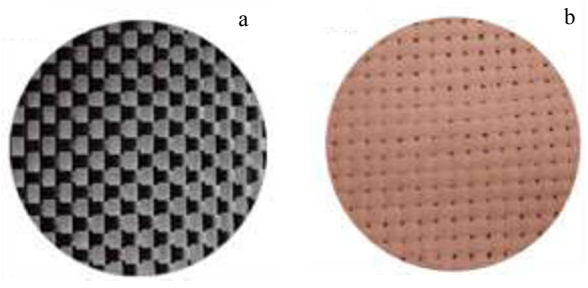

Fig.1 Images of CFC before (a) and after (b) electroplating of Cu