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Information on applications

# Glass fracture due to thermal stresses

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# WHY DOES GLASS BREAK?

## Watch out for a source of trouble: incorrect use of glass

The enormously important role that glass plays in everyday life isn't noticed – until that valuable wine glass is dropped or the view through a window pane is impaired by cracks. When a broken glass pane breaks into pieces, it no longer provides protection from wind, weather and intruders. It can no longer provide thermal insulation, and might even present an injury risk.

Glass is elastic, but very brittle: glass breaks without prior plastic flow. Cracks in glass are treacherous because they can occur well after their actual cause.

Modern glass types with innovative features have been optimized to meet the demands placed on them, thanks to professional advice. That applies for the safety standard as well as for the functions of thermal insulation, sound insulation and solar control.

# THE MECHANISM THAT TRIGGER
## THERMAL GLASS FRACTURE

The strength of glass is not determined solely by its chemical makeup and molecular structure: internal stresses caused by manufacturing processes, as well as minor glass defects such as cracks and occlusions, reduce its fracture strength.

Glass has a very high compressive strength of 700 – 900 N/mm² depending on its composition. That corresponds to the mechanical tension arising if a person weighing about 70 – 90 kg were to stand on one square millimeter of area (or 7 – 9 tonnes on one square centimeter).

Glass is very resistant to loads causing compressive stresses, but not to those creating tensile stresses. The tensile strength of glass is only about a tenth of its compressive strength.

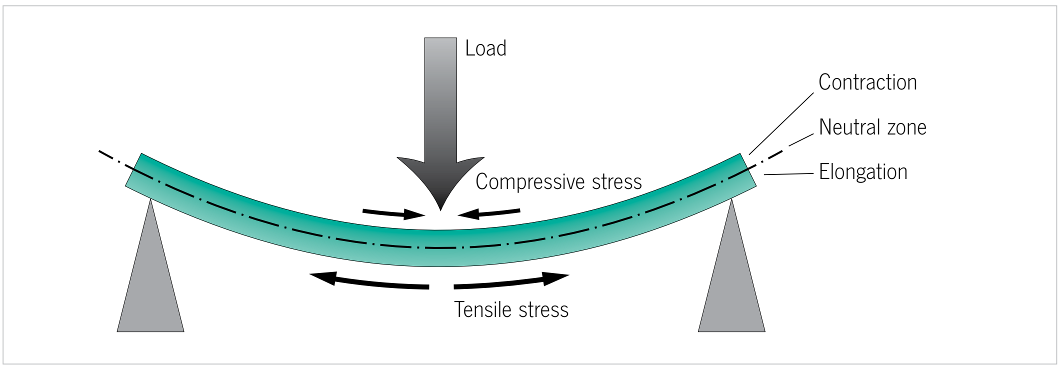
However, compressive-only loads are encountered only very rarely in glass. Whenever a pane is bent, it always generates a combination of tensile and compressive stresses. Glass breaks whenever its tensile strength is exceeded due to load on it.

Heat-strengthened glass and toughened safety glass have higher tensile strengths than float glass. The load capacity of laminated safety glass depends on the type of glass it was made from. Thanks to its film covering, laminated safety glass holds the fragments together even after a fracture. By contrast, the wire embedded in wired glass weakens the homogeneous cross-section of the glass and reduces its strength in a number of ways.

The weakest zone of a glass pane is usually the glass edge: most microdefects arise here due to the cutting, snapping and finishing of the glass. The quality of the edge finish is crucial for the bending tensile strength: the poorer the edge quality, the weaker the glass. A splintered cut edge with heavy indentations and flaking, as well as damage to the edge incurred in transit, can drastically reduce the loading capacity of a pane. By contrast, finishing the edge by sanding or polishing increases its load capacity.

! The tensile strength at the edge is crucial for the glass fracture risk.

The fact that glass brittle-fractures is also deliberately exploited when glass is cut to size: scoring with a glass cutter ensures that its surface is weakened in a controlled way, allowing it to then be subjected to a tensile stress until it breaks along the predetermined line.




When a glass pane is bent, its upper side is contracted (compression) and its underside is elongated (tension).

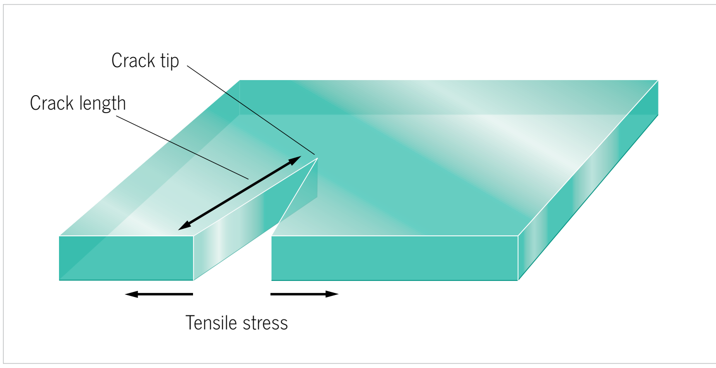
## Fracture mechanics

In a homogeneous material, the tensile stresses spread evenly over its cross-section. However, at indentations, cracks and defects they result in complex stress structures with the highest stresses at the crack tips. When sufficient energy is applied by mechanical or thermal stresses, a crack grows in size.

A tough material can dissipate applied energy by plastic deformation at the crack tip. A crack in it therefore only continues to expand when there a great deal of energy is applied. Glass does not however have internal "crush zones" like this: as a brittle material, it only has a low fracture toughness.

The longer a micro-crack is, the higher the tension at its tip and the lower the tensile strength of the material. In short: the longest crack determines the strength. If the critical stress intensity is exceeded by the load, the result is unstable crack growth in the glass.

After a slow start characterized by a smooth fracture area, a fracture attains a constant maximum speed typical for each glass type and recognizable by a roughened fracture surface. Together with further phenomena at the fracture surfaces (Wallner lines, radial fractures), this can provide clues as to the location of the fracture starting point, the magnitude of the stress initiating the fracture and also the direction of the fracture by a microscopic analysis. Cracks with particularly high fracture stress can split at the cold-hot interface.




Due to tensile stress, a crack can open and spread rapidly when the critical stress intensity at the tip is exceeded.

## Mechanical and thermal properties of different glass types

| Property | Unit | Float glass | Heat-strengthened glass | Toughened safety glass |
|---|---|---|---|---|
| Bending strength* | N/mm² | 45 | 70 | 120 |
| Compressive strength | N/mm² | 700 – 900 | 700 – 900 | 700 – 900 |
| Resistance to changing temperatures | K | 40 | 100 | 150 |
| Finishing after manufacture | | Yes | No | No |
| Fracture behaviour | | Radial incipient cracks, large fragments | Radial incipient cracks, smaller pieces | Reticulate cracks, blunt-edged cullet |

*For structural verification for the dimensioning of glass panes, the values of the standards relevant for the required application apply!

# THE CAUSES – THERMAL STRESSES IN A GLASS PANE

Heavy and uneven heating up (partial shading) can lead to high stresses in the glass and in extreme cases trigger a so-called thermal shock, i.e. a glass fracture as a result of thermal overloading. In innovative construction, stresses are frequently underestimated:

- In the case of glass types with higher demands on design and function
- In complex structures or with special geometries or designs (e.g. edge length less than 60 cm and unfavourable side ratio).

The selection of glass products must be adapted to the respective load situation. Thermal stresses must be considered as well as snow, wind and climate loads.

All parties concerned should already be informed during the planning phase of special features, so that they can detect thermal stresses at an early stage and prevent overstressing by an appropriate selection of the glass products and thicknesses.

## Planning and installation

If the temperature distribution is nonhomogeneous, thermally induced stresses will occur in a material. A glass surface heated in some areas by sunlight or other heat sources will expand. This subjects the unheated and cold areas to tensile stress. If the failure-relevant tensile strength is exceeded, a fracture will follow. The temperature change resistance or thermal shock resistance indicates which temperature difference a material can still withstand without being damaged. In glass, a thermally induced fracture always originates from the edge at a right angle, because it is there that the tensile strength is lowest.

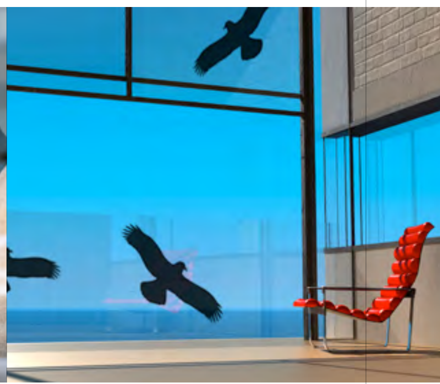
The edge of a glass pane is always in shade because of its installation in a frame. With sudden incident sunlight on the cold outer pane of a window during winter, the glass surface is rapidly heated by absorption of the sun's rays. But the edge remains cold: this causes tensile stresses in the concealed edge area. Recent studies have shown that the depth of the glazing channel does not play a major role here (ift Rosenheim, research project HIWIN, 2003): a deeper glass channel in conjunction with highly thermally insulating frames does not lead to a significantly higher glass fracture risk when compared with systems using a standard glass channel of about 15 mm. The rule is however that the bigger the glass pane, the higher these thermally induced edge stresses can become. Nor is the type of spacer used crucial for the glass facture risk. Differing temperatures within a glass pane also occur however due to sudden partial shading (cast shadow).

In triple insulating glass, only the two outer panes (items 2 and 5) should have a coating where possible. If the middle pane has a thermal insulation coating, it cannot pass on absorbed heat by radiation, hence it heats up considerably. If the temperature difference between the middle and the edge is too high – and that in combination with a poor edge finish – then the maximum permissible edge tensile stress is quickly exceeded. The result is a thermal fracture of the middle pane – and the poorer its edge, the faster the fracture. The use of toughened safety glass increases the temperature change resistance several times over.




## Covering and painting of glass

If films or paints are retrospectively applied to glass panes, the result is that they heat up to a differing degree when exposed to direct sunlight. Dark and highly absorbing materials are particularly critical, as the temperature differences can increase the glass fracture risk. Subsequently applied solar control films can also have unwelcome consequences.

## Partial shading

If one part of the glass pane is in shade while the other part is exposed to strong sunlight, the thermal load is greater. Uneven heating up can trigger thermal stress inside the glass. Recommendation: partial shading can be prevented at least to some extent by external blinds or shutters.

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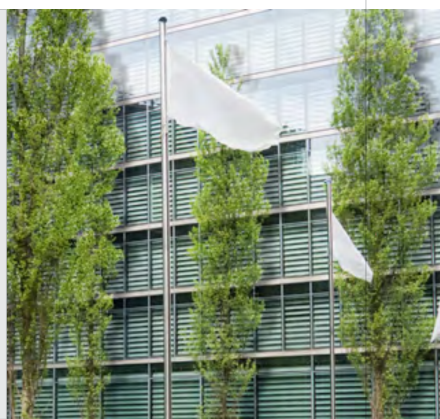
If it is already known before an glazing is designed that partial shading will result in heavy thermal stresses on the glass involved, it is recommended that toughened safety glass be used to reduce the fracture risk in individual cases.



## Heat build-up

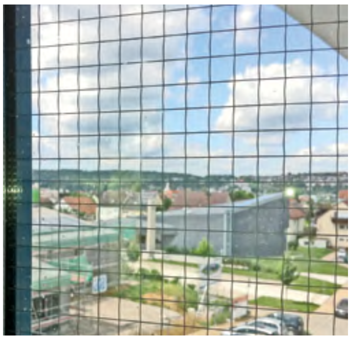
Subsequent provision of an inside shade system creates thermal stress for the glass. It is important here to ensure sufficient ventilation or a sufficient clearance between the glass and the solar control system. Radiators or light fittings close to the glass also cause thermal stresses, so sufficient clearance must be assured here too. In the case of glazing close to the floor, heat can build up due to items of furniture placed close to it. In case of any doubt, these situations should be avoided.

## Sliding doors and windows

Heating up can also result from glass units being slid in front of one another. When the glass units are slid so that they completely overlap, the resultant heat is considerable. This heat cannot escape: do not slide glazed elements completely in front of one another.

## Glass types with increased absorption or wire insert

Coloured glass and glass with absorbent coatings are also subject to higher thermal stresses. Glass with wire insert is more critical in its behaviour, as glass and metal have different thermal expansion values.



## Cleaning

Very hot water or steam should not be used for cleaning. Since a precise “pain threshold” for the glass is not certain, it is recommended that the glass be cleaned without any thermal stress.

Sources: VFF Technical Guide V.02 –
Thermal stress on glass in windows and facades

## Thermal and mechanical stresses during manufacture, movement, heating

Deformations during movement of a pane, elongation, bending and twisting cause stresses in it. However, mechanical stresses might also be generated by temperature changes in the glass even without external forces being applied. Glass breaks if these stresses exceed its tensile strength.

The tensile strength of glass is not always the same: micro-defects or damage to the glass edge can drastically reduce its tensile strength. There are many causes of glass fractures, and not all of them can be immediately identified from the fracture pattern. Whether a pane cracked all the way through has failed due to thermal or mechanical stress cannot be ascertained until it has been more precisely analysed. In unclear cases, an expert should be consulted to study the fracture pattern and the shape and size of the fragments, and then draw the correct conclusions about the stresses that caused the fracture.
SANCO's applications-related information and glazing guidelines must be followed during manufacture, movement and installation.

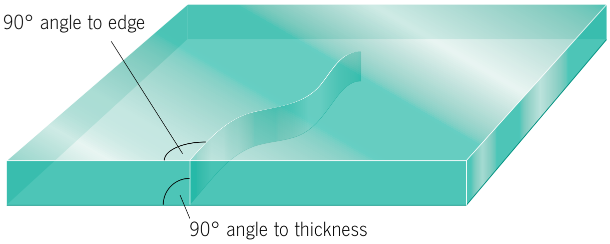
## Causes and examples of thermal glass fracture

| Time of fracture | Type of stress | Examples |
|---|---|---|
| During handling and transport | Direct sunlight | - Non- (or transparently) covered large glass packages<br>- Non- (or transparently) covered thick glass packages<br>- Non- (or transparently) covered thermally insulating or solar control insulating glass in stack<br>- Transport straps not undone for storage |
| In installed state | Partial shading, cast shadows | - Projecting roofs<br>- Window reveal<br>- Awnings or roller shutters<br>- Trees and shrubs<br>- Objects outdoors in front of window<br>- Neighbouring building |
| | Heat build-up | - Internal solar control with insufficient clearance<br>- Heavy curtains close to the inner pane<br>- Sliding doors and windows overlapping and in sunlight |
| | Increased heat absorption of sunlight | - Painting or covering of glass panes, especially if dark colours are used<br>- Partial covering on the room side by inside blind directly at the pane, or by posters, signs, large plant leaves directly on the pane<br>- Dark objects directly behind the pane, such as chairs/sofas, briefcases, suitcases, pianos etc.<br>- Thermal insulation coating for triple insulating glass on the middle pane without extra precautions<br>- Subsequent provision of solar control film products on glass |
| | Local heating up by heat sources | - Hot air fan, barbeque, welding equipment, exhaust pipe, blowlamps, heat-emitting light fittings or similar close to the pane<br>- Radiators too close to the pane<br>- Laying of melted asphalt with insufficient protective cover<br>- Washing glass with very hot water/steam |
| | Installation in cavity | - Increased heat absorption by roller blinds, dark bars or electric operators for shade systems |

## Mechanical causes and examples for glass fracture

| Time of fracture | Type of stress | Examples |
|---|---|---|
| During handling and transport | Mechanical point load | - Knock/impact on edge or corner when setting down on a hard surface<br>- Edge impact with hard object or knocking against it<br>- Rotating/tilting of pane on a corner contacting the ground<br>- Incorrect handling on transport racks<br>- Small stones between glass panes |
| | Mechanical surface load | - Altitude differences too high when transporting insulating glass without pressure equalization (in mountains) |
| During installation | Mechanical point load | - Undersized glass blocks<br>- Incorrect handling of block lever<br>- Small stone or metal particle between edge and block<br>- Too high contact pressure of glazing bead due to screwed or nailed connection<br>- Hammer blow on glass retaining strip<br>- Other knock or impact effects |
| | Mechanical line load | - Bending of pane<br>- Warping of casement frame |
| In installed state | Mechanical surface load | - Air pressure, temperature and altitude differences too high between production and installation locations<br>- Roof snow avalanche or long-term heavy snow load on overhead glazing<br>- Undersized pane with high wind load (wind gusts) |
| | Mechanical line load | - Incorrect dimensioning of glass relative to frame (length changes not taken into account)<br>- Incorrect dimensioning of glass thickness<br>- Warping or jamming casement frame<br>- Movements in system that are transmitted to the glass pane<br>- Too small cavity when bars are inside<br>- Barred panes produced not plane-parallel but concave |
| | Mechanical point load | - Attack using weapons<br>- Projectile from catapult<br>- Thrown stone or other heavy/hard objects<br>- Hammer blows<br>- Thrown ball<br>- Hailstones<br>- Bird impact<br>- Impact of human body<br>- Spacer points at bar crossovers too hard<br>- Contact by structure or by objects during use (opened window impacting them) |

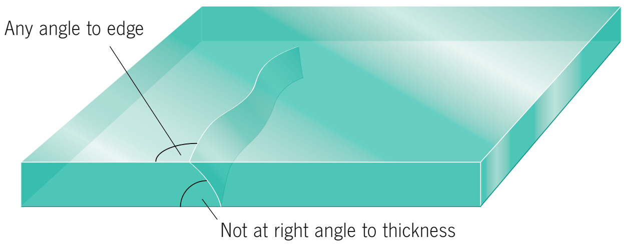



### Characteristics for detecting thermal crack

- Right-angled course from edge into the pane surface
- Right-angled course through the pane thickness

A thermal crack always follows the path of least resistance.
Thermal cracks can frequently change direction.




### Characteristics for detecting mechanical crack

(e.g. due to bending stress)

- Course from edge into the pane surface at right angle or not
- Not at right angle to pane thickness

A bending crack does not always follow the path of least resistance.

# GLASS CAN BE MORE!

ta-werbeagentur.de 04.2020

Mechanical or thermal or even both - there are various trigger mechanisms for cracks in the glass. Problems can be identified and avoided even in thorough planning.

You can get detailed information from your local SANCO partner.

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