**Introduction**

The breakage of glass impairs the safety, security and comfort of buildings. Matching and installing replacement panes of glass or glass units can also be expensive. This Technical Note describes the causes of glass breakage and presents measures to minimise its occurrence and diagnose its cause(s).

Breakage characteristics depend on the glass type. Annealed glass breaks into sharp-edged shards, although these may remain in the frame, depending on the glazing method. Toughened glass, when broken, disintegrates into small, relatively blunt particles (‘dice’) that will generally fall out of the frame, preventing examination of the breakage pattern. With laminated glass the broken panes will remain adhered to the laminate, enabling the breakage pattern to be examined and the cause of breakage to be identified. The manufacture and properties of different glass types are described in Technical Note 11 *Glass Types*.

**Causes of glass breakage**

Glass is potentially very strong as shown by its use in glass fibre reinforced plastic however in sheet form the strength is reduced by the presence of invisibly small defects, known as Griffith cracks, which cause stress concentrations allowing cracks to propagate. Strength may be reduced further by larger visible defects.

The potential causes of breakage of annealed glass are as follows:

- Uniform load,
- Impact,
- Edge damage,
- Poor glazing,
- Site damage,
- Thermal stress.

These factors may also cause breakage of toughened glass but the failure loads will be higher. Breakage of toughened glass may also be caused by nickel sulphide inclusions.

**Annealed glass**

**Uniform load**

The most significant form of uniform loading on glass is normally wind load although other causes such as snow may occur in some situations. The safe load on a pane of glass is related to the size of the pane and glass thickness. BS 6262 gives guidance on the selection of glass thickness.

If the glass has been incorrectly selected (i.e. it is not thick enough) or if the peak wind load has been incorrectly assessed, then the glass may not have adequate bending resistance and will ultimately break. Figure 1 shows the glass fracture pattern due to excessive, uniform load.

**Figure 1** Breakage pattern in annealed glass due to uniform mechanical stress
**Impact**

Glass may break as a result of impact. The impact may be accidental, (e.g. from human collision), or deliberate, (e.g. through vandalism). Breakage may also be caused by thrown or wind borne projectiles (e.g. gravel blown from roofs).

The breakage pattern depends on whether the impact is soft (e.g. human impact) or hard (e.g. small projectile) (Figures 2 & 3).

**Figure 2** Breakage pattern of annealed glass due to soft body impact

**Figure 3** Breakage pattern in annealed glass due to hard body impact

Part N of the Building Regulations places limitations on the use of glass in locations vulnerable to impact and BS 6262: Part 4 gives recommendations on the use of glass in areas liable to human impact.

**Edge damage**

Edge damage, which is usually caused by poor handling, can impair the bending strength of a pane of glass by creating stress concentrations. Edge damage can also occur when cutting glass (difficulty increases with thickness) although this is much less likely to lead to breakage than damage due to poor handling.

There are no standard acceptance criteria for the edge condition of glass, although glass with edges that are severely feathered or have deep, pointed shells/vents are generally unacceptable, especially in glass types that absorb a high percentage of solar energy. Figure 4 illustrates some edge conditions of glass.

**Figure 4** Degrees of edge damage
**Poor glazing**

Insufficient clearance between the glass edge and glazing frame will cause the glass to come into contact with the frame under frame movement or glass expansion, increasing the likelihood of breakage, especially if there is localised contact (e.g. with a fixing screw). Insufficient clearance may result from the incorrect sizing of glass, or deviations of size.

Before glazing, the glass should be checked for size against that of the glazing opening. Glass that is wrongly-sized must not be glazed and nor should its size be reduced by nipping or grinding as this could damage the edge of the glass and the seal of glass units.

The wrong width of setting block may result in uneven support across the bottom of a glass unit or piece of laminated glass. In general, the width of setting blocks should be equal to the sum of the glass unit thickness and the back face clearance to guarantee full support across the width of the unit.

Glass breakage can also arise from setting blocks being too rigid (e.g. very hard nylon) and damaging the edge; a slightly softer compound would eliminate this risk and may also prevent relative movement between the block and glass unit. Too soft a material may cause the glass to sink into the setting block and cause localised frame contact.

Recommendations on good workmanship in relation to glazing are given in BS 6262 and BS 8000: Part 7.

**Site damage**

Spatter from nearby site welding or grinding/cutting operations can cause pitting of the glass surface and in some cases hot metal particles can fuse into the surface (Figure 5). The embedded metal may subsequently corrode and expand inducing a high, local stress in the glass and causing it to crack or shatter.

**Figure 5** Damage to glass caused by weld spatter

**Thermal stress**

Glass can break as a result of excessive thermal stress. Thermally induced stress within a pane of glass results from a temperature differential between two areas of the pane. For instance, in hot weather, the centre of the glass warms up faster than the edge, because the edge is within the glazing rebate and shaded from direct solar radiation. Assuming the area of glass within the frame is insignificant compared with that exposed to solar radiation, as the centre of the pane expands due to the increase in temperature, the edge will be forced to expand by a similar amount inducing a tensile stress.

The expansion in the edge of the glass is given by:

$$\Delta L = \alpha \times L \times \Delta T$$

where $\alpha$ is the coefficient of thermal expansion, $L$ is the original length and $\Delta T$ is the temperature difference between the edge and centre of the pane.

The induced stress is given by:

$$\sigma = (\Delta L / L) \times E$$

where $E$ is the Young’s modulus.

The stress induced by a temperature difference of one degree is therefore $\alpha \times E$. Assuming $\alpha = 10 \times 10^{-6}/^\circ C$ and $E = 70,000$MPa(N/mm$^2$) a
Glass breakage

A temperature difference of one degree results in a stress of approximately 0.7MPa (N/mm$^2$).

The risk of thermal breakage in annealed glass becomes significant when stress levels exceed about 20MPa (N/mm$^2$). A difference of 30 degrees can, therefore, be sufficient to result in thermal fracture. If the glass has been poorly cut, damaged during handling or improperly glazed, breakage could occur at lower temperature differentials.

Thermal stress fractures always start from some tiny imperfection in the glass edge because this acts to concentrate the induced stress. These fractures are easily identified as they run perpendicular to the glass edge at the location of the damage.

Figure 6 illustrates a typical thermal stress breakage pattern. The number of cracks depends on whether the edge of the pane of glass is damaged (single crack) or clean cut (more than one crack).

**Figure 6** Typical thermal stress fracture pattern

Glass should be stored on edge, in racks and on blocks of wood or felt, in dry, ventilated conditions, and out of direct sunlight to prevent thermal fracture.

**Solar control glass**

Both body tinted and coated solar control glass will heat up more than plain glass when exposed to solar radiation increasing the risk of thermal breakage. This effect is increased when the solar control glass is used in insulating glazing units. The use of low-E coatings on the inner pane of insulating glazing units with solar control glass as the outer pane will further increase the temperature of the solar control glass and the risk of thermal breakage.

**Insulating glazing units**

The risk of thermal fracture will be increased in insulated glazing units, as the glass will heat up faster than single glazing.

The edge spacer will also have an effect. Glass units typically contain an aluminium edge spacer to separate the panes of glass. The spacer acts as a thermal bridge and in cold winter conditions will conduct heat to the edge of the outer pane, so reducing the centre-to-edge temperature difference when the sun is shining. ‘Warm edge’ spacers are increasingly being specified and, although they enhance the overall insulating properties of the unit and reduce the risk of condensation, they will increase the risk of thermal breakage.

**Framing design**

The thermal safety of glass is also influenced by frame design. The important factors are heat loss from the frame to the surrounding structure and the response of the frame to solar radiation.

The risk of thermal breakage will be increased if the frame is in good thermal contact with a substantial heat sink thus keeping the edge of the glass cool. The most severe example is where the glass is glazed directly into concrete or brickwork.

Frame material, colour and design will affect the temperature rise of the frame and hence the edge of the glass in response to solar radiation. The risk reduces as the frame is changed from wood to metal and then plastic and dark frames give a lower risk than light ones.

**Internal features**

Conditions and features on the room side of the glass affect the amount of heat absorbed and lost by the glass. Internal blinds may reflect radiation.
and reduce heat loss by restricting air movement, structural elements may reflect solar radiation back to the glass and radiant heaters can direct additional heat towards the glass.

**External features**

External features, which affect the risk of thermal fracture, are shadows, which may cause areas of cooler glass, and reflections, which may increase the temperature of the glass.

Shadows may be created from overhanging balconies or walkways, nearby buildings or trees. Projecting mullions or columns will produce slowly moving shadows and give rise to large temperature differentials. The shadow from a cleaning cradle parked for any length of time in front of a glass panel can induce thermal fracture.

**Handling/glazing**

Correct handling and glazing of the glass is essential to avoid edge damage and minimise the risks of thermal and mechanical stress fracture. The glass should be properly supported and have adequate clearance to allow thermal and structural movements to occur without causing glass to metal contact, especially localised contact. Window and curtain wall glazing gaskets should be compatible with the service temperature.

**Checking for thermal safety**

Project-specific stress analysis using suitable software should be undertaken and any glazed areas found to be at risk should be thermally treated by heat-strengthening or toughening (and heat soaked). The safety check should take account of temporary conditions such as scaffolding and cleaning cradles and future conditions such as trees planted in close proximity to a glazed wall.

**Toughened glass**

Uniform load, impact, weld spatter, inadequate clearance and edge damage may also cause breakage of toughened glass, although the risk of breakage is lower since higher stress levels are tolerable.

Thermal breakage of toughened glass with clean cut edges will not occur in normal circumstances because this requires a centre-edge temperature difference of about 90 to 150°C. Stress concentrations such as edge damage can cause thermal breakage of toughened glass.

**Nickel sulphide (NiS) inclusions**

Glass may contain nickel sulphide impurities, in the form of small crystals. As glass is heated during the toughening process these impurities change state. The high temperature α-state of the impurities may be ‘frozen’ when the glass is quenched, and recovery to the low temperature β-state may then take several years. Spontaneous breakage of the glass may follow, as the low temperature β-state of the nickel sulphide impurities occupies a slightly greater volume and generates a local stress concentration. However, only the largest impurities will cause failure, and only then if they are in the core (tensile zone) of the glass.

Nickel sulphide failures start to appear immediately after production, with a peak failure rate around four to five years after production, but may occur for 20 years.

**Diagnosing NiS failure**

Nickel sulphide breakage of glass exhibits a characteristic fracture pattern. However, it is not unusual for toughened glass to fall out of its frame when broken, thereby preventing examination of the fracture pattern and origin.

Assuming that the fractured pane remains in place, at the origin or epicentre of the fracture there should be located two fragments which are larger than the rest and which form a ‘figure of 8’ or ‘butterfly’ (Figure 7). In the centre would be located the inclusion which is a small, round, shiny, yellow-black particle which may be as small as 0.05mm in diameter.
The risk of nickel sulphide failure can be reduced by heat soaking as described in Technical Note 11 Glass Types.

Summary

Glass breakage can be prevented by:

- Selecting glass thickness to resist wind loading;
- Selecting glass type (e.g. annealed, toughened) to resist predicted thermal stress;
- Specifying that toughened glass be heat soaked;
- Handling and storing glass carefully, particularly toughened and solar control glasses;
- Ensuring that the glazing rebate is free of protrusions (e.g. screws) and there is adequate clearance between it and the glass to accommodate expansion and movement.

References


