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Interface study of carbon fibre reinforced Al–Cu composites

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ABSTRACT

The application of continuous carbon fibre-reinforced aluminium matrix composites (C_f/Al) in aerospace, automobile, and electric power cable industries is of considerable interest because of their high specific strength, specific modulus, and low coefficient of thermal expansion. In this paper, we report the study on the alloy contribution to the interface of a carbon fibre reinforced aluminium alloy matrix composite. The composites were produced using squeeze casting technology. An Al–Cu alloy was used as the matrix material. Detailed investigations revealed that the aluminium alloy melt fill in the gaps between fibres. The important feature is that the solidification microstructure of Al–Cu matrix alloy is altered by the presence of carbon fibre. The surface of carbon fibre acts as the nucleation site of Al_2Cu phase. Al_2Cu phase prefers to form at the interface between carbon fibre and Al–Cu alloys. Ni coated on carbon fibre does not change the feature.

1. Introduction

Carbon fibre (C_f) reinforced aluminium matrix composites are of great interest because of their high specific strength and stiffness, low coefficient of thermal expansion, and high thermal/electrical conductivity [1]. These advantages make them potential structural and functional materials in such as automotive and aeronautic applications [2]. Some different techniques have been developed to fabricate such composite materials, such as squeeze casting, metal spray and metal infiltration [3].

However, the poor wetting characteristics of carbon by liquid aluminium and reaction of carbon fibres with some aluminium alloys hindered the development of Al/C_f composites [4]. Improper wetting and chemical reactions at the interface during synthesis or under service conditions can degrade the mechanical properties of the composites. The reaction at the carbon–aluminium interface when produced in liquid state was also considered to affect critically the strength of Al/C_f composites [5] by influence the load transfer from fibre to matrix. Formation of Al_4C_3 may deteriorate the strength of carbon fibre. However, the liquid processes have several advantages on other production routes, such as high production rate, low cost and potential of production of complex parts are some of them.

Though many investigations [6–10] have been concentrated on fabrication, tensile properties and fracture behavior of Al reinforced with continuous carbon fibre, not too much attention has been paid on the influence of alloy matrix. Therefore, in this investigation, an attempt has been made to elucidate the influence of the alloy on the microstructure of aluminium matrix composites produced by squeeze casting method.

2. Experimental

The matrix aluminium alloy used in the present study is an Al–Cu alloy. Table 1 presents the chemical composition of the alloy. Carbon fibre used in the present study is T-300, with a diameter of 7 μm (Fig. 1a). The volume fraction of carbon fibre is 40%. Squeeze casting was performed on a YA32-200A hydraulic presser with a maximum pressure of 2000 kN. The parameters of squeeze casting were as follows: Al–Cu melt casting temperature is 730 °C; preheat the casting mould to 550 °C before casting; squeeze pressure is 100 MPa; pressure holding time is 2 min. Surface treatment of carbon fibre by Ni electroplating (Fig. 1b) was performed to study the contribution of surface treatment of carbon fibre during squeeze casting.

The microstructure characterization of produced specimens was performed on a Hitachi S-4700 scanning electron microscope. The phase determination was carried out on a Rigaku D-max-rB X-ray diffractometer (XRD) with a Cu target (λ = 0.15418 nm).

3. Results and discussions

Fig. 2 shows the microstructure of matrix Al–Cu alloy. Al grains are very coarse (roughly 100–300 μm) with some eutectic structure (bright phase). EDS analysis revealed that the bright grey phase is Al_2Cu phase (Al:Cu = 67.3:32.7). XRD analysis confirmed that the alloy is composed of Al phase and Al_2Cu phase (Fig. 3).

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Table 1
Chemical composition of Al alloy used as matrix.

Element	Cu	Mn	Ti	Ca	Zr	V	B	Al
Concentration (wt.%)	4.6–5.3	0.3–0.5	0.15–0.35	0.15–0.25	0.05–0.20	0.05–0.3	0.005–0.06	Balance

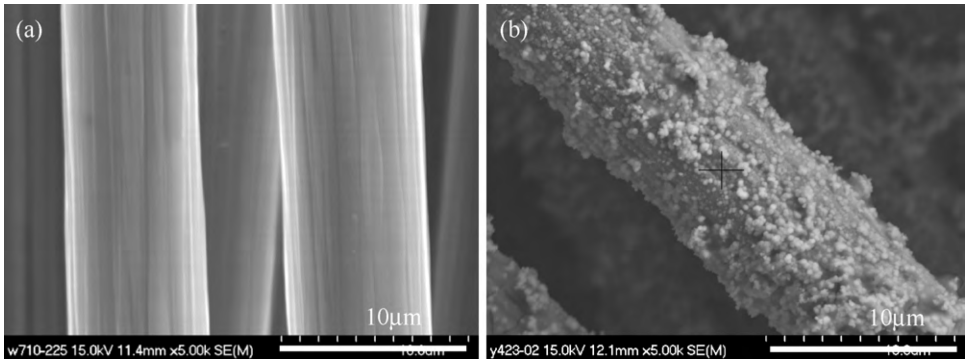

Fig. 1. SEM images of carbon fibre used in the present study: (a) without and (b) with Ni coating.

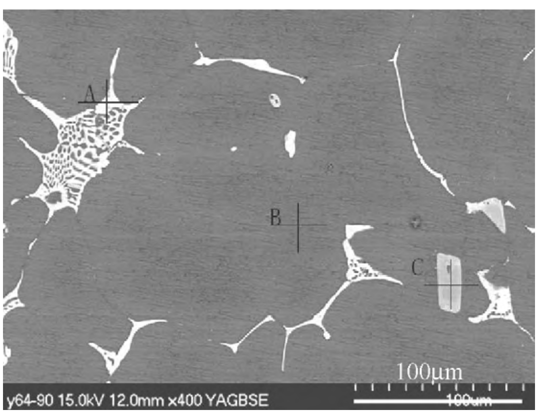

Fig. 2. BSE image showing microstructure of Al–Cu matrix alloy. Al matrix (B) and eutectic structure can be identified (A region). Region C is Al enriched with Ti and V.

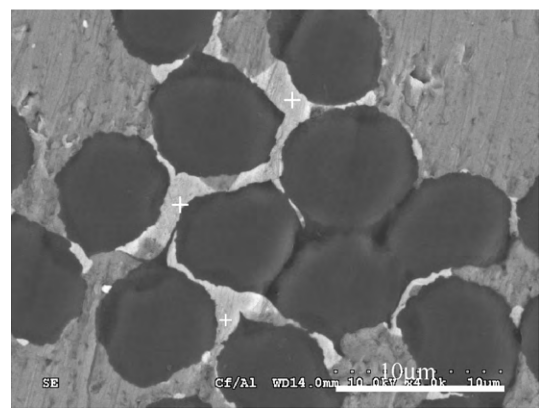

Fig. 4. SEM image showing microstructure of C_f/Al composite with carbon fibre not coated with Ni. Al_2Cu phase around carbon fibre is clearly shown (the bright region as cross indicated).

Fig. 4 shows the microstructure of squeeze cast C_f/Al composite. It was found that Al matrix appears grey while carbon fibre appears dark. Between carbon fibre and Al matrix there exist bright grey phase which was characterized as Al_2Cu phase by EDS analysis. XRD analysis also confirmed the existence of Al_2Cu phase (see Fig. 5). The diffused peak around 26° is determined as carbon. It has been studied previously that during the solidification of this Al–Cu alloy, Al phase solidifies at higher temperature and the low melting point eutectic forms between the Al grains at lower temperature [11,12]. It seems that the Al_2Cu phase prefers to form around carbon fibre,

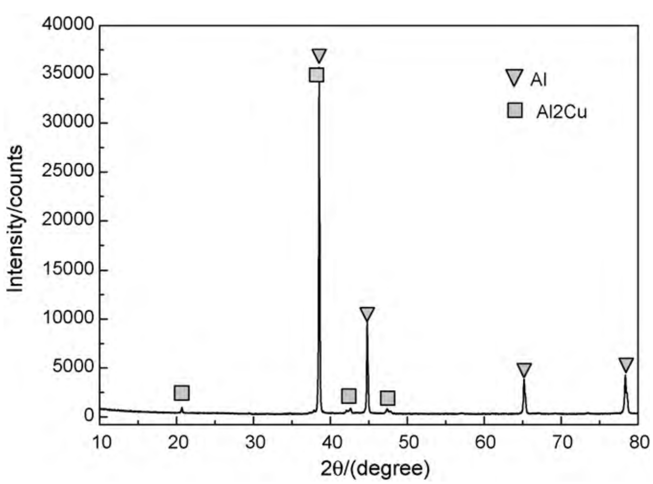

Fig. 3. XRD pattern of Al–Cu matrix alloy. Al and Al_2Cu phases were determined.

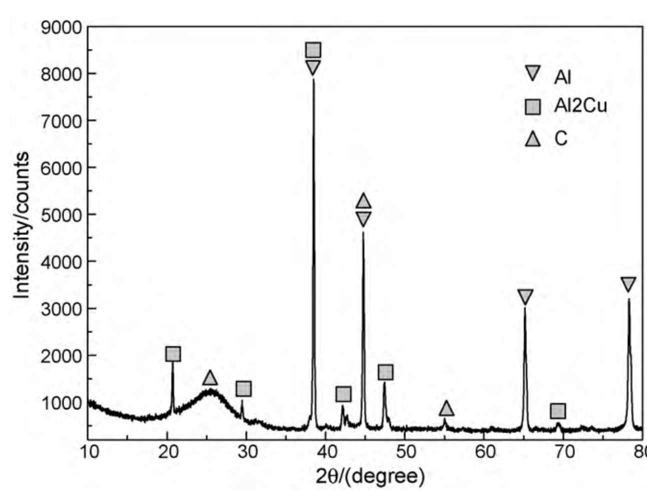

Fig. 5. XRD pattern of C_f/Al composite with carbon fibre without Ni coating. Carbon, Al and Al_2Cu phases were determined.

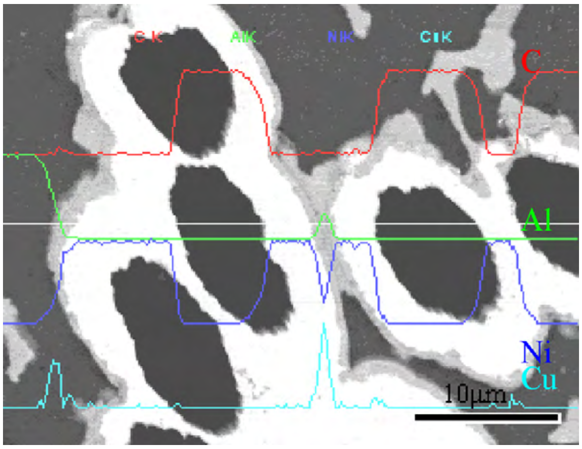

Fig. 6. EDS ling scanning (white horizontal line) showing the microstructure of C_f/Al composite with carbon fibre coated with Ni. Ni (white region) around carbon fibre (black oval) and Al_2Cu phase (bright grey region surrounding Ni region) around Ni are clearly shown.

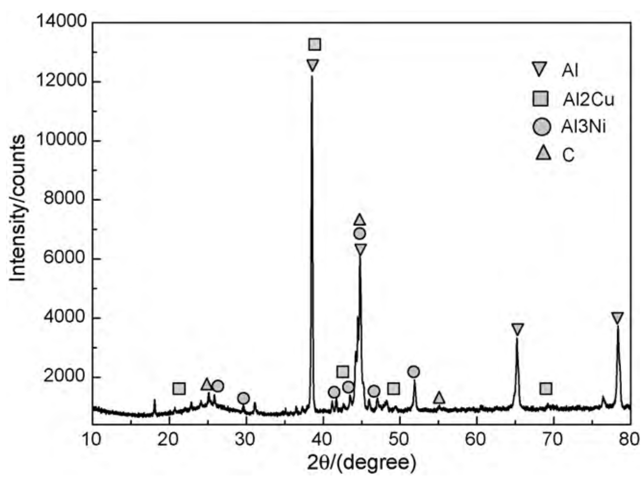

Fig. 7. XRD pattern of C_f/Al composite with carbon fibre with Ni coating. Carbon, Al, Al_2Cu and $NiAl_3$ phases were determined.

and therefore, the eutectic structure was reduced and eliminated around carbon fibre. No Al_4C_3 phase was detected in this sample.

Fig. 6 shows the microstructure of squeeze cast C_f/Al composite with carbon fibre electroplated with Ni. It was interesting to notice that C_f/Al composite with carbon fibre electroplated with Ni shows similar microstructure to that with carbon fibre without Ni coating. Al_2Cu phase tends to form around carbon fibre preferentially. EDS line scanning revealed the existence of Ni coating and Al_2Cu phase. The eutectic structure was reduced and even eliminated as well around carbon fibre. However, one evidently different phenomenon is the formation of $NiAl_3$ phase (see XRD patterns shown in Fig. 7). It is apparently from the reaction between electroplated Ni and Al melt during solidification. The formation of Al_4C_3 phase was not observed. The reaction between carbon fibre and Al melt was hindered.

From the results above presented, it is found evidently that for Al–Cu alloy the introduction of carbon fibre significantly change the microstructure of matrix alloy. The eutectic structure was reduced and even eliminated around carbon fibre. Al_2Cu phase tends to form around carbon fibre no mater the carbon fibre is coated by Ni or not. It is suggested that carbon fibre supplies the nucleation of Al_2C phase during solidification process. Similar behaviour has been found in other carbon fibre reinforced Al alloys [12,13]. It is therefore believed that the control of matrix alloy composition and microstructure is also critical to the microstructure and properties of the composite.

4. Conclusions

Investigation on the squeeze cast C_f/Al–Cu composite revealed that carbon fibre supplied preferential nucleation sites for Al_2Cu phase to form around carbon fibre during solidification. The characteristic eutectic structure of Al–Cu matrix alloy was reduced and eliminated. The surface treatment with electroplated Ni of carbon fibre does not change this feature at all. But the existence of Ni coating leads to the formation of $NiAl_3$ phase by the reaction of Ni with Al melt.

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