A Study on Stress Analysis and Design of Composites
Shaft on Small Ship by Filament Winding Process
ABSTRACT

NOMENCLATURE

1.1 

1.2 

2.1 

2.2 

2.3 

2.4 

2.5 

3.1 

3.2
NOMENCLATURE

\( \sigma_{ij} \) : Vertical stress

\( \tau_{ij} \) : Shear stress

\( \gamma_{ij} \) : Shear strain

\( \varepsilon_{i} \) : Vertical strain

\( E_{ij} \) : stiffness

\( x, y, z \) : Direction of axis

\( Q_{ij} \) : Reduced stiffness

\( \overline{Q}_{ij} \) : Transformed reduced stiffness

\( S_{ij} \) : Compliance

\( l \) : \( \cos \theta \)

\( m \) : \( \sin \theta \)

\( N_{ij} \) : Positive resultant forces

\( M_{ij} \) : Positive resultant moments

\( t \) : Total thickness of laminate

\( k_{ij} \) : Bending curvature

\( \varepsilon_{i}^{0} \) : Midplane tensile strain

\( A_{ij} \) : Extensional stiffness

\( B_{ij} \) : Coupling stiffness
$D_{ij}$ : Bending stiffness

$PS$ : Horse power

$Toq$ : Torque

$D$ : Diameter of shaft

$R$ : Ratio of diameter

$\bar{\sigma}_l$ : Average stress of shaft direction

$\bar{\tau}_{xy}$ : Average shear stress

$(\tau_{xy})_M$ : Average shear stress of shaft
Abstract

Filament Winding Process is a comparatively simple operation in which continuous reinforcements in the form of roving are wound over a rotating mandrel. And now well established as a versatile method for storage tanks and pipe for the chemical and other industries.

This paper investigates that technology is ensured by filament winding process and composites shaft of small ship is developed. Property of composites shaft has high strength and effect of materials reduction as it is compared to metal shaft. So, purpose of the study is to ensure manufacture process of composites shaft, stress analysis and design of structure for small ship.

The purpose of this study is to design and to analyze the stress of composite shaft which is wound by filament winding method. The composites shaft has high strength and reduction in weight compared to metal shaft. Manufacturing composites shaft is used to metal shaft (SUS420), it is diameter (D=40), length (L=300). The shaft is designed to considerate tensile, compression, torsion and vibration.

As composites shaft which is influenced the largest by torsion was analyzed, the diameter is as large as shear stress is smaller. If angle of winding is 90-degree, shear elongation becomes large and torsion moment is large. In order to replace metal shaft with composite shaft, the diameter of shaft was determined on 40mm and the ratio of
diameter was determined on 0.4 for torsion moment. As angle of winding is 30-60 degree, shear elongation was not different. In the case that angle of winding is 75-degree over, composites shaft may be fractured by torsion. So, diameter of composite shaft must be grown, because of safe of composite shaft.
1.1 Filament winding

Filament winding, autoclave, RTM, FRP, filament winding, filamentwinding, RT M [1]. Filament winding, autoclave, RTM [2].
1.2 "FRP"

"FRP"

"Resin bath"

"Filament winding"
<table>
<thead>
<tr>
<th></th>
<th>Steel shaft</th>
<th>Composites shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Materials</strong></td>
<td>Steel</td>
<td>FRP</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>1 (100%)</td>
<td>0.3 (30%)</td>
</tr>
<tr>
<td><strong>Corrosion resistance</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Specific strength</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Specific elongation</strong></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Absolution of vibration</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Numbers of bearing</strong></td>
<td>Many</td>
<td>A little</td>
</tr>
<tr>
<td><strong>Property of repair</strong></td>
<td>Bad</td>
<td>Good</td>
</tr>
</tbody>
</table>
2.1 Filament Winding Method

Filament Winding Method \([3,4,5]\) refers to the process of winding fibers onto a mandrel to form a composite structure. This method involves controlling the tension \([6]\) during the winding process to ensure a uniform distribution of fibers. There are two main types of Filament Winding: wet winding and dry winding. The choice between these methods depends on the specific application and the properties required of the final composite. For instance, prepreg roving is often used in dry winding processes to achieve optimal fiber placement.

- 4 -
2.2 2.2.1 2.2.2

2.2.1

a. (glass fiber)

b. (advanced composite materials)

2.2.2 (matrix)

(matrix)

(thermosetting)

(thermoplastics)
2.3 MAIN BODY

a. Headstock, Tailstock, Base, Carriage, Carriage Bed, Resin Bath, Eye, Eye Bath. (Fig. 1)

b. (headstock)
- Spindle Motor, Timing Belt, Chuck, Tailstock, Carriage, Bed. (Fig. 2)

c. (tailstock)
- (carriage)

- (bed)
Spindle (cross feeder), bath, eye

e. carriage bed

(Fig. 3)

f. resin Bath

(Fig. 4)

g. eye, eye support

(Fig. 5)

h. controller panel

RPM (speed setting) S/W, S/W, S/W,
S/W, cycle counter, S/W.

i. curing oven (curing oven)

FRP molding. (Fig. 6)

j. FRP molding
Fig. 1 Main body

Fig. 2 Headstock and tailstock

- 9 -
Fig. 3 Carriage and carriage bed

Fig. 4 Resin bath
Fig. 5 Eye and eye support

Fig. 6 Curing oven
2.4 Filament winding fabrication system

Fig. 7 Filament winding fabrication system

Yarn, Tow, (cure), mandrel, (polyester), (vinylester), (epoxy resin), frame, aramid.
(Filament Winding) mandrel, winding precure, alignment (alignment)

a. Mandrel

Mandrel is typically made of a material with a high temperature tolerance, such as 100°C. It is important that the mandrel is aligned correctly.

b. Winding

Winding is done with a tension of 10 N. The winding tension should be maintained at 25~27 mmHg. The correct tension ensures uniform winding.

c. Winding (winding)

Winding (winding) is typically done using a strand and a spring. The strand and spring are carefully aligned and wound to ensure a uniform and consistent final product.
2.5.1  

1. layer winding parts. The winding parts are carefully "rolled" and "wound" to an autoclave.

2. Fiber $V_f$ (volume fraction) is calculated to the appropriate. Autoclave is used to maintain the fiber at a high temperature for a prolonged period of time.

3. Fiber $V_f$ (volume fraction) is calculated to the appropriate.

4. Fiber $V_f$ (volume fraction) is calculated to the appropriate.
5 Prepreg

2.5.2

1 mandrel

2 Mandrel

3 Lamina

4 Mandrel

5
3.3 ファイバー複合材料の応力・ひずみ特性

3.3.1 ステーク-ストレーン関係

ファイバー複合材料においては、ラミネート (ply laminate)、ファイバー (fiber)、マトリックス (matrix) の3つの要素から構成されており、応力 (stress) とひずみ (strain) の関係は重要である。

1mm の厚さのラミネートが用いられている。ステーク-ストレーン関係において、ひずみの変化を観察する。

a. ステーク-ストレーン関係 (Stress-Strain Relation)
\[
\begin{pmatrix}
\sigma_1 \\
\sigma_2 \\
\sigma_3 \\
\tau_{23} \\
\tau_{31} \\
\tau_{12}
\end{pmatrix} =
\begin{pmatrix}
Q_{11} & Q_{12} & Q_{13} & 0 & 0 & 0 \\
Q_{21} & Q_{22} & Q_{23} & 0 & 0 & 0 \\
Q_{31} & Q_{32} & Q_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & Q_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & Q_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & Q_{66}
\end{pmatrix}^{-1}
\begin{pmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\gamma_{23} \\
\gamma_{31} \\
\gamma_{12}
\end{pmatrix}
\]

\[(1)\]

\[
\begin{pmatrix}
\sigma_1 \\
\sigma_2 \\
\sigma_3 \\
\tau_{23} \\
\tau_{31} \\
\tau_{12}
\end{pmatrix} =
\begin{pmatrix}
S_{11} & S_{12} & S_{13} & 0 & 0 & 0 \\
S_{21} & S_{22} & S_{23} & 0 & 0 & 0 \\
S_{31} & S_{32} & S_{33} & 0 & 0 & 0 \\
0 & 0 & 0 & S_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & S_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & S_{66}
\end{pmatrix}^{-1}
\begin{pmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\gamma_{23} \\
\gamma_{31} \\
\gamma_{12}
\end{pmatrix}
\]

\[(2)\]

\[
\begin{pmatrix}
\sigma_1 \\
\sigma_2 \\
\sigma_3 \\
\tau_{23} \\
\tau_{31} \\
\tau_{12}
\end{pmatrix} =
\begin{pmatrix}
Q_{11} & Q_{12} & 0 & 0 & 0 & 0 \\
Q_{12} & Q_{22} & 0 & 0 & 0 & 0 \\
0 & 0 & Q_{66} \\
0 & 0 & 0 & Q_{44} & 0 & 0 \\
0 & 0 & 0 & 0 & Q_{55} & 0 \\
0 & 0 & 0 & 0 & 0 & Q_{66}
\end{pmatrix}^{-1}
\begin{pmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\gamma_{23} \\
\gamma_{31} \\
\gamma_{12}
\end{pmatrix}
\]

\[(3)\]
(stiffness) \( E \) and \( v \).

b. \( \text{ å·»·áÇ««} \) \( \text{ á·®·áÇ««} \) \\

\[
E \text{ (1)}, \quad v \text{ (2)}, \quad \theta \text{ (3)}.
\]

The \( E \) and \( v \) for the \( \theta \) are given by:

\[
E_x, \quad E_y
\]

and

\[
(2)\text{.}
\]
\[
\begin{pmatrix}
\varepsilon_1 \\
\varepsilon_2 \\
\varepsilon_3 \\
\gamma_{23} \\
\gamma_{31} \\
\gamma_{12}
\end{pmatrix} = \begin{pmatrix}
\frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_2} & 0 & 0 & 0 \\
-\frac{\nu_{12}}{E_2} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\
-\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\
0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\
0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\
0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}}
\end{pmatrix} \begin{pmatrix}
\sigma_1 \\
\sigma_2 \\
\sigma_3 \\
\sigma_{23} \\
\sigma_{31} \\
\sigma_{12}
\end{pmatrix} \quad - (4)
\]

\[
\frac{\nu_{ji}}{E_i} = \frac{\nu_{ij}}{E_j} \quad i, j = 1, 2, 3
\]
Fig. 8 Rotation of the main fiber axis for the optional x, y axis

\[
\begin{pmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{pmatrix} = [T]^{-1} \begin{pmatrix}
\sigma_1 \\
\sigma_2 \\
\tau_{12}
\end{pmatrix}
\tag{5}
\]

\[
\begin{pmatrix}
\varepsilon_x \\
\varepsilon_y \\
\gamma_{xy} / 2
\end{pmatrix} = [T]^{-1} \begin{pmatrix}
\varepsilon_2 \\
\varepsilon_1 \\
\gamma_{12} / 2
\end{pmatrix}
\tag{6}
\]

\[ [T] = \begin{bmatrix}
\cos^2\theta & \sin^2\theta & 2\sin\theta\cos\theta \\
\sin^2\theta & \cos^2\theta & -2\sin\theta\cos\theta \\
-\sin\theta\cos\theta & \sin\theta\cos\theta & \cos^2\theta\sin^2\theta
\end{bmatrix}
\tag{7}
\]
\[ (5), (6), (7) \Rightarrow (3) \text{ with } x, y \rightarrow x, \gamma_{xy} \rightarrow \varepsilon_{xy} \]

\[
\begin{pmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{pmatrix} =
\begin{bmatrix}
\overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\
\overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26} \\
\overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66}
\end{bmatrix}
\begin{pmatrix}
\varepsilon_x \\
\varepsilon_y \\
\gamma_{xy}
\end{pmatrix}
\]

\[ \overline{Q}_{11} = Q_{11} l^4 + (2 Q_{12} + 2 Q_{66}) l^2 m^2 + Q_{22} m^4 \]
\[ \overline{Q}_{12} = S_{22} (l^4 + m^4) + (Q_{11} + Q_{22} - 4 Q_{66}) l^2 m^2 \]
\[ \overline{Q}_{22} = Q_{11} m^4 + 2(Q_{12} + 2 Q_{66}) l^2 m^2 + Q_{22} l^4 \]
\[ \overline{Q}_{16} = (Q_{11} - Q_{22} - 2 Q_{66}) l^3 m - (Q_{22} - Q_{12} - 2 Q_{66}) l m^3 \]
\[ \overline{Q}_{26} = (Q_{11} - Q_{22} - 2 Q_{66}) l m^3 - (Q_{22} - Q_{12} - 2 Q_{66}) l^3 m \]
\[ \overline{Q}_{66} = (Q_{11} + Q_{22} - 2 Q_{12} - 2 Q_{66}) l^2 m^2 + Q_{66} (l^4 + m^4) \]

\[ l = \cos \theta, \quad m = \sin \theta \]
3.2 $\ldots$ 

\[
[\sigma_y]_k = [\overline{Q_y}]_k [\varepsilon_y]_k \quad \text{(9)}
\]
\[ \sum_{k=1}^{N} [\sigma_y]_k = \sum_{k=1}^{N} [\overline{Q}_{y}][\varepsilon_y]_k \]
\[
\begin{pmatrix}
N_x \\
N_y \\
N_{xy}
\end{pmatrix}
= \sum_{k=1}^{N} \int_{z_{k-1}}^{z_k} \begin{pmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{pmatrix} dz \hspace{1cm} (11)
\]

\[
\begin{pmatrix}
M_x \\
M_y \\
M_{xy}
\end{pmatrix}
= \sum_{k=1}^{N} \int_{z_{k-1}}^{z_k} \begin{pmatrix}
\sigma_x \\
\sigma_y \\
\tau_{xy}
\end{pmatrix} zdz \hspace{1cm} (12)
\]

\[\sigma_y = \frac{N_y}{t}\hspace{1cm} (12-1)\]

**Fig. 10** Positive resultant forces and moment

- 24 -
\[
\begin{pmatrix}
N_x \\
N_y \\
N_{xy}
\end{pmatrix} =
\begin{pmatrix}
A_{11} & A_{12} & A_{16} \\
A_{12} & A_{22} & A_{26} \\
A_{16} & A_{26} & A_{66}
\end{pmatrix}
\begin{pmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{pmatrix}
+ \begin{pmatrix}
B_{11} & B_{12} & B_{16} \\
B_{12} & B_{22} & B_{26} \\
B_{16} & B_{26} & B_{66}
\end{pmatrix}
\begin{pmatrix}
k_x \\
k_y \\
k_{xy}
\end{pmatrix}
\tag{13}
\]

\[
\begin{pmatrix}
M_x \\
M_y \\
M_{xy}
\end{pmatrix} =
\begin{pmatrix}
B_{11} & B_{12} & B_{16} \\
B_{12} & B_{22} & B_{26} \\
B_{16} & B_{26} & B_{66}
\end{pmatrix}
\begin{pmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{pmatrix}
+ \begin{pmatrix}
D_{11} & D_{12} & D_{16} \\
D_{12} & D_{22} & D_{26} \\
D_{16} & D_{26} & D_{66}
\end{pmatrix}
\begin{pmatrix}
k_x \\
k_y \\
k_{xy}
\end{pmatrix}
\tag{14}
\]

\[
A_y = \sum_{k=1}^{N} \int_{k_{s-1}}^{k_s} \overline{Q}_{k_s} \, dz
\tag{15}
\]

\[
B_y = \sum_{k=1}^{N} \int_{k_{s-1}}^{k_s} \overline{Q}_{k_s} \, z \, dz
\tag{16}
\]

\[
D_y = \sum_{k=1}^{N} \int_{k_{s-1}}^{k_s} \overline{Q}_{k_s} \, z^2 \, dz
\tag{17}
\]
\[ A_{ij}, \quad N_{ij}, \quad x-y \quad \text{and} \quad D_{ij}, \quad M_{ij} \]
\[ B_{ij}, \quad x-y \quad \text{and} \quad \text{etc.} \]

\[ d. \quad \text{etc.} \]

\[ \text{etc.} \]
\[ A_{ij} = \sum_{k=1}^{N} [ \overline{Q}_{ij} ]_k \int_{k_{z-1}}^{k_z} dz = \overline{Q}_{ij} t^{1} \quad \text{--------------------------- (18)} \]

\[ B_{ij} = \sum_{k=1}^{N} [ \overline{Q}_{ij} ]_k \int_{k_{z-1}}^{k_z} z \, dz = 0 \quad \text{--------------------------- (19)} \]

\[ D_{ij} = \sum_{k=1}^{N} [ \overline{Q}_{ij} ]_k \int_{k_{z-1}}^{k_z} z^2 \, dz = \frac{1}{12} \overline{Q}_{ij} t^{3} \quad \text{--------------------------- (20)} \]
Fig. 11 Shape of shaft for small ship
\[(\tau_{xy})_M = \frac{16 T_{oq}}{\pi D^3 (1 - R^4)} \quad - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - (21)\]

\[ (\tau_{xy})_M \text{ is the torsion stress (N/mm}^2\text{), } T_{oq} \text{ is the torque, } D \text{ is the shaft diameter, } R \text{ is the radius of gyration.} \]

\[(\tau_{xy})_M \text{ is the mean shear stress.} \]

\[(\tau_{xy})_M = \overline{\tau}_{xy} \quad - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - (22)\]

\[(\tau_{xy})_M \text{ is the torsion stress.} \]

\[
\begin{pmatrix}
N_x \\
N_y \\
N_{xy}
\end{pmatrix} =
\begin{bmatrix}
A_{11} & A_{12} & A_{16} \\
A_{12} & A_{22} & A_{26} \\
A_{16} & A_{26} & A_{66}
\end{bmatrix}
\begin{pmatrix}
\varepsilon_x^0 \\
\varepsilon_y^0 \\
\gamma_{xy}^0
\end{pmatrix} \quad - - - - - - - - - - - - - - - - - - - - (23)
\]

\[(21)\]

\[
N_x = A_{11} \varepsilon_x^0 + A_{12} \varepsilon_y^0 + A_{16} \varepsilon_{xy}^0 \]

\[
N_y = A_{12} \varepsilon_x^0 + A_{22} \varepsilon_y^0 + A_{26} \varepsilon_{xy}^0 \quad - - - - - - - - - - - - - - - (24)
\]

\[
N_{xy} = A_{16} \varepsilon_x^0 + A_{26} \varepsilon_y^0 + A_{66} \varepsilon_{xy}^0
\]
\[ N_x = t \left[ \bar{Q}_{11} \varepsilon_x^0 + \bar{Q}_{12} \varepsilon_y^0 + \bar{Q}_{16} \varepsilon_{xy}^0 / N \right] \]
\[ N_y = t \left[ \bar{Q}_{12} \varepsilon_x^0 + \bar{Q}_{22} \varepsilon_y^0 + \bar{Q}_{26} \varepsilon_{xy}^0 / N \right] \]
\[ N_{xy} = t \left[ \bar{Q}_{16} \varepsilon_x^0 / N + \bar{Q}_{22} \varepsilon_y^0 / N + \bar{Q}_{26} \varepsilon_{xy}^0 \right] \]  

\[ \bar{\sigma}_x = \bar{Q}_{11} \varepsilon_x^0 + \bar{Q}_{12} \varepsilon_y^0 + \bar{Q}_{16} \varepsilon_{xy}^0 / N \]
\[ \bar{\sigma}_y = \bar{Q}_{12} \varepsilon_x^0 + \bar{Q}_{22} \varepsilon_y^0 + \bar{Q}_{26} \varepsilon_{xy}^0 / N \]
\[ \bar{\tau}_{xy} = \bar{Q}_{16} \varepsilon_x^0 / N + \bar{Q}_{22} \varepsilon_y^0 / N + \bar{Q}_{26} \varepsilon_{xy}^0 \]
5.1

\[
\frac{D_0}{D_1} = 0.4
\]

Fig. 12. Table 1.
Fig. 12 Shear stress for rate of dimension
### Table 2 Design condition for composite shaft

<table>
<thead>
<tr>
<th>Horse power</th>
<th>196 (PS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPM</td>
<td>6,000</td>
</tr>
<tr>
<td>Tensile elastic modulus of glass/epoxy composites ($E_1$)</td>
<td>42,770 (MPa)</td>
</tr>
<tr>
<td>Tensile elastic modulus of glass/xpoxy composites ($E_2$)</td>
<td>11,720 (MPa)</td>
</tr>
<tr>
<td>Poisson's ratio ($\nu_{12}$)</td>
<td>0.27</td>
</tr>
<tr>
<td>Shear modulus ($G_{12}$)</td>
<td>4,130 (MPa)</td>
</tr>
</tbody>
</table>

**Fig. 13** Shear strain for angles and ratio of dimension ($\varepsilon_{xy}^0$, $D_0=40$)
Fig. 14 Modulus of rigidity for angles
Fig. 15 Shear strain for angles and dimensions ($D_0/D_1=0.4$)

Fig. 16 Shear strain for angles and dimensions ($D_0/D_1=0.6$)
Fig. 17 Shear strain for angles and dimensions ($D_n/D_s=0.8$)
5.2 材料和方法

a. 矩阵 (matrix)

<table>
<thead>
<tr>
<th>类型</th>
<th>E.E.W (g/eq)</th>
<th>粘度 (CPS at 25 °C)</th>
<th>比例</th>
<th>备注</th>
</tr>
</thead>
<tbody>
<tr>
<td>环氧树脂 (KBR-1729)</td>
<td>170-190</td>
<td>5,000-6,000</td>
<td>100</td>
<td>F/W, Laminating</td>
</tr>
<tr>
<td>固化剂 (KBH-1085)</td>
<td></td>
<td>30-60</td>
<td>80</td>
<td>F/W, Laminating</td>
</tr>
<tr>
<td>催化剂 (BDMA)</td>
<td>300-700</td>
<td></td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Properties of matrix used in this study

b. 增强 (reinforcement)

- 玻璃纤维（Glass roving）
- T EX® 卷 (TEX® roll)
- 直接缠绕卷绕 (Direct winding roving)
Table 4 Properties of fiber used in this study

<table>
<thead>
<tr>
<th>Kinds</th>
<th>TEX</th>
<th>Tensile strength (g/Lox)</th>
<th>Dia. ((\phi))</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS 2310 FW</td>
<td>2310</td>
<td>MIN.20</td>
<td>13</td>
<td>F/W, Pultrusion</td>
</tr>
</tbody>
</table>
### Table 5 Spec of filament winding machine

<table>
<thead>
<tr>
<th></th>
<th>Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winding Dia.</td>
<td>25-300mm</td>
</tr>
<tr>
<td>Winding length</td>
<td>1200mm</td>
</tr>
<tr>
<td>Weight of mandrel</td>
<td>Max. 20kg</td>
</tr>
<tr>
<td>No. of spindle</td>
<td>1 Axis</td>
</tr>
<tr>
<td>Height of spindle</td>
<td>1000mm</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of axis</td>
<td></td>
</tr>
<tr>
<td>- X Axis: Mandrel rotation</td>
<td></td>
</tr>
<tr>
<td>rpm: 0-200rpm</td>
<td></td>
</tr>
<tr>
<td>- Y Axis: Carriage traverse</td>
<td>stroke of traverse: 0-1400mm</td>
</tr>
<tr>
<td>- Z Axis: Cross feed</td>
<td>stroke of cross feed: 0-300mm</td>
</tr>
<tr>
<td>Winding angle</td>
<td>0-90</td>
</tr>
<tr>
<td>No. of roving</td>
<td>2 Rovings</td>
</tr>
</tbody>
</table>
(a) A mixture of resin  
(b) fixed Mandrel  
(c) winding  
(d) cure  
(e) shaft  

**Fig. 18 Process of Shaft**
Fig. 19 Cycle of cure

(\(\text{Fig. 19 Cycle of cure}\))

(1) (1) (1) (1) (1)
第5章

· 不同角度（30°～60°）的切削试验表明，75°的切削角度和75°的切削角度对材料（STS 420）的切削速度为60%。
Reference

3. Technology and status of composites applications C.S. Hong pp. 334-341, 1994


15. Filament winding, its development manufacture application, and design, John wiley and Sons Inc, Rosto, D.V. and Grove, C.S, pp. 216-248


   pp. 147~156 Johnes, R, M, 1975


22. アイクリスホウイ 5 ナノ 3 ドイ 3, 1997

23. マシンデザイン 5 パート, Robert L. Norton