1 Introduction

In recent years, continuous fiber reinforced thermoplastic composites are attracting a lot of attention in various areas such as automobile industry and aircraft industry because of the improvement of the fuel efficiency and the capability of automobile and aircraft. Thermoplastic composites can be molded in high cycle compared to thermo-setting composite and it has also second workability and recyclability. However, the combination of continuous fiber and thermoplastic resin have disadvantage that impregnation of resin to fiber bundle is difficult since the melting viscosity of thermoplastic resin is high. Therefore, the high cycle molding with the use of high impregnation materials have been expected.

Hollow structural products with high strength and high rigidity by continuous carbon fiber are demanded as primary member for automobile industry. Frame structure as shown in Fig.1 can be constructed by welding thermoplastic composites such as cylindrical pipe, square pipe, pipe joint and so on because thermoplastic composite has second workability.

The purpose of this study is to construct frame structure with high impregnation materials by high cycle molding. In this study, inner pressure molding by heating device of high frequency IH was adopted as high cycle molding for braided fabric reinforced thermoplastic composites.

In this study, versatile members such as cylindrical pipe and square pipe by this molding method were molded and these members were evaluated formability.

Cylindrical pipes were molded with braided fabric at different molding time. Molding state was evaluated by measurement of molding temperature history at molding and cross-sectional observation of these cylindrical pipes. And molding time was determined. Molding time of square pipes was determined by a method similar to cylindrical pipe. Then, square pipes was made with braided fabric and woven fabric by the determined molding time. Molding state was evaluated by cross-section observation of molding products and mechanical property was evaluated by tensile test in each reinforcements.

2 Materials

2.1 Intermediate material

Intermediate materials selected in this study are pre-impregnated tape (PT). PT consists of carbon fiber and polypropylene resin. Use of PT was intended to decrease the impregnation time. Cross-sectional photograph of PT were shown in Fig.2. The specifics of PT obtained by cross-section observation are as indicated below; PT was 5mm in width, 0.15mm in thickness, 0.4% in Un-
impregnation containing void (UCV), and 49% in Vf. Definition of UCV is shown in Fig.3. UCV was defined the proportion of un-impregnation area and void in fiber bundle for cross-section area of molding products.

Fiber bundle Un-impregnation area Void

Cross-section of molding product

Fig.2. Cross-section photograph of PT

2.2 Reinforcements

Reinforcements was used in this study are indicated below. Braided fabric consists of only diagonally-oriented braiding yarn as shown in Fig.4. Braided fabric-MEY consists of diagonally-oriented braiding yarn and longitudinally-oriented middle-end-yarn as shown in Fig.5. Woven fabric consists of warp and weft yarns as shown in Fig.6. Reinforcements used in molding of cylindrical pipe are braided fabric. The braided fabric consists of 24 braiding yarns. The number of staking layer was 2ply. Reinforcements used in molding at different molding time of square pipe were braided fabric, braided fabric-MEY and woven fabric. Fabrication method of reinforcements was shown in Table 1. The braided fabric consisted of 48 braiding yarns with 45 degree of braiding angle. The number of staking layer in braided fabric was 7ply. The braided fabric-MEY consisted of 48 braiding yarns with 45 degree of braiding angle and 24 middle-end-yarns. The number of staking layer in braided fabric-MEY was 7ply. The number of staking layer in the woven fabric was 7ply.

Table 1 Fabrication of square pipes

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Number of braiding yearn</th>
<th>Number of middle end yearn</th>
<th>Braiding angle(deg)</th>
<th>Number of layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-S</td>
<td>48</td>
<td>-</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>BM-S</td>
<td>48</td>
<td>24</td>
<td>45</td>
<td>5</td>
</tr>
<tr>
<td>W-S</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
</tbody>
</table>
3 Molding method

3.1 Inner pressure molding by heating device of high frequency IH

Inner pressure molding system is shown in Fig.7 and this molding method is shown below. Materials with hollow structure designed for the molding die were inserted into the die. The bag used in inner pressure molding was made by kapton film and PTFE tape such that this bag shape was equal to inside sectional area of molding products. This bag was inserted into inside of base materials, and the die was closed. This bag was expanded by injected air. Therefore, base material received pressure from inside. Then thermoplastic resin was melted by rapidly heated die, and the melted resin was impregnated into fiber bundle. And hollow structure product was molded by high cycle.

3.2 Molding time

Definition of molding cycle is shown in Fig.8. In this study, heating time was defined the time that the die is heated to mold temperature from ordinary temperature. Holding time was defined the time from the setup mold temperature until the start of cooling. Cooling time was defined the time from the start of cooling to mold temperature that is able to eject the molding product.

![Fig.8. Definition of molding cycle.](image)

3.3 Molding condition

3.3.1 Cylindrical pipe

Cylindrical pipes (50mm in external diameter, 200mm in length) were molded by molding condition as shown in Table 2. Molding temperature and time was kept at 200 °C and 5min (Heat up

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Molding time (min)</th>
<th>Mold temperature (℃)</th>
<th>Inner pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-C-T1</td>
<td>1</td>
<td>230</td>
<td>0.7</td>
</tr>
<tr>
<td>B-C-T2</td>
<td>1</td>
<td>230</td>
<td>0.7</td>
</tr>
<tr>
<td>B-C-T3</td>
<td>1</td>
<td>230</td>
<td>0.7</td>
</tr>
<tr>
<td>B-S-T1</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
<tr>
<td>B-S-T3</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
<tr>
<td>B-S-T5</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
</tbody>
</table>
time: 1min, holding time: 1min, 2min, 3min cooling time: 1min). Inner pressure through the bag by air was 0.7MPa.

### 3.3.2 Square pipe
Square pipes (50mm in width and height, 200mm in length, 5mm in radius of corner) were molded shown in Table 2. Molding temperature and time was kept at 200 °C and 5min (Heat up time: 1min, holding time: 1min, 3min, 5min, cooling time: 1min). Inner pressure through the bag by air was 0.2MPa.

### 4 Experimental method

#### 4.1 Measurement of mold temperature history
Mold temperature history of the cylindrical pipe was measured using the thermocouple placed in the center of the die during molding.

#### 4.2 Cross-sectional observation
Cross-section of molding products were observed by microscope (PME3: Olympus Corporation) to examine effects of difference in holding time on impregnation state of cylindrical pipes and square pipes. And, Cross-section of square pipes were observed by microscope to examine effects of difference in reinforcements on thickness of molding products and impregnation state. For the observation on cross section, the samples were emery grinded (#100–#2,000) and buffed (alumina particle, average particle size: 100 nm) after they were embedded in epoxy resin.

#### 4.3 Tensile test
Specimens were cut from side section of square pipe in reinforcements into 20mm in width and 200mm in length and tensile test was performed. Test speed was 1mm/min and span length was 100mm.

### 5 Result and discussion

#### 5.1 Cylindrical pipe

##### 5.1.1 Measurement of mold temperature
Mold temperature histories are shown in Fig.8. The die was heated to setup mold temperature from ordinary temperature about one minute later and this die was held setup mold temperature for each hold time. Then, this die was rapidly cooled about one minute.

![Fig.8. Temperature history of each product.](image)

5.1.2 Cross sectional observation
Cross-sectional photographs of each product are shown in Fig.9. According to Fig.9, Un-impregnation area in carbon fiber bundle and voids between the layers existed cross-sectional area of cylindrical pipes, because air between the layer s remained.

![Fig.9. Cross-section of cylindrical pipes.](image)
HOLLOW STRUCTURAL PRODUCT OF CONTINUOUS FIBER REINFORCED THERMOPLASTIC COMPOSITES BY HIGH CYCLE MOLDING

Relationship between UCV and holding time are shown in Fig.10. According to Fig.10, UCV decreases with an increase in holding time. UCV was the constant value in holding time of two minute and three minute. Therefore, it was clarified that cylindrical pipe of continuous fiber reinforced composite could be molded about four minute.

![Fig. 10 Relationship between UCV and holding time.](image)

5.2 Square pipe

5.2.1 Cross sectional observation

Cross-sectional photographs of corner section and side section are shown in Fig.11. Un-impregnation area in carbon fiber bundle and voids between the layers existed cross-sectional area of each product, because air between the layers remained. Relationship between UCV and holding time are shown in Fig.12. Value of UCV decreased with an increase in holding time. UCV of corner section and side section was the constant value in holding time of three minute and five minute. Therefore, it was clarified that square pipe of continuous fiber reinforced thermoplastic composite can be molded about five minute.

Square pipes of each reinforcements were molded by molding condition as shown in Table 3 because square pipe of continuous fiber reinforced thermoplastic composite could be molded about five minute (heating time:1min, holding time:3min, cooling time:1min).

Square pipes of each reinforcements were molded by molding condition as shown in Table 3 because square pipe of continuous fiber reinforced thermoplastic composite could be molded about five minute.

![Fig.11. Cross-section of square pipes by a change in holding time.](image)

Table 3 Molding condition of reinforcements

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Heating time (min)</th>
<th>Molding time (min)</th>
<th>Cooling time (min)</th>
<th>Mold temperature (°C)</th>
<th>Inner pressure (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-S</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
<tr>
<td>BM-S</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
<tr>
<td>W-S</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>200</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Cross-sectional photographs of corner section and side section are shown in Fig.13. Thickness of corner section was thicker than that of side section, and voids existed between the layers. Void content of woven fabric was the highest in molding products. The measurement point of thickness is shown in Fig.14 and thickness of corner section and side section is shown in Fig.15. According to Fig.15, thickness of corner section was thicker than that of side section. Materials received pressure from inner bag was not constant, because thickness of corner section was thicker than side section. The difference between thickness at corner section and side section of both braided fabric was drastically reduced compared to that of woven fabric.

Result of UCV in cross-section of molding products is shown in Fig.16. UCV of molding products was higher than that of PT, because voids existed between layers of molding product. UCV of corner section was higher than that of side section for all samples. UCV of braided fabric was similar to that of braided fabric-MEY and UCV of woven fabric was the highest. Since deformability of braided fabric was higher than that of woven fabric, higher internal pressure was applied to reinforcements.
5.2.2 Tensile test

Tensile modulus, strength and achievement ratio of modulus are shown in Table 4. The achievement ratio was calculated from experimental modulus divided by theoretical modulus with FEM analysis. Use of FEM model was considered the internal structure of braided composite as shown in Fig.17. [1] Theoretical modulus was a major difference between experimental modulus and theoretical modulus for all composites. Then, tensile specimen of braided fabric was made with fully pressure by press machine to examine the effect of molding pressure, and theoretical modulus was calculated.

Table 4 Modulus, maximum stress and achievement ratio

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Modulus (GPa)</th>
<th>Maximum stress (MPa)</th>
<th>Achievement ratio by inner pressure molding (%)</th>
<th>Achievement ratio by press machine (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-S</td>
<td>6.7</td>
<td>62</td>
<td>56</td>
<td>84</td>
</tr>
<tr>
<td>BM-S</td>
<td>35</td>
<td>345</td>
<td>59</td>
<td>-</td>
</tr>
<tr>
<td>W-S</td>
<td>40</td>
<td>470</td>
<td>41</td>
<td>-</td>
</tr>
</tbody>
</table>

Achievement ratio of this specimen was 84%, and higher than that of specimen made by inner pressure molding. Pressure on braided fabric by inner pressure molding was lower than that by compression molding. It is considered that modulus of each reinforcements would be increased by use of deformable inner bag.

Thermoplastic composite such as cylindrical pipe and square pipe by use of continuous fiber reinforced thermoplastic composites could be molded at short time. Also, pipe joint product by use of continuous fiber reinforced thermoplastic composites could be molded. [2] Finally frame structure was obtained by connecting pipe joint product and cylindrical product as shown in Fig.18.
6 Conclusions

By measurements of cross-sectional observation and UCV in the cylindrical pipe with braided fabric, it was clarified that this pipe of continuous fiber reinforced thermoplastic composite were molded about four minute.

By measurements of cross-sectional observation and UCV in the square pipe with braided fabric, it was clarified that this pipe of continuous fiber reinforced thermoplastic composite were molded about three minute.

By measurements of cross-sectional observation, thickness and UCV in the square pipe with reinforcements, thickness of corner section was thicker than that of side section in reinforcements but the difference between thickness at corner section and side section of both braided fabric was drastically reduced compared to that of woven fabric and braided fabric was higher than that of woven fabric, higher internal pressure was applied to reinforcements.

As a result of comparison of experimental modulus obtained by tensile test with the theoretical modulus use of FEM analysis in the square pipe, pressure on braided fabric by inner pressure molding was lower than that by compression molding. It is considered that modulus of each reinforcements would be increased by use of deformable inner bag.

Thermoplastic composite such as cylindrical pipe and square pipe by use of continuous fiber reinforced thermoplastic composites could be molded at short time. Also, pipe joint product by use of continuous fiber reinforced thermoplastic composites could be molded. Finally frame structure was obtained by connecting pipe joint product and cylindrical product.

References
