

CFRTP pipe molding process using high-frequency direct resistance heating

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Abstract

To deal with environmental issues, the gasoline mileage of passenger cars can be improved by reduction of the car weight. Carbon Fiber Reinforced Thermoplastics (CFRTP), which are superior in specific strength and specific modulus, is expected to be used for car body. Many pipe-shaped members have been used for structural materials for cars, and low cost and high-speed molding method for CFRTP pipe has been required. Although rapid heating process of mold has been developed by applying high-frequency direct resistance heating to the mold itself in previous studies, sufficient mechanical properties of CFRTP pipe could not be obtained because of the high viscosity of thermoplastic resin. In CFRTP molding, impregnation improvement of the resin is one of the important issues to be solved. In this study, carbon fiber thermoplastic resin pre-impregnated sheet, which was impregnated with thermoplastic resin beforehand, is used as molding material to improve the quality of the CFRTP pipe. The CFRTP pipe molded with pre-impregnated sheet had less void and higher strength than the pipe molded with dry carbon and nonwoven fabric.

Keywords: CFRTP prepreg sheet, high-frequency direct resistance heating, rapid molding process.

1 Introduction

Within the automobile industry, in order to improve gasoline mileage and reduction of CO₂ emission, light weight technology for car body is necessary to be improved [1, 2]. Pipe-shaped parts are well used for car component parts such as suspension arm, torsion beam, door guard bar and impact beam. The reduction of weight of car by using Carbon Fiber Reinforced Thermoplastics (CFRTP) which have advantages in high specific strength and high specific modulus is



expected [3, 4]. Therefore, low-cost and high-speed molding method is required for CFRTP pipe molding.

Filament winding method and sheet winding method are used as the pipe molding process. Sheet winding method has an advantage that its production cycle time is shorter than that of filament winding method [5]. In previous studies, CFRTP pipe was produced by using Non-woven Stitched Multi-axial Cloth (NSMC) as semi-product material of CFRTP in sheet winding method [6]. NSMC is sheet-shaped intermediate material for CFRTP that was made by stitching carbon fibers and nonwoven matrix resin simultaneously in the process of manufacturing non-crimp stitched fabric (NCF). The composite material using NCF as reinforcement has less disorder in the fiber direction, and has mechanical properties superior to the composite material using textile as reinforcement [7–9]. The use of NSMC makes the lamination process simplify, and makes possible to shorten a production cycle time. For heating method of mold, high-frequency direct resistance heating of mold itself was used to reduce the production cycle time. Since this heating method does not require a coil like electromagnetic induction heating, the reduction of molding cost can be expected.

Although CFRTP pipe mold was heated rapidly by using high-frequency direct resistance heating, molded CFRTP pipe has tensile strength of 427 MPa that was 70% of the expected value [6]. Impregnating and shaping processes were performed at the same time for the purpose of shortening the molding time. However the mechanical properties were not sufficiently obtained because of the high viscosity of the matrix resin. In CFRTP pipe molding, since a void is a cause of strength reduction, the impregnation of the resin is an important issue to be solved.

In general, in order to compensate the weak point of the high viscosity of the thermoplastic resin, in the molding of continuous fiber reinforced thermoplastics, reinforced thermoplastic laminated composites in which the resin was impregnated beforehand to reinforced fabrics are manufactured and they are formed to final products as secondary process. By separating the impregnation process and the forming process, high quality products are obtained. In this study, carbon fiber reinforced thermoplastic prepreg sheet, in which reinforcing carbon fabric was impregnated with thermoplastic resin beforehand, was manufactured and used as semi-product material for CFRTP pipe molding to improve the quality of the pipe. In addition, mechanical properties of the molded pipe were evaluated by tensile test and lateral compression test.

2 Molding method

2.1 Materials for CFRTP prepreg sheet

Non-woven Stitched Multi-axial Cloth (NSMC, Fig. 1) was used for semi-product material of CFRTP. NSMC, in which NCF having $[0^\circ/+45^\circ/90^\circ/-45^\circ]$ and 240 g/m² in the weight per unit area, and polyamide 6 non-woven fabric with a melting point of 211°C, having 50 g/m² in the weight per unit area were stitched simultaneously, was used in this study. Furthermore, polyamide 6

nonwoven fabric having 100 g/m^2 in the weight per unit area was put on this NSMC so that the volume fraction of fiber (Volume Fraction: V_f) was set for 50%. Continuous carbon fiber thermoplastic prepreg sheet of 0.2 mm thickness was molded by a hot press molding machine under a pressure of 1.6 MPa at 265°C .

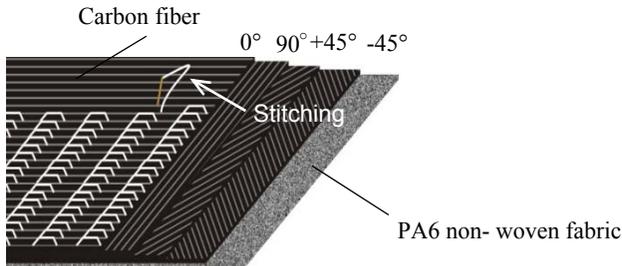


Figure 1: NSMC (Non-woven Stitched Multi-axial Cloth).

2.2 Pipe molding procedure

CFRTP pipe molding process is shown in Fig. 2. Carbon steel round bar made of SUS430 in the size of 300 mm in length and 25 mm in diameter was used for the inner mold. For the outer mold, carbon steel tube in the size of 50.8 mm in outside diameter, 2.3 mm in thickness, and 200 mm in length was used. Teflon pipe in the size of 40 mm in outside diameter, 7.5 mm in thickness, and 200 mm in length was covered to the inner mold. To improve the releasing property, Kapton sheet coated with a releasing agent was wound around a Teflon pipe, and CFRTP prepreg sheet of 200 mm in length was wound seven times on it. Kapton sheet was wound around them before covering it with the outer mold, and the outer mold was tightened by a stainless steel band.

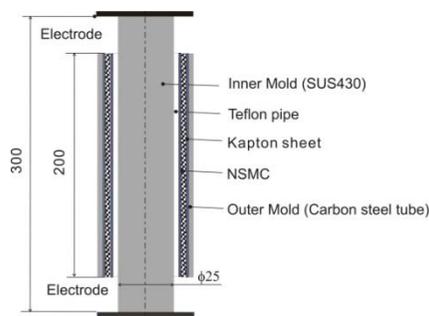


Figure 2: CFRTP pipe molding process.

The inner mold was heated by high-frequency direct resistance heating. Vacuum-tube oscillator with 30 kW maximum output and 185 kHz current frequency was used as the high-frequency oscillator. After the inner mold was heated to 265°C at 6 kW power output as the molding temperature, it was held

for one minute and air-cooled. For the production of references, NSMC and nonwoven fabric instead of prepreg sheet was used for CFRTP pipe molding as shown in the previous study [6].

3 Tensile test for the specimens cut out from the pipe

3.1 Evaluation of mechanical properties

The tensile tests were conducted by the universal testing machine (Autograph AG-100kN, Shimadzu Co., Japan), and the video non-contact extensometer (DVE-100, Shimadzu Co., Japan) was used to measure the displacement between gauge points of the specimen. The specimen, whose length and width were 170 mm and 10 mm respectively, was cut out from the molded pipe by a fine cutter. As the specimen has curvature, aluminium tab was attached to both ends of the specimen and the gap between specimen and the aluminium tab was filled with epoxy resin. The gauge length and the displacement rate were 50 mm and 1.0×10^{-5} m/s respectively. For evaluating the impregnation properties of a resin into fiber bundle, the section of the specimen was polished and observed with confocal microscope (Lasertec, OPTELICS H1200 M-BM).

3.2 Results and discussions

Fig. 3 shows the temperature history of the surface of the prepreg sheet, which was contacting to the outer mold, during pipe molding process. It was heated to the molding temperature of 265°C from 25°C in 239 seconds. Fig. 4 shows an overview of the molded CFRTP pipe. Dimensions of the pipe were 46.2 mm in outside diameter, 1.8 mm in thickness, and 180 mm in length. Fig. 5 shows the cross section image of the CFRTP pipe. Voids were not observed and good impregnated pipe was molded.

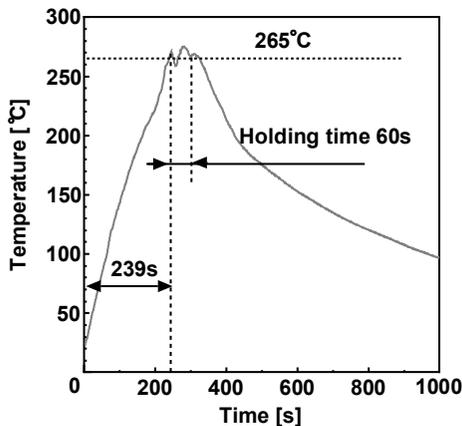


Figure 3: Temperature history of the contact surface of the prepreg sheet and the outer mold during molding process.

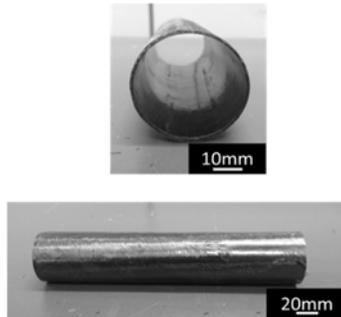


Figure 4: Molded CFRTP pipe.

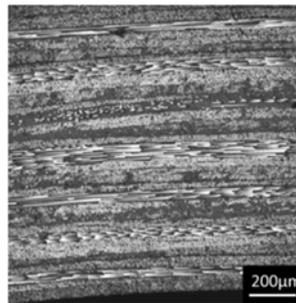


Figure 5: Cross-section image of molded CFRTP pipe.

Fig. 6 shows stress strain curve of the tensile test. Brittle behaviour was observed and the tensile strength and tensile modulus of the specimen cut out from the CFRTP pipe which was molded with prepreg sheet were 538 MPa and 27.9 GPa respectively. The ratio to each expected value was 95% and 89%. The tensile strength and the tensile modulus of the pipe, which was directly molded with NSMC and nonwoven resin fabric, were reported to be 427 MPa and 26.4 GPa respectively in previous study [6]. By using the prepreg sheet for pipe molding, better quality pipe can be manufactured.

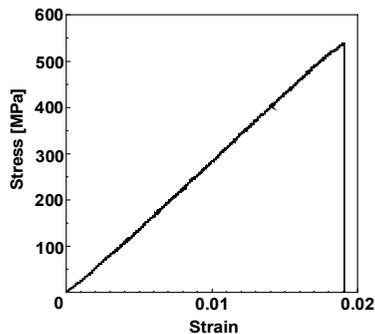


Figure 6: Stress strain curve of the specimen cut out from the CFRTP pipe.

4 Lateral compression test of the pipe

4.1 Evaluation of mechanical properties

The lateral compression test for the molded pipe was conducted by the universal testing machine (Autograph AG-250kN, Shimadzu Co., Japan). Specimen of 50 mm in length was cut out from the molded pipe. The displacement of the pipe was defined as crosshead displacement, and displacement rate was set at 2.0 mm/min based on JIS K7013. Lateral compressive strength was calculated using the next expression in reference to JIS K6911.

$$\sigma_{fB} = \frac{3P(D_0+D)^2}{\pi LD(D_0-D)^2} \quad (1)$$

where σ_{fB} is lateral compressive strength, P is maximum load, L is specimen length, D_0 is outside diameter of the specimen, and D is inside diameter of the specimen.

4.2 Results and discussion

Fig. 7 shows lateral compressive load displacement curves of CFRTP pipes that were molded with prepreg sheet and NSMC with nonwoven resin fabric. Fig. 8 shows the compressed specimen during the lateral compression test at each displacement shown in Fig. 7. When the load reached 1903 N, the specimen broke at the upper part, point A as shown in Fig. 8 (b). Then the load rose again, the specimen broke at lower part, point B as shown in Fig. 8 (c).

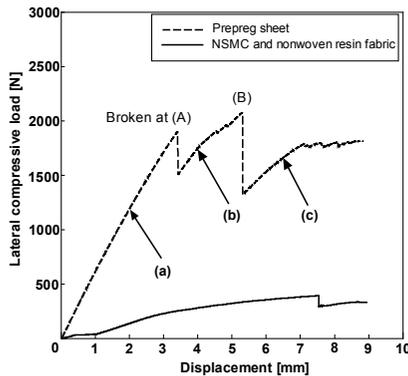
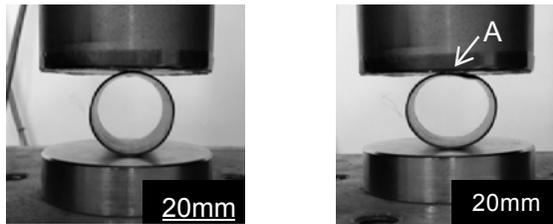


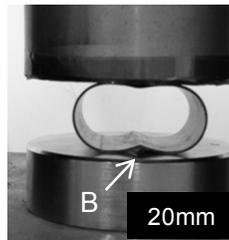
Figure 7: Lateral compressive load- displacement curve of molded pipe.

In this study, the maximum load that the specimen initially broke at point A was used for the expression (1) to calculate the lateral compressive strength. The lateral compressive strength of the pipe molded with prepreg sheet was 478 MPa. On the other hand, that of the pipe molded with NSMC and nonwoven resin fabric was 66 MPa. The lateral compressive strength of the pipe molded with prepreg sheet is higher than that of the pipe molded with NSMC and nonwoven resin fabric.



(a): Displacement 2 mm

(b): Displacement 4 mm



(b): Displacement 6.5 mm

Figure 8: Compressed specimen at each displacement shown in Fig. 7.

5 Conclusions

Carbon fiber reinforced thermoplastic prepreg sheet, in which reinforced carbon fabric was impregnated with thermoplastic resin beforehand, was manufactured and used as semi-product material for CFRTP pipe molding. And mechanical properties of the molded pipe were evaluated by tensile test and lateral compression test. The investigation yields the following conclusions:

1. High-frequency direct resistance heating enables the heating of the mold to the molding temperature of 265°C from a room temperature in 239 seconds.
2. By using thermoplastic prepreg sheet, good quality CFRTP pipe, whose tensile strength, tensile modulus and lateral compressive strength were 538 MPa, 27.9 GPa and 478 MPa respectively, can be molded.

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