# PULTRUSION PROCESS FOR CONTINUOUS FIBER REINFORCED THERMOPLASTIC COMPOSITES

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**Introduction**

Recently continuous fiber reinforced thermoplastic composite (c-FRTP) is paid attention. Molding-cycle of FRTP is shorter than that of FRP, so that thermoplastic resin enables c-FRP to be produced at high-cycle-molding. However, combination of continuous fiber and thermoplastic resin results in the difficulty in the impregnation because of the high melt viscosity. We have proposed one of the high-cycle-molding for c-FRTP with fibrous intermediate material and pultrusin systems by using braiding technology. Braided fabric was pulled in the pultrusin die having a cylindrical hole. While the resin fiber of the braided fabric was passing through the die, it melted and impregnated into reinforcing fiber.

The purpose of this study is to clarify the effects of pultrusion parameters such as selection of intermediate materials, structure of reinforcements, molding condition on the impregnation state and mechanical properties. In this paper, the effects of fiber volume fraction of commingled fiber with keeping same fiber volume fraction of molded composites were mentioned because of space limitations.

**Materials and molding method**

A feature of braiding structure is that fiber bundles called braiding yarns are continuously oriented without cutting and the fiber bundles called middle-end-yarns (MEY) are inserted between braiding yarns in longitudinal direction. Since it is possible to arbitrarily set the fiber orientation angle, the mechanical properties can be designed according to the required performance. In this study, commingled fiber was used as intermediate material made from carbon fiber (T700-12k-60E: Toray industries) as reinforcing fiber and PA66 fiber (L235-35BAU: Asahi Kasei) as resin fiber. Pultrusion device is constituted by 5 equipment, mandrel having an electric heater, far infrared heater for heating the braided fabric prior to molding, molding die, cooling system and pulling device. Temperature of the molding die can be controlled in each electric heater inserted into the upper and lower molding die and in this study they were set to 290, 290, 290, 290, 290, 285, 280, 275℃ from the entrance side. Cooling system employs the air cooler device set at the exit of molding die. Flow rate of the air cooler was constant. Cylindrical pipe with outer diameter of 18mm and inner diameter of 15mm was molded. Taper zone was provided at the entrance of molding die; the inner diameter was changed from 28mm to 18mm at the taper zone. The role of taper zone is to prevent backflow of melted resin and the fiber breakage due to rapid increase in molding pressure.

**Experimental method**

In order to investigate the effects of filling ratio of materials to molding die, the fineness of intermediate material was changed; here the fiber volume fraction of commingled fiber was changed by changing amount of resin fiber in the intermediate material as three stages of 752, 540.5, 329tex and carbon fiber was constant as 800tex for keeping same fiber volume fraction of molded composites. Then resulted fiber volume fraction in the intermediate material was changed as 40, 45, 50%. If the filling rate is less than 100%, it is not possible to apply the pressure to the braided fabric. Conversely, even if the filling rate is more than 100%, pultrusin can carried out because the melted resin with void flows backward of molding die. In this study, the filling rate was increased as 102, 109, 123% with increase in volume fraction of intermediate material. The pultrusion speed was constant as 70mm/min.

For impregnation state, the cross section was observed by an optical microscope at the distance of 400, 600, 800 mm from the forefront of braided composite. Un-impregnation ratio was defined as the ratio of un-impregnation area inside of fiber bundle to the cross-sectional area of each reinforcing fiber bundle and evaluated as a measure of the impregnation state. Void was existed between fiber bundles and was distinguished from un-impregnation area. Void ratio was defined as the ratio of total area of void to the area of cross section. In order to investigate the effect of the impregnation state on the mechanical properties of the molded product, specimens were cut out into 190mm in length at the position of 400-590mm and 600-790mm from the forefront of braided composite for four-point bending test. Molding history of two specimens was the same.

**Experimental results and discussion**

Fig.1 shows relationships between un-impregnation and void area and carbon fiber volume fraction of intermediate material. It was found that un-impregnation and void area was linearly decreased with decrease in the volume fraction. It was considered that, the increase in the filling rate by increasing the amount of resin fiber, resulted in the increase in the applied pressure to the braided fabric. Fig.2 show relationship between the bending strength and sum of un-impregnation and void area. Also normalized strength by considering difference in Vf in composite and braiding angle was plotted. Bending strength was linearly increased with decrease in the sum of un-impregnation and void area.

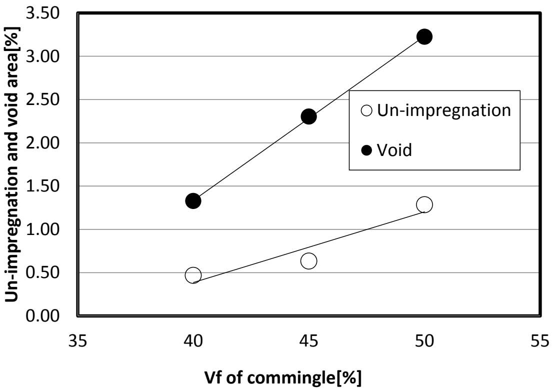


Fig.1: Un-impregnation and void area.

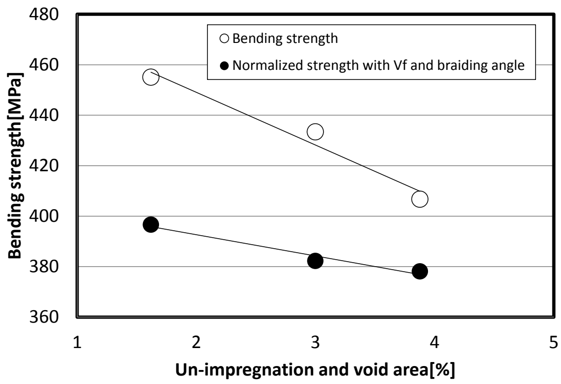


Fig.2: Bending strength.

**Conclusion**

Increasing in filling rate of intermediate materials to molding die are considerable as the one of effective measure which decrease un-impregnation area and void area in the molding product. It was difficult that increasing in filling rate by increase in amount of reinforcement fiber, due to the fiber breakage by increasing pulling force and friction between braided fabric and molding die. However, it was clarified that the increase in filling rate was achieved without large pulling force by increasing resin fiber in the intermediate material. As results, un-impregnation and void area was decreased with increase in the filling rate and bending strength was improved with decrease in un-impregnation and void area.