BOROFLOAT® & Sight Glass: A Union of Inspiration & Quality

White Paper
BOROFLOAT® & Sight Glass: A Union of Inspiration & Quality

The performance requirements for sight glasses to monitor for instance chemical reactions in industrial reactors are extremely high. Subjected to elevated temperatures, chemical attack and high pressure, specifying the right material is critical to ensuring safety in the harshest of environments. Such environments are where BOROFLOAT® feels right at home.

1. Introduction

BOROFLOAT® 33 borosilicate glass can be used as sight glass or viewing window in many applications including chemical, pharmaceutical, food & beverage, off-shore drilling, nuclear, biological, mining, electrical and general manufacturing. The use of BOROFLOAT® 33 borosilicate glass for these applications can be attributed to its outstanding abilities to resist chemical attack and its exceptional thermal properties, which allow for higher temperature exposures. The chemical composition of BOROFLOAT® 33 borosilicate glass is in accordance with ASTM E 438-92 (2001), Type 1, class A. In certain cases BOROFLOAT® 33 borosilicate glass can be heat strengthened to withstand even higher pressure loads. Following common international standards* this paper will discuss ways to calculate i) the sight glass thickness for given mechanical and/or thermal loads or ii) mechanical and/or thermal loads for given glass thicknesses. It will further provide calculation examples and pressure charts for easy value determination.

2. Mechanical & Thermal Loads

The thickness and size of a sight glass must be determined in order to satisfactorily meet the expected pressure loads to ensure safety. Thermal stresses must also be accounted for since these will reduce the allowable mechanical stress from the pressure load. The allowable stress limit is determined by combining the mechanical and thermal loads placed upon the sight glass.

2.1 Mechanical Stress

The mechanical stress for a circular sight glass can be calculated per the following equation [3]:

Circular Sight Glass

\[ \sigma_{\text{mech}} = \frac{3Dp(3+\mu)}{2t^2} \]

where:
- \( D \): diameter of unsupported area
- \( p \): applied pressure
- \( t \): sight glass thickness
- \( \mu \): Poisson's ratio

The mechanical stress for a rectangular sight glass can be calculated per the following equation [3]:

\[ \sigma_{\text{mech}} = 0.75 \frac{pb^2}{t^2} \left( 1 + \frac{1.61b}{a} \right) \]

where:
- \( a \): length of unsupported area (long side)
- \( b \): width of unsupported area (short side)
- \( p \): applied pressure

With \( \mu = 0.2 \) for BOROFLOAT® 33 borosilicate glass, eq. (2) simplifies to:

\[ \sigma_{\text{mech}} = \frac{3Dp}{2t^2} (3+\mu) \]

One commonly referenced standard used for sight glass calculations is British Standard BS4463 „Observation and gauge glasses for pressure vessels“ [1]. It provides recommended maximum working temperatures, temperature differentials and pressures and applies solely to circular sight glasses within defined dimensions.

Another commonly followed standard is provided by the Association of German Technical Inspection Services VdTÜV: AD 2000-Merkblatt N4 „Pressure vessels made of glass“ [2]. This standard considers mechanical and thermal stresses as further explained below. Appendix 3 shows pressure charts derived when applying this standard’s calculation schema to annealed and toughened BOROFLOAT® 33 borosilicate glass.

* This paper is to be seen in conjunction with referenced standards. The reader is required to refer to and obey by such standards. Design of mounting, characteristics of gasket material and assembly procedures must be considered and are not within the scope of this paper. This disclaimer: SCHOTT supplies BOROFLOAT® 33 borosilicate glass in raw sheet form only. Secondary processing is performed by others who cut and finish the glass to end user specifications. The finishing process, combined with the strengthening process (if applied), has a significant influence on thermal shock resistance and mechanical properties that affect the maximum usable pressure. Therefore, determining the suitability of our product and any product specifications or requirements necessary for your particular application(s) remains entirely your responsibility. SCHOTT assumes no responsibility or liability and makes no warranty or guarantee with respect to any suggestion, advice or information related to the use of sight glasses or any reliance on this paper.
2.2 Thermal Stress

In order to determine the thermal stress of the sight glass, the exact temperature distribution over the entire surface of the sight glass needs to be known for all times when high temperature gradients are probable. Unfortunately this data is not always available. However, a simplified calculation can be done using the following equation (Association of German Technical Inspection Services VdTÜV: AD 2000-Merkblatt N4): 

\[ \sigma_{\text{therm}} = \frac{\alpha \cdot E \cdot \Delta T}{2(1-\mu)} \]

with heat strengthening \( S_h \). Values for heat strengthening depend on equipment performance, temperature/time profile applied and - especially for low-thermal expansion glasses - the rapid cooling ability during the quenching step. Details and confirmation of applicable pre-stress the manufacturer of heat strengthened glass should be consulted.

As a guide for calculating sight glasses, typical examples (following VdTÜV: AD 2000-Merkblatt N4) are given below:

Example (1): mechanical load, circular sight glass, maximum pressure to be determined

Example (2): mechanical load, rectangular sight glass, maximum pressure to be determined

Example (3): mechanical load, toughened circular sight glass, maximum pressure to be determined

Example (4): mechanical and thermal load, toughened circular sight glass, maximum pressure to be determined

In addition to below samples, appendix 3 shows pressure charts for some typical conditions which apply to below defined sight glasses at room temperature.

- Circular sight glasses with a design strength of 870 psi for annealed glass
- Square sight glasses with a design strength of 870 psi for annealed glass and 3000 psi for heat strengthened glass
- Rectangular sight glasses with side ratio 1:4, resp. 1:2 with a design strength of 870 psi for annealed glass and 3000 psi for heat strengthened glass

Example (1):

In the first example the maximum pressure for an annealed BOROFLOAT® 33 borosilicate glass circular sight glass at room temperature is determined.

From eq. (3) (calculation for a circular sight glass) the maximum pressure \( p \) is:

\[ p = \frac{\sigma_{\text{mech}} \cdot \pi \cdot t^2}{0.3 \cdot D^2} \]

For this example, a maximum pressure of 65 psi is determined. (The same result may be derived from the pressure chart in appendix 3.)

Example (2):

In the second example, the maximum pressure for an annealed BOROFLOAT® 33 borosilicate glass rectangular sight glass at room temperature is determined.

From eq. (4) (calculation for a rectangular sight glass) the maximum pressure \( p \) is:

Applying this equation, a maximum pressure of 49 psi is determined. (The same result may be derived from the pressure chart in appendix 3.)

Example (3):

In the third example the maximum pressure for a high pressure toughened BOROFLOAT® 33 borosilicate glass circular sight glass at room temperature is determined.

From eq. (3) (calculation for a circular sight glass) the maximum pressure \( p \) is:

Applying eq. (8) (example 1), a maximum pressure of 675 psi is determined. (The same result may be derived from the pressure chart in appendix 3.)

Example (4):

In the fourth example the maximum pressure for a high pressure toughened BOROFLOAT® 33 borosilicate glass circular sight glass at 500 °F (260 °C) is determined.

From eq. (6) the thermal stress equals \( \sigma_{\text{therm}} = 10.5 \cdot 430 ^\circ F = 4515 \) psi. Regarding the total design strength of \( S_{\text{total}} = 9000 \) psi and the thermal stress \( \sigma_{\text{therm}} = 4515 \) psi, the mechanical stress is limited to 4485 psi.

Applying eq. (8) and inserting \( \sigma_{\text{mech}} = 4485 \) psi, a maximum pressure of 336 psi is determined.
Appendix 1: mechanical stress in rectangular sight glasses: full calculus

Step 1: defining normalized values

Normalized pressure:

\[ p' = \frac{p}{E} \left( \frac{t}{a} \right)^4 \] (A1)

Normalized deflection:

\[ f' = \frac{f}{t} \] (A2)

Step 2: defining auxiliary factors

Normalized mech. stress:

\[ \sigma' = \frac{\sigma}{E} \left( \frac{b}{t} \right)^2 \] (A3)

Side ratios:

\[ e = \frac{a}{b} \] (A4)

\[ d = 5.141 \cdot (e^2 + 0.2) \] (A5)

Step 3: derive deflection \( f' \)

The relation between deflection and pressure is given by eq. (A9):

\[ p' = Af'^3 + Bf' \] (A9)

Since eq. (A9) is cubic, solutions for deflection \( f' \) are numerical in most cases.

Step 4: derive stress \( \sigma' \)

With deflection \( f' \), stress can be calculated according to:

\[ \sigma' = f' \cdot (Cf' + D) \] (A10)

Recalculating the mechanical stress \( \sigma \) from its normalized value \( \sigma' \) will be done by eq. (A3).

Note

This calculus refers to sheets of glass which are supported, not clamped. Clamped glasses lead to slightly lower stresses. Similar formulae are available for clamped glasses. Nevertheless, clamped glasses are difficult to establish in reality. Therefore and for the sake of safety this calculus for supported glasses is recommended.

Appendix 2: design strength of annealed sight glasses: full calculus

The design strength of glass for pressure vessels is defined by various standards as, e.g., BS 3463 or AD 2000-Merkblatt N4. These two standards define design strength as 7 MPa and 6 MPa, respectively. In these standards the design strength is derived from generally recognized glass strength data, measured by standardized laboratory equipment in the state as delivered, reduced by an overall safety factor.

Since this safety factor has to cover all applications irrespective of the severity of the single load condition (size of sight glass, duration of peak load), sight glass calculation may undervalue the design strength for this special purpose. A useful tool to calculate the safety factor and the design strength of sight glasses for individual applications is given in literature [5]. This procedure comprises:

- Standardized measurement of glass bending strength (e.g. ring-on-ring test according to EN 1288-5) with its surface abraded to simulate long-term exposure
- Evaluation of the results in a statistical manner (e.g. Weibull statistics)
- Derivation of first safety factor \( f_a \) (area factor): The area factor takes into account that larger sizes are more prone to critical flaws and therefore yield lower strength
- Derivation of second safety factor \( f_p \) (probability factor): The probability factor takes into account that the strength of glass is a statistical property with certain scattering for inevitable physical reasons
- Derivation of third safety factor \( f_f \) (fatigue factor): The fatigue factor takes into account that the strength of glass is a time-dependent property. For a certain load the risk of failure increases with time

This procedure, adapted to BOROFLOAT® 33 borosilicate glass, yields an individualized design strength \( S_{ind} \) acc. to eq. (A1):

\[ S_{ind} = 1140 \cdot \left( \frac{1}{t} \right)^{0.033} \cdot \left( \frac{1}{A} \right)^{0.0861} \] (A11)

With \( t \) time of load at pressure \( p \) between 65 % and 100 % maximum pressure in hours, \( A \) the sight glass area in \( \text{in}^2 \), and individualized design strength \( S_{ind} \) in psi.

Nevertheless, if \( S_{ind} \) is calculated as less than 870 psi, the standardized design strength of 870 psi should be used.

BS 3463: Observation and gauge glasses for pressure vessels

AD 2000-Merkblatt N4: Pressure vessels made of glass, Published by German Technical Inspection Agency VdTÜV


Drouven, G. (Bayer AG): Application-technical information 199/78


German Technical Inspection Agency VdTÜV

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Appendix 3: pressure charts: circular sight glass
(following AD 2000-Merkblatt N4)

Circular sight glass at room temperature
annealed BOROFLOAT® 33 (design strength 870 psi)

Circular sight glass at room temperature
BOROFLOAT® 33 high pressure heat strengthened 8130 psi (design strength 9000 psi)

Circular sight glass at room temperature
BOROFLOAT® 33 heat strengthened 2130 psi (design strength 3000 psi)

Appendix 3: pressure charts: square sight glass
(following AD 2000-Merkblatt N4)

Square sight glass at room temperature
annealed BOROFLOAT® 33 (design strength 870 psi)

Square sight glass at room temperature
BOROFLOAT® 33 heat strengthened 2130 psi (design strength 3000 psi)

Appendix 3: pressure charts: rectangular sight glass: side ratio 1.4 : 1
(following AD 2000-Merkblatt N4)

Rectangular sight glass at room temperature
annealed BOROFLOAT® 33 (design strength 870 psi)

Rectangular sight glass at room temperature
BOROFLOAT® 33 heat strengthened 2130 psi (design strength 3000 psi)

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Appendix 3: pressure charts: rectangular sight glass: side ratio 2 : 1
(following AD 2000-Merkblatt N4)

Rectangular sight glass at room temperature
annealed BOROFLOAT® 33 (design strength 870 psi)

<table>
<thead>
<tr>
<th>Calculated maximum pressure $p$ [psi]</th>
<th>Sight glass unsupported area: length of long edge $a$ [in]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>$\frac{a}{b}$</td>
</tr>
<tr>
<td>100</td>
<td>$\frac{a}{1.5b}$</td>
</tr>
<tr>
<td>10</td>
<td>$\frac{a}{1.1b}$</td>
</tr>
<tr>
<td>1</td>
<td>$\frac{a}{b}$</td>
</tr>
<tr>
<td>0.1</td>
<td>$\frac{a}{1.8b}$</td>
</tr>
<tr>
<td>0.01</td>
<td>$\frac{a}{2.5b}$</td>
</tr>
</tbody>
</table>

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