New Marine Glazing Developments

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Abstract
The marine industry demands more and more the use of glass in ships that will withstand both human and wave impacts and harsh climates. Moreover, all windows are required to protect against water pressure, water leakage, and to minimize the chance of glass disengaging from the supporting structure in the event of breakage. In this paper we discuss Naval Register requirements for marine glazing and compare different glazing constructions characteristics of differing laminate constructions are presented along with durability characteristics that are pertinent to the marine water environment

Introduction
The appearance of modern cruise ships and super-yachts is dramatically different from those of yesteryear due to the extensive use of glass construction elements. Glass, more than any other material, has changed the aesthetics and styling of marine vessels generally. Today, the material offers unparalleled opportunities for designers to develop a new look, as well as the practical possibilities for yacht builders to realise a design vision. Glass enhances the view, gives a sense of openness to the outside, and brings in the natural light, beauty and emotions of the sea (Figure 1).

Glass is, however, a brittle material. As is well known in the construction and automotive industry, it is an unforgiving material to engineer and requires special design practices. In the marine industry, The International Maritime Organization (IMO) is responsible for developing norms and standards that define the resistance criteria required to specify structural performance of a glazing material for use on ships. The main countries that build ships have often defined their own norms, such as the British Standard BS MA25, which is widely recognized and used. There are International standards, ISO addressing mainly the use of tempered glass such as:

• ISO 614:1989 Toughened safety glass panes for rectangular windows and side scuttles – Punch method of non-destructive strength testing
• ISO 3434 - Heating glass panes for ship rectangular windows
• ISO 3903:1993, Shipbuilding and marine structures – Ships’ ordinary rectangular windows
• ISO 1751:1993, Shipbuilding and marine structures – Ships’ side scuttles

All of these standards provide stringent test methods and design criteria, since the consequences of tempered glass breakage in a marine application can be quite serious. In addition to the norms described above, each super-yacht or cruise ship project is assigned to a Naval Register; the ship is defined to be a certain class depending on the Naval register, such as Rina class or Lloyd's class etc. The Naval register ensures that the ship is built in accordance with approved plans and in full compliance with the classification rules, as well as the international regulations that have been adopted by the International Maritime Organization (IMO). New glazing constructions, that are different to the ones recognized and specified by the norms, need to be approved by the Naval Register assigned to each super-yacht or cruise ship project.

Laminated Glass for Marine Applications
In comparison to tempered glass, laminated glass is still considered to be a new material for such a conservative industry. However, the safety and structural performance attributes of laminated glass are now being recognized as beneficial for marine applications. One attribute of especial interest is the post-glass breakage structural properties of laminated glass. Tempered glass, although strong and displaying relatively safe breakage characteristics when properly fabricated, is a brittle material and fails catastrophically. Additionally, catastrophic failure may occur spontaneously from well-known phenomena, such as nickel sulphide impurity phase transformations and sub critical crack growth of contact damage. Laminated glass by comparison is fabricated from glass plies that are bonded together by a tough polymer interlayer. In the case of glass breakage, glass fragments tend to remain adhered to the polymer thus reducing cutting hazards and the intact polymer membrane provides some structural capacity.

The most commonly used polymer interlayer for laminated glass is polyvinyl butyral, or PVB. This material has been available commercially for some seventy years now and was developed initially for use as safety glass in automobiles. The main attributes of laminated glass made with PVB are good impact resistance and human safety performance, with respect to cutting injuries. Because of the requirements for car windshields, PVB is a compliant, elastomeric polymer primarily designed for one impact event and to minimize head trauma in the case of a person hitting a car windshield in an accident. The chemistry of PVB is not only optimized for the mechanical and processing requirements of the automotive industry but also for the automotive industry but also for the automated automotive industry. The main polymer interlayer does not efficiently couple the glass plies together mechanically, a laminate often generates greater glass stress than a monolithic glass for a given load. Associated with this, the laminate is often more compliant than the monolith. This usually results in the requirement that the individual glass plies in the laminate need to be made thicker to compensate for the inefficient coupling, resulting in laminates that are overall heavier than monolithic.
glass. This is especially true for loading/support combinations that result in bending-dominated deformation of the laminate, such as cantilevered structures and point-supported applications. The increased weight associated with fulfilling a loading requirement using laminated glass versus monolithic glass has restricted the use of laminated glass in marine applications.

**High Performance Laminated Glass using an Ionoplast Interlayer**

Ionoplast interlayers have been in existence for several decades now. The generic definition of an ionoplast interlayer is “A stiff sheet comprised primarily of ethylene / methacrylic acid copolymers containing small amounts of metal salts, that may be permanently bonded to glass.” This chemistry is different from PVB and the main physical difference is that ionoplast interlayers are much stiffer and tougher than PVB interlayers. The largest commercialization of ionoplast interlayers was initiated by DuPont™ in 1998 with the launch of SentryGlas®. This product was developed initially for the high building envelope protection needed for hurricane glazing in the United States. We have seen expansion of usage of this product as the performance benefits developed for hurricane applications have been recognized as being beneficial for many other applications of laminated glass such as: faced building overhead glazing, balustrades, glass floors & steps, doors & partitions. The primary performance benefits versus traditional PVB-based laminates are: 1) structural performance, especially strength and deflection over an extended range of temperatures; 2) post-glass breakage integrity, and 3) durability. We review these attributes in context of marine applications.

**Strength Performance**

A key benefit of the mechanical properties of a SentryGlas® interlayer is the full structural coupling achieved between glass plies in the laminate. These structural properties are maintained to elevated temperatures and long-term load durations. This provides much enhanced strength behaviour and reduced laminate deflection versus a conventional PVB laminate. The result of such efficient structural performance is reduced laminate thicknesses, increased panel sizes, lighter supporting structure and generally lower overall system weight. Often, this reduced weight takes significant cost out of an application and the use of thinner glass plies in the laminate offers further opportunities for cost savings. An example of the strength properties of ionoplast laminates using the ISO 614 test is shown in Table 1. The ISO 614 test consists of loading a 250 mm X 250 mm glass samples with a spherical punch following a prescribed load history. Samples are loaded at 1000 N/s to a specified peak (proof) load that is held for 5 s. The glass sample shall remain unbroken and shall show no signs of damage. As can be seen from table 1, tempered glass/SentryGlas® laminates show similar strength performance to monolithic tempered glass. For thicker tempered glass applications (>12 mm), equivalent performance may be achieved with SentryGlas® laminates fabricated with less overall glass, hence reduced weight.

<table>
<thead>
<tr>
<th>Tempered Monolithic Glass</th>
<th>Tempered Laminated Glass with 1.52 mm SentryGlas® interlayer</th>
<th>ISO 614 Proof load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>Total thickness (mm)</td>
<td>Type A</td>
</tr>
<tr>
<td>10 mm</td>
<td>11,5 mm*</td>
<td>10,200</td>
</tr>
<tr>
<td>12 mm</td>
<td>13,5 mm*</td>
<td>15,500</td>
</tr>
<tr>
<td>15 mm</td>
<td>15,5 mm*</td>
<td>24,000</td>
</tr>
<tr>
<td>19 mm</td>
<td>17,5 mm*</td>
<td>33,400</td>
</tr>
<tr>
<td>25 mm</td>
<td>19,5 mm*</td>
<td>53,000</td>
</tr>
<tr>
<td>28 mm</td>
<td>22,5 mm*</td>
<td>65,000</td>
</tr>
</tbody>
</table>

Table 1

ISO 614 test for various tempered glass and tempered/ionoplast laminates (Germanisher Lloyd certificate, courtesy of Saint Gobain Kinon)

Lloyd’s register has established new safety rules for one of the most critical areas of the ship such as the superstructure exterior glass balustrade: tempered glass has to be replaced with tempered laminated glass (ref. July 2005 edition of the “Rules and Regulations for the classification of Ships”, Part 4, Chapter 2, Section 12 and it is generally applicable to external balcony balustrades fitted on board Ferries and Passenger Ships). A common construction for cruise balustrade is 10 mm tempered glass. Timoshenko’s rule is often applied in the marine glazing to establish the equivalent laminated glass thickness, therefore a 10 mm monolithic glass is equivalent to 8 mm + 6 mm laminated glass with PVB. This means a glass thickness increase of 4 mm and an associated weight increase of approximately 10 kg/m². However, 10 mm tempered glass can be replaced by a 6mm + 4mm construction using SentryGlas®, without increasing the glass thickness. This same construction has been adopted for the new Ruby Princess cruise ship balustrade launched on November 6th 2008 in Miami. The glass in this case has been extensively tested and approved by Lloyd’s Register Tieste Design Support Center. SentryGlas® brings increased safety without any weight increase.

**Post Glass Breakage Characteristics**

In the case of glass breakage, the polymer interlayer imparts some degree of structural performance to laminated glass. An advantage of the structural properties of SentryGlas® is the improved mechanical performance of a laminate after glass breakage. The stiffness advantage over PVB, which is maintained to high temperatures, results in a more robust condition if the laminate is broken accidentally. This attribute is shown in Figures 2 & 3, where we have examined the post glass breakage behaviour of cantilevered balustrades (i.e. supported along one edge only) fabricated from two plies of 10 mm tempered glass and different interlayers. Figure 2 shows the behaviour of a balustrade fabricated with 1.52 mm SentryGlas® after breakage of both tempered glass plies. The balustrade remains in place, even after repeated loading with a 50 kgf concentrated load applied to the middle of the upper balustrade edge. Compare now the performance of a balustrade fabricated with 1,52 mm
PVB after breakage of both glass plies. Application of a 10 kgf concentrated load results in rapid collapse of the broken laminate.

Apart from the clear structural advantage in balustrade applications, this attribute has been exploited in walkable glazing (floors and stairs) and in overhead glazing. Post breakage robustness is an especially desirable characteristic for frameless or minimally supported glazing systems.

Weathering and Durability

The glass surface of modern cruise ships needs to be protected against the harsh sea environment and humidity. Sea salt in particular is problematic as this stains and discolors glass and makes cleaning difficult. As with all ships, safety is of course paramount, so the view from the command bridge requires maximum visibility. The guests also want optimum vision in order to make the most of their experience onboard the ship. SentryGlas® laminates have shown excellent durability performances both after Florida 10 years natural weathering in the marine environment, (ASTM 711B salt water spray test), no discoloration or haze has been observed after the tests.

Extensive product testing and surveys of actual SentryGlas® Plus-containing laminates in service for over ten years in Florida have shown that this interlayer maintains its mechanical/structural performance and is less prone to the development of edge features typical of many other type of laminated glass. For example measurements of bending stiffness for laminates exposed to varying weathering, up to seven years natural exposure in Florida (temperature excursions between 0 to 45 ºC, and relative humidity up to 90 %) show the bending stiffness is essentially unchanged over time and is direct evidence of the interlayer durability. The interlayer also passes the USA Florida Dade County requirements of 5 years accelerated weathering with less than 10 % change in physical properties.

Also the Finnish Marine Industry, hugely important in Europe and which built the biggest cruise ships in the world such as Genesis and the Freedom of Sea has been looking at SentryGlas®. Pilkington Marine Oy, a key glass project manager is considering the product especially for its strength and durability in the marine environment.

Conclusions

We are witnessing a trend in marine glazing to use more laminated glass as the benefits of this class of safety glazing become apparent. Superior structural performance can be obtained using laminated glass fabricated with an ionoplast interlayer, such as DuPont™ SentryGlas®. Strength advantages over PVB laminates and monolithic tempered glass lead to opportunities for weight saving and value engineering. Enhanced post glass breakage characteristics increase safety factors for performance in case of accidental glass breakage. Inherent durability and weathering performance advantages of ionoplast interlayers over PVB are further driving interest in the use of ionoplast laminates for marine glazing.