International Journal of Modern Physics B
Vol. 33, Nos. 1–3 (2019) 1940044 (9 pages)

DOI: 10.1142/S0217979219400447

Electroplating and brazing joining of 5083 aluminum alloy to CFRP

K. Guo*, Y. Liu*, G. Gou*,¶, W. Zhang†,
W. Gao‡ and Wanjng Wang§

**Key Laboratory of Advanced Technologies of Materials,
Ministry of Education China, Southwest Jiaotong University,
Chengdu 610031, P. R. China*

*†State Key Laboratory of Material Processing
and Die & Mould Technology,
Huazhong University of Science and Technology,
Wuhan 430074, P. R. China*

*‡Department of Chemical and Materials Engineering,
The University of Auckland, PB 92019,
Auckland 1142, New Zealand*

*§CRRC Qingdao Sifang Co. Ltd,
Qingdao 266000, P. R. China*

¶gouguoqing1001@163.com

Received 1 July 2018
Revised 30 August 2018
Accepted 15 September 2018
Published 11 January 2019

This study has analyzed the welding joint of carbon fiber reinforced plastics (CFRP) and aluminum alloys. The surface of CFRP and 5083 Al alloy was modified by electroplating with nickel at first. Then the effect of electroplating parameters on coating was explored. SEM images revealed that the coating gradually became well but then began to fall off with the current density and the plating time increased. CFRP and aluminum alloys were brazed at 285°C and held for 20 s. Shear test was used to evaluate the strength of the joint and the strength was probably 7.56 MPa. SEM and EDS tests showed that there existed diffusion of the elements in the welding process and the joint reached the bonding of atomic or molecular sizes. Thus, this experiment achieved the tight brazing joining between thermoset CFRP and aluminum alloys providing the joining method of the application for CFRP.

Keywords: 5083 Al alloys; CFRP; electroplating; brazing.

PACS numbers: 81.15.Pq, 81.20.Vj

¶Corresponding author.

1. Introduction

In order to reduce weight and save energy, carbon fiber reinforced plastics (CFRP) is the focus of recent research due to their excellent mechanical properties and low density.[1–3] Aluminum alloys have high specific modulus and specific strength. Limited by the properties of CFRP and processing equipment, CFRP is usually necessary to connect with metal.[4] Traditional connection methods include adhesive connection and mechanical connection, however, the joints experience aging or stress concentration problems.[5] The previous welding connection study most focused on the thermoplastic CFRP and these technologies included ultrasonic welding,[6] laser joining[4,7,8] and friction lap joining.[9] Jung *et al.*[8] researched on the laser welding between CFRP and A5052, and the shear test results showed the lap joint strength was about 8 MPa. The principle of the connection was the secondary melting of the resin under the effect of the heat source. The resin of thermosetting CFRP which is widely used in high-speed trains and aircrafts is epoxy and its pyrolysis is very low. Melting welding will damage the resin of CFRP by high temperature, so the brazing method is adopted.

In this paper, the surface of CFRP (thermosetting, epoxy) was modified by electroplating with nickel, and then A5083/CFRP brazed joint was investigated; the joining quality of CFRP and 5083 Al alloy was evaluated by shear test; the joint fracture morphology and the element distribution were observed.

2. Material and Experimental Techniques

The chemical composition of 5083 Al alloy is listed in Table 1. The CFRP used in the paper is composed of epoxy resin with the volume fraction of 40% and

Table 1. Chemical composition of A5083-LF4 aluminum alloy.

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
A5083-LF4	0.40	0.40	0.10	0.40–1.0	4.0–4.9	0.05–0.25	0.25	0.15	Bal.

Table 2. The composition and basic information of CFRP.

Material	CF weave	Resin	Forming method	Tensile strength
CFRP	Plain and twill	Epoxy (5028A/5028B)	Vacuum import	600 MPa

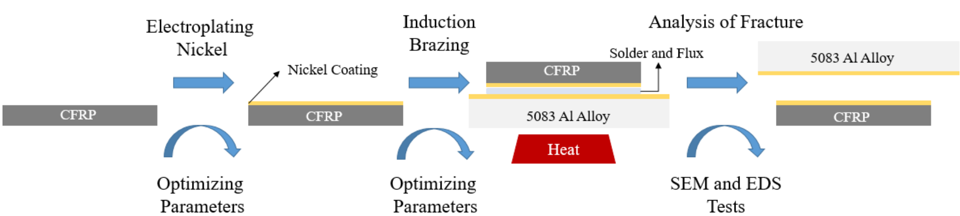


Fig. 1. (Color online) Experimental process list.

T400 carbon fiber with the volume fraction of 60%. The specific composition and basic information of CFRP are listed in Table 2. The CFRP used for joining was 12 mm × 20 mm × 3 mm and the A5083 plating was 50 mm × 30 mm × 3 mm. The experimental process is shown in Fig. 1.

2.1. *Base materials*

2.2. *Electroplating nickel process*

In the brazing process, the solder was hard to spread out on the surface of CFRP, so electroplating nickel process was applied to metalize CFRP. The CFRP need to be sanded first because the colloid on the surface would hinder the deposition of Ni^{2+}. Then it was soaked in acetone for 12 h and soaked in dilute nitric acid for 20 min, which could improve the surface activity and hydrophilicity.

The experimental equipment is shown in Fig. 2. Ni^{2+} was deposited on the CFRP under the effect of electrical energy. The optimal bath composition and conditions of the electroplating nickel process on the surface of CFRP were: $NiSO_4$ (270 g/L), $NiCl_2$ (70 g/L), H_3BO_3 (40 g/L) and $CH_3(CH_2)_{11}OSO_3Na$ (0.3 g/L), temperature 50°C. The plating current density was set to be 2.0 A/dm^2 and the plating time was 10 min for CFRP. Current density was set to be 1.0 A/dm^2 and time was 5 min for 5083 Al alloy. After the electroplating process, the effect of electroplating process parameters on the coating was explored by SEM (JSM-6490LV QUANTA FEG 250), and the element distribution of CFRP surface coating was investigated by EDS (GENESS 2000XMS).

2.3. *Brazing joining A5083 to CFRP*

Induction brazing equipment (HFP-50A) was applied to join 5083 Al alloy to CFRP. In the experiment, CFRP was placed above the Al alloy, and the infrared thermometer scanned on the surface of Al alloy to monitor temperature (Fig. 3). In the welding process, the induced electromagnetic field generated eddy currents on the base materials to provide heat. Solder (Sn-9Zn, 91.2 wt.% Sn) and flux (90 wt.%

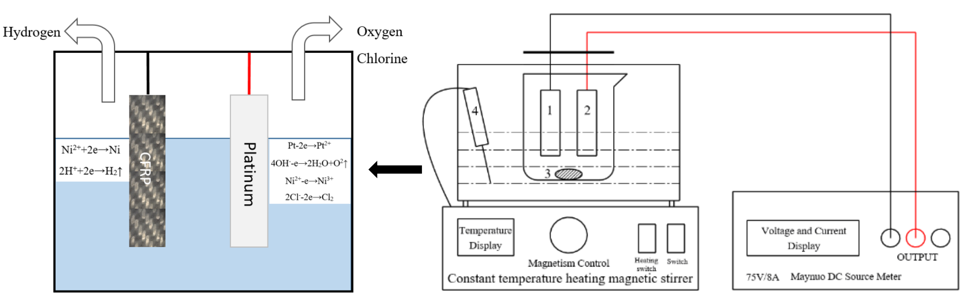


Fig. 2. (Color online) Electroplating nickel experimental equipment for CFRP (1: CFRP, 2: Platinum, 3: Magnet, 4: Resistance heating).

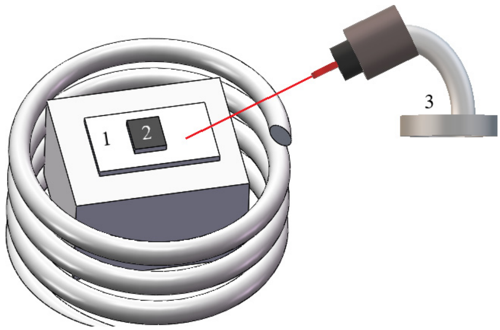


Fig. 3. (Color online) Induction brazing test equipment for joining Al alloy to CFRP (1: 5083 Al alloy, 2: CFRP, 3: Infrared thermometer).

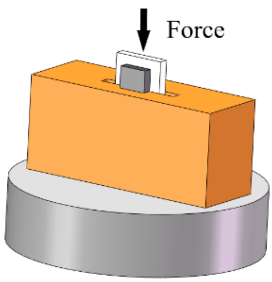


Fig. 4. (Color online) Equipment of shear test.

$ZnCl_2$, 8 wt.% NH_4Cl, 2 wt.% NaF) were melted by the heat source, and the molten solder connected the A5083 and CFRP to form a tight joint. The temperature was set to be 285°C and the holding time was 20 s. Shear test was used to evaluate the strength of the dissimilar joint by shear testing equipment (CMT4304) which is shown in Fig. 4, and EDS and metallography were applied to observe the fracture morphology and element distribution of the joints.

3. Results and Discussion

3.1. *Effect of parameters in the electroplating nickel process*

Figure 5 shows the effect of current density on microscopic morphology of Ni Coatings. Current density changed and the plating time was maintained for 20 min. When the current density was low, the coating formation rate was low so the coating was sparse [Fig. 5(a)]. As the current density increased, the thickness of the coating became thicker [Figs. 5(b) and 5(c)]. However, when the current density was rather high, the coating would fall off [Fig. 5(d)]. The bath was an acidic environment (pH 3.0–3.5), when the current density increased, the additional reaction such as hydrogen evolution also increased, and the hydrogen gas adsorbed on the surface of the coating causing partial coating to fall off.

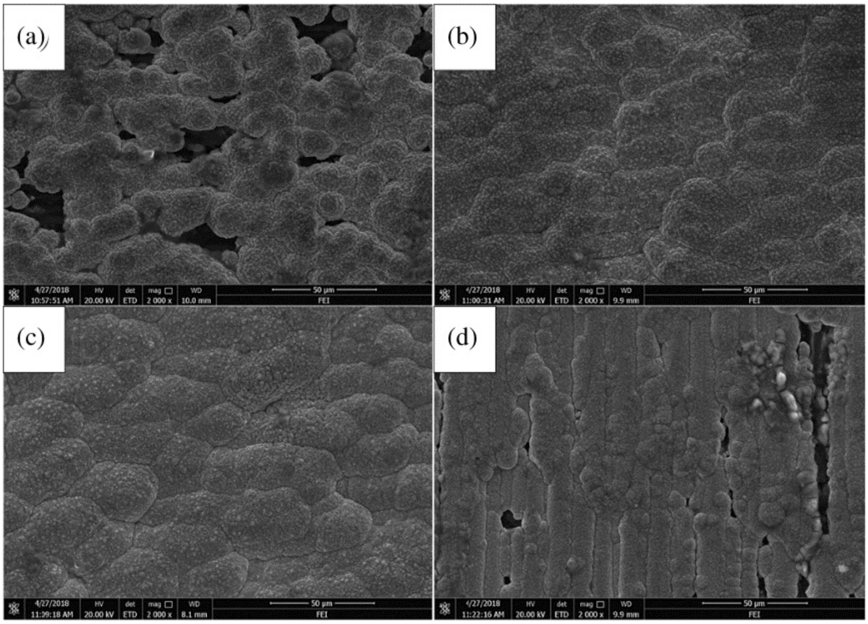


Fig. 5. SEM images of Effect of current density on Ni Coatings: (a) 2.0 A/dm^2, (b) 4.0 A/dm^2, (c) 8.0 A/dm^2 and (d) 12.0 A/dm^2.

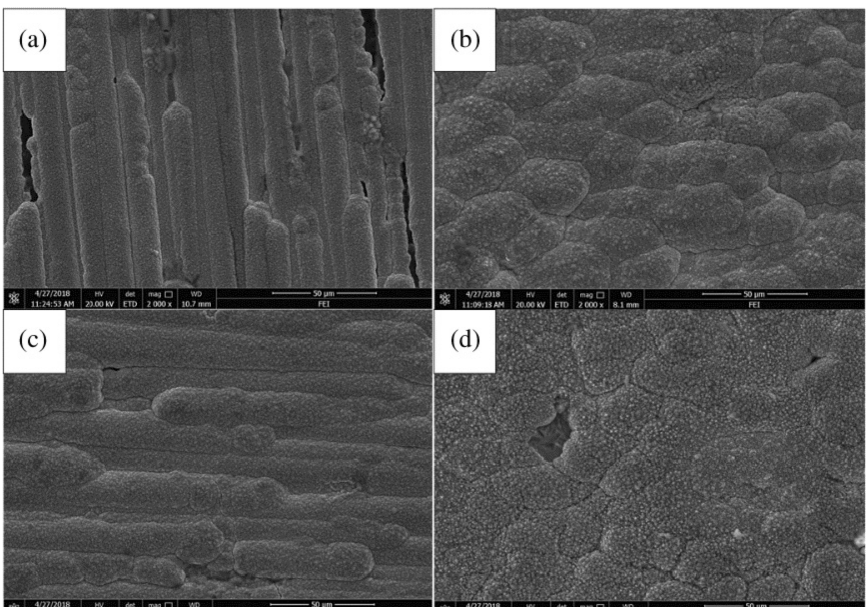


Fig. 6. SEM images of Effect of plating time on Ni Coatings: (a) 10 min, (b) 20 min, (c) 30 min and (d) 40 min.

Figure 6 shows the effect of plating time on SEM images of nickel coatings. Plating time changed and the current density was maintained for 8.0 A/dm^2. Nickel coatings became dense as the plating time increased [Figs. 6(a)–6(c)], but irregularly shaped crystals appeared on the surface when the plating time was over [Fig. 6(d)].

3.2. *Element distribution and growth mode of nickel coating*

A line was selected on the coating to perform semi-quantitative analysis of the element, and the EDS test results showed that the used most element in the coating was nickel, but other elements of the plating solution such as O, S, Al, Fe and Co

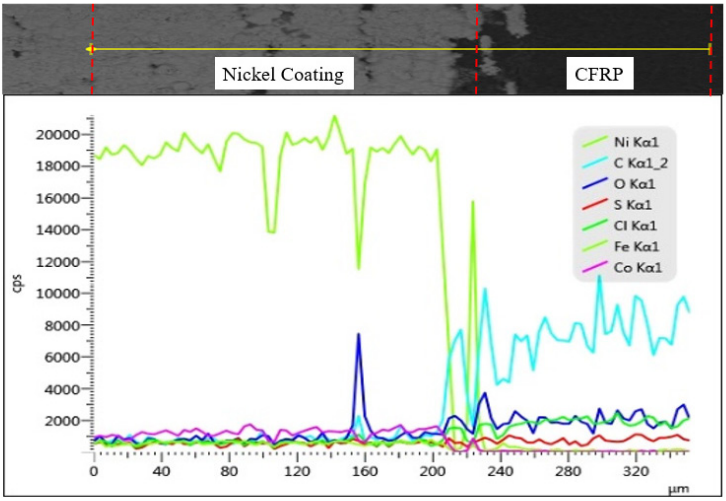


Fig. 7. (Color online) Element distribution of CFRP surface nickel coating (0–220 μm referred to coating, 220–320 μm referred to CFRP).

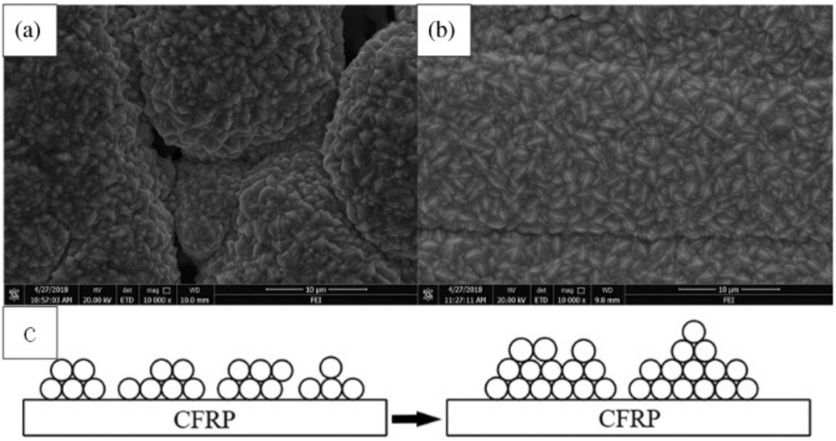


Fig. 8. Growth form of nickel coating on the CFRP: (a) and (b) SEM images, (c) physical model.

still existed in the coating (Fig. 7). The formation of the nickel coating was a continuous nucleation process [Figs. 8(a) and 8(b)], and the growth mode of the nickel coating presented Volmer–Weber mode[10] [Fig. 8(c)]. The nickel ion particles were first deposited on the surface of CFRP, then gathered to form large particles followed by mesh coating and finally developed uniform coating.

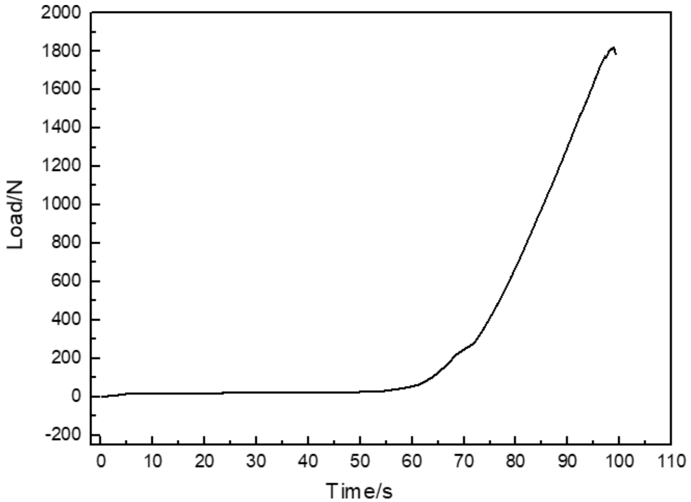


Fig. 9. Results of load-time curve in tensile test of joint between CFRP to 5083 Al alloy.

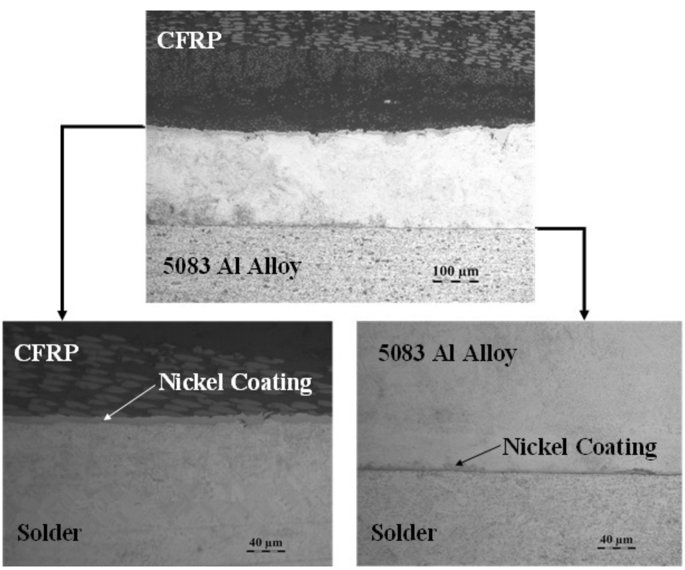


Fig. 10. Cross section of grafted CFRP/5083 Al alloy joint.

3.3. *Shear strength and analysis of A5083/CFRP joint*

The shear test results (Fig. 9) showed that when the contact area was 240 mm^2, the shear strength of CFRP/5083 Al alloy was approximately 7.56 MPa. In Fig. 9, the fracture occurred on the nickel coating of the CFRP and the CFRP, and the solder spread well on both sides of the base material. The cross-sectional photo in Fig. 10 indicates there exist three layers in joint interface, nickel coating layer on CFRP, solder layer and nickel coating on 5083 Al alloy.

In addition, the epoxy was little melted under the heat source impeding the spread of solder (Fig. 10), which resulted in poor joint strength. From the electronic images, there existed some bubbles inside the joint which might be formed by the pyrolysis of the epoxy. The bubbles reduced the contact area of the dissimilar materials and then reduced the joint strength.

The fracture surface was scanned and analyzed by EDS to confirm the bonding between A5083 and CFRP, and the scanned area was the nickel layer of CFRP and the brazing layer (Fig. 12). It was confirmed that the part of solder was detected on Ni enriched in coating on the base material, and the coating on the surface of CFRP was detected on Zn and Sn enriched in solder. When the temperature reached the melting temperature of the solder, the nickel diffused into the solder and the zinc on the solder also diffused to the base metal. Elements produced not

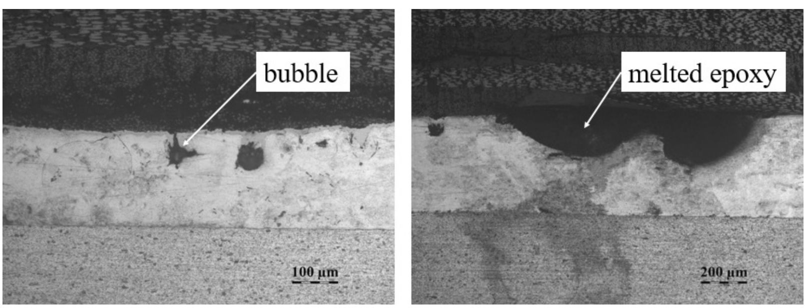
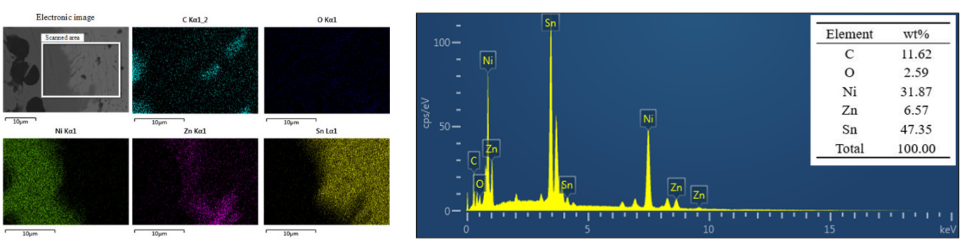


Fig. 11. Defects in joint between 5083 Al alloy to CFRP.



(a) (b)

Fig. 12. (Color online) (a) EDS layered images of different elements and (b) area analysis of nickel coating and brazing layer.

only physical but also chemical reactions in the welding process. It was revealed that the elements were diffused during the brazing process and the joint reached the bonding of atomic or molecular sizes.

4. Summary

The electroplating nickel process on CFRP and the brazing joining between 5083 Al alloy to CFRP have been studied in this paper, and the following conclusions can be drawn:

(1) The CFRP was soaked in acetone for 12 h and soaked in dilute nitric acid for 20 min before electroplating, and coating quality could be controlled by adjusting current density and plating time. The growth mode of nickel coating presented the Volmer–Weber mode.
(2) The brazing temperature was 285°C and the holding time was 20 s. The joint strength was 7.56 MPa, and the fracture occurred on the nickel coating on the CFRP and the CFRP. According to the EDS images, there existed diffusion of the elements and the joint reached the bonding of atomic or molecular sizes.
(3) This experiment achieved the brazing joining between thermoset CFRP and aluminum alloys and the connection principle revealed not only the spread and connection of the solder but also elements' diffusion occurring with chemical reaction.

Acknowledgment

The authors acknowledge the financial support from the National Key R&D Program (No. 2016YFB1200602-16).

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