White Paper

Compression vs. Fusion: The Source of Strength in Fused Sight Glasses for Chemical and Pharmaceutical Processes

Manufacturers of sight glasses use different combinations of metal and glass to achieve a strong, leak-proof view into a variety of chemical, pharmaceutical and industrial processes. Sight glass users must sort through the controversies surrounding the relative merits of each combination, the alloys used, and the glass formulation. These controversies are compounded by a common misunderstanding of the role of compression on the glass element, the strength of the bond between the metal and the glass, and how these considerations impact the optimum operating pressure and maximum limit realized. This paper compares the two most common combinations and discusses the correct methodology for calculating the strength resulting from each. The study concludes that whichever combination of glass and metal provides the most compression also provides the highest strength, and therefore it is compression, rather than fusion, that predicts the reliability of a sight glass.

Manufacturing Process

During heating, the glass is melted within the metal ring as the ring expands. Then, temperature is raised to the point where the glass and the metal ring fuse together. When the unit cools, the glass hardens before the metal ring shrinks back to its original size. This places the metal ring in tension and the glass in uniform radial compression.

This compression strengthens the glass because it is stronger than tensile forces that could cause a bending moment (internal torque) on the glass. In fact, under very high compression, glass actually becomes elastic: the surprising ability to bend without cracking.

The most compression is produced by using an alloy of metal that shrinks a lot as it cools in combination with a type of glass that shrinks little when it cools: the greater the difference, the greater the compression. This is trickier than it sounds: too much compression and the sight glass will shatter.

Sight glass manufacturers have tried different steel alloys and different kinds of glass, but in practice, soda lime glass and borosilicate glass are the two types of glass used because these provide the optimal coefficients of thermal expansion. Various types of metal are used by manufacturers, including Duplex, Hastelloy®, and carbon steel. The 316 stainless steel is not recommended because its coefficient of thermal expansion is too high and will crack the glass. Whichever materials are used, the amount of compression can be predicted by the difference in the thermal coefficients of expansion between the materials.

Comparison Methodology

To compare these glass/metal combinations, this paper employs mathematical models based on the known physical properties of each material, as described in published sources. These mathematical models are able to determine precisely how much compressive force is generated as the glass solidifies and the metal ring contracts, approaching its theoretical diameter.

For the purpose of the study, 20°C (68°F) was assumed. A standard sight glass size was selected with the following characteristics:

- Outside diameter: 100 mm (3.94 in.)
- Inside diameter of 55 mm (2.17 in.)
- Thickness of 15 mm (0.59 in.)

The primary goal of this study was to quantify the amount of radial compression created by the difference between the glass and the metal in coefficient of thermal expansion as the sight glasses cool. In order to make this determination the following formula is used:

$$\tau_G = \rho_G = \frac{(\alpha_G - \alpha_S)\cdot(T_i - T)}{\dfrac{-2\cdot\mu_G + 1}{E_G} + \dfrac{-2\cdot\mu_S\dfrac{r_1^2}{r_2^2} + \left(1 + \dfrac{r_1^2}{r_2^2}\right)}{E_M\cdot\left(1 - \dfrac{r_1^2}{r_2^2}\right)}}$$

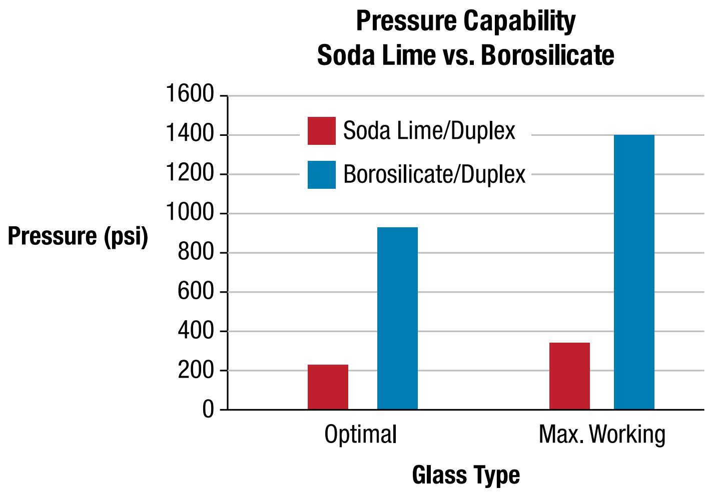
E [N/mm²]	modulus of elasticity
μ	Poisson ratio
$\alpha_{20/300}$ [K^{-1}]	coefficient of thermal linear expansion
T_i	inversion temperature
r_1	inner radius of metal ring
r_2	outer radius of metal ring
T	operating temperature
Ti	inversion temperature = 380°C (653°K)

Results: Soda Lime versus Borosilicate Glass

Applying this equation to two sight glasses, we see that a sight glass made with borosilicate glass creates significantly more compression than one made with soda lime glass. Also, there is a direct relationship between the amount of compression and the strength of the sight glass. The borosilicate sight glass has far greater pressure capability. Strength is also important for worker safety and because it reduces the need for sight glass maintenance and replacement.

Soda-lime glass with Duplex stainless steel frame:
Compression: 73.5 MPa (10660 psi)
Max. Pressure Working Pressure: 24 bar (348 psi)
Optimal Working Pressure: 16 bar (232 psi)

Borosilicate glass with Duplex stainless steel frame:
Compression: 195.9 MPa (28412 psi)
Max. Pressure Working Pressure: 96.9 bar (1405 psi)
Optimal Working Pressure: 64.6 bar (937 psi)

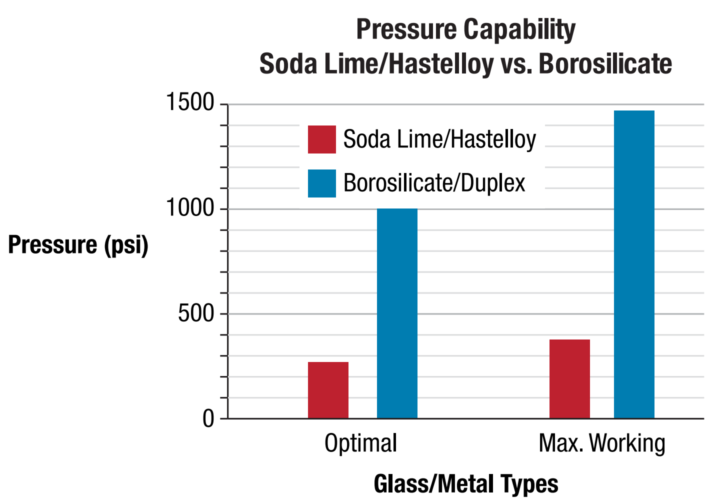


Resolving the Controversy: Soda Lime/Hastelloy versus Borosilicate/Duplex

Recently, a sight glass made with proprietary soda-lime glass coupled with a Hastelloy C22 stainless steel ring has been introduced to the industry. This glass/metal combination has been the source of some of the controversies discussed earlier because its supplier claims its combination of glass and metal is superior because it has better glass-metal fusion. The central questions of this paper are: Where does the strength of a sight glass come from? Which alloys of metal and which types of glass create the strongest sight glasses? The answers come from comparing the compressive force of a Hastelloy/soda-lime sight glass with the compressive force of a Duplex/borosilicate sight glass.

Soda lime glass with Hastelloy C-22 stainless-steel frame:
- Compression: 67 MPa (9717 psi)
- Max. Working Pressure: 21.2 bars (307 psi)
- Optimal Working Pressure: 14.1 bars (204 psi)

Borosilicate glass with Duplex stainless-steel frame:
- Compression: 159.9 MPa (28412 psi)
- Max. Pressure Working Pressure: 96.9 bar (1405 psi)
- Optimal Working Pressure: 64.6 bar (937 psi)



Such results were not at all unexpected. The difference in coefficients of thermal expansion among the materials in question predicts the differing results.

Coefficients of Thermal Expansion	
Soda lime glass 9.40×10^{-6}	Hastelloy C22 1.23×10^{-5}
Borosilicate glass 4.15×10^{-6}	Duplex stainless steel 1.38×10^{-5}

The result of compression on the borosilicate glass translates to three times the compression realized on the proprietary soda-lime glass. In turn, **we can confidently rate the borosilicate glass/duplex stainless steel construction as providing four and a half times the pressure capability.**

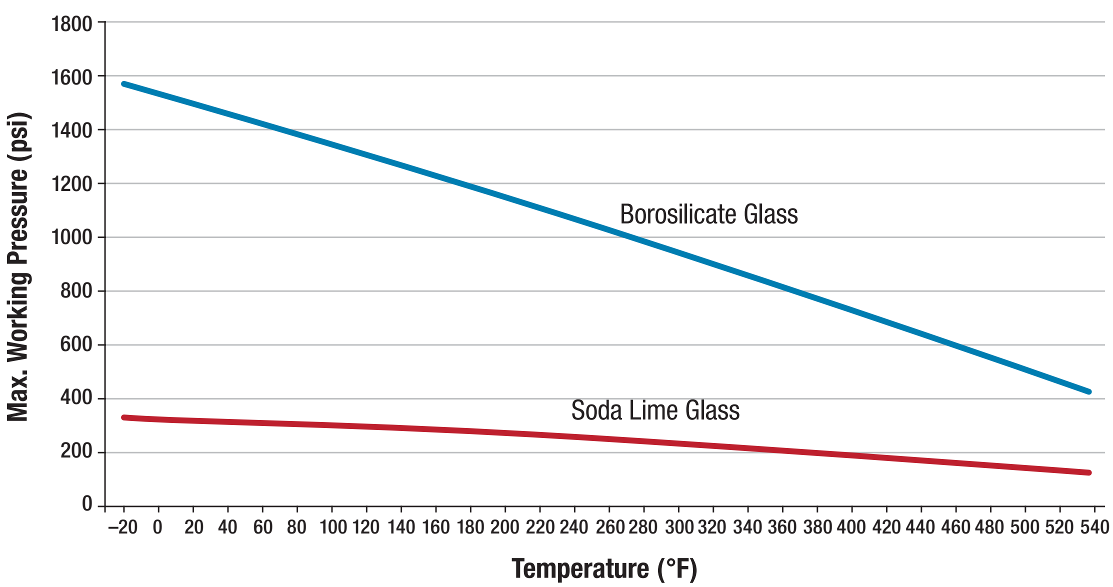
In addition, these results may explain why there has never been a reported case of a fused borosilicate sight glass that leaked. In addition to the normal fusion between glass and metal, the extreme pressure secures the bond between the duplex stainless steel and the borosilicate glass **making it, for all practical purposes, a fused transition rather than a junction.**

Operating Pressure Comparison

Having determined that the borosilicate glass coupled with a Duplex stainless steel ring produces the strongest fused sight glasses, we then produced a chart of Maximum Working Pressure over a wide range of operating temperatures. Maximum working pressure is the highest continuous pressure that the sight glass can accept without exceeding a safety factor of 8. It is not the bursting pressure. No cracks will appear on the glass at this pressure. The study results were arrived at by iterations of a mathematical model above with the following results:

Pressure/Temperature Comparison

Borosilicate vs. Soda Lime



This chart compares a sight glass comprised of duplex stainless steel and borosilicate glass with a sight glass comprised of Hastelloy C-22 steel and soda lime glass. The sight glass that uses borosilicate glass is many times stronger across a range of operating temperatures.

In conclusion, the strength of a fused sight glass is directly related to the amount of compression on the glass. Fusion – getting the glass to stick to the metal – is easy to achieve; it is a normal byproduct of manufacturing. However, **the reliability of a sight glass has almost nothing to do with fusion. Rather, it is compression that secures the glass to the metal and creates a leak proof seal.**

In addition, a strong (high compression) sight glass provides reliability in other ways. Its glass is more elastic, making the glass more resistant to cracking during cold water washdowns, temperature cycling, high pressure, scratches, misaligned installation, and impacts. Moreover, improper sight glass maintenance, wear, and other factors can dramatically lower the failure point and endanger workers. The best safety strategy is to start with the strongest sight glass available.

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