INTERFACIAL PROPERTY AND WELDING PROPERTY OF CONTINUOUS FIBER REINFORCEMENT THERMOPLASTIC COMPOSITE

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1 Introduction

Continuous fiber reinforced thermoplastic composites have a number of advantages such as high fracture toughness, recyclability and possibility to re-melt and reprocess compared with thermosetting composite. Therefore, the continuous carbon fiber reinforced thermoplastics (CFRTP) is very keen under global environmental issue in which natural resources are effectively used. However, there are two problems for the CFRTP. The first one is that thermoplastics as matrices generally have high melt viscosity so that it is difficult to impregnate resin into reinforcing fiber bundle in continuous fiber reinforced thermoplastic composites. The other one is lower interfacial properties between the fiber and the matrix. It is considered that interfacial properties in continuous fiber reinforced thermoplastic composites can be characterized by the wetting ability and chemical interaction between fiber and matrix surfaces. Wetting ability would affect resin impregnation state during molding while chemical reaction affects composite strength. Therefore, interface design of CFRTP is very important to obtain materials with improved processability and mechanical performance [1].

Welding process is one of the secondary processing methods of the CFRTP. Welding is necessary technology to put CFRTP to practical use, because it has a number of advantages such as low cost, short time, recyclability. For the welding process, thermoplastic resin is heated more than melting point, and pressure is applied on materials to weld the material. Ultrasonic welding is a technique to unite materials by vibrating the materials surface and producing heat with ultrasonic wave.

In this study, CFRTP was fabricated by using carbon fiber and polypropylene (CF/PP). Micro-braided yarn (MBY) was used as an intermediate material for the impregnation. The schematic drawing and photograph of MBY are shown in Fig.1 MBY was fabricated by braiding matrix resin fiber bundles around reinforcement fiber bundle. To examine the interfacial shear strength, micro droplet test with single fiber was carried out. Then, by using ultrasonic welding, the effect of interfacial property on the welding strength of welded specimen was investigated by tensile test.

2 Experiments

2.1 Materials

CF (T700SC-12000 Toray Co.,ltd) coated with four different contents of sizing agents was used as reinforcement. PP (462dtex Daiwabo Polytec Co.,ltd) and maleated PP (MAPP) (462dtex Daiwabo Polytec Co.,ltd) were used as matrix resin.

2.2 Evaluation

To evaluate interfacial shear strength of the CF/PP interface micro-droplet test was performed. The resin fiber was melted by using a hot plate at 220 degree and a small droplet of resin was applied to a single fiber. Micro-droplet test machine (HM410 Tohei Sangyo Co.,Ltd) was used with a fiber pull-out speed of 0.03 mm/min. The maximum load F measured before matrix detachment from the fiber is related to the fiber/matrix shear strength. The interfacial shear strength (τ) was calculated by equation 1,

$$\tau = \frac{F}{\pi d l} \quad (1)$$

where F is the maximum load, is the fiber circumference, and l is the embedded fiber length. The values of the fiber circumference and embedded length were characterized by using microscope images.

The MBY was wound 60 times onto a parallel metallic frame equipped with a spring mechanism to accept thermal shrinkage of carbon fiber during molding as shown in Fig.2. The frame was then placed into a pre-heated mold before performing compression molding at 190 ℃ with a molding pressure of 5MPa. The heating time was 20min and cooling time was 20 min. Cooling was subsequently performed by running water through the mold while keeping the specimens under constant pressure.

Welded specimens were fabricated by using ultrasonic welding machine (SONOPET-1200B P34A SEIDENSHA ELECTRONICS CO., LTD). The frequency of ultrasonic wave was 19.15kHZ, the dimension of the welded specimens was 30mm in length, 15mm in width, and 3.5mm in thickness. As shown in Fig.3, welded specimens were held on workbench, and added pressure by the ultrasonic welding machine. Welding area was 15mm in width, 8mm in length. For the welding condition, welding pressure was 0.15MPa and welding time was 2.0 second. In this study, no other welding condition could succeed. In the case of molding pressure higher than 0.15MPa, welded specimen was broken and in the case of molding pressure lower than 0.15MPa welding did not occur.

To examine welding strength, tensile test of welded specimen was carried out. Here, welding strength was defined as the maximum load at the tensile test of welded specimen.

In this study, five different type of the unidirectional composites were fabricated for welded specimen by using CF/PP MBY.

To examine the effect of maleated PP and the quantity of a sizing agent on the welding strength, CF coated with two different quantity of sizing agents and maleated PP were used.

Moreover, in order to improve welding strength by control interfacial property, two different type of hybrid resin unidirectional composite with PP and MAPP, the schematic drawing shown in Fig. 3, was used.

The one was fabricated by braiding MAPP resin fiber around reinforcement fiber bundles and braiding PP resin fiber around MAPP layer. The other one was fabricated by braiding PP resin fiber around reinforcement fiber bundles and braiding MAPP resin fiber around MAPP layer.

Welded specimens were fabricated by using ultrasonic welding machine. The dimension of the welded specimens was 30mm in length, 15mm in width, and 3.5mm in thickness. A plate with same size with welded specimen was put both ends of specimen to introduce fracture at welded area. The tensile speed was 1mm/min.

3 Results and discussion

3.1 Interfacial strength

Fig.5 shows the relationship between interfacial strength and sizing content. The interfacial shear strength decreased linearly with increasing the sizing content. It is considered that too much sizing agents inhibited adhesion between CF and PP. By using MAPP, interfacial shear strength was greatly improved.

3.2 Welding strength

Fig.6 shows welding strength with two different content of sizing agents. Here, welding strength was defined as the maximum load at the tensile test of welded specimen. Welding strength yielded little difference between 1.1wt% and 0.2wt%. Fig.7 shows the welding strength using PP and MAPP with sizing content of 1.1wt%. By using MAPP, not only interfacial shear strength but also welding strength were greatly improved. The rate of increase was about 215%.

Fig.8 shows welding strength using PP and MAPP resin hybrid with sizing content of 0.6wt%. By braiding MAPP at first layer and PP at second layer, both interfacial shear strength and resin strength were improved, so welding strength was greatly improved. The rate of increase was about 639%.

By braiding PP at first layer and MAPP at second layer, interfacial shear strength was higher than that of monolithic one, so welding strength was improved. The ratio of increase was about 465%.

Fig.9 (a) and (b) show SEM photograph and schematics of the fracture surface of welded specimen with sizing content of 1.1wt% after tensile test. Here, Fig (a) shows upper side of welded specimen, Fig (b) shows down side of welded specimen. A little resin adhered to the surface of the carbon fiber at the surface of welded area. Fig.10 (a) and (b) show SEM photograph and schematics of the fracture surface with sizing content of 0.2wt%. There was more resin around fiber than 1.1wt% of sizing content. In these specimens, there was also more resin on the surface of upper side than that of down side. It was considered that interfacial fracture occurred relatively at down side. Fig.11 (a) and (b) show SEM photograph and schematic of the fracture surface with MAPP. A lot of resin adhered on the surface of carbon fiber compared to PP composite.

In these specimens, resins adhered to both upper and down side. It was considered that fracture occurred between resins of welded layer, since interfacial shear strength was higher than welding strength.

Fig.12 (a) and (b) show SEM photograph and schematic of fracture surface with MAPP-PP hybrid specimen. There was a lot of resin adhered on the surface of carbon fiber. Moreover fragment of carbon fiber was adhered on fracture surface, it was considered that fracture occurred at inside fiber bundles and welding area at the same time.

Fig.13 (a) and (b) shows SEM photograph and schematic of fracture surface with PP-MAPP hybrid specimen. The same as Fig.9, a little resin adhered fracture surface. It was considered that interfacial fracture occurred around fiber bundles.

In the case of monolithic layer, the higher interfacial strength was, the more resin was around fiber at the surface of welded area. From the observation of welded specimen, fracture mode was affected by the content of sizing agents, but the content unaffected welding strength. On the other hand, MAPP affected both of fracture mode and welding strength.

By resin hybridization, fracture mode was same as monolithic layer. In the case that MAPP resin fiber was braided around reinforcement fiber bundles, there was a lot of resin adhered on fracture surface.

In the case that PP resin fiber was braided around reinforcement fiber bundles, little resin adhered on the fracture surface. However, both of them, welding strength was higher than that of monolithic layer.

4 Conclusions

In this study, the effect of the sizing content of CF and acid denaturation with maleic acid on the interfacial adhesion and welding strength was investigated. It was clarified that interfacial shear strength of CF/PP and CF/MAPP decreased with increasing amount of sizing agents because sizing agents inhibited adhesion of them. In the case of monolithic layer, sizing content affected fracture mode, but unaffected tensile strength of welded specimen. MAPP greatly affected both fracture mode and tensile strength of welded specimen. From these results, to improve welding strength, it is important to control interfacial property.

By resin hybridization, fracture mode was same as monolithic layer. However, both of them, welding strength was higher than that of monolithic layer.

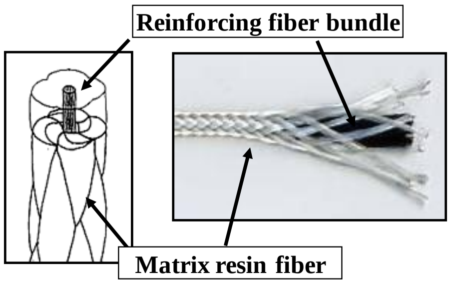


Fig.1. Fabrication of micro-braided yarn.

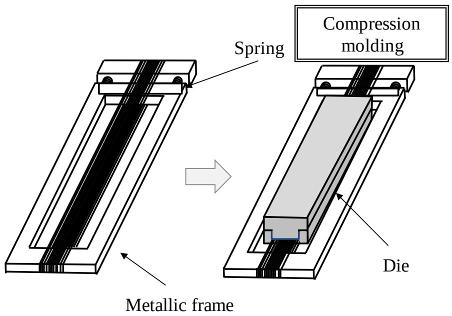


Fig.2. Fabrication method of unidirectional specimens.

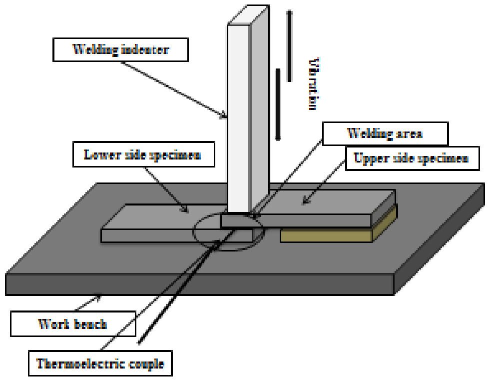


Fig.3. Welding process

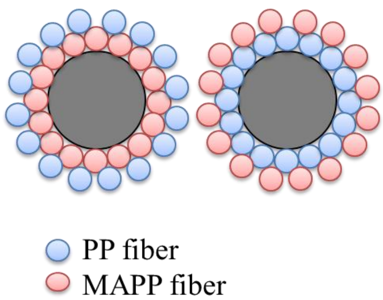


Fig.4. Schematic of hybrid resin MBY

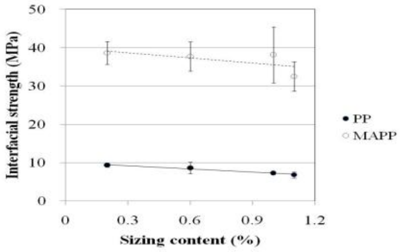


Fig.5. Relationship between interfacial shear strength and sizing content.

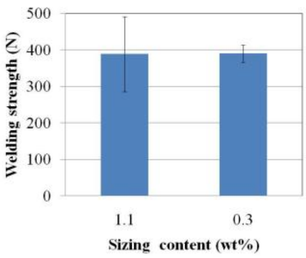


Fig.6. Effect of sizing content on welding strength.

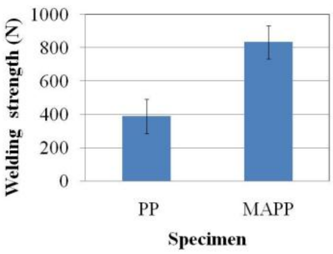


Fig.7. Effect of maleted PP on welding strength.

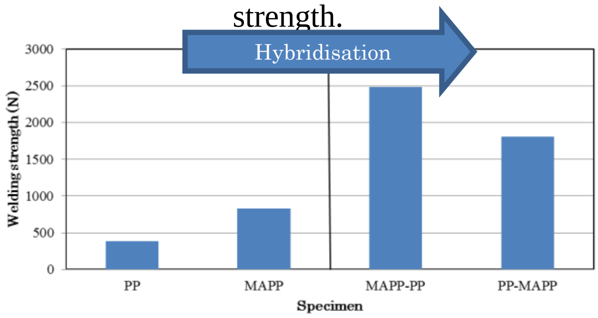
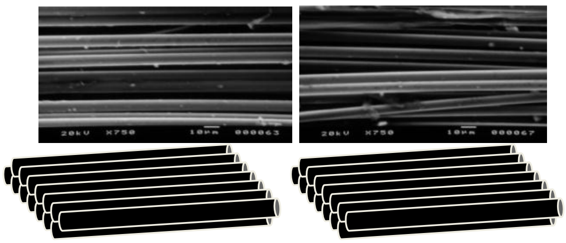
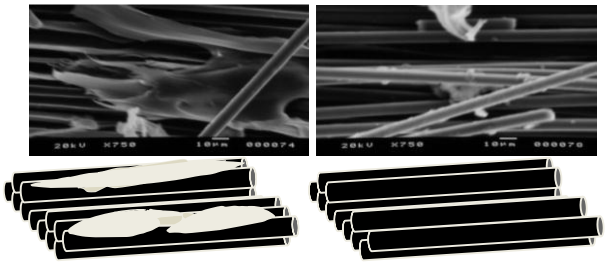


Fig.8. Effect of hybridisation on welding strength.



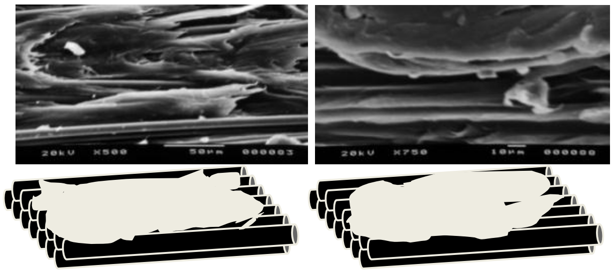
(a) Upper side (b) Down side

Fig.9. Photographs and schematics of fracture surface of welded specimen with 1.1wt% sizing content.



(a) Upper side (b) Down side

Fig.10. Photographs and schematics of fracture surface of welded specimen with 0.2wt% sizing content.



(a) Upper side (b) Down side

Fig.11. Photographs and schematics of fracture surface of welded specimen with MAPP.

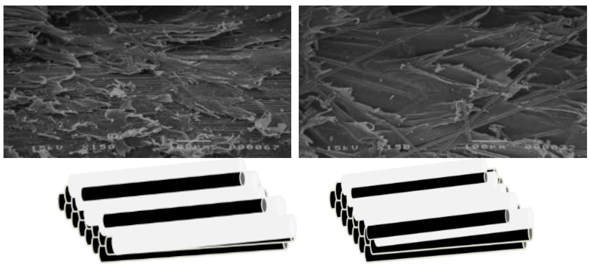


Fig.12. Photographs and schematics of fracture surface of welded specimen with MAPP-PP.

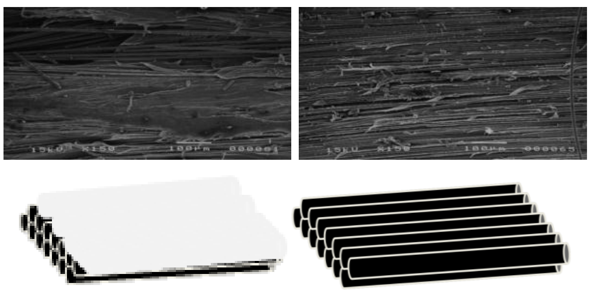


Fig.13. Photographs and schematics of fracture surface of welded specimen with PP-MAPP.

Reference

[1] Yositaka T, Hajime N, Asami N, Akio O, Nobuo I,"Effect of interfacial property on CF/PP continuous fiber reinforcement thermoplastic composite", Proceeding of the eight joint CANADA-JAPAN WORKSHOP ON COMPOSITES (2010)