EFFECT OF ATMOSPHERIC PRESSURE PLASMA TREATMENT ON INTERFACIAL BONDING OF CF/PP COMPOSITES

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Keywords: CF/PP, Interface Control, Atmospheric Pressure Plasma Treatment

Abstract
Recently, we are aiming to develop a high-productive and minimally invasive device, which can continuously mold CF/PP prepregs with optimized interfacial bonding and without heavy damage of CFs and PP, utilizing the atmospheric pressure plasma treatment method. In this study, we developed a prototype, which can conduct the surface treatment of CFs and PP separately by the air dielectric barrier discharge. Here, we developed a fiber winding device, which enable the application of atmospheric pressure plasma also to CFs without floating of size-removed CFs. UD-CF/PP films were prepared by hot-pressing after atmospheric pressure plasma treatment. The effect of treatment condition on interfacial bonding was evaluated using tensile strength perpendicular to fiber direction, which is strongly related with interfacial bonding strength, in prepared UD-CF/PP films. As results, within the range of this study, the best atmospheric pressure plasma treatment condition was 10 [W] of electric power for 30 [sec] and 20 [W] of electric power for 30 [sec] against CFs and PP, respectively. This optimum treatment improved the interfacial tensile strength of CF/PP, whereas excessive atmospheric pressure plasma treatment damaged surface of CFs.

1. Introduction

Carbon fiber reinforced thermosets (CFRTSs) have been applied into many industrial fields, such as aircrafts, wind turbines, automobiles and so on. However, CFRTS structures cannot be remolded after usage. On the other hand, carbon fiber reinforced thermoplastics (CFRTPs) can be reused, owing to their fusibility against heating. Among them, polypropylene (PP) is one of the strong candidates as matrix resin of CFRTPs for primary structures of automobiles, infrastructures and so on, owing to its fracture properties, heat-resistance, mass-productiveness and recycling efficiency. However, the interfacial adhesive property of PP against carbon fibers (CFs) is low due to absence of polar groups on its surface [1]. Therefore, many studies have developed interface-control methods for PPs, such as modification by maleic anhydride [2-4]. Although these methods have high modification effect, low mass-productiveness due to batch processing should be overcome to apply CF/PP to infrastructures.

Excerpt from ISBN 978-3-00-053387-7

Therefore, we are aiming to develop a high-productive and minimally invasive device, which can continuously mold CF/PP prepregs with the optimized interfacial bonding property and without the damage of CFs and PP by surface treatment, utilizing the atmospheric pressure plasma treatment method. Thus, we developed a prototype, which can conduct the surface treatment of CFs and PP separately by the air dielectric barrier discharge. In this study, we aimed to cralify the effect of atmospheric pressure plasma treatment condition on interfacial bonding of CF/PP composites. Unidirectional CF-reinforced PP composite films were prepared by hot-pressing using spread CF strands and PP films, after the atmospheric pressure plasma treatment. The effect of atmospheric pressure plasma treatment condition on the interfacial bonding was evaluated using the tensile strength perpendicular to fiber direction, which is strongly related with interfacial bonding strength, in prepared unidirectional CF-reinforced PP composite films.

2. Experimental Procedure

In this study, CF strands spread using T700SC-12K (Toray Industries, INC.) and PP films (Mitsui Chemicals Tohcello, INC.) were used. First, only PP films were modified by atmospheric pressure plasma treatment, in order to optimize the atmospheric pressure plasma treatment condition against PP. Here, a prototype, which can conduct the surface treatment of CFs and PP separately by the air dielectric barrier discharge, was developed. Fig. 1 shows the schematic diagram for circuit of the developed device. Electric power and time of atmospheric pressure plasma treatment was 20, 50, 80 [W] and 10, 30, 50, 90 [s], respectively. Then, CFs were modified by atmospheric pressure plasma treatment, under the fixed atmospheric pressure plasma treatment condition of 20 [W] for 30 [sec] against PP, in order to optimize the atmospheric pressure plasma treatment condition against CFs. In this case, floating of size-removed CFs by atmospheric pressure plasma should be prevented. Therefore, we developed fiber winding device in the atmospheric pressure plasma chamber. Fig. 1 shows the schematic diagram of developed fiber winding device.

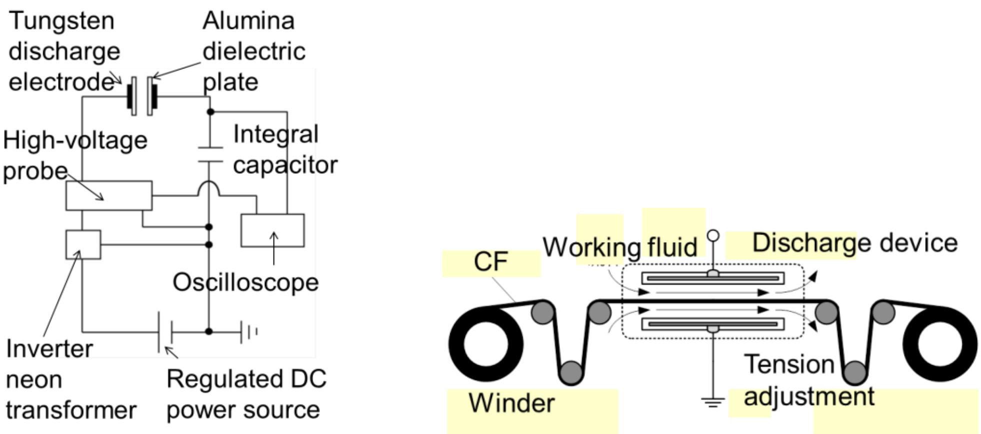


Figure 1. Schematic diagrams for circuit of developed device for atmospheric pressure plasma treatment and developed fiber winding device.

For molding, polyimide films (DuPont-Toray, CO., LTD., 300 V) with 75 μm of thickness was put on both sides of aluminium alloy plate (80 [mm] x 60 [mm], t = 2 [mm]), followed by wrapping them in PP films with 80 [μm] of thickness, spread CF strands and PP films with 80 [μm] of thickness, in turn. Then, CF/PP composite films were prepared at 180 °C under the pressure of 4 [MPa] for 10 min using a hot-pressing device (Orihara Manufacturing CO., LTD., G-12), followed by cooling for 15 [min]. CF/PP specimens with 45 [mm] in length and 10 [mm] in width were cut out from prepared composite films, as shown in Fig. 2. Here, the fiber orientation was perpendicular to the longitudinal direction of specimens. As reference, neat PP specimens with 45 [mm] in length and 5 [mm] in width were also prepared.

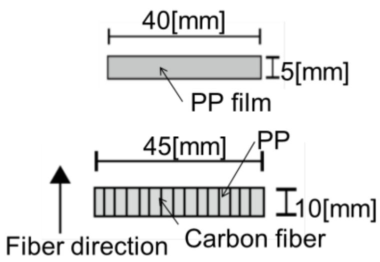
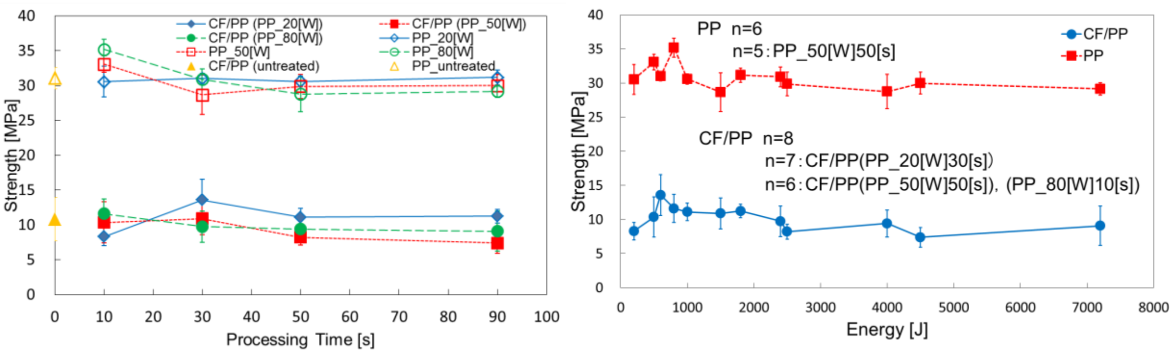


Figure 2. Schematic diagram of specimen for tensile test perpendicular to fiber orientation.

The effect of the atmospheric pressure plasma treatment on the interfacial bonding was evaluated by tensile tests perpendicular to the fiber orientation. Tests were carried out using a compact tabletop universal testing machine (Shimadzu, AGS-X 500[N]) with a load cell of 500 N in capacity. The crosshead speed was 0.5 [mm/min]. The gauge length of specimens was 20 [mm]. After tests, fracture surfaces and treated CFs were observed using a scanning electron microscope (Hitachi High-Technologies Corporation, TM-1000) and a field emission scanning electron microscope (JEOL LTD., JSMJSM-7100F).

3. Results and Discussion

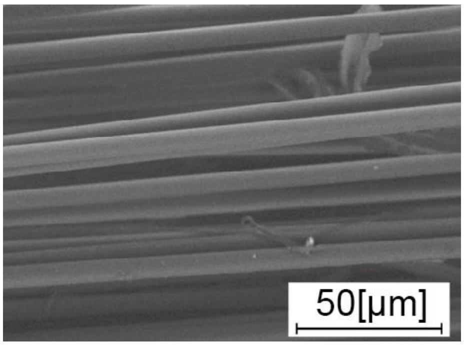
Figs. 3 (a) and (b), respectively, show the effects of processing time and given electric energy on tensile strength perpendicular to fiber orientation, in the case that only PP films were modified by atmospheric pressure plasma treatment. The average tensile strength in the perpendicular direction to fiber orientation of unmodified neat PP and unmodified CF/ unmodified PP was 30.1 [MPa] and 10.8 [MPa], respectively. The condition of atmospheric pressure plasma treatment affected tensile strength in the perpendicular direction to fiber orientation. The tensile strength in the perpendicular direction to fiber orientation was maximized as 35.2 [MPa] under processing electric power of 80 [W] and processing time of 10 [s] for neat PP. Since whitening was observed on PP surface, it is suggested that the crystallization induced the increase in tensile strength in the perpendicular direction to fiber orientation.



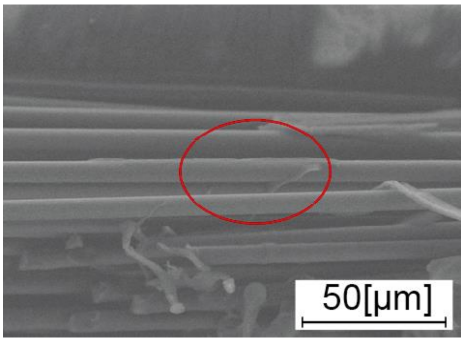
(a) (b)

Figure 3. Results of tensile tests perpendicular to the fiber orientation for unmodified CF/PP.

On the other hand, the tensile strength in the perpendicular direction to fiber orientation was maximized as 13.6 [MPa] under the processing electric power of 20 [W] and processing time of 30 [s] for CF/PP. Fig. 3 (b) indicates that the given electric energy of 500 – 800 [J] can optimize the interfacial bonding. Fig. 4 shows SEM images of fracture surfaces of unmodified CF/PP. Even in unmodified CF/modified PP, PP matrix barely stuck on CFs. It is suggested that the improvement in interfacial bonding was limited because CFs were not modified. Therefore, it is expected that the atmospheric pressure plasma treatment within the range, where CFs are not heavily damaged, could improve interfacial bonding between CFs and PP matrix.



(a) Unmodified CF/unmodified PP



(b) Unmodified CF/modified PP

Figure 4. Fracture surfaces of unmodified CF/PP.

Since it was suggested that the effect of atmospheric pressure plasma treatment against only PP was limited, we developed a fiber winding device, which enable the application of atmospheric pressure plasma without floating of size-removed CFs. Then, the atmospheric pressure plasma treatment was conducted to CFs and the tensile strength perpendicular to fiber direction of modified CFs/modified PP composite films was evaluated. Fig. 5 shows the effect of processing time on tensile strength perpendicular to fiber orientation, in the case that both CFs and PP films were modified by atmospheric pressure plasma treatment. The tensile strength perpendicular to fiber orientation of modified CF/modified PP increased and the decreased with increasing processing time. The tensile strength perpendicular to fiber orientation for electric power of 10 [W] was successfully higher than that for unmodified specimen. The condition of 10 [W] for 30 [sec] maximized the tensile strength perpendicular to fiber orientation. On the other hand, the tensile strength perpendicular to fiber orientation decreased in the condition of 20 [W].

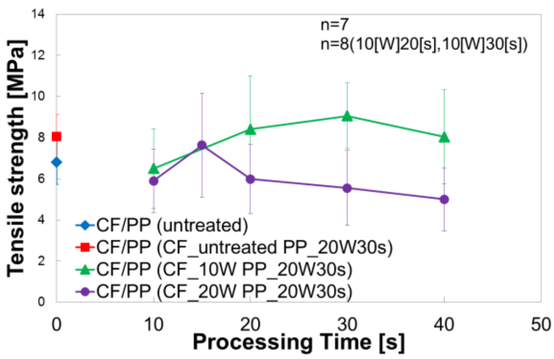


Figure 5. Results of tensile tests perpendicular to the fiber orientation for modified CF/PP.

Fig. 6 shows SEM images of fracture surfaces of modified CF/modified PP. Here, PP was modified under the condition of 20 [W] for 30 [sec]. Comparing with unmodified CF/PP, PP matrix stuck on

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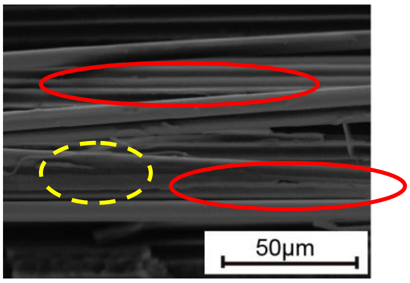
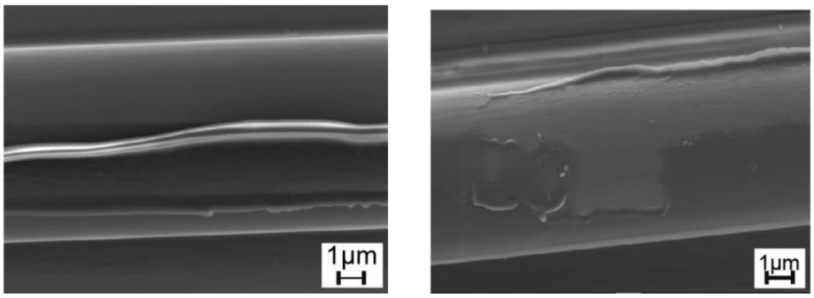
CFs in modified CF/modified PP. Paticularly, the sticking area was markedly large in the case that CFs were modified under the condition of 10 [W] for 30 [sec], corresponding to the result of the tensile test perpendicular to fiber direction. This suggests that the interface control method employed in this study is effective, and the best atmospheric pressure plasma treatment conditions was 10 [W] of electric power for 30 [sec] against CFs.



(a) Modified under 10[W] for 30[sec] (b) Modified under 20[W] for 40[sec]

Figure 6. Fracture surfaces of modified CF/modified PP. Here, PP was modified under the condition of 20 [W] for 30 [sec].

In order to verify the damage of CFs by atmospheric pressure plasma treatment, surfaces of modified CFs were observed using a field emission scanning electron microscope. In the case of treatment condition of 10 [W] for 30 [sec], clear damage was not observed, as shown in Fig. 7 (a). On the other hand, CF surface was damaged in the case of treatment condition of 20 [W] for 40 [sec], as shown in Fig. 7 (b). Thus, it is suggested that excessive atmospheric pressure plasma treatment against CFs induced the fracture of CF surface itself, resulting in the decrease of the tensile strength perpendicular to fiber orientation of modified CF/modified PP.



(a) Modified under 10[W] for 30[sec] (b) Modified under 20[W] for 40[sec]

Figure 7. Surfaces of modified CFs.

4. Conclusions

In this study, we developed a prototype, which can conduct the surface treatment of CFs and PP separately by the air dielectric barrier discharge. The effect of atmospheric pressure plasma treatment condition on the interfacial bonding was evaluated. As results, within the range of this study, the best atmospheric pressure plasma treatment condition was 10 [W] of electric power for 30 [sec] and 20 [W] of electric power for 30 [sec] against CFs and PP, respectively. This optimum treatment improved the interfacial tensile strength of CF/PP, whereas excessive atmospheric pressure plasma treatment damaged surface of CFs.

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Acknowledgments

This research is supported by the Center of Innovation Program from Japan Science and Technology Agency, JST.

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