As discussed above, the FRP is commonly used on the front of the car in stainless steel cars because of the front design configuration. The FRP single plate material has a low degree of rigidity since it is designed in a thin structure. It requires a complicated internal framework on the side when it is mounted on the car body. Further, the installation work requires subtle liner adjustment that takes much time and effort.

For this reason, it has been necessary to establish a countermeasure for reducing the required man-hours centering on the installation of the front FRP on the car body.

To meet this requirement, we have developed the “front cover” made of highly rigid composite material and a “reinforced frame” used as a connecting material when the “front cover” is installed on the side of the car body. Assuming application to the car, we have made our development effort, mainly to establish a countermeasure for reducing the time for assembling the front portion of the car body, particularly in installing the front FRP on the car body.

In the railway rolling stock, an assembly of the reinforcing members comprising the underframe, framework and outer plate is generally called the body structure. The area containing the driver’s cab is independently called a leading body structure because of its configuration. For the purpose of the present description, it particularly refers to the area constituting the front portion. Thus, the structure of the leading body structure in this development comprises two major elements of the “front cover” and “reinforcing frame”.

FRP sandwich structure, Composite material

Keyword: FRP sandwich structure, Composite material

1 Introduction

As discussed above, the FRP is commonly used on the front of the car in stainless steel cars because of the front design configuration. The FRP single plate material has a low degree of rigidity since it is designed in a thin structure. It requires a complicated internal framework on the side when it is mounted on the car body. Further, the installation work requires subtle liner adjustment that takes much time and effort.

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2 Study of basic structure

2.1 Structure

In the railway rolling stock, an assembly of the reinforcing members comprising the underframe, framework and outer plate is generally called the body structure. The area containing the driver’s cab is independently called a leading body structure because of its configuration. For the purpose of the present description, it particularly refers to the area constituting the front portion. Thus, the structure of the leading body structure in this development comprises two major elements of the “front cover” and “reinforcing frame”.

Fig. 1 Image of leading body structure configuration
The strengths of the front cover and reinforced frame are shared as follows: The reinforced frame is mainly used to protect against collisions of serious or medium level, while the front cover is mainly used to protect against accidents resulting in personal injury.

2.1.1 Front cover
The front FRP used in the conventional car is a single plate of fiber-reinforced plastics made of 3 to 8 mm thick polyester resin. Accordingly, the front FRP itself has little rigidity. So when it is installed on the car, it must be supported by a framework and prop mounted on the stainless steel structure side. Further, when a prop is mounted to support the front FRP, it is necessary to adjust the liner to distribute the local force. This increases the time required for modification.

To solve this problem, we have determined that we should build a front FRP using the "FRP sandwich structure" that is characterized by high rigidity and extensively used in the fields of aircraft, space, ships, automobiles and architecture.

It should be noted that the sandwich structure referred to in this paper means a structure where the material having a large modulus of elasticity is laid out on the surface of the plate, and a hollow or soft layer is formed inside to reduce the weight and to increase the modulus of elasticity, as shown in Fig. 2.

![Fig. 2 Sandwich structure](image)

The sandwich structure is mainly characterized by the following:
<1> Lightweight and high modulus of elasticity (high rigidity)
<2> excellent heat insulation
<3> excellent sound insulation

Characteristics <2> and <3> in particular result largely from the development of various types of plastic preformed materials characterized by development of excellent heat insulation and sound insulation properties.

2.1.2 Reinforced frame
The reinforced frame is an important member located between the body structure and front cover, and serves as an intermediary for their installation. At the same time, its high rigidity is used to minimize the damage in the event of an accident at a crossing.

In this development project, an angle material made of stainless steel and a but material have been employed in order to ensure that the strength would be on the same level as that of the Series 209 car, suburban commuter trains on the Keihin-Tohoku Line and Chuo-Sobu Local Train Line.

The front markup lamp (headlight), rear markup light (taillight) and destination indicator are centrally laid out on the front top to simplify the structure of the reinforced frame.

2.2 Material

2.2.1 Selection of surface material and core material
To select the surface material and core material, we have been performing various comparative tests and verification tests since 1999.

In these tests, we have evaluated the strength, combustibility and possibility of recycling. “Phenol resin plus glass fiber” were used as the surface material, while “foamed phenol resin plus paper honeycomb (product)” and “glass 3D fiber” (product C) were used as the core material. They were used at appropriate positions.

Table 1 shows the result of the evaluation performed on the basis of various comparison tests and verifications tests that were conducted before selection of the surface and core materials.

<table>
<thead>
<tr>
<th>Core material</th>
<th>Strength</th>
<th>Combustion</th>
<th>Preliminary core test</th>
<th>Bend strength</th>
<th>Modularity</th>
<th>A-dimension formed in impact test</th>
<th>Sound transmission</th>
<th>Overall evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A (16mm)</td>
<td>□</td>
<td>□</td>
<td>Only carbonizes</td>
<td>□</td>
<td>Protection against blister required</td>
<td>□</td>
<td>1.5mm</td>
<td>□</td>
</tr>
<tr>
<td>Product B (16mm)</td>
<td>□</td>
<td>□</td>
<td>Burns</td>
<td>□</td>
<td>Curved surface?</td>
<td>□</td>
<td>4.5mm</td>
<td>□</td>
</tr>
<tr>
<td>Product C (10mm)</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td></td>
<td>□</td>
<td>2.5mm</td>
<td>□</td>
</tr>
</tbody>
</table>
2.2.2 Phenol resin \[2\]
Phenol resin has a 130-year old history as thermosetting plastic. It has many excellent characteristics such as mechanical characteristics, electrical characteristics, heat resistance, flame retardative properties and chemical resistance. So with the advent of the age of industrialization, it came to be employed as an artificial material to take the place of conventional materials.
However, the conventional phenol resin was powder or high-viscosity liquid. It was necessary to use it as a compound, or to use it by reducing the viscosity using a solvent and impregnating a substrate with it. Further, high temperature and high pressure for condensation reaction were necessary at the time of curing. Such restrictions were imposed.
After that, nonvolatile aqueous phenol resin of comparatively low viscosity was developed. This has made it possible to impregnate the substrate directly with it, and to laminate it without using solvent. It has also made it possible to cure at the normal temperature. Thus, research efforts are being made for further progress. These materials are collectively called “second-generation phenol resin”.
Further, the development of curing agent has allowed composite materials to be molded according to the same molding technique as that of the unsaturated polyester resin (contact pressure molding, press molding, SMC/BMC and FW draw molding), where glass fiber and carbon fiber are used as reinforcing materials.
The composite material made of this second-generation phenol resin is called “phenol composite”.
One of the biggest features of phenol resin is its high degree of heat resistance and flame retardative properties. Of all polymers, it has the highest flame retardative properties. Its flame retardative properties are greater than that of the polyvinyl chloride that is regarded as being hard to burn.
It has self-extinguishing properties, and there is little fuming and no poisonous gas produced even when exposed to forcible ignition from the outside. It has such excellent properties that cannot be found in other types of resin.

2.3 Method for connection
The increased rigidity of the front cover can be expected by adoption of the FRP sandwich structure. For connecting it with the front reinforced frame, screws are used around the front cover and window.
The planer structure is adopted for the reinforced frame since this structure allows the front cover supporting area to be reduced. Only the fittings required for support around the window are installed. Based on the prospective of the future demand for stainless steel cars, we assume that existing intermediate cars will be modified into leading cars. According to this assumption, it has been determined that the reinforced frame is mounted directly on the corner post of the end body structure and the arched beam, thereby ensuring easy modification.

3 Analysis of the reinforced frame strength at the time of rear-end collision

3.1 Details of analysis
Giving consideration to measures against a possible problem or accident at a crossing, we analyzed the strength of the reinforced frame. Evaluation was made by comparison with the above-mentioned Series 209. The following two points were subjected to comparison:
- Cross sectional characteristics when regarded as a beam in the direction of a sleeper at the central portion of the front cover
- Maximum deflection and stress when the front reinforced frame and the leading body structure of the Series 209 were formed into a model, and the unit centralized load of $1 \times 10^4 \text{N}$ (about 1 ton) is applied to the center of the car body 1,700 mm from the rail surface

3.2 Result of analysis
(1) Comparison of the cross sectional characteristics when regarded as a beam in the direction of a sleeper at the central portion of the front cover
The secondary moment of the cross section was $7.33 \times 10^6 \text{mm}^4$ for the front reinforced frame as compared to $1.42 \times 10^7 \text{mm}^4$ for Series 209. The value was about half that of Series 209.
To get the value equal to or greater than that of Series 209, it has been revealed that the transverse frame must be provided with a slight reinforcement.
(2) Comparison by FEM analysis
The maximum deflection when the unit centralized load of $1 \times 10^4 \text{N}$ (about 1 ton) is applied to the center of the car body 1,700 mm from the rail surface was 0.27 mm for the front reinforced frame as
compared to 0.19 mm for Series 209. It was about 42 percent greater than that for Series 209.

The maximum stress was 7.31 MPa for the front reinforced frame and 9.93 for Series 209. The value for Series 209 was about 36 percent greater.

(3) Conclusion

Based on the result of analysis, the strength of the assumed front reinforced frame is slightly insufficient when compared to the front strength of Series 209. When consideration is given to application in an actual car, it is clear that the front reinforced frame structure must be improved.

4 Manufacturing the leading body structure prototype

4.1 Manufacturing the prototype front cover and reinforced frame

We manufactured a prototype front cover of phenol resin FRP sandwich structure utilizing a "phenol foam plus paper honeycomb" as the core material (26 mm thick portion) at the center and "glass 3D fiber" as the core material (10 mm thick portion) close to the installation position.

4.2 Evaluating the workability of leading body structure

Body structure installation work was performed on a simulation basis using the prototype front cover and reinforced frame. Evaluation at the manufacturing site has verified that workability can be improved and assembling time can be reduced sufficiently when compared to those of the conventional manufacturing method, although this evaluation is based on qualitative comparison.

5 Strength verification test

To verify the strength of the front cover, we conducted a "uniformly distributed load test" with wind pressure in the high-speed traveling mode taken into account, and an "impact test" to check the status of breakdown on impact.

The strength verification test was carried out with the front glass mounted in position. This test has also verified a high rigidity of the front cover in a sense.

5.1 Wind pressure test

5.1.1 Objective

Using the prototype front cover, we applied a distributed load below the window to perform wind pressure test, assuming a load equivalent to the wind pressure when the train was traveling at a speed of 160 km per hour.

5.1.2 Result of measurement

(1) Deflection

Table 2 shows the measurement results. The maximum deflection was 1.7 mm when the load was 30.14N.
Table 3 shows the measurements. The maximum stress was 0.9 MPa (0.1 kg/mm²) at the center and screw installation site when the load was 30.14 N.

Table 2 Measurements of deflection

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Deflection (mm)</th>
<th>Load (N)</th>
<th>Deflection (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Return</td>
<td>1.2</td>
</tr>
<tr>
<td>1096</td>
<td>0.6</td>
<td>Return 1096</td>
<td>0.8</td>
</tr>
<tr>
<td>1918</td>
<td>1.1</td>
<td>Return 0</td>
<td>0.1</td>
</tr>
<tr>
<td>3014</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2) Stress

Table 3 shows the measurements. The maximum stress was 0.9 MPa (0.1 kg/mm²) at the center and screw installation site when the load was 30.14 N.

Table 3 Measurements of stress

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N.o.1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1096</td>
<td>0.2</td>
</tr>
<tr>
<td>1918</td>
<td>0.3</td>
</tr>
<tr>
<td>3014</td>
<td>0.4</td>
</tr>
<tr>
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<td>0.3</td>
</tr>
<tr>
<td>1096</td>
<td>0.3</td>
</tr>
<tr>
<td>0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

5.1.3 Considerations

The maximum deflection was 1.7 mm and the maximum stress was 0.9 MPa. They were both very small.

Relative comparison is difficult since load test data based on the conventional FRP is not available. It can be considered that a high degree of rigidity is the result of using a sandwich panel structure.

5.2 Impact test

5.2.1 Objective

An impact test was conducted to make sure of the strength in case of impact to the prototype front cover, as well as conditions when breakdown had occurred to the cover.

In this test, a steel ball having a diameter of 230 mm (50 kg) was subjected to a free fall from a height of 567 mm. Then the status of breakdown was verified and the range of breakdown was measured.

5.2.2 Test result

Tests were conducted by dropping the steel ball on a buffering material (plate rubber) laid on the FRP surface and by dropping it directly on the FRP surface. In either case, no breakdown of the front cover was observed.

5.2.3 Considerations

When the steel ball was dropped directly on the FRP surfaced without any buffering material, the steel ball just bounded. It was confirmed that the sandwich structure effectively absorbed the impact.

However, when the FRP was cut off around the relevant section, there was insufficient adhesion between part of the core material and surface layer away from the portion where the steel ball was dropped.

Clearance was observed in the area from the handle mounted position to the portion corresponding to the collar band. This was where there was a level difference in profile.

When the handle is mounted on the portion containing a level difference in profile, the core material is chamfered. It can be considered that, on this separated portion, the amount of chamfered core material was insufficient, and so the surface layer of the core material was separated and was not adhered sufficiently from the
beginning. In future, care must be taken at the time of molding to avoid this problem. After completion of the product manufacture, it is also necessary to conduct a hammering test to check the degree of adhesion.

6 Conclusion

As discussed at the outset of this paper, the development in this project allows the leading body structure assembly work to be reduced, with consideration given to manufacturing of future stainless steel cars and modification of existing intermediate cars into leading cars. This project was intended to develop a method for building a leading body structure using composite materials.

We have manufactured the prototype front cover and reinforced frame of composite materials based on the sandwich structure. They were combined with each other, and a uniformly distributed load test and an impact test were conducted to check the strength. At the same time, we verified the workability when connecting them. Thus, we have obtained the following results:

(1) The "front cover" itself of composite material has a high degree of rigidity. This ensures easy connection with the reinforced frame, and does not require meticulous adjustment work that was required in the work of connecting the body structure and FRP according to the conventional method. Thus, it has been verified that installation time can be reduced. It has also been confirmed that the reinforced frame can be manufactured in a planar structure. This is very effective in cutting the cost.

(2) We have manufactured a prototype front cover of the FRP sandwich structure of phenol resin, where "phenol foam plus paper honeycomb" is used as the core material (26 mm thick located at the center, while "glass 3D fiber" is used as the core material (10 mm thick) close to the installation site. It has been revealed that the result of this attempt can be reflected in the subsequent mass production. However, partial separation occurred due to poor adhesion between the core material and surface layer. It has been shown that particular care is essential in the molding process.

(3) To verify the strength of the front cover made of composite material, we conducted a uniformly distributed load test and impact test. Both deflection and stress were very small, without any problem. Further, there was no problem in the impact test where a steel ball was dropped without a buffering material. It has been verified that a very high rigidity can be ensured.

(4) To evaluate the strength of the reinforced frame, we made a comparison with the Series 209. The percentage of the cross sectional characteristics was about 42 percent less in the case of a reinforced frame due to the difference in the dimensions and profile of the aggregate used for analysis (Series 209 was higher). It has been shown for subsequent commercialization programs that adequate reinforcement is essential in order to ensure the rigidity on the level equal to or greater than that of the Series 209.

From the above-mentioned discussion, it has been made clear that part of the reinforced frame design must be improved. At the same time, we could verify the validity of the leading body structure based on this method. Thus, we consider that most of the technological goals have been reached.

After this project, cars were modified according to the method based on the results of this development. We already have a track record of five cars including the Series 205 operating on the Nanbu Branch Line (between Shitte and Hamakawasaki), whose leading car was modified. In these examples, modification time has been greatly reduced.

Series 205 commuter trains currently running on the Yamanote line will be used on other lines one after another. There are still eighty cars where intermediate cars must be modified into leading cars in order to reduce the trainset length. The results of this development will be incorporated in the modification of these cars.

This method will find extensive application in new cars as well as modified cars.

References: