Materials and Design 57 (2014) 442–448

Contents lists available at ScienceDirect

Materials and Design

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

Fabrication and mechanical properties of Cu-coatedwoven carbon fibers reinforced aluminum alloy composite

Qiurong Yang, Jinxu Liu *, Shukui Li, Fuchi Wang, Tengteng Wu

School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, China

ARTICLE INFO

Article history:
Received 23 May 2013
Accepted 22 December 2013
Available online 8 January 2014

Keywords:
Carbon fibers
Aluminum alloy
Composites
Interfaces
Mechanical characterization

ABSTRACT

Cu-coatedwoven carbon fibers/aluminum alloy composite (C_f/Al) was prepared by spark plasma sintering. Microstructure and mechanical properties of the composite were investigated. Microstructure observation indicates that the interface reaction is evidently inhibited by Cu coating. Woven carbon fibers are adhered to the matrix alloy by anchor locking effect of matrix alloy immersing into the interstices between carbon fibers. Under the quasi-static and dynamic compressive conditions, the composite exhibits excellent ductility even when the strain reaches 0.8. Adding carbon fibers into ZL205A alloy has no obvious influence on compressive flow stress of the composite. The compressive true stress–true strain curves show that the composite is a strain rate insensitive material. During the tensile tests, the elongation of the composite shows a sharp increase from 4.5% to 13.5% due to the adding of woven carbon fibers. Meanwhile, the tensile strength of the composite is increased slightly from 168 MPa to 202 MPa compared to that of ZL205A alloy. The good ductility of the composite is ascribed to the cracks deflection, fibers pulling out, debonding and breakage mechanisms.

1. Introduction

Carbon fiber has been one of the most ideal candidates for composites reinforcement due to its high specific strength, good flexibility, high elastic modulus and especially the light weight [1,2]. Due to low density, high ductility and high specific strength, aluminum and aluminum alloys are the most important matrix materials for the composites applied to aerospace and military vehicles. In order to further improve the performance of aluminum alloys, researchers reinforced aluminum and aluminum alloys with carbon fibers. They expected to combine the high strength and high modulus of carbon fibers with the good ductility and high toughness of aluminum alloys.

In recent years, more and more researchers focusing on carbon fiber/aluminum composites have been interested in interface bonding, fibers dispersion and fabrication process [3–6]. Harmful interface reaction is one of the major problems during the fabrication of carbon fiber reinforced aluminum matrix composites. Carbon fibers tend to react with the molten aluminum and thus the Al_4C_3 is formed, which may severely damage the fibers and deteriorate the mechanical properties of the composites. Deng et al. [7] reinforced 2024Al with carbon nanotubes, and found that carbon nanotubes were completely reacted and changed into Al_4C_3 during sintering. Lee et al. [5] deposited SiC on carbon fibers and solved the problem of interface reaction. However, the SiC coating was too brittle, which would reduce the ductility of the composites. Daoud [6] successfully prepared the composite consisting of unidirectional Ni-coated carbon fibers in 2014 aluminum alloy matrix. The interface between fiber and matrix is smooth, and neither discontinuities nor significant layer of brittle inter-metallic compound (Al_3Ni) was observed. Singh and Balasubramanian [8] investigated Cu-coated carbon fibers reinforced aluminum alloy composites. By coating Cu on the carbon fibers and adding Mg into the matrix alloy, the interface reaction was avoided and the wettability between carbon fiber and aluminum alloy was improved.

In terms of the fabrication processes, powder metallurgy [9–11], casting [12] and especially the pressure infiltration [13] are the main processing methods to prepare fiber reinforced metal/alloy composites. Stein et al. [14] reinforced aluminum alloy AA5083 with homogeneously dispersed multi-walled carbon nanotubes by powder metallurgy. Tensile strength of the reinforced material was increased by 17%. Due to a series of advantages, gas pressure infiltration has been one favorite technique to fabricate continuous fibers reinforced composites. Daoud [13] fabricated carbon fibers/aluminum composites with high compactness and improved wear performance by gas pressure infiltration. The application of pressure could force the liquid metal to surround the carbon fibers and improve the wettability between liquid metal and fibers, which effectively increased the compactness and interface bonding force of the composites. However, the temperature of the infiltration process was so high that the interface reaction was difficult

* Corresponding author. Tel.: +86 010 68913937x802; fax: +86 010 68913937.
E-mail address: liujinxu@bit.edu.cn (J. Liu).

0261-3069/$ - see front matter
http://dx.doi.org/10.1016/j.matdes.2013.12.064

to be avoided. Sánchez et al. [15] fabricated Ni-coated carbon fibers reinforced aluminum composites by centrifugal infiltration process, finding that the carbon fibers reacted with aluminum and Al_3Ni formed. In addition to the above fabrication processes, spark plasma sintering (SPS) has already been employed to prepare carbon fiber reinforced metal/alloy composites. Liao et al. [16] prepared multi-wall carbon nanotubes reinforced aluminum matrix composites by SPS under 773 K, and obtained composite without the formation of Al_4C_3.

Besides, most researches focus on the short carbon fibers and nanofibers/nanotubes reinforced aluminum/aluminum alloys [17,18], which aims to improve the abrasion resistance and the strength of composites. Liu et al. [19] investigated the friction and wear properties of short carbon fiber reinforced aluminum matrix composites, concluding that the incorporation of carbon fibers in aluminum alloy improved the wear resistance greatly. Bakshi and Agarwal [20] analyzed the factors affecting strengthening in carbon nanotube reinforced aluminum composites, and found that the homogenous dispersion of carbon tubes in the composite is very critical for obtaining high strengthening material. Choi and Bae [21] reported that the addition of carbon nanotubes to the aluminum matrix may block the propagation of necks and cracks, improving the strength and ductility of the composite. However, Wu et al. [22] studied the tensile property of the carbon nanotube/aluminum composites, finding that the elongation of the composites showed a sharp decline because of the adding of carbon nanotubes. Naji et al. [23] investigated the influence of carbon fiber aspect ratio (respectively 300, 500, 800) on fracture toughness of the aluminum matrix composite, finding that the carbon fibers with aspect ratio of 800 increased the plane-strain fracture toughness of aluminum in the largest extent compared to the carbon fibers with other two aspect ratios.

As reinforcements, continuous fibers have the advantage to full play the high axial strength. However, the present studies on continuous carbon fibers, especially the woven carbon fibers reinforced aluminum alloy are seldom reported [24]. Firstly, woven carbon fibers applied as the reinforcements can take full advantage of the high performance of carbon fibers. Secondly, the braided structure of carbon fibers contributes to reducing the stress concentration and improving the pressure equilibration when they are suffering stress. Moreover, the continuous fibers can absorb more energy than short carbon fibers when they are pulled out from the matrix, which would increase the toughness of the composites. In addition, the orientation and content of the fibers are easily to be controlled in the carbon fibers reinforced composites, which would also simplify the fabrication process.

In the present study, woven carbon fibers were selected to reinforce aluminum alloy by SPS. Cu was coated on the surface of carbon fiber woven by electroplating to improve the wettability of carbon fibers with aluminum alloy, and inhibit the severe interface reaction under high temperature condition during the fabrication process. Although Cu-coating on carbon fiber woven would increase the weight, and which may go against the trend of lightening composite, since the content of Cu in the whole composite is very little, the influence of Cu coating on density of the composite is little. By charging materials with electrical energy and applying high temperature effectively, SPS is an efficient synthetic technique to fabricate materials at lower sintering temperature and in a shorter period [25], which can effectively help to inhibit the interface reaction between carbon fibers and aluminum alloy. Meanwhile, the applied pressure during SPS process can force the semi-liquid aluminum to immerse into carbon fibers for the purpose of improving the bonding force. After SPS process, the microstructures, interface characteristics and mechanical properties of the Cu-coatedwoven carbon fibers/aluminum alloy (C_f/Al) composite were investigated.

2. Materials and methods

2.1. Raw materials

The matrix alloy employed in the present study was casting ZL205A aluminum alloy, with the composition of 94Al–5Cu–0.5Mn (weight%). Plain weave PAN-based carbon fiber woven (T-300) was selected as the reinforcement. The carbon fiber woven has approximately 1200 fibers per bundle, and the average diameter of the fibers is 6 μm. The woven structure and microstructure of the carbon fibers are shown in Fig. 1(a) and (b).

For the purpose of getting rid of epoxy resin glue from the surface, carbon fibers were placed in a furnace for 30 min under 673 K. Then the fibers were treated by acid, which was aimed to roughen the surface and improve the bonding force. After acid treatment, the fibers were cleaned several times using deionized water.

The initial attempts to produce aluminum alloy matrix composite with reinforcement of uncoated carbon fibers by SPS technique were unsuccessful, which was mainly due to the poor wetness between the fibers and the semi-liquid aluminum alloy. In order to solve the problem of the unwettability of carbon fibers with aluminum alloy and inhibit the interface reaction, Cu was coated on the surface of carbon fiber woven by electroplating method. According to the thermodynamic analysis, Cu would not react with carbon at even very high temperature. Moreover, as a strengthening element of ZL205A alloy, the introduced Cu element would not weaken the strength of material as impurity. Meanwhile, the good ductility of Cu can make a contribution to the immersion of aluminum into carbon fibers and obtaining composite with high compactness. The composition of the plating liquid was 150 g/L copper sulfate with 50 g/L sulfuric acid. The electroplating process was carried out for an appropriate time to obtain Cu coating with thickness of about 50 μm. Fig. 1(c) shows the Cu coating on the surface of carbon fiber woven.

2.2. Fabrication of the C_f/Al composite

SPS was chosen to fabricate C_f/Al composite. The laminar preform, with structure of alternate Cu-coatedwoven carbon fiber layers and aluminum alloy sheets, was put into a graphite die and sintered at 753 K for 15 min with a heating rate of 50 °C/min and a maintained pressure of 50 MPa. With the aim to prevent materials from carbonization and sticking to the inner wall of the die during sintering process, the preform was covered by thin layers of graphite and molybdenum. After sintering, the graphite and molybdenum layers were removed from the surfaces of the C_f/Al composite. Fig. 1(d) shows the obtained C_f/Al composite. The thickness of each aluminum alloy layer was about 1 mm. Fig. 2 shows the schematic diagram of the structure of the laminar preform during SPS process and the direction of the stress applied on the preform.

2.3. Measurements

Metallographic samples from the composite produced were cut from transverse directions to carry out the examinations. Scanning electron microscope (SEM) was used to reveal the microstructural features. The phase analysis was tested by X-Ray diffraction (XRD). The interface characteristics analyses were performed around the fibers by transmission electron microscopy (TEM).

The quasi-static properties of the C_f/Al composite were tested by a conventional testing machine with a strain rate of $10^{-4}\ s^{-1}$ at room temperature. Considering the applications on aerospace and military vehicles, the dynamic compressive properties of the composites were also examined. The dynamic tests were