Development of Window Unit of Insulation Glass & Polycarbonate (IGP)

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Abstract

It is currently found that railway operators employ polycarbonate plate in passenger room windows in a railway vehicle to prevent the damage to the window, rather than traditionally used glass. The introduction of this method, however, is disadvantageous to be applied in limited express trains due to heat insulation, dew condensation and noise problems despite its cost-saving effect. Meanwhile, composite polycarbonate and double-grazing unit commercially used in Shinkansen bullet trains (known as polycarbonate composite) includes such drawbacks as limited size of polycarbonate composite material to be processed and high costs three times those of normal tempered glass. Also, it is pointed out that the glass can be damaged when ballasts, which collide to the window at a high speed after bouncing from the ground, don’t pass through the window, due to its inability to completely absorb the resulting impact in a thin resin layer placed between the polycarbonate and glass.

To solve these technical problems, we found a new method for coating existing glass windows with a polycarbonate plate with a certain space (guard by polycarbonate). This method can protect glass windows from damage by absorbing the impact by ballasts with a high-strength polycarbonate plate and removing resulting deflection by the space provided between the polycarbonate and glass. We believe that this method is effective in remodeling existing train vehicles at a minimal level and improving shockproof property at low costs. Despite this significant advantage, however, there have been many reports in this “guard by polycarbonate” method, in which dew concentration between the polycarbonate and glass was found in some vehicle cars to make the glass obscure. Moreover, additional problems, such as larger train weight and higher installation costs, must be solved.

By examining the advantages in the guard by polycarbonate method, JR Hokkaido developed Window Unit of Insulation Glass & Polycarbonate (IGP), composed of a polycarbonate plate (8mm thick), a glass (4mm thick) and an air layer (10mm thick) provided therebetween via a dedicated spacer with butyl rubber, installed in a stainless frame through packing, etc. This unit in a new type of limited express train vehicle is described as follows.

1. Introduction

In winter, Hokkaido’s railway vehicles run through vast powdery snow-covered areas of land known as a local attractive feature. With such a beautiful local landscape, this powdery snow can cause railway operations and services tremendous problems. Under the circumstances, JR Hokkaido has continuously developed winter-specific vehicle structures and equipment to make the operational level stable throughout the year. As a major year-long R&D activity, the railway operator started “Preventive measure against the damage to train window glass,” in partnership with Toho Sheet&Frame Co., Ltd, with the aim of maintaining safe train operations and stable transportation services.

Under Japanese laws, a passenger room on a train vehicle must employ safety glass or its equivalent. The safety glass is a processed plate glass (tempered glass, laminated glass or double-grazing unit glass), aimed at reducing injury accidents on passengers from damaged window glass. Japan’s limited express train vehicles usually employ double-grazing unit glass with favorable heat insulation property, but there have been many reports, in which a lump of snow attached to and frozen at a vehicle in winter, after falling and hitting on ballasts, bounced the ballasts from the ground to damage the glass. To eliminate such accidents, JR Hokkaido started an R&D project using polycarbonate plate.

2. Preventive measure against the damage to train window glass

2.1 Characteristics of polycarbonate

In November 1999, JR Hokkaido found frequent damage cases on passenger room window glass in
“Super Ohzora” (283-series limited express train diesel car), along with an injury accident report at passenger room window from damaged laminated glass (both internal and external) on “Super White Arrow” (785-series limited express train electric car) in December 1999. It is believed that all of these accidents were caused by ballasts bounced between the tunnel wall surface and vehicle body, after a lump of snow attached to and frozen at the vehicle has fallen on the ballasts.

Then, JR Hokkaido started to develop its own “No damage to glass” technique. Specifically, this technique focused on polycarbonate resin plate, having higher strength and transparency than ordinary glass and used in windows for aircraft and construction machinery, etc. Table 1 shows the properties of polycarbonate plate. The use of this polycarbonate plate in various applications need considering numerous factors such as fire resistance, shock resistance, load bearing, weather resistance, moisture permeability, thermal expansion, dew concentration, abrasion resistance, sound insulation, chemical resistance, optical performance and weight.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Polycarbonate</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>-</td>
<td>1.2</td>
<td>2.5</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>63</td>
<td>32~79</td>
</tr>
<tr>
<td>Elongation</td>
<td>%</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>Izod impact strength</td>
<td>J/m</td>
<td>784</td>
<td>-</td>
</tr>
<tr>
<td>Coefficient of linear expansion</td>
<td>$10^{-5}/\degree C$</td>
<td>7.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/(m·K)</td>
<td>0.19</td>
<td>0.8~1.36</td>
</tr>
</tbody>
</table>

### 2.2 Development of guard by polycarbonate

JR Hokkaido examined the first solution to the damage to train window glass by introducing composite polycarbonate and double-grazing unit (polycarbonate composite) that is being employed in Shinkansen bullet trains. However, we eventually determined that its application to our train vehicles is unfavorable after some test runs due to the following drawbacks: limited size of polycarbonate composite material to be processed and high costs three times those of normal tempered glass. Also, it is pointed out that the glass can be damaged when ballasts, which collide to the window at a high speed after bouncing from the ground, don’t pass through the window, due to its inability to completely absorb the resulting impact in a thin resin layer placed between the polycarbonate and glass.

To solve these technical problems, we found a new method for coating existing glass windows with a polycarbonate plate with a certain space (guard by polycarbonate). This method can protect glass windows from damage by absorbing the impact by ballasts with a high-strength polycarbonate plate.
and removing resulting deflection by the space provided between the polycarbonate and glass. We believe that this method is effective in remodeling existing train vehicles at a minimal level and improving shockproof property at low costs. Meanwhile, since polycarbonate plate can be prone to scratches generated in vehicle washing operation due to a lower excoriation resistance than glass, the surface of polycarbonate plate was coated with silicon (silicon hard coat). According to the initial plan, the window would be replaced about every 5 years, but there are no specific problems with the first guard by polycarbonate window on the train vehicle that has already been operated for 7 years. This train is still operated to check the degree of aged deterioration.

Fig. 2: Structure of polycarbonate composite
Fig. 3: Structure of guard by polycarbonate

Fig. 4: Guard by polycarbonate installed
Fig. 5: 283-series diesel car with guard by polycarbonate

2.3 Improvement in guard by polycarbonate
Despite the significant effect of preventing the damage to passenger room window, there have been many reports in this “guard by polycarbonate” method, in which dew concentration between the polycarbonate and glass was found in some vehicle cars. This dew condensation is primarily attributed to the moisture existing between the polycarbonate and glass due to insufficient sealing at a screw for fixing a shape for holding a polycarbonate plate or the corrosion of aging car body. Our improved sealing method and procedures successfully reduced dew condensation, but failed to solve this technical problem completely.

Then, the guard by polycarbonate was produced in a unit, aimed at facilitating the installation and preventing dew concentration. This window unit is composed of double-grazing unit glass and polycarbonate plate produced as a single unit, respectively, from aluminum extrusion, to be installed into the car body. In this method, the car body must be designed to be properly connected to the window unit, leading to its application only for new type of vehicle. However, this technique can
improve sealing property between the glass and polycarbonate plate to eliminate dew concentration. Moreover, this window unit is of easier maintenance, i.e. inner-side glass and/or outer-side polycarbonate can be replaced without removing the entire unit, but lower costs and lighter body weight must be considered in future researches.

Fig. 6: Structure of unit-type guard by polycarbonate

Moreover, this window unit is of easier maintenance, i.e. inner-side glass and/or outer-side polycarbonate can be replaced without removing the entire unit, but lower costs and lighter body weight must be considered in future researches.

Fig. 7: Unit-type guard by polycarbonate

Fig. 8: 789-series electric train with unit-type guard by polycarbonate

3. Development of IGP

3.1 Structure

From the above descriptions, JR Hokkaido developed window unit of insulation glass & polycarbonate (IGP), composed of a polycarbonate plate (8mm thick), a glass (4mm thick) and an air layer (11mm thick) provided therebetween via a dedicated spacer with butyl rubber, installed in a stainless frame through packing, etc.

Fig. 9: Comparison in structure
3.2 Specifications and performance

The basic specifications and performance in developed IGP are described as follows.

(1) Prevention of damage to glass windows
   Using polycarbonate resin plates with which the window is coated with an impact strength over 30 times that of tempered glass, a glass window can be protected from damage.

(2) Improvement in abrasion resistance
   Since the surface layer of polycarbonate resin plates is coated with silicon in hard structure, the window is highly abrasion proof.

(3) Production of lighter railway vehicles
   With a specific gravity of polycarbonate resin plates half that of the glass, lighter vehicles can be produced.

(4) Improvement in heat insulation capacity
   Due to low thermal conductivity of polycarbonate resin which is one fourth that of the glass placed in outer surface of the window, and higher thermal resistance in multi-layered structure, the heat insulation capacity can be improved.

(5) Improvement in sound insulation performance
   With a combination of different types of materials (polycarbonate and glass), sound insulation
performance can be improved.

In addition, the surface layer of this unit window for train vehicle is prone to cracks due to the dust while running and vehicle washing brush. In a falling-sand wear test, whose impact seems equivalent to vehicle washing brush, the haze value after the test was 1.0% in polycarbonate plate product coated with silicon in hard structure and 4.0% in ordinary glass, showing more advantageous surface property in the polycarbonate plate product.

3.3 Solution to the problems
The commonly known double-grazing unit manufacturing method caused the following problem in IGP development. A water-tight butyl rubber that is primarily sealed at both ends of an aluminum spacer around the window in the double-grazing unit can cause chemical attack in the polycarbonate plate, resulting in lower strength and cracks due to less water-tight property and solvent crack. According to the researches to date, this is affected by age inhibitor (such as xylene) contained in the butyl rubber. Specifically, this butyl rubber cannot absorb linear expansion of the polycarbonate plate, thereby breaking the sealing material used in train vehicle window with significant temperature change. It was also found that the secondary sealing material of polysulfide monomer (commonly known as Thiokol grouping in Japan), used in common double-grazing unit for railway train vehicles, can cause chemical attack in the polycarbonate plate.

In a joint development project with raw material manufacturers, JR Hokkaido successfully developed sealing materials that can maintain the conventional level of water-tight property, cause no chemical attack in polycarbonate plate and remove the difference in linear expansion between polycarbonate plate and glass.

3.4 Results of performance test
In IGP passenger room window in 261-series 1000 limited express train diesel car, the deflection and strain were measured in a running vehicle to examine the strength and rigidity properties. The changes in temperature and humidity in IGP’s air layer were observed to confirm the quality and air tightness.

In the performance test, the displacements were measured in the middle of outer polycarbonate plate and inner glass, and in the inner car body, from the passenger room, using laser displacement gauge. The deflection was determined from the difference among the displacements. Using a strain gauge placed between the polycarbonate plate and glass, each external stress was calculated from the measured data to find that it is within the allowable design value. Fig. 13 shows schematic diagram of test window installed, and Fig. 14 shows equipment arranged in on-track test.

![Fig. 13 :Schematic diagram of test window installed](image-url)
The data obtained are as follows.
○ The maximum deflection was +6.88mm in the outer polycarbonate plate and +5.82mm in the inner glass.
○ In the 2-day performance test, the maximum deflection was found at the same point (while running in the tunnel).
○ From the results of strain measurement, there was no stress problem.
○ From the results of temperature and humidity measurement, the data in the air layer within double window was favorable at 7~11%RH.
○ The maximum residual deflection was a small value at 0.4mm after the test, showing favorable window design and installation.

![Fig. 14: Equipment arranged in on-track test](image)

Maximum measuring waveform

![Fig. 15: Data measured](image)

From the strains calculated, "stress by strain," "maximum and minimum principal strains," "maximum share strain," "maximum and minimum principal stresses" and "maximum share stress" were determined.
Table 2: Results of strain and stress

<table>
<thead>
<tr>
<th>Item</th>
<th>Center of polycarbonate</th>
<th>End of polycarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum principal strain (×10^{-6})</td>
<td>408</td>
<td>109</td>
</tr>
<tr>
<td>Minimum principal strain (×10^{-6})</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Maximum share strain (×10^{-6})</td>
<td>388</td>
<td>107</td>
</tr>
<tr>
<td>Maximum principal stress (MPa)</td>
<td>1.14</td>
<td>0.30</td>
</tr>
<tr>
<td>Minimum principal stress (MPa)</td>
<td>0.48</td>
<td>0.12</td>
</tr>
<tr>
<td>Maximum share stress (MPa)</td>
<td>0.33</td>
<td>0.09</td>
</tr>
</tbody>
</table>

The tensile stress and compression stress under the condition of “continuous load, room temperature and in the air” in the polycarbonate plate was 13.7MPa. From the results obtained, the maximum principal stress was favorable within the allowable stress.

\[
\frac{13.7}{1.14} > 1 \quad (\approx 12)
\]

4. Conclusion

To eliminate continuous accidents with damaged passenger room glass in winter, JR Hokkaido started “Preventive measure against the damage to train window glass” to ensure comfortable riding for our passengers and provide stable transportation in a harsh winter season. Along with each passenger room’s IGP, we will install more polycarbonate windows for each door, and all areas to which passengers and crew members can have access, other than the front window at the driver’s seat.

References