MANUFACTURING PROCESS OF SANDWICH CRADLE FOR THE COMPUTED TOMOGRAPHY MEDICAL INSTRUMENT

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1 Introduction
In the past, the characteristics of Composite materials are lightweight and superior specific stiffness/specific strength. Composite materials were used aircraft parts and defense components that such characteristics are required for[1]. In recent years, be expanding its application field, Sandwich composites as the structures of trains, buses and vehicles are widely used[2-7]. Since the early 2000s, composites have been applied to medical device components and nowadays, are also satisfied X-ray transmission performance requirements as well as the lightweight characteristics. The components of CT (Computed Tomography) equipment and diagnostic X-ray equipment required X-ray transmission performance are produced to use the carbon material. On the other hand, the glass fiber materials are used as the parts of MRI(Magnetic Resonance Imaging) equipment.

This paper decided the 3D shape of sandwich composite for the cradle of CT instrument, suggested the stacking sequence with satisfaction on structural criteria using the Finite Element Analysis, and introduced the manufacturing method to meet the X-ray transmission performance uniformly. The design of Cradle was considered the space between other parts, fixing method, and assembly condition with headrest part. It is decided the stacking sequence to meet the criteria that the deflection at the end point is less than 20 mm when it is applied to 135 kg load at the specific locations. In site of manufacturing method, at first, it is used the hand lay-up for carbon UD and carbon fabric/polyester resin, but it had the un-uniform X-ray transmission performance due to the void and excess resin. For solving this problem, it was replaced with the infusion method for the first layer of face material and the application of carbon UD or fabric/epoxy resin prepreg for other layers. Therefore, the property of X-ray transmission was improved.

2 3-Dimensional Design of Cradle
2.1 Configuration of Test Device
Fig. 2 shows the 3 dimensional shape of Cradle. Cradle consists of the region inserted Headrest supported with patient's head in detail "A" of Fig. 2 and the region fixed at the main frame in detail "B". The total length of cradle is 2,322 mm and the width is 465 mm. The core material of Sandwich Cradle has the shape inserted in the headrest at front portion as showed Fig. 3 and the shape be inserted reinforcement block for the part bolted through the hole.
3 Properties of Applied materials

Cradle of sandwich structure is formed to bond two thin layers of facing materials and thick core material. Thus, each component of the X-ray permeable material should be evaluated the X-ray transmission performance and mechanical performance.

3.1 X-ray Transmission performance

3.1.1 Configuration of Test Device

X-ray transmission equipment used in performance evaluation is a digital X-ray system made by Listem, Inc. Configuration of the device for performance evaluation of X-ray transmission is shown as following Fig. 4. The distance between source and detector is 1,000 mm and test sample is located in the center. The field size is 40 × 40 mm. The conditions of X-ray transmission were 100 kV, 200 mA, and an exposure of 0.1 second.

![Fig. 4 Test configuration of X-ray transmission.](image)

3.1.2 Facing material

The materials of facing material were applied carbon UD (Uni-Directional) material and carbon fabric. It was produced by vacuum infusion process. The results were no difference depending on UD or fabric material, but it shows significant difference through the thickness as following Fig. 5. Depending on the thickness of face material confirmed that the transmittance decreases rapidly.

![Fig. 5 X-ray Transmission ratio of facing materials.](image)

3.1.3 Core material

PMI Foam 31 IG of Rohacell was used as core material, and it had 32 kg/m3 density. In this study, PMI Foam 2, 11, 45, 60 mm thicknesses were considered. The thickness of core material with low density was no significant effects as following Fig. 6. Due to the lower density of the core, depending on the thickness of core material was that the transmittance was no difference.

![Fig. 6 X-ray Transmission ratios of core material.](image)

3.2 Mechanical Properties

In this study, it was considered CU 250NS that is uni-directional material of carbon fiber, MCU 250 NS with excellent mechanical properties, and plain-woven fabric CF 3327 as the facing materials. Core materials used PMI foam. Mechanical properties of applied materials are shown in Table 1.
Table 1 Mechanical properties of applied materials

<table>
<thead>
<tr>
<th>Property Material</th>
<th>Tensile modulus (GPa)</th>
<th>Shear modulus (GPa)</th>
<th>Poisson's ratio</th>
<th>Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU 250NS</td>
<td>$E_1=127.6$</td>
<td>$G_{12} = 4.05$</td>
<td>$\nu_{12} = 0.34$</td>
<td>2,650</td>
</tr>
<tr>
<td></td>
<td>$E_2=7.58$</td>
<td>$G_{21} = 0.05$</td>
<td></td>
<td>65.5</td>
</tr>
<tr>
<td>MCU 250NS</td>
<td>$E_1=191.4$</td>
<td>$G_{12} = 5.10$</td>
<td>$\nu_{12} = 0.24$</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>$E_2=8.58$</td>
<td>$G_{21} = 0.04$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CF 3327</td>
<td>$E_1=48.3$</td>
<td>$G_{12} = 3.81$</td>
<td>$\nu_{12} = 0.07$</td>
<td>548.9</td>
</tr>
<tr>
<td>PMI foam</td>
<td>0.036</td>
<td>0.013</td>
<td>0.02</td>
<td>1.0</td>
</tr>
</tbody>
</table>

4 Prediction of Stacking Sequences

Structural performance criteria of cradle is that the end point deflection should not exceed 20 mm as shown in Fig. 7 when the total load of 135 kg was applied at a specific locations. The finite element analysis for prediction of Stacking sequence were used for the ANSYS Version 11. Using 3-D CAD data, core was modeled by solid element and facing materials were applied with layered Shell elements.

Each attributions, such as the proposed stacking patterns, material property, thickness, and stacking direction were assigned to each portions of facing material.

Proposed stacking pattern is that it is applied CF 3327 (4 plies) for the upper skin and reinforced CF 3327 (2 plies) in addition for the headrest area and that for lower skin, CF 3327 (4 plies) and CU 250 NS (7 plies) were proposed at section "D" and were reinforced with total 32 plies at section "C". The result of finite element analysis for this stacking sequence was that the requirements were no satisfied as the tip deflection was 27.2 mm over than 20 mm(Fig. 9). For additional reinforcements, in the Fig. 8 Section "C" and "D", CU 250NS-4 plies were replaced by the MCU 250NS 4 plies. As the result, the end deflection was estimated as 19.02 mm to meet the requirements shown in Fig. 10.
4 Manufacturing Process and X-ray Transmission performance of Cradle

The most important factors required to composite cradle are the good appearance with no surface finish and the uniform performance of x-ray transmission equal or greater than the x-ray performance of aluminum 1.5 mm thick with purity 99.9 %.

4.1 Fabrication of Composite Cradle
Cradle designed as sandwich structure was composed of top skin, bottom skin and foam core between skins. Top skin and bottom skin were made to infuse unsaturated polyester resin into each mold as following Fig. 11 after stacking carbon UD or carbon fabric as the thickness estimated by Finite Element Analysis.

After applying additional resin on cured skin, machined core was inserted between two molds as following Fig. 12, and it was assembled by clamping. And then, the assembly was cured in a dry-oven.

After curing, the assembly was demolded and the completed cradle was trimmed at the bonded area (Fig. 13).

4.2 Stiffness Evaluation of Cradle
Stiffness Test of cradle determined whether it is satisfied to meet the criteria that is 20 mm or less deflection at the end point of cradle when total 135 kg load was applied. Loading bar connected to the loadcell and LVDT were equipped and it were measured the applied load and deflection at the prescribed point as following Fig. 14.

As the result, the deflection at end point of cradle was 19.49 mm. So, it was satisfied the criteria.
4.3 X-ray Transmission performance of Cradle

Uniform x-ray transmission performance of composite cradle that the first ply for upper skin and lower skin was made by infusion process and the remaining layers were used prepreg is showed in Fig. 15. The X-ray transmission ratio of the final fabricated composite cradle shows in Table 2. Cradle consisted of sandwich composites with transmittance 78.7 % is better than the 77.8% of aluminum 1.4 thick.

![Fig. 15 Uniform X-ray transmission of Composite Cradle](image)

<table>
<thead>
<tr>
<th>Table 2 X-ray transmission Ratio of Cradle</th>
</tr>
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<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>---------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>initial value (I₀)</td>
</tr>
<tr>
<td>Composite Cradle</td>
</tr>
<tr>
<td>Aluminum 1.6t</td>
</tr>
<tr>
<td>Aluminum 1.4t</td>
</tr>
<tr>
<td>Aluminum 1.2t</td>
</tr>
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</table>

5 Conclusions

In this study, the shape of a sandwich composite cradle was decided to consider the bolting conditions and interface with other parts. The stacking sequences of each skin were proposed to estimate the stiffness of cradle by finite element analysis. The first layers for upper skin and lower skin were made by infusion process and the remaining layers were used prepreg. After the upper and lower skin was molded, it was integrally bonded to core and the sandwich cradle was finished.

X-ray transmission performance of final fabricated cradle was uniform in the whole area. Cradle consisted of sandwich composites with transmittance 78.7 % is better than the 77.8% of aluminum 1.4 thick.

References