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Development of Carbon fiber Assisted Universal Joints of Metals and different Metal or polymers (M/M, M/P)

Yoshitake Nishi[†], Hitoki Hasegawa[*], Masataka Tomizawa[*], Shigehito Inui[*], Kazuma Shiraishi[*], Sho Ishii[*], Yoshihito Matsumura[†] and Michell C. Faudree[†]

[*]Department of Materials Science, Tokai University
4-1-1 Kitakaname, Hiratsuka, 259-1292, Japan
west@tsc.u-tokai.ac.jp

[†]Graduate School of Engineering, Tokai University
4-1-1 Kitakaname, Hiratsuka, 259-1292, Japan
west@tsc.u-tokai.ac.jp

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Summary: *A new method with extremely large friction force by broad interface of carbon fiber (CF:6μm-diameter) have been suggested for a joint (M/CF/P and M/CF/M) of carbon fiber (CF) reinforced polymer (P) and metal (M). The new joint part was strengthened by impregnated carbon fiber (CF). The joint tensile strength (σ_B) values of both M/CF/P and M/CF/M joints were tremendously higher than that of the glue joint (M/Glue/P and M/Glue/M) and wrap-casting joint (M/P and M/M). The new joint method by using carbon fiber remarkably improved the σ_B. In order to improves the safety level, the new joint method with extremely large friction force by broad interface of carbon fiber (CF:6μm-diameter) coated by nickel (Ni) to prevent carbides formation and to enhance the ability of fiber rapping by molten metals have been suggested for joints (M/Ni-CF/P and M/Ni-CF/M) of carbon fiber (CF) reinforced polymer (P) and metal (M). The new joints part was strengthened by impregnated nickel-coated carbon fiber. The σ_B values of both M/Ni-CF/P and M/Ni-CF/M joints were tremendously higher than that of the glue joint (M/Glue/P and M/Glue/M) and wrap-casting joint (M/P and M/M). In addition, Ni coating improves the decreased the experimental errors. Since the new joint part was strengthened by impregnated carbon fiber (CF), the Charpy impact values (a_{uc}) of M/CF/P joints were tremendously higher than that of the glue joint (M/Glue/P) and wrap-casting joint (M/P). The new joint method by using carbon fiber remarkably improved the a_{uc}, resulting in the high fracture toughness with lightweight. Furthermore, the a_{uc}, of M/Ni-CF/P joints were tremendously higher than that of the glue joint (M/Glue/P) and wrap-casting joint (M/P). In addition, Ni coating improves the decreased the experimental errors. Consequently, the new joint method by using carbon fiber coated with Ni remarkably enhanced the safety level with lightweight and high resistance to fracture toughness of airplane-parts.*

1 INTRODUCTION

Airplanes are dream worthy mover machines. They are constructed with carbon fiber reinforced polymer (CFRP), titanium alloys, aluminum alloys, steels and other materials. The

CFRP is typical light structural materials not only to save the energy, but also to enhance the mobility of aircraft, have been already utilized for dream worthy mover machines as well as airplanes and automobiles [1-3]. CFRP has recently applied to not only wing, but also fan blades of turbo fan engines. To prevent impact fracture, leading edge of titanium is often mounted on the CFRP fan blades by adhesive force. On the other hand, Al alloys are light structural materials to enhance their mobility and to save their energy. Elements of titanium and aluminum, which are utilized for the seat side and aluminum use for the body frame, exhibit the high resistance to corrosion with light weight, as well as specific proof stress. As a result, the joint is currently required in a frame lounge under the seat of A380 type airplane. Since the four conventional joints of rivet connecting, welding, blazing and glue mostly reduce the materials strength, strengthening of fiber-reinforced metals has been expected. Therefore, CFs are used due to their high resistance to pull-out generated by their huge friction force.

Joining processes of carbon fibers to iron [4] have been successfully developed by using percussion welding method, respectively. Furthermore, a copper-aluminum joint process by using carbon fiber reinforced metal, which was carbon fiber felt of 7 mm thickness in Cu-25at%Al alloy [5], has been also developed. Also, if the copper-aluminum welding with light, high strength and high thermal diffusivity is developed, it may be applied for parts of racing car fuel systems to save their energy and to enhance their mobility with large heat sink.

Furthermore, joint of titanium and aluminum is expected to save the weight of an airplane.

In order to enhance the joining strength, a new method to join Metal/Metal and Metal/CFRP with extremely large friction force by broad interface surface area of carbon fiber (CF: 6 μm-diameter) coated by nickel (Ni) has been suggested [6-9]. Since the Ni coating prevents the formations of carbides at Metal/CF interface in both Metal/CF/Metal and Metal/CF/CFRP samples, the high resistance to pull-out carbon fibers has been expected by their huge friction force. Therefore, the purpose of the present work is to evaluate the effects of the new method of the carbon fiber reinforced joints of Metal/CF/CFRP and Metal/CF/Metal on the tensile strength and Charpy impact value.

2 EXPERIMENTAL PROCEDURE

2.1 Preparation of Metal/CF/CFRP and Metal/CF/Metal

The experimental procedure is as follows. When the Ni interlayer surface skin film was coated around CF, it was performed by electrical plating or DC-magnetron spattering device. The 1st step of the welding method was that the CF bundle was contacted and wrapped with molten metal by capillary phenomena before solidification. After solidification, the 2nd step was that other side of the CF bundle was poured and wrapped in the polymers and molten metals. The CF junction device was a CF reinforced composite material and probably acted as one of ideal joint parts.

2.2 Tensile test and Charpy impact test

The joint strength was evaluated by a tensile test. Stress-strain curves were obtained at a constant strain rate of 2.0×10^{-3} s^{-1} using by means of an Instron type tensile machine. In order to evaluate the dynamic fracture toughness, the Charpy impact values were measured by using a standard impact fracture energy measurement system (JIS K 7077-1991) and Charpy impact machine (FC-3002, Fuji-Shikenn seisakusyo, Japan).

Accumulative probabilities (P_B, P_i) by the median-rank method [10] often employed in quality control (QC) are one of the widely used and convenient ways to analyze mechanical probabilities of joint strength [9] and are employed here to quantitatively analyze our

experimental values by the following equation. [10]

$$P = (I-0.3)/(n+0.4) \quad (1)$$

Here, n and I are total number of samples (n = 11) and rank order of each sample from weakest to strongest ($1 < I < 11$), respectively. When the I values are 1, 6 and 11, the P_i values are 0.06, 0.50 and 0.94, respectively.

2.3 EPMA and X-ray diffraction

The morphology was observed and composition distributions of carbon, titanium, aluminum and nickel elements were detected by using a EPMA (SHIMADU EPMA-1610). The X-ray diffraction was measured by using an XRD (Miniflex, Rigaku, Cu-Kα) on 10^{-3} deg/s of scanning rate.

3 RESULTS and DISCUSSION

3.1 Tensile stress-strain curves

As illustrated in Figure 1, the brittle fracture occurs at Ti/Al joint interface of the simple welded joint sample, whereas the ductile fracture occurs at aluminum part in the Ti/Al joint with carbon fiber reinforcement (CFR).

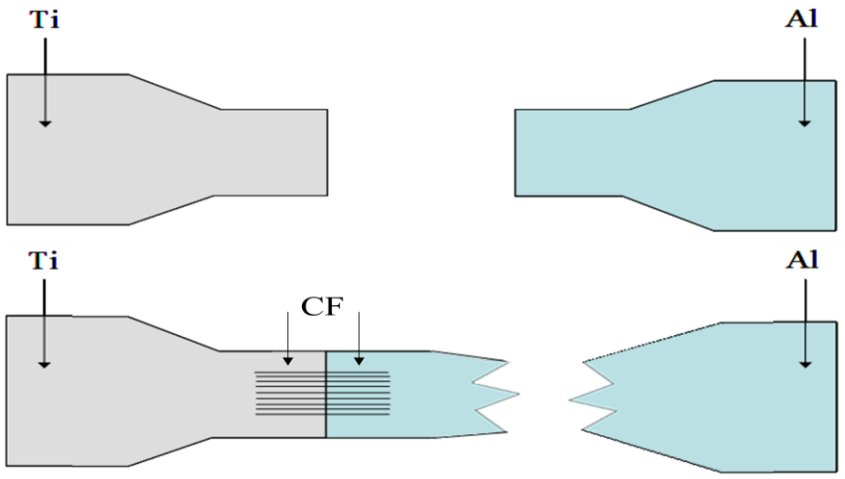

Figure 1 Schematic drawing of fractured form of Ti/Al joints with and without carbon fiber reinforcement.

Based on the SEM, EDS and X-ray diffraction, carbon doesn't largely diffuse in Matrix metals [3]. On the other hand, matrix metal elements cannot detect in carbon fibers [3].

Figure 2 shows stress-strain curves of Ti/Al joints with and without CFR, together with tensile strength (σ_b), its strain (ε_b) and fracture strain (ε_f). The ε_b and ε_f of the CFR-Ti/Al joint with ductile fracture are 1.8 and 2.5 times higher than those of the Ti/Al joint with brittle fracture because of huge static and dynamic friction force induced by the high resistance to pull out narrow carbon fibers, respectively. The carbon fiber reinforcement (CFR) elongates the strain significantly at tensile strength (ε_b) and fracture strain (ε_f).As shown in Figure 2, CFR doesn't increases the tensile strength (σ_b). Since the joint sample is melted and the solidified, the process increases the grain size, resulting in tensile strength decreasing.

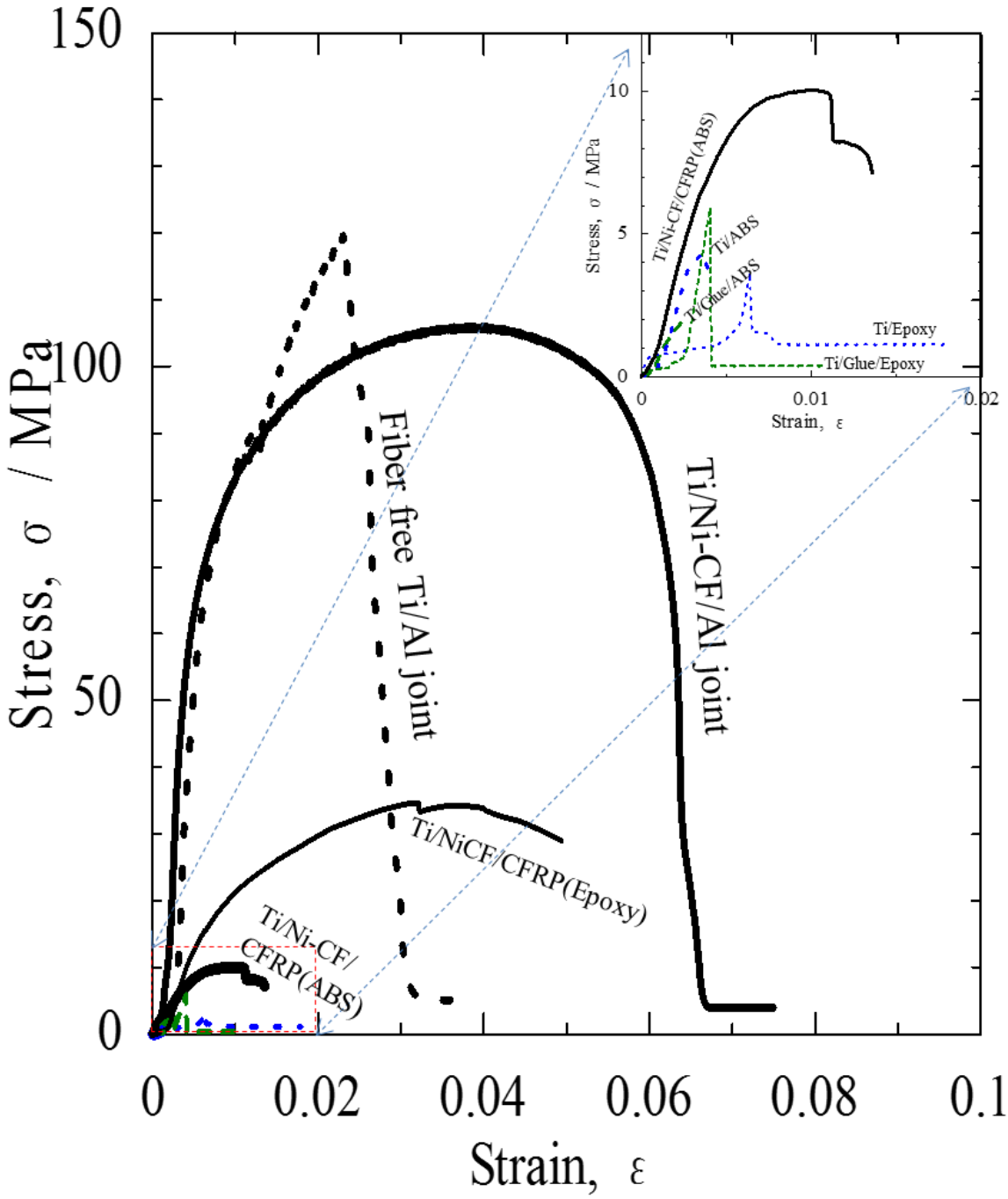

Figure 2 Stress-strain curve of Ti/Al, Ti/CFRP(Epoxy) and Ti/CFRP(ABS) joints with and without carbon fiber reinforcement, together with glue one.

Fine lines in Figure 1 exhibits tensile stress-strain curves of Ti/Epoxy-CFRP joint reinforced by carbon fiber cloth (Ti/NiCF/CFRP(Epoxy); Solid fine line), together with Ti/Epoxy joins with and without glue (Ti/Glue/Epoxy; Broken fine line and Ti/Epoxy; Dotted fine line). The tensile strength (σ_b) and its strain (ε_b) of Ti/NiCF/CFRP(Epoxy) are tremendously (7 +/- 2 times) larger and extremely (6 +/- 2 times) higher than those of Ti/Glue/Epoxy and Ti/Epoxy, respectively. Fat lines in Figure 1 also exhibits tensile stress-strain curves of Ti/ABS-CFRP joint reinforced by carbon fibers (Ti/NiCF/CFRP(ABS); Solid fat line), together with Ti/ABS joins with and without glue (Ti/Glue/ABS; Broken fat line; and Ti/ABS; Dotted fat line), respectively. The σ_b and ε_b of Ti/NiCF/CFRP(ABS) are extremely higher than those of Ti/Glue/ABS and Ti/ABS.

Based on the SEM photograph of Ni-coated carbon fibers before dipping in molten titanium, the carbon fibers were remarkably covered with nickel film with 0.5+/-0.3 μm in thickness [7,8]. When the carbon fiber without Ni-coating has been directly contacted with molten titanium, titanium carbide has been formed at CF/Ti interface. On the contrary, the Ni-coating is predicted to prevent the carbide formation.

Thus, the Ni coating has controlled the formation of Ti- carbides at in the Ti/NiCF/CFRP joint sample [6]. Since molten titanium doesn't radically bite the carbon fiber, the Ni coating maintains the high strength of carbon fibers [6-9].

The σ_b and ε_b of Ti/NiCF/CFRP(Epoxy), are approximately three times higher than that of Ti/NiCF/CFRP(ABS). When the resistance to fiber pull out of Epoxy/CF is much higher than that of ABS/CF. it can be explained.

A new method with extremely large friction force by broad interface of carbon fiber (CF:6 μm-diameter) cloth coated by nickel (Ni) to control Al_4C_3 formation rate and to enhance the ability of fiber rapping by molten Al have been suggested for a joint (Al/cloth/ABS-CFRP) of carbon fiber reinforced ABS polymer (ABS-CFRP) and aluminum (Al). The new joint part was strengthened by impregnated nickel-coated carbon fiber cloth. The Al/cloth/ABS-CFRP joint exhibited the high values of the tensile strength (σ_b) of Al/cloth/ABS-CFRP (8.38 MPa), which was 5.3 and 16.1 times higher than that of Al/Glue/ABS and Al/ABS, respectively. Based on the XRD analysis and EPMA observation, aluminum carbide could not be detected. Consequently, the new joint method by using carbon fiber cloth remarkably enhanced the safety level with lightweight and high resistance to fracture of airplane.

3.2 Impact test

Based on the EPMA and X-ray results [6], carbides cannot be detected in carbon fibers and matrix metals in metal part of Ti/NiCF/CFRP (Epoxy) and Ti/NiCF/CFRP (ABS), whereas the diffusion layer has been observed in metal matrix. Figure 3 illustrates fracture forms of Ti/CFRP joints with and without carbon reinforcement. Both Ti/Epoxy and Ti/ABS joints fractured at interface. On the other hand, the fiber pull out occurs at polymer/fiber interface of Ti/NiCF/CFRP (Epoxy) and Ti/NiCF/CFRP (ABS) joints.

The stress was measured by a following equation, when stress, load, gravity acceleration rate and cross sectional area are σ, m, g and S. respectively.

$$\sigma = mg/S \tag{2}$$

The a_{uc} values of the new joint of Ti/NiCF/CFRP were 2.3 and 4.7 kJm^{-2} at low, middle and high P_f of 0.1 and 0.9, respectively. They were about two times higher than those (0.8 and 2.3 kJm^{-2}) of the joint sample without carbon fibers (Ti/Epoxy).

The Al/CFRP joint reinforced by nickel-coated carbon fiber also improved the Charpy impact

value, as well as tensile strength.

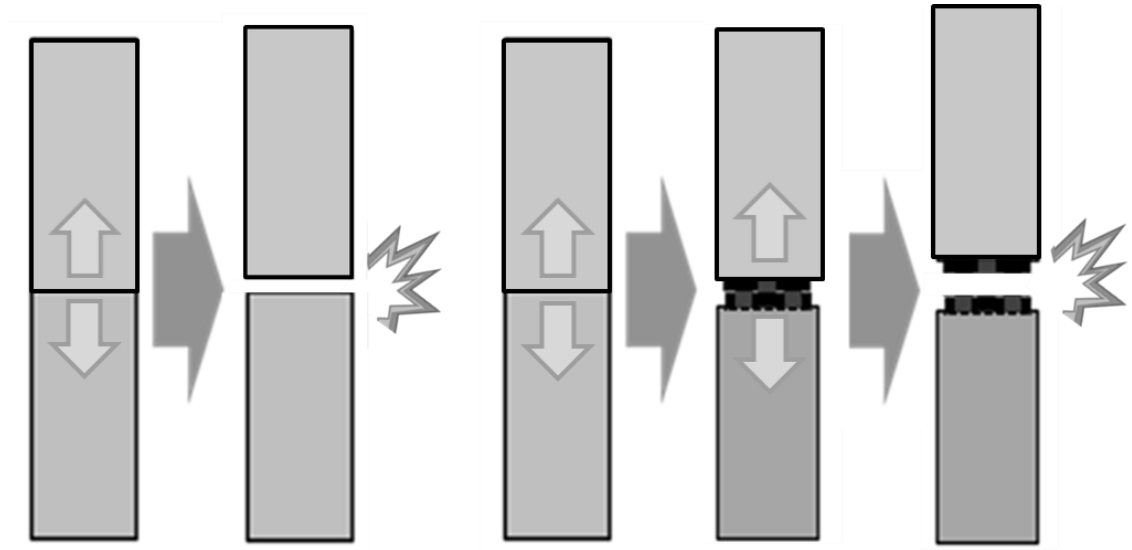

Figure 3 Schematic drawing of fracture form of Ti/CFRP joint with and without carbon reinforcement.

4 CONCLUSION

In summary, a new method with extremely large friction force by broad interface of carbon fiber (CF:6μm-diameter) have been suggested for a joint (M/CF/P and M/CF/M) of carbon fiber (CF) reinforced polymer (P) and metal (M). The new joint part was strengthened by impregnated carbon fiber (CF).

1:The joint tensile strength (σ_B) values of both M/CF/P and M/CF/M joints were tremendously higher than that of the glue joint (M/Glue/P and M/Glue/M) and wrap-casting joint (M/P and M/M). The new joint method by using carbon fiber remarkably improved the σ_B.

2:In order to improves the safety level, the new joint method with extremely large friction force by broad interface of carbon fiber (CF:6μm-diameter) coated by nickel (Ni) to prevent carbides formation and to enhance the ability of fiber rapping by molten metals have been suggested for joints (M/Ni-CF/P and M/Ni-CF/M) of carbon fiber (CF) reinforced polymer (P) and metal (M).

3:The new joints part was strengthened by impregnated nickel-coated carbon fiber. The σ_B values of both M/Ni-CF/P and M/Ni-CF/M joints were tremendously higher than that of the glue joint (M/Glue/P and M/Glue/M) and wrap-casting joint (M/P and M/M). In addition, Ni coating improves the decreased the experimental errors.

4:Since the new joint part was strengthened by impregnated carbon fiber (CF), the Charpy impact values (a_{uc}) of M/CF/P joints were tremendously higher than that of the glue joint (M/Glue/P) and wrap-casting joint (M/P). The new joint method by using carbon fiber remarkably improved the a_{uc}, resulting in the high fracture toughness with lightweight. Furthermore, the a_{uc}, of M/Ni-CF/P joints were tremendously higher than that of the glue joint (M/Glue/P) and wrap-casting joint (M/P). In addition, Ni coating improves the decreased the experimental errors.

5: Based on the XRD analysis and EPMA observation, the carbides formation and carbon diffusion in fiber and matrix could not be detected by Ni-coating.

Consequently, the new joint method by using carbon fiber coated with Ni remarkably enhanced the safety level with lightweight and high resistance to fracture toughness of airplane-parts.

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