Tempered glass: It’s not always what you see

Joel M Feingold clarifies the role of tempered glass detectors and strain viewers.

With increased attention to quality control of tempered glass used in applications such as laminated glazing, solar glass and glass containers, some clarification is in order about devices being marketed as ‘tempered glass detectors’ or strain viewers. These products are sometimes said to be capable of determining if glass has been suitably tempered. In fact, the only things revealed by these devices are that the glass has been through a tempering furnace and possibly, non-uniform heat treatment. It is impossible to assess the level of tempering using these instruments because surface compression, the determining factor, cannot be observed by simply looking through the glass thickness.

SURFACE COMPRESSION

For decades, glass manufacturers and fabricators worldwide have used quantitative measurement of residual surface compression (also known as prestress) as a reliable, non-destructive indicator of both mechanical strength and a predictable break pattern in heat treated glass. Any imbalance between the compressive stresses at the surface and the tensile stresses in the mid-plane will weaken the glass, often causing it to rupture unpredictably and dangerously.

With adequate surface compression, however, tempered glass will be many times stronger than untreated glass and if broken, will shatter into very small, relatively safe pieces (figure 1). The reason why visual inspection is not suitable can be easily explained by a simplified description of the thermal tempering process and how it affects stress distribution in glass.

The strength of tempered glass is created by uniformly heating it to approximately 600°C, after which it is slowly cooled (quenched) rapidly. Because the surfaces of the glass cool more quickly than the interior, a strong compressive stress layer is formed at the surfaces to counteract the tensile stresses of the still warm interior. With the surface and mid-plane of the glass at ambient temperature, temporary stresses disappear and the glass is at dynamic equilibrium (figure 2). In other words, the compressive stress $$\frac{1}{2}$$ at the two surfaces equals the mid-plane tension (+). In this state, the thin but strong layer of surface compression is resistant to loads caused by wind pressure, thermal shock, impact or other applied forces.

STRESS BIREFRINGENCE, RETARDATION AND PHOTOLEASTICITY

When viewed in a polariscope, stress becomes visible due to an optical property in glass, plastics and other transparent or translucent materials known as birefringence. This interesting phenomenon causes the incident light to exhibit two indices of refraction offset at 90° to each other and moving at different speeds, with a resulting phase shift (retardation) that is proportional to stress and represented by an interference pattern that appears as a distinctive and repeating sequence of colours.

These so-called photoelastic colours range from black or dark grey (little or no stress) to white, yellow, purple/red, blue, green and repeating hues of colour that get less intense as stress increases. The transitions from red or purple are known as fringe orders, or simply ‘fringes’ (figure 3).

However, the stress observed is the algebraic sum of the similar stresses through the thickness (the distance of the light path through the material). That means tensile stress, which by convention is denoted with a positive sign (+), is offset by the compressive stress, which is denoted by a negative sign (-). Because tensile compression in tempered glass are ideally at equilibrium, the NET stress observed is close to zero (black or dark grey) and therefore, provides no useful information about the magnitude of surface compression.

The operating principle behind...
the GASP polarimeter (figure 4) and similar instruments is based on the measurement of the difference between the two indices of refraction resulting from the stress birefringence in the compressive surface layer of the glass. Because of the distinctive optical coupling required, the measurement must be done on the tin side of the glass. This limits the instrument’s application to float glass (soda lime or borosilicate) with an adequate tin pick-up. The molecular diffusion of tin into the glass surface serves as a waveguide to enable much of the light to enter the glass, propagate parallel to the surface for a short distance and exit into the instrument’s measuring components.

If the surface of the glass is not suitable for this measurement method, due to lack of tin, patterns or coatings on the glass, it is often possible to use edge stress measurements as an alternative method of quality control. Because the edge is technically a surface, edge stress can be a good approximation of surface compression – all things being equal. However, the edges are cooled on three sides instead of two and there are many different edge finishes in tempered glass, making correlation with destructive testing important.

Edge stress measurement has become a well-accepted test method using edge stress meters, such as those shown in figure 5. In addition, edge stress measurement is critical for glass that is bent, intended for use in IG or LG applications or where it will be subjected to frame loading or bonded to non-glass materials.

Because stress at the edges of tempered glass is compressive only, it is also possible to arrive at an approximation of temper value by observing and counting the colour bands representing ‘fringe’ orders in polarised light under magnification, as seen in figure 3. Each fringe represents a multiple of one wavelength of optical retardation (565nm), so multiplying the number of bands by 565 will provide an estimate of total retardation.

To convert retardation to the common stress unit of Megapascal (MPa), simply divide the retardation by the thickness of the material in millimeters and the stress-optic constant (SOC). For soda-lime float glass, the SOC is typically 2.65. To convert to psi units, multiply MPa by 145. An example taken from the fringe pattern shown in figure 3, assuming 10mm glass, would be:
- Retardation = 4 fringes = 4x565 = 2260nm.
- SOC = 2.65.
- Thickness = 10nm.
- Stress = 2260/2.65*10 = 85 MPa (12,325 psi).

This glass would be considered fully tempered according to most standards for edge stress, including ASTM C1048 and would likely pass any fragmentation test, including ANSI 297.1 and similar specifications for particle count. It may or may not meet the bending/mechanical strength requirements for safety glass in buildings mandated by EN12150 for CE marking. However, when correlation with destructive tests is documented, non-destructive measurements of surface stress and edge stress using the instruments described here are acceptable.

**SUMMARY**

Quality control of thermally tempered glass is essential to ensure compliance with government and industry standards where applicable, to help prevent costly field failures, injury and product liability and control stress-related distortions in sealed and laminated architectural and solar glazing.

For safety glass applications, the results of destructive testing must be correlated with quantitative measurement of surface compression and/or edge compression. For any heat strengthened or tempered glass application, stress measurement using surface or edge stress polarimeters can help to ensure product quality, optimise furnace parameters and reveal problems in the heating and/or cooling process that could degrade the performance of the glass after it reaches the customer.

Visual inspection using strain viewers, or polariscopes, can be useful for detecting problems, such as blocked nozzles or temperature control issues. However, they cannot be relied upon for determining whether a glass product complies with any standard or safety requirement for tempered glass.

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