USE OF GLASS AND THE REGULATIONS

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SUMMARY

The paper focuses on ISO 11336, Part 1 as a phase step in the rationalization of requirements for glazing on yachts. It shows how the standard fits in the regulatory framework. It also briefly looks into the way ahead; how glass can be considered as a structural material.

Introduction

Today's yachts follow the trend in construction of buildings. Roofs and bulkheads used to be solid structure with relatively small openings in which windows were fitted where light and view were required. We now see the inverse: proposals with glass panels all over, and covers or shades on the inside where light and/or view are not desired. From inside their air conditioned saloons yacht owners want unobstructed view of the surroundings. From outside, the sleek shiny look of shaded glass greatly adds to the yacht's allurement.

There is a fundamental difference though between a yacht and a building: Where a building stands safely on its foundations even without the glass fitted, a yacht depends on the glazing to maintain its water- and weathertight integrity. If the glazing fails, the vessel will be open to ingress of water and it may be prone to sinking or capsizing. Also, in case of eventualities, those on board cannot evacuate to a garden or a street. At sea, a risky transfer into a raft drifting on a bumpy sea may be the best that can be arranged for hours or even days. The sea can always turn into a much more hostile environment than any land area you visit for pleasure can possibly be.

1. REGULATIORY FRAMEWORK

The means to prevent water coming into the ship are part of the so called 'Conditions of Assignment' that have to be fulfilled before a Load Line can be assigned to a vessel. The International Convention on Load Lines (ICLL), 1966 as amended, excludes vessels 'built for sport or pleasure, not engaged in trade' and therefore yachts are excluded from its scope. However, when a yacht is offered for charter, it is considered to be in commercial use, and needs to have a Load Line assigned. Even when a yacht is built for private use, the possibility to offer a yacht for charter has a positive influence on the resale value. The majority of the yachts today therefore is designed and built to meet the regulations of their Flag States for having a Load Line assigned. The requirements in ICLL are tailored to commercial ships, and not easy to apply to yachts. That is why Flag States who want to keep or attract yachts in their registry have developed National Equivalents as permitted by article 8 of ICLL. The MCA Large Commercial Yacht Code, first published in 1997 and now entering its third version (LY3), is adopted by most Flag States popular for yachts. Other Flag States operate their own code, which in some cases is quite similar to this de-facto standard originally set by the United Kingdom.

The Large Yacht Code, in chapter 5, gives requirements for the weathertight integrity, with sections 5.4 and 5.5 regulating portholes and windows. The Code does not give specific criteria but requires that portholes and windows should meet 'an appropriate national or international standard'. The Large Yacht Code follows the same line here as ICLL, but in this UK code for windows the UK national standard BS MA 25 is specifically mentioned. There is also a line of international (ISO) standards describing the same windows.

2. EXISTING STANDARDS FOR GLAZING ON COMMERCIAL VESSELS

BS MA 25 and the ISO standards for glazing on commercial vessels are entirely prescriptive. They were clearly developed with the aim to ease of production and maintenance of vessels. All elements of the windows and portholes are fully specified, so they would be inter-changeable to a large extent, and ease repair.

Since their development in the 1970's, the standards only have had minor updates. Obviously they served the marine industry. Marine engineers, trained to think in steel construction and plastic materials, were happy to leave glass, a brittle material with many aspects they were not familiar with, safely out of consideration. The glass was not to be trusted; it was a necessary evil, accepted because access of daylight was needed and the holes needed to be closed. Glass was considered, so to say, as a black box; a fragile thing in all respects, best left untouched. This approach worked as long as the windows were, relative to today's standards, small.

In addition to meeting the requirements of a standard, the Load Line Convention, and the Large Yacht Code in its wake, require some additional measures (provision of deadlights or storm covers) to reduce the chance of glass breakage or to mitigate the effect of such an event.

The Flag inspections for Load Line assignment, including examination of the glazing, are generally delegated to the surveyors of the Class Society involved in the building of the vessel. For these inspections, Class surveyors are bound to work in accordance with the instructions given by the Flag State.

The builders and owners of superyachts however were not satisfied with windows and portholes produced to or on the basis of the standards. This was not only because of the restriction to fixed sizes or even rectangular shape. The standards give methods to determine the required thickness of the glass for different sizes trough calculation, but other objections remained:

- For portholes, the permissible size, 450 mm diameter, was found too small for guest cabins. In some regulations this was even translated into a criterion that the clear opening size of a porthole should not exceed 0.16 m^2. Where this is considered acceptable for crew areas, for guest cabins larger openings in the hull are generally asked for.

- Thermally Toughened Safety Glass, the only glazing material specified in the standards, does not have good optical quality. The thermal hardening process is performed at a temperature above glass transition range, so glass is, in some way, "softened" and the shape of the surface is distorted resulting in a bad optical quality. The alternative, chemically strengthened glass, does not have these drawbacks, but it was not covered by the marine standards.

- Lamination of glass was not accounted for in the standards. A 'rule of thumb' based on equal deflection of all layers as generally applied, but this rule does not account for the transfer of shear stress between the layers. Using thick glass is not a solution. Optical quality of sheet glass reduces with thickness, and also the mechanical properties of the glass (characteristic breaking strength) reduce significantly with thickness. The existing standards do not take this into account.

- The standards refer uniquely to appliances where the glass is framed in a metal frame. Most deckhouse windows today are bonded directly to the structure.

- The storm covers, required on windows by the marine regulations, required fixing points on the outside bulkheads. They were considered un-aesthetic and storage on board was reported as a problem. This last argument could be discarded as a matter of priorities, since space on board can always be made available if needed. It is however clear that reliable storm covers for very large windows will be heavy and difficult to handle. Also, it is not very clear what should be done with the windows of the wheelhouse. Obviously the view from the bridge is to be maintained.

- Yachts are not built to carry cargo. The volume of the hull is defined by the space required for living, for recreation, for the engine room, and for storing the toys. Consequently the main deck is much higher above the water than for a cargo vessel of the same size. The method applied in the standards to allow for height above the waterline expressed in the terms of 'tiers above the freeboard deck', therefore is open to interpretation. Under certain conditions, the excess freeboard can be accounted for in a so called 'Virtual Freeboard Deck', a concept that, again, added to the complexity of freeboard assignment. Then there is the question of deck height. The accommodation on the main deck is prime guest area and the deck height is much more than the 1.80 m of a 'tier' assumed by ICLL.

- The available standards were inclined heavily towards large vessels. Many of the requirements in the standards related to requirements in SOLAS. SOLAS, however, applies only to vessels with more than

12 passengers or with a Gross Tonnage larger than 3000 GT. The yacht industry, with the vast majority of the vessels carrying not more than 12 passengers and with size usually well below the GT limit, questioned the applicability of the standards to the yachts they build. Builders and designers working on yachts in the lower end of the size range, were particularly un-happy because they felt the requirements were much more onerous than those given in for example ISO 12216; a standard for windows and hatches in yachts up to 24 meters in length.

Regardless of the objections, Yachts were being built. The Superyacht Industry, meaning in this case that colourful complex of owners, builders, designers and surveying bodies from which the world yacht fleet comes forth, as ever found a way to meet these challenges using much debate and case-to-case decisions. Clause 5.5.2 of the Large Yacht Code opens the possibility to 'qualify' windows that are not in compliance with a relevant standard by pressure testing. This clause was instrumental in finding solutions. The favourite glazing material of the yacht builder, laminated chemically toughened glass, was not covered by any of the marine standards. Pressure testing became the method of choice for demonstrating sufficient strength of the glazing. While pressure tests were convincing enough- (the applied test pressure was 2.5 to 4 times the design pressure-) there were substantial drawbacks to this method:

- The tests were costly. Each test required a window tested to destruction. This caused test series to be limited to 3 samples only.

- The results were difficult to repeat. A variation in break pressures of a factor 2 or more found for 'identical' samples was not uncommon.

- Strictly speaking the result of a test is valid only for the size, shape and laminate tested. Full coverage of a yacht's windows arrangement glazing would require a large number of tests.

- The code section on pressure testing was quite open to interpretation and no criteria were given for the test parameters. Number of samples to be tested, pressure rise time, hold period, and more parameters affecting the result were not given and this again made test results difficult to interpret.

The good thing learned from the pressure test results was that hardly breaking the test panels by water pressure did hardly ever lead to leakage. This is the marked difference compared to the monolithic thermally toughened safety glass, fitted in a metal frame, which is assumed in BS MA 25 and equivalent. Of course the resistance to pressure of a glass pane is reduced after breakage, but the residual integrity allows time for the crew to apply emergency closures and, not un-important on a yacht, the residual integrity limits water damage to the interior.

3. DEVELOPMENT OF SPECIFIC STANDARD FOR GLAZING ON YACHTS

In an attempt to improve the situation a group of experts from yacht builders, glazing manufacturers, flag authorities and classification societies joined forces and formed a workgroup under the International Standardization Organisation ISO to develop ISO 11336; a standard for yacht glazing. Part 1 of this standard, dealing with pre-fabricated units and in that sense replacing BS MA 25 is now completed. Work continues on parts 2 and 3 covering integral glazing and quality control/inspection respectively.

3.1 Features of the new standard ISO11336-1: 2012

The application of Part 1 is formally limited to 'independent glazed openings'. In clause 3.2 the standard describes an 'independent glazed opening' as follows: '*glazed opening where the behaviour of the pane can be considered independent from adjacent structure, e.g. framed appliance*'.

In other words: Part 1 covers glazed openings that are fitted in frames. This means the interface between the glazing and the vessel structure is made through conventional connection methods for metal or Fibre Reinforced Plastic (FRP).

Let us look at the most important aspects of the new standard.

3.1.a) No distinction between 'portlights' and 'windows'

The standard makes no difference between a porthole and a window. The term 'glazed opening' is used instead. This was done to accommodate the large variety in shapes and executions of glazed openings found in the hulls of modern yachts. The criteria a glazed opening has to comply with depend on the position and whether the opening is above or below the freeboard deck. As said, the term 'Freeboard Deck' can be ambiguous on a yacht, especially where decks are stepped or where there are swim platforms. In the end, the term was maintained to keep reference with ICLL.

3.1.b) Design pressures lined up with small yachts

The standard gives design pressure criteria more dependent on the size of the vessel. The pressure criteria given aim to make a smooth transition between the criteria from the small craft standard ISO 12216 at 24 m in length to the existing standards at 80 m in length. For a conventional motor yacht a length of 80 m by and large corresponds with 3000 GT, being the upper validity limit of the standard. For a given size of vessel, the design pressure is then a function of the position along the ship and the height above the waterline. Influence of internal decks, a factor open to debate about its relevance to sea pressures on deckhouse walls, is removed.

3.1.c) Freedom of choice of glazing material

The standard treats glazing material as a structural material. Glass, strengthened either thermally or chemically, will be the most common choice, but the standard supports in principle any other suitable transparent material (polycarbonate, acrylic) alone or in combination with glass. The standard gives a simple method to estimate mechanical properties of laminated glass taking into account the properties of the interlayer. For laminates made from or containing different materials there is a method provided also, but in that case the shear transfer between the plies is ignored. The standard explicitly allows use of flexural properties derived from 4-point bending tests (for glass) or 3-point bending tests for other materials.

3.1.d) Material qualification procedure

The standard provides qualification procedures for the glazing cross section. The qualification process uses 4-point bending tests according to the method of ISO 1288-3. The results are used to determine characteristic breaking strength and flexural rigidity of the glazing. The 4-point bending test is used for both monolithic glass and for laminated glass.

The choice of the 4-point bending test method was made after ample consideration by the workgroup. The size of the samples, 1.10m x 0.36m, was considered a proper balance between the requirements of cost and production. Larger samples would bring higher cost, not only for the production of the samples but also because of required test equipment. For smaller samples the results would be too inaccurate and overly optimistic[1]. The 4-point bend test addresses both the breaking strength of the surface and the breaking strength of the edges of the samples. In a glass panel that is supported on all sides and subjected to a pressure, the stresses in the edges are much less than those found in the middle of the pane. It can therefore be argued that failure of a sample by breaking starting at one of the edges is not entirely representative for the application. The alternative, a ring-in-ring test method according to ISO 1288-2, leaves the edges un-loaded, but it needs larger samples (1.0 m x 1.0 m) it is much more costly to carry out and the test equipment is much more complicated. Also, the material

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[1] Glass as a material has very high theoretical strength when evaluated on the basis of the chemical bond between Silicon and Oxygen (which are the backbone elements of inorganic glass) . The tensile stress that will cause a piece of glass to break depends on the presence and orientation of microscopic defects (flaws) on the glass surface. The material is very brittle and where in plastic materials like construction steel or aluminium local stress peaks around defects are compensated by local yielding, in glass cracks will occur and those will propagate. Whether a test piece breaks under a certain load depends on the presence of defects. The larger the loaded area is, the greater the chance that there is a critical defect in that area that will set off breakage. This is opposite to ductile material, where in a larger test piece there is more material to compensate local defects. For critical glazing projects tests are generally performed on real scale test pieces, for example 3.0 meters long and 1.0 m wide for glazing spanning a full floor height. For the purpose of this standard, unification on test pieces of 1.0 m was considered appropriate. Further to this, static fatigue plays a role in the strength of glass. There exists a subcritical crack growth chemical mechanism that, at constant load, can lead to delayed sudden breakages.

characteristics are less easily derived. A simply supported beam under two symmetric point loads represents a simple two-dimensional static case open to analysis with simple means.

It is noted that ISO1288-2 and ISO1288-3 formally are valid for monolithic glass only. Therefore ISO11336-1 for laminated glass refers to the *method* of ISO 1288-3 to determine the laminated properties and not to the standard itself.

The 'Characteristic Failure Strength' (CFS) that can be used in the design of the glass cross section is to be derived from statistic analysis of the test results using the t-Student distribution. It must be taken as the lower threshold of the 90% reliability interval. Therefore, 95% of the material (the 90% of the interval plus the 5% with strength greater than the interval) can be expected to have greater strength than this lower threshold.

The ISO 614 punch test method which formed the core of the existing commercial standards was not selected. It is well known in the marine industry, but it is a production control type pass/fail test and results cannot practically be used for material qualification. It has no application outside the marine industry, and cannot be used for laminated glass.

3.1.e) Defined pressure test procedures

The standard provides criteria for pressure testing of glazed openings. When the glazing cross section is qualified, a single pressure test can be used to show the adequacy of the framing system. If the glazing cross section is not qualified, pressure tests can be used to show the capability of the appliance, but no less than three samples are to be tested, and all should pass the test without failure.

The standard offers three alternative methods of pressure testing: The first method (*Method A*) uses loading the sample up to design pressure, then a hold period of 300 seconds, and then increasing the pressure up to the test pressure in three cycles, and then, optionally, up to failure. The second method (*Method B*) involves making the pressure cycles to design load prior to the 300 seconds hold period, and then increase up to breakage. When it is desired to show compliance for a higher design pressure, the pressure cycles and the hold period can be repeated for this second design pressure level before the pressure is increased until breakage of the sample. The standard presents this as *Method C.*

The pressure cycles and the hold period make the pressure test more time consuming than the traditional pressure test in which the pressure in the chamber is simply raised until failure of the sample occurred. Experience with this test method indicates that these elements in the test cycle make the outcome of pressure tests more consistent.

3.1.f) Bonded mounting

The standard briefly touches on the bonding of windows to their frames but does not go into detail with regard to bonding of windows. This aspect is deferred to part 2.

3.1.g) Criteria for storm shutters and deadlights

The standard provides criteria for storm shutters and deadlights. They can be made of materials normally acceptable for ship construction. The standard gives scantling criteria for storm covers and deadlights in steel, aluminium and composite. Where the Flag requirements allow, most yacht builders prefer to use glazing of increased strength in lieu of storm covers. The Large Yacht Code 2 and 3 for example require an increase of equivalent monolithic thickness of the glazing by 30%. This would be consistent with design to a pressure increased by a factor $1.30^2 = 1.69$.

3.1.h) Examples and background information

In three normative annexes ISO11336-1 gives methods to calculate the equivalent unsupported rectangular areas for windows with different shapes, the calculation of the deflection, and the effective width of plating for use in the storm cover criteria.

In addition, five informative annexes give

- background information to the glass scantling equation.

- a worked example of the statistic reduction of a series of test results.
- worked examples of calculation of equivalent thickness of laminated glazing.
- backgrounds to the proposed design pressures and about the application of storm covers.

The working group has made a first step, and developed a standard that for LY2 type yachts can replace BS MA 25 and its equivalents and provides criteria for some of the areas that were not clearly defined before. At the moment of writing this paper, the standard had been accepted by ~~most of the~~ National Authorities of ~~the~~ leading Registries for application on yachts up to 3000 GT that do not go to sea with more than 12 passengers.

3.2 Next steps

Bonding of windows is deferred to Part 2. The workgroup had to make this choice in order to meet the time schedule for completion imposed by ISO regulations. Part 2 of ISO 11336, now under development, will likely refer to Part 1 for the design pressures and the material qualification. There will be more elaborate sections on bonding and the way to deal with the deflections of the supporting hull and deckhouse structure under both sea loads and thermal loads. There may also be a modified method to calculate the required glass thickness using a non-linear method to calculate the stress and the deflection. For the larger windows this part aims at, non-linear effects become dominant in determining the deflection and stress at failure load and the assessment method used in Part 1 is no longer applicable.

Part 3, Quality control and Inspection, will adopt wherever possible QA procedures and known standards from the glazing industry. It will describe the required documentation and describe the survey procedures. This is not just more paperwork. Modern laminated and specially treated glass with pre-scribed bonding design is a special product. To prevent faults, full documentation must be provided on board to ensure the right materials are used for replacement.

As a last note on ISO11336: The standard deals with glass from a Load Line assignment point of view only. Depending on the application there may be other criteria to be complied with. In escape routes and above and below muster stations glass type and fitting may need to be chosen in a way to protect the people on board in case of fire. Also, any other load than sea load and thermal loads are not considered.

4. OTHER APPLICATIONS OF GLASS ON BOARD OF YACHTS

Qualification of glass as a structural material opens a world of opportunities for yacht designers. Transparent bulwarks and stairs are proposed. Some owners have ideas of building a deckhouse with internal structure and replace the bulkheads with glass facades. With sound engineering, many of these ideas can become reality, provided the right considerations are made during design, with proper attention to the peculiarities of glass.

4.1 Aspects to be considered when selecting glass as a structural material.

Float glass is strengthened in a thermal or chemical process that brings a residual compressive stress in the outer surface. The compressive stress in the surface generates a margin against tensile stresses, and hence moves the point at which the tensile stress around a defect becomes critical to a higher stress level. This is experienced as 'strengthening'. The thermal process brings the Critical Failure Stress (CFS) from about 50 MPa for the base float glass to typically 160 MPa for the strengthened glass. The chemical process brings the CFS typically to 250 MPa. The hardening layer the chemical process induces has a typical thickness ranging from 30 to 100 μm for common soda-lime glass. Deeper layers may be achieved with special glass chemical compositions. Scratches and surface damage may therefore penetrate the hardening layer when this is too thin and reduce the surface condition of the glass so to say to its natural (not strengthened) state. Edges are particular vulnerable: slipping a sharp knife along the edge may be sufficient to cut the hardening layer. Therefore, edges and surface areas likely to be touched are to be protected. Damage can occur from everyday routine actions. A glass elements rising from the floor or deck can be subject for example to surface damage by the suction head of a vacuum cleaner, simply because the floor is cleaned every day, a line of damage can develop with time. Same holds for contact with shoes, or that a bit of sand in the sponge used by the crew member who cleans the window, every day, same swipe, simple routine, slowly grinding in. To protect against such wear, sacrificial outer layers can be added.

Like any material, glass may fail under cyclic loading. On yachts spending most of their time in a berth in the marina, same heading all the time in a sunny area, thermal loads may be of importance. The load cycle in that case is 24 hours.

4.2 Considerations pertaining to vessels

Ships, opposed to buildings, move with the waves and can experience a substantial angle of roll. This can cause furniture and loose items to move along the deck and people on board will need a steady grip. Building standards for glass railings therefore form a good basis for design, but enhanced criteria are to be applied to allow for the ship's movements.

4.3 Applications on board

For application of glass elements on board of yachts therefore redundancy, monitoring, and awareness of the nature of the loads and nature of the material and of the consequences of failure are the keys to success. Some designs are feasible, some are not. In any case the consequences of failure of a single glass ply, not only due to overload from sea pressure but due to whatever cause is to be considered. For example, in some cases operational measures like closing the sun deck for access in bad weather could be considered in association with proposals to accept glass railings. If the area is not accessible, there is no danger of falling overboard either.

5. CONCLUSION

ISO 11336, part 1 provides relevant and dedicated applicable criteria for design and examination of the larger part of the glazing on board of yachts. It approaches glass as a structural material. This approach will support the application of glass in items other than windows and portholes. The standard uses techniques well established in other industries.

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