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## Thermal stress and glass strength

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# Thermal stress and glass strength

This information is intended for use by window fabricators, glaziers, and their customers, to gain a better understanding of thermal stress and how to reduce or eliminate thermal risk. We hope by using this information, the glass installer can objectively assess risks prior to glass installation.

## Stress in glass

Glass is manufactured through the float glass process where the raw materials are heated at very high levels, forming a molten ribbon. It is then slowly cooled in a process called annealing. As the outside surfaces of the glass cool first, the interior of the glass ribbon remains hot. This introduces a stress profile into the glass surface which needs to be carefully controlled in order for the glass sheet to be further scored, cut and processed.

## Glass strength vs stress

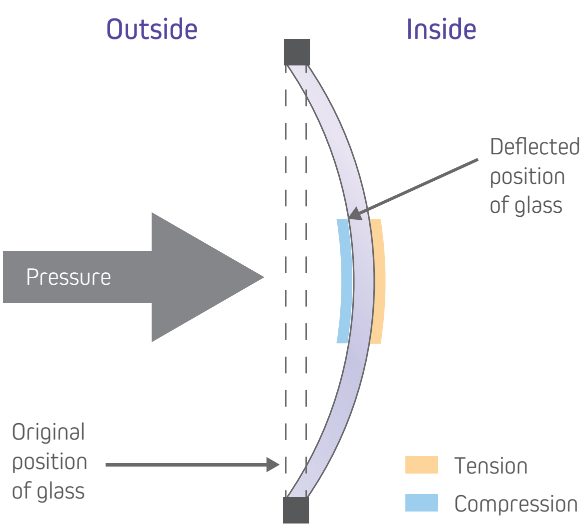
The strength of a material is the value of the stress in which it deforms permanently. For brittle materials which generally only fracture, such as glass, it is tensile stress that is critical not compressive strength.

The compression strength of glass is very high in comparison to other structural materials.

Nominally around 1000 N/mm$^2$ = 1000 MPa. This means that to shatter a 1cm cube of glass a load of 10t is theoretically required.

However, when a glass panel is placed under a load and allowed to deflect, one face will be under compression but the other will be in tension. Whilst the resistance of glass on the compressed side is high, its resistance to tensile stress is significantly lower and will therefore be the side to eventually fail.

Diagram 1. Deflection: tension and compression

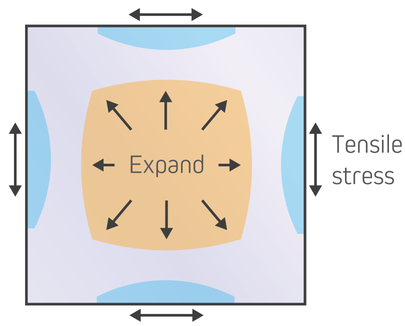



The resistance to breakage for annealed glass on deflection is approximately 40 MPa (N/mm$^2$) and can be closer to 20 MPa at the glass edge. However, this compressive strength increases tremendously when the panel is tempered in the toughening furnace from 120 to 200 MPa.

## What is thermal stress?

Thermal stress is caused by unequal temperatures between the main body and edge of the same glass pane. The main body of glass expands due to heat build-up, causing the edge to resist due its cooler temperature. This creates stress in the glass. Thermal fractures occur at the edge of the glass when the stress that is generated in the main body of glass is greater than the edge strength.

Diagram 2. Tensile stress and expansion




It has been estimated that for every one-degree difference in temperature between the edge and main body of the glass, a stress of approximately 0.62 MPa is generated. Therefore, where temperature differences of 20 to 30°C exist from one part of a panel to another, stress levels of 12 to 19 Mpa can easily form. In annealed glass, introducing levels of stress over these magnitudes will likely cause breakage.

The most common form of heat source that we deal with is the sun. The ability of a material to heat up is directly influenced by the materials ability to absorb heat. We see this in darker materials, as they absorb heat at a much higher rate than lighter materials. In respect to glass, clear products actually have very little ability to absorb radiant heat as it travels through clear glass easily. As an example, touching a clear glass panel in full sun will demonstrate a similar temperature to the ambient air surrounding.

It would be difficult to introduce a temperature profile to cause a thermal break in clear glass through normal atmospheric conditions. Claims of thermal breaks in clear glass are considered unlikely, unless associated with other factors including bad edge damage which has already substantially weakened the glass edge.

As clear glass allows radiant heat to pass straight through, this may not be desirable in an energy efficient building environment. Therefore, to introduce more energy efficient properties, we use tints and/or apply metallic coatings onto glass surfaces. Tints and metals absorb heat and when in combination, they absorb even more.

The greater the absorption, the less amount of solar heat travels into the building. For example, touching a solar absorbing glass type in full sun will have a far greater temperature level to the ambient air around. When the panel is part in shade, this greater temperature level is where the thermal break issues will occur.

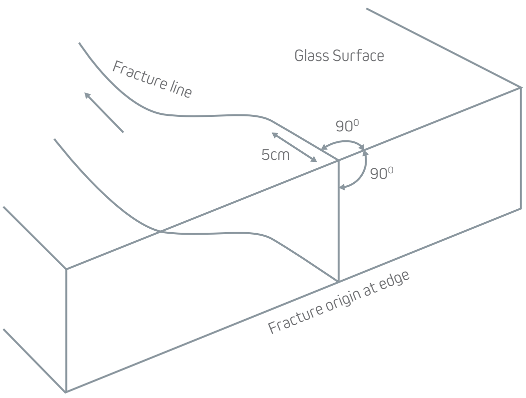
## How to identify a thermal break?

A thermal stress breakage is easily identified and can be distinguished against a breakage caused by impact or other mechanical means.

The start of the crack is always at a 90° angle to both the edge and the face of the glass. Depending on the intensity of the released energy, the crack will travel perpendicular to the edge for approximately 30-50mm before branching out and veering offline.

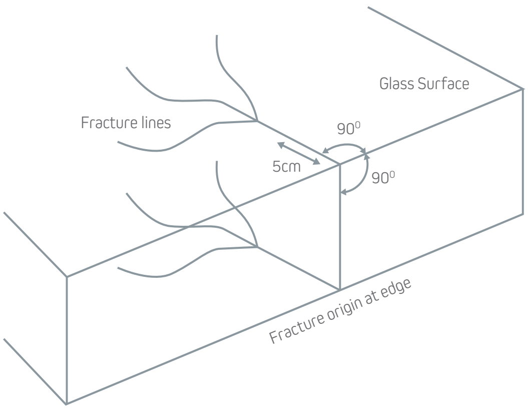
Low stress thermal breakage forms a single 90° crack that then meanders across the glass surface and is often related to a small shell or edge damage.

Diagram 3. Low stress thermal breakage




A high stress thermal breakage can be seen to initially have one crack which then branches into a number of separate cracks a short distance from the origin of the thermal break.

Diagram 4. High stress thermal breakage




## Contributing factors

There are other contributing factors that can cause and increase the risk of thermal breakage. These factors are inclusive of but not limited to the following: glass edge quality, glass size, shading of glass, glass films and tints, orientation, climate and frame factors.

## Glass edge quality

The amount of thermal stress a glass panel can withstand is affected by the quality of the glass edge. The edges that best resist thermal stress are good clean-cut edges. These can be fragile and the ability of maintaining clean cut edges from the initial cutting process all the way through to the final installation is challenging.

In addition, poor quality cut edges can reduce the glass strength by 50% or more. Edge damage caused by manufacturing or installation is the main cause of low stress thermal breakage.

## Glass size

The larger the pane of glass, the greater the main body area has to absorb heat. The differential temperature from the large heated area compared to the narrow band of cooler glass hidden inside the frame may result in thermal breakage.

## External shading of glass

External shading, such as overhead eaves, verandas and trees, can increase differential temperatures across a pane of glass, causing increased risk of thermal breakage.

Shading that covers less than 50% of the glass is an issue, shading that is static is worse.

Partial shading on glass can include the framing itself.

## Internal factors

Internal window treatments, such as blinds and curtains absorb and trap heated air around the glass. In addition, there may be mechanical appliances directing heated or cooled air against a glass surface.

## Glass films and tints

After market applied films can introduce much higher levels of absorbed heat and need careful assessment by the film installer.

Sliding windows can also be an issue as any subtle tints can be subject to greater heat levels when slid in front of another absorbing panel.

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## Orientation and climate

Easterly elevations are often an increased risk due to the glass being cold from the cool evening conditions and then exposed to rapid heating from the rising sun.

Westerly elevations however heat up gradually with the morning sun, becoming acclimatised to ambient temperatures so when the glass is exposed to the afternoon direct sun, they are already relatively warmer.

Climates typically at higher altitudes, where the nights are cooler and days are quite warm are considered to be a higher risk compared to climates that have relatively colder or warmer weather conditions all year round.

## Frame factors

Dark frames absorb more heat and are effective at heating the glass edges hidden inside rebates. Light frames are more likely to reflect heat away and will keep edges relatively cool.

Framing materials, such as aluminium, will absorb and transfer heat to the glass edges as opposed to more insulating materials such as timber and PVC.

## How to reduce or eliminate thermal risk

We can easily eliminate thermal risk by simply increasing the surface tension of the glass panel through either heat strengthening or toughening the panel. However, this often creates further complication and expense when laminated glass properties are a necessary part of the glass design.

Tempered laminates are generally thicker and need to be made to size, increasing the cost substantially.

Smooth ground and polished edges improve resistance to thermal stresses by removing edge faults, this makes the glass panel more robust when it is subject to other processes, transport and glazing.

## Glass options to minimise thermal risk

The following tables are a guide for the assessment of glass options to minimise thermal risk.

Table 1 acts as an approximate guide on how to assess the risk of thermal breakage based on the solar absorption percentage of a specific glass type.

Table 1. Thermal breakage risk

| Glass Type (6mm) | Solar Absorption (%) | Risk of Thermal Breakage |
|---|---|---|
| Clear | 15% | Low |
| Tinted | 30-50% | Medium |
| Pyrolytic coating on clear glass | 25-40% | Low-Medium |
| Pyrolytic coating on tinted float | 40-50% | Medium-High |
| Sputter reflective coating on clear | 60-70% | High |
| Sputter reflective coating on tinted | 70-85% | Very High |

Table 2 acts an approximate guide on how to outline the allowable difference in temperature when comparing glass type and edgework.

Table 2. Allowable temperature difference

| Glass Type | Allowable Temperature Difference ($\Delta t_{adm}$) | | |
|---|---|---|---|
| | As/Cut Arissed | Smooth Ground | Polished |
| Float Glass ($t \leq 12$mm) | 35 | 40 | 45 |
| Laminated Glass | Smallest Value of the Component Panes | | |
| Heat Strengthened Glass | 100 | 100 | 100 |
| Thermally Toughened Glass | 200 | 200 | 200 |

These two tables are based on estimates and should be used as a guide only, please refer to a technical consultant for further information.