MOLDING CONDITION FOR SHORTENING MOLDING TIME DURING PULTRUSION MOLDING OF THERMOPLASTIC COMPOSITES

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ABSTRACT

In one of the high cycle molding system for continuous fiber reinforced plastic with thermoplastic resin, there is pultrusion molding system. We have proposed one of the high cycle molding for FRTP with fibrous intermediate material and pultrusion systems by using braiding technology. However, pultrusion molding system has issues that productivity is still lower for mass production such as automotive application. If the molding speed is increased, pultrusion force is extremely increased due to the friction between melted materials and moldings. Therefore, establishment of molding conditions which shortens molding time is demanded. The purpose of this study is to increase the pultrusion speed by decreasing the pultrusion force. In this study, the simple harmonic motion to the mandrel was applied during pultrusion molding. By applying the simple harmonic motion, the decrease in pressure and pultrusion force was achieved. Therefore, the pultrusion speed was increased without increasing the pultrusion force. Also mechanical properties were improved. There are possibility that the repeating applied pressure at the taper end, the interfacial properties were increased with increase in the frequency.

1 INTRODUCTION

Recently, continuous fiber reinforced thermoplastic is in the spotlight. What thermoplastic resin gives to molding is the secondary workability and the recyclability. Molding system without chemical reaction can shorten the cycle time than the system with thermosetting resin. In one of the high cycle molding system for continuous fiber reinforced plastic with thermoplastic resin, there is pultrusion molding system. We have proposed one of the high cycle molding for FRTP with fibrous intermediate material and pultrusion systems by using braiding technology[1]. Braided fabrics fabricated with fibrous intermediate materials are pulled into the pultrusion molding die. Resin fiber in the braided fabric was melted and impregnated in the molding die and then melted resin was solidified. The moldings are continuously pulled out with pulling device.

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2 EXPERIMENTS

2.1 Material and Molding System

In this research, glass fiber was used for a reinforcement fiber and PA66 was used for resin fiber and they were commingled by air processing. The braided fabrics with braiding angle of 30 degree were fabricated by 16 braiding yarns and 8 middle-end yarns and the number of layers of braided fabric was 5 layers. Resin fiber in the braided fabric was solidified after heating and impregnated in the molding die, moldings were continuously withdrawn with a drawing device.

Schematic diagram of pultrusion molding system are shown in Fig.1. The system is composed of five devices such as mandrel having electric heater on the inside, preheater by far infrared ray, molding die, cooling system, drawing device. Molding die is composed of two parts such as taper part and straight part. The area of taper part was gradually decreased from the entrance to straight part and the impregnation of resin into fiber bundle was encouraged at the taper part. The area of straight part was constant equivalent to the final shape of product. The molding die can manufacture cylindrical composite material with a diameter of 18mm and an inside diameter of 15mm. In Fig.1, H1~H8 indicate electric heater which was inserted into lower and upper molding die. These electric heaters can control heating temperature independently.

After passing through the molding die, pultruded pipe was subjected to the contractive force caused by drawing force. To prevent the deformation of the cross section, the tip of mandrel was protruded from the exit of molding die. Here, the length that mandrel was protruded from molding die was defined as protrusion length. At the exit of molding die, pultruded pipe was cooled by cooling air.

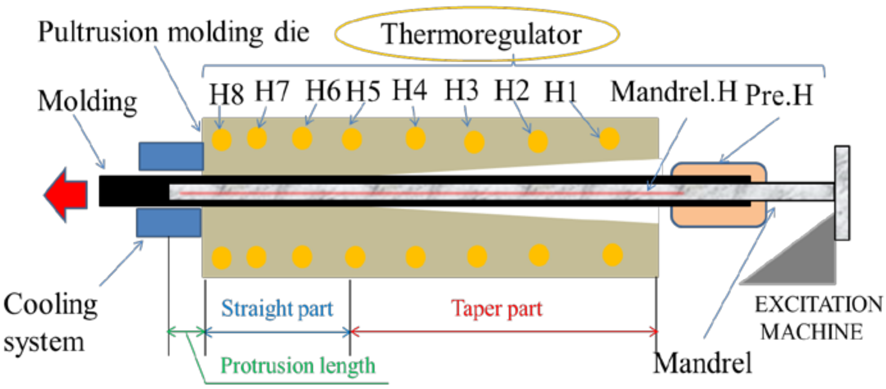

Fig. 1: Schematic of pultrusion molding system.

2.2 Experiments

In order to decrease the pultrusion force, in this study, the simple harmonic motion was applied to the mandrel during pultrusion molding. Pultrusion molding condition is shown in Table1. Temperature was set in common for all samples. The frequency of the simple harmonic motion was changed as shown in this table.

During pultrusion molding, temperature history, pressure history and pultrusion force were monitored. Then, after molding, the impregnation state and mechanical properties were investigated for the molded pipe.

Table 1: Pultrusion molding condition.

Pultrusion speed [mm/min]	Vibration [Hz]	Thermolegulator[℃]									
		Mandrel	Pre	H1	H2	H3	H4	H5	H6	H7	H8
150	0	265	300	330					300	270	263
150	1										
150	2										
150	4										
200	2										

3 RESULTS AND DISCUSSION

3.1 Process Monitoring

Figure 2 shows temperature history. The horizontal axis is distance from entrance of molding die; 0 means just entrance of molding die. At the entrance, the material did not reach immediately to the setting temperature. Then the temperature was gradually increased. Here important region is that material reach to the melting temperature and the time over melting temperature is called as essential molding time. Table 2 shows essential molding distance and essential molding time calculated by Fig.2. When the frequency of the single harmonic motion was changed, temperature history did not change and the essential molding time was almost same. On the other hand, when the pultrusion speed was changed, temperature history was drastically changed and essential molding time was largely decreased.

The pressure was measured at the fixed point; the distance from entrance of molding die was 455 mm. When the material came to the pressure sensor positon, the pressure was gradually increased. And then, the mandrel was stopped by stopper, the pressure was rapidly decreased. After stopping of mandrel, material was slipped on mandrel and the pressure became steady state. After that, we have applied the simple harmonic motion.

Figure 3 shows pressure history after stopping of mandrel by changing frequency of the vibration under the constant pultrusion speed. By applying the vibration, the pressure was decreased and reached constant value. By increasing pultrusion speed, the pressure was largely increased. The reason for the increase in pressure was that; the hating time was decreased with increase in pultrusion speed, and then melt viscosity became higher and increased friction between material and mold.

Figure 4 shows the pultrusion force during pultrusion molding. As same as pressure history, the vertical axis is the position of mandrel tip from the entrance of molding die. After stopping of mandrel, material was slipped on mandrel and the pultrusion force was drastically increased and became constant value. With increase in the frequency, the pultrusion force was drastically decreased from 1Hz to 2Hz and then increased again. In the case of higher pultrusion speed, the braided fabric was broken with increase in the pultrusion force and then the pultrusion force was decreased.

The reason for increase in pultrusion force was resistance between material/molding die and material/mandrel. The resistance consists of friction force by molding pressure and force caused by the viscosity. The relative speed and the direction of braided fabric to mandrel were changed according to the frequency. Also mandrel was vibrated, the direction of the force was changed and the relative speed was also changed. If the direction of mandrel movement and braided fabric were same, the pressure was decreased with optimum frequency. If the direction of mandrel movement and braided fabric were opposite, the force caused by viscosity was increased with increase in frequency. This is the reason for optimum frequency to pultrusion force.

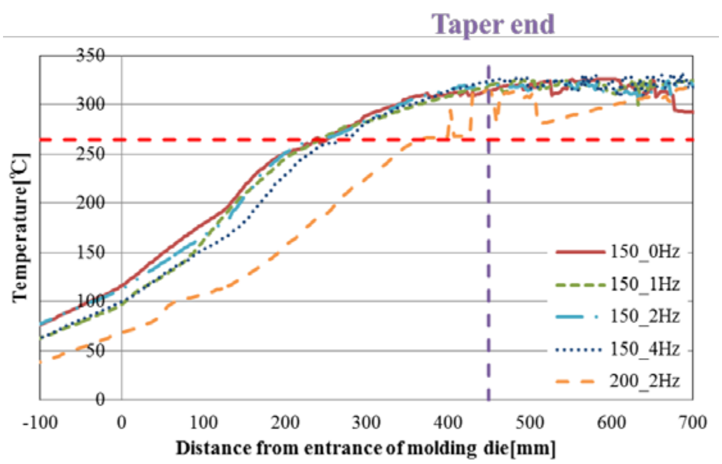

Fig. 2: Temperature history.

Table 2: Essential molding time.

Pultrusion speed[mm/min]	Vibration [Hz]	Essential molding distance[mm]	Essential molding tme[sec]
150	0	198	79
	1	208	83
	2	208	83
	4	180	72
200	2	83	25

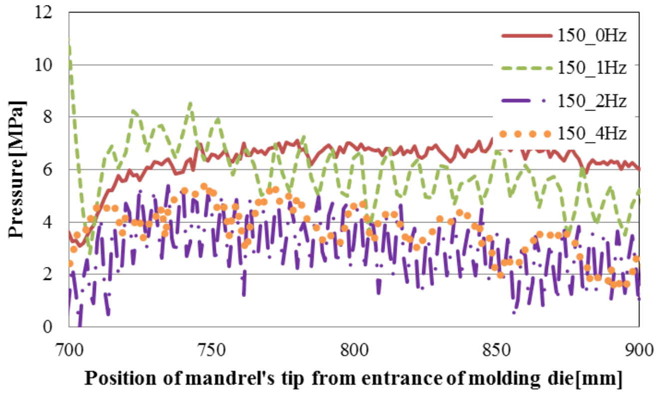

Fig. 3: Pressure history.

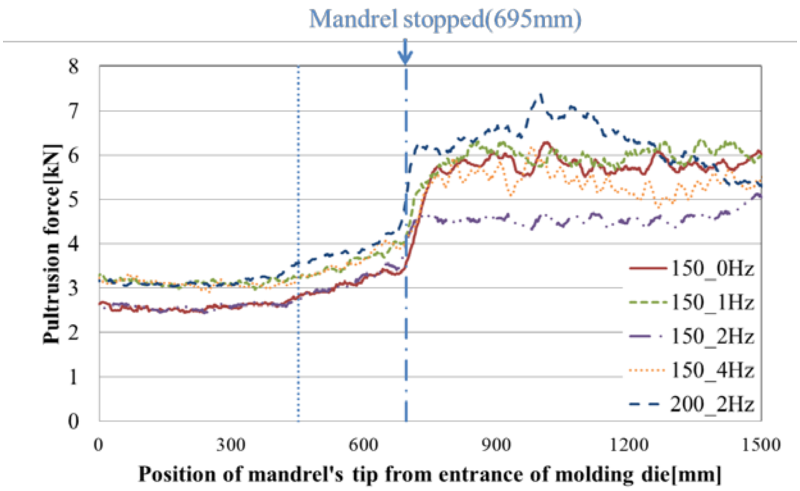

Fig. 4: Pultrusion force history.

3.2 Mechanical Properties

In order to investigate the effect of the impregnation state on the mechanical properties of the molded product, 4 points bending test was carried out. Table 3 shows result of observing cross section and bending test. Since the vibration condition and pultrusion speed were different, how the vibration condition affected impregnation state was investigated by using essential molding time. And also, the effects of the impregnation state on the mechanical property was investigated.

Figure 5 shows the relationship between the un-impregnated ratio and essential molding time. Generally, the un-impregnated ratio was linearly decreased with increase in the essential molding time. However, in the case of 4 Hz of vibration, the un-impregnated ratio was drastically decreased.

Figure 6 shows relationship between the bending strength and un-impregnated ratio. The bending strength was increased with decrease in the un-impregnated ratio. According to the previous results with same material system, under the 1 % of un-impregnated ratio, the strength kept constant value. However, in the case of 4 Hz of vibration, the strength was slightly increased. Among these samples, fiber volume fraction and fiber orientation angle were not changed by vibration condition. But, the number of micro cracks inside of fiber bundle was decreased with increase in the frequency. There are possibility that the repeating applied pressure at the taper end, the interfacial properties were increased with increase in the frequency.

Table 3: Un-impregnated ratio and bending strength.

Pultrusion speed [mm/min]	Vibration [Hz]	Essential molding time[sec]	Un-impregnated ratio[%]	Bending strength [Mpa]
150	0	79	0.9	190
	1	83	1	175
	2	83	0.8	185
	4	73	0.2	217
200	2	25	1.6	143

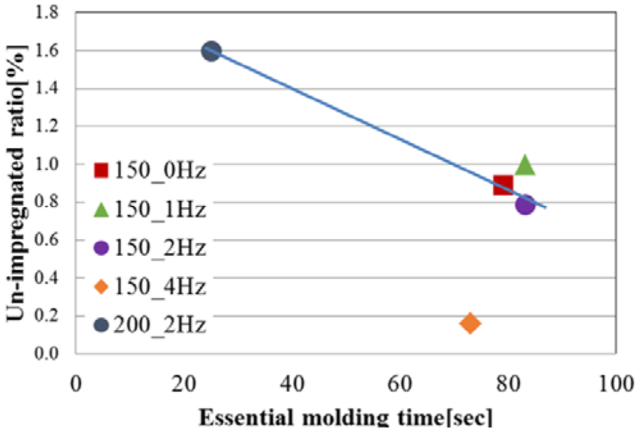

Fig. 5: Relationship between un-impregnated ratio and essential molding time.

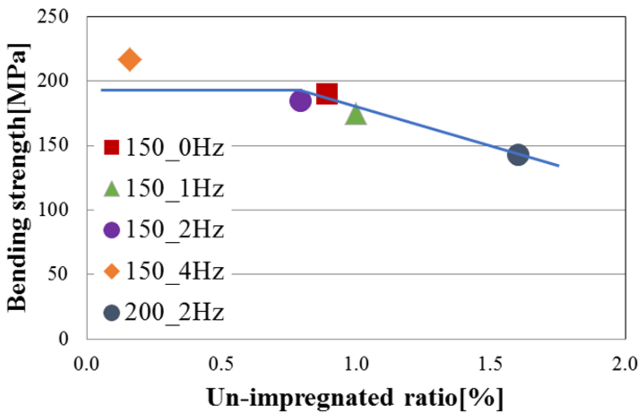

Fig. 6: Relationship between bending strength and un-impregnated ratio.

4 CONCLUSION

The purpose of this study is to increase the pultrusion speed by decreasing the pultrusion force. In this study, the simple harmonic motion to the mandrel was applied during pultrusion molding. By applying the vibration to the mandrel motion, the decrease in pressure and pultrusion force was achieved. If the direction of mandrel movement and braided fabric were same, the pressure was decreased with optimum frequency. If the direction of mandrel movement and braided fabric were opposite, the force caused by viscosity was increased with increase in frequency. Consequently, the pultrusion speed was increased without increasing the pultrusion force. Also mechanical properties were improved since the interfacial properties were increased with increase in the frequency by the repeating applied pressure at the taper end.

REFERENCES

[1] Louis Laberge Lebel, Asami Naka *"1) Design and manufacturing of an L-shaped thermoplastic composite beam by braid-trusion"*, Composites Part A: Applied Science and Manufacturing, Vol. 43, No. 10, 1717-1729 (2012).