Journal of Materials Processing Technology 231 (2016) 366–373

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

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

Fabrication process and bending properties of carbon fibers reinforced Al-alloy matrix composites

Junjia Zhang, Shichao Liu, Yiping Lu, Yong Dong, Tingju Li*

School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China

ARTICLE INFO

Article history:
Received 5 August 2015
Received in revised form
21 December 2015
Accepted 11 January 2016
Available online 15 January 2016

Keywords:
Al-matrix composite
Woven carbon fibers
Electroless plating
Electromagnetic casting
Defects
Bending strength

ABSTRACT

Woven carbon fibers reinforced Al–Mg (95–5 wt%) matrix composites were successfully prepared by an electromagnetic casting method. In order to improve the wetting behavior, different stabilizers were respectively used in the electroless plating process to coat the fibers with a better Ni/P layer. The lactic acid offered the most outstanding stabilizing effect. The casting results indicated that the contact time between the molten metal and the carbon fibers was vital to the bonding degree: increasing the solidification time significantly reduced the cavity defects which located near the interface; however, an overly long solidification time would result in a tendency to crack in the centers of the woven fibers. The hot-pressing treatment with optimum parameters significantly mitigated the crack and cavity defects which are common in the composite prepared through casting method. The appropriate applied compression ratio turned out to be approximately 6%. Three point bending test showed that the bending strength of the composite had an improvement for 33.6% than that of Al-alloy matrix.

© 2016 Published by Elsevier B.V.

1. Introduction

Carbon fibers reinforced Al-matrix composites (CFRACs) were reported by Hajjari et al. (2010) to have lots of excellent mechanical and physical properties. Based on previous literatures, Rams et al., 2007 noted that the poor wettability and the harmful chemical reaction seriously limited the industrial application of CFRACs. One commonly used solution to overcome these problems is the deposition of coatings on the carbon fiber surface. Urena et al. (2007) reported that Cu coating could obviously improve the wettability and reduce the alloying element micro-segregation in the matrix. Sanchez et al. (2010) evaluated the effect of Ni coating in the fabrication. It showed that with the presence of this coating, the carbon fibers were easily wetted by molten Al and the undesired reaction of Al_4C_3 formation was significantly inhibited.

Development of the fabrication process is another research hotspot. Squeeze casting method was successfully adopted by Hajjari et al. (2010), and 30 MPa was proved to be the appropriate pressure. Daoud (2005) fabricated 2014 Al-30 vol.% carbon fibers composite using a gas pressure infiltration method. The results indicated that the application of pressure could force the liquid metal attaching closely to the carbon fibers, which effectively increased the interface bonding degree of the composites. Ultrasonic infiltration method was successfully used by Matsunaga et al. (2007) to prepare continuous M40J carbon fibers reinforced Al–Mg matrix composite wires. The ease of infiltration of the molten alloys was found to be proportional to the maximum intensity of the acoustic cavitation, and the addition of surfactant elements could enhance the infiltration ability of molten Al. Yet, the size of the samples obtained by above methods is all limited by the production equipment. It is still difficult to prepare bulk composites and maintain efficient production, as reported by Alhashmy and Nganbe (2015). The shear strength of the carbon fibers is poor, the fibers are easy to be damaged during the strengthening process. Hence, it is of high practical value to develop a convenient method to prepare bulk composite samples, as well as the matching strengthening technology.

Because of the mutual restriction between longitudinal and latitudinal direction fibers, the woven carbon fibers could remain in good distribution in the composites and fiber clustering is inhibited, as reported by Qiurong et al. (2014). The addition of Mg element in the Al-matrix could improve the wettability obviously, according to Kimura et al. (1984), and also inhibit the formation of the Al_4C_3 brittle phase, as report by Zhang et al. (2015a). Therefore, the woven carbon fibers reinforced Al–Mg (95–5 wt%) matrix composites were chosen as research materials. With the high specific strength and good ductility, they are expected to have a specific applications possibility in the aerospace and automotive industries, such as the

* Corresponding author. Fax: +86 411 84708940.
E-mail addresses: luyiping@dlut.edu.cn (Y. Lu), tjuli@dlut.edu.cn (T. Li).

http://dx.doi.org/10.1016/j.jmatprotec.2016.01.007
0924-0136/© 2016 Published by Elsevier B.V.

aircraft skin and the automobile hub. Since the woven structure could offer a reinforcement effect in two-dimensional direction, the composites are also expected to be used in the pressure vessel. Chen et al. (2014) found that applying a pulsed magnetic field (PMF) could produce the magnetic pressure to the molten metal. This pressure was introduced in the solidification process to improve the infiltrating ability of the Al–Mg (95–5 wt%) matrix. A hot-pressing treatment were then adopted in the strengthening process to reduce the common casting defects such as cracks and cavities.

2. Experimental procedure

2.1. Material and pre-treatment

Commercial pure Al and Mg (99.7 wt%) were used as raw materials to prepare the experimental Al–Mg (95–5 wt%) alloy. Plain weave polyacrylonitrile-based woven carbon fibers (T-300) produced by the Institute of Coal Chemistry, Chinese Academy of Sciences, were selected as the reinforcement. The woven carbon fiber had approximately 3000 fibers per bundle.

According to previous report (Zhang et al., 2015b), the woven carbon fibers were placed in a furnace for 45 min under 773 K to eliminate epoxy resin glue. After the original fiber surfaces were fully exposed, the electroless plating process was conducted, including etching, sensitization, activation and deposition. Table 1 shows the experiment reagents and parameters. In the deposition stage, six common stabilizers, (a) potassium sodium tartrate, (b) sodium citrate, (c) propionic acid, (d) boric acid, (e) sodium acetate, and (f) lactic acid, were used. Sulfuric acid and sodium hydroxide maintained a PH value close to 4. The coating morphologies were observed by a scanning electron microscope (SEM). An energy dispersive spectrometer (EDS) was used to analyze the micro-components. Afterwards, six regions with 100 μm diameter were random selected from each coatings. The P content of the selected regions were measured by an Electron Probe Microscopic Analyzer (EPMA).

2.2. Fabrication and measurement

The pre-heated woven carbon fibers (673 K) were fixed in the pre-heated graphite mold (993 K). The molten Al–Mg (95–5 wt%) alloy (993 K) was poured into the mold. The solidification process was conducted under a PMF, and more details of the applied fabrication method can reference Zhang et al. (2015a). Different thickness of asbestos were covered on the mold to control the solidification times around 100 s, 300 s, 500 s, and 700 s, respectively. Samples with a 10 mm thickness were cut from the composites. Then, they underwent a hot-pressing treatment at 773 K. Compression ratios of 3%, 6%, 10%, 15% were chosen, respectively.

The mechanical properties of the samples were analyzed by a three-point bending test with a span length of 20 mm and a crosshead speed of 1.2 mm min^{-1}. Samples (with dimension of 50 mm × 10 mm × 3.5 mm) were cut from the composite and the matrix without the reinforcements. SEM was used to reveal the features of the failure samples.

Table 1
Reagents and parameters used in electroless plating.

Step	Stage	Reagent	Temperature
1	Etching	50 g/L H_2SO_4,200 g/L$(NH_4)_2S_2O_8$	313 K
2	Sensitization	15 g/L $SnCl_2$,40 mL/L HCl,Sn	303 K
3	Activation	0.5 g/L $PdCl_2$,10 mL/L HCl	323 K
4	Deposition	20 g/L NaH_2PO_2 H_2O,20 g/L $NiSO_4$, Stabilizer	333 K

3. Results and discussion

3.1. Ni/P coating on carbon fibers

In order to achieve a better solution stability, six common stabilizer were respectively used in the plating process. The results showed that potassium sodium tartrate or sodium citrate had no stability effects to the solution, and the plating solution turned to turbid only 5 min after the deposition reaction starting. When the coated fibers were cleaned under ultrasonic agitation, there are many grey powders of Ni/P separating from the coatings, which made the cleaning water become turbid. It suggests that much of the coating layers are made up of the adsorption of Ni/P particles which generates in the solution, rather than made up of Ni/P crystalline grain which in-situ generates and grows up on the fiber surface. When propionic acid or boric acid was used as the stabilizer, the plating solution could maintain clear for about 20 min. Among all stabilizers, lactate and sodium acetate offer the best stable effects. They could keep the plating solution clear for more than 60 min. No Ni/P powders were observed to separate from the coatings during ultrasonic cleaning, which indicates a strong combination in the coatings. The EPMA results show that all coatings consist of only Ni and P elements; when lactic acid or sodium citrate is used, the coatings has the lowest P content at 10.2 wt%, as shown in Fig. 1. As reported by Yu et al. (2001), the lower P content is, the higher Ni_3P formation temperature would be. The Ni/P coating obtained using a lactic acid or sodium acetate as stabilizer is optimal for future casting processes.

Fig. 2 shows the surface characteristics of the uncoated fibers (Fig. 2a), as well as the morphologies of the coated ones obtained using lactate as stabilizer (Fig. 2b–d). There are many gullies on the original fibers, and these gullies are all filled up with the Ni/P deposition after plating process. The coating would obviously improve the wetting behavior by reacting with the Al–Mg (95–5 wt%) matrix. The morphologies of the Ni/P layer obtained after 45 min metallization, is shown in Fig. 2(c,d). It shows a smooth and uniform morphology. The thickness of the coating is about 0.5 μm, which would offer the coating a best continuity on the carbon fiber surface, as reported by Ramesh et al. (2009).

3.2. Electromagnetic casting

Fig. 3 shows the cross-section morphologies of the composite samples with different solidification times. When the matrix metal solidification time is 100 s, an obvious segregation region around the woven carbon fibers (light color section) can be easily observed in Fig. 3(a). EDS analysis shows that this region is mainly consisted of Al (57.59 wt%) and Ni (36.14 wt%) elements plus a small quantity of Mg (3.72 wt%) and P (2.55 wt%) elements. This high content of Ni element is related to the insufficient diffusion of the reaction product Al_3Ni phase. While, there is few Ni atoms (lower than 1 wt%) detected in the matrix region. Many cavity defects are located across the interface between the segregation region and the matrix, as shown in Fig. 3(a). It strongly suggests that the cavities are caused by the significant difference in the composition. As the solidification time of Al alloy increasing to 300 s, which is long enough for the Al_3Ni phase diffusing into the matrix, the segregation region and the cavity defects almost completely disappear. A uniform interface between the matrix and the reinforcement is observed in Fig. 3(b). The magnified micrograph also implies that the alloy infiltrates the carbon fiber interstices and has a good fiber adherence.

When the solidification time increases to 500 s, many tiny cracks are detected in the woven fiber interior, as shown in Fig. 3(c). This cracking tendency is enhanced and concentrated with the further increased solidification time. At 700 s, only one serious crack defect

Download English Version:

https://daneshyari.com/en/article/7176762

Download Persian Version:

https://daneshyari.com/article/7176762

Daneshyari.com