THERMAL SAFETY 3A
THE RESISTANCE OF GLASS TO THERMAL STRESS

The resistance to glass to thermal stress is dependent upon its strength (determined by glass type), the quality of the edgework and the presence of any damage to the edges.

In the absence of any formalised harmonized European Norm or British Standard for allowable temperature differences, the Structural Use of Glass [1] can be used as a reference. Additional reference can be made to Norme Française NF DTU 39 P3 [2] and the draft standard under development by the European Committee for Standardisation.

STRESS GENERATED

The amount of stress (σ_{th}) generated by a temperature differential between the centre and the edge (ΔT) is related to the coefficient of thermal expansion (α) and the Young's modulus (E), by the equation;

$$\sigma_{th} = \alpha \cdot E \cdot \Delta T$$

For glass, this will typically result in a stress of 0.63 MPa per 1ºC temperature difference between the centre and edge of the glass. In order to be considered thermally safe, the thermal stress must be less than the strength of the glass under assessment.

EDGEWORK

As the stresses generated by thermal gradients will most typically lead to failure at the edge of the glass, good quality edgework is essential in reducing the risk of thermal failure. Any fracture or chip can act as a focal point for stress, and as such be the origin for thermally induced fractures.

As a minimum, glass should have a good clean-cut edge. A good quality arrissed edge is typically considered to be as good as clean as-cut, however, they will tend to be less susceptible to damage during handling and installation as the corners are, to an extent, removed. For thicker glasses and laminated glasses, a minimal amount of feathering is considered acceptable but not preferable. No venting or shelling of the edges should be present.

Smooth ground and polished edges increase the resistance to thermal stress further still, by removing faults such as feathering.

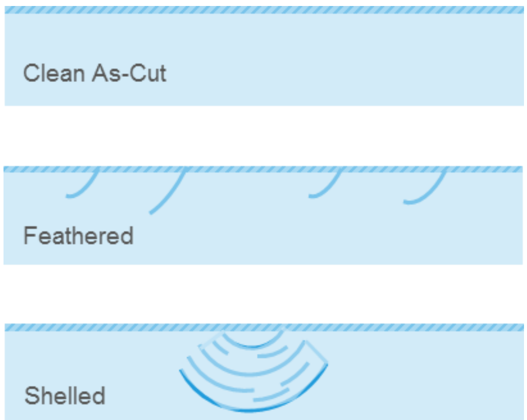

Figure 1 - Illustration of Edgework

For thermally toughened and heat strengthened glass, edges would be arrissed as a minimum. Due to the stresses imparted to the glass during processing, polished or ground edges are no better than arrissed when resistance to thermal fracture is considered.

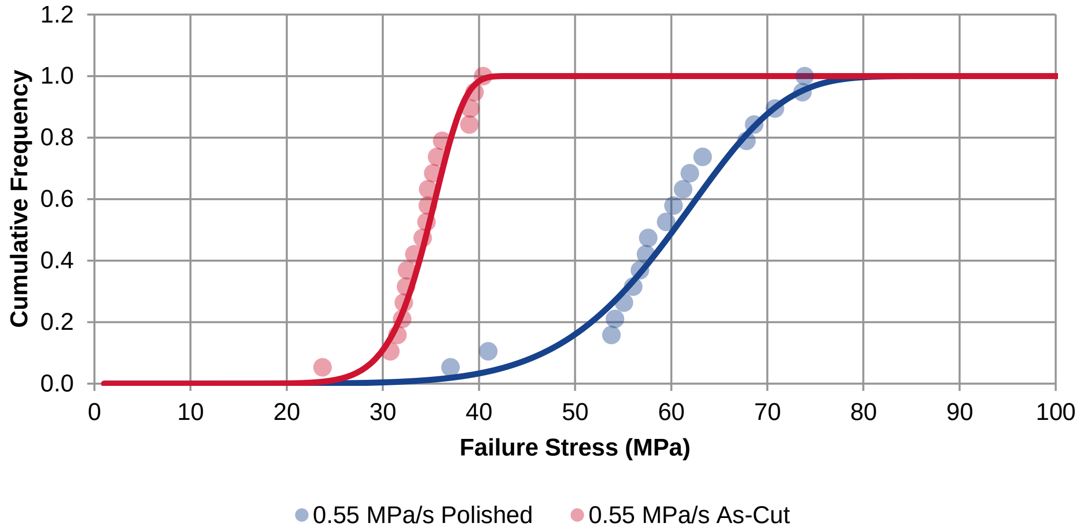

Figure 2 - Measured Edge Failure Stress Based on Edgework

Experimental data, as shown above, illustrates the variability in edge strength when as-cut and polished glass is tested [3]. Weibull distributions can be fitted in order to allow a statistical fit of edge strength distribution to be estimated. For the above example data, if an allowable temperature difference of 35ºC were considered for as-cut edgework, this would correspond to a permissible stress of approximately 22 N/mm², with a failure probability, from the Weibull distribution, of approximately 0.2%.

For polished edges, if an allowable temperature difference of 45ºC were considered for as-cut edgework, this would correspond to a permissible stress of approximately 28 N/mm², with a failure probability, from the Weibull distribution, of, as with as-cut, approximately 0.2%.

ALLOWABLE TEMPERATURE DIFFERENCE (IABSE/DRAFT EN)

The below allowable temperature differences are provided within Structural Use of Glass and the draft European Standard, which are shown below.

Table 1 - IStructE Permissible Temperature Differences

Glass Type	Allowable Temperature Difference, Δt_{adm}		
	As-Cut/ Arrissed	Smooth Ground	Polished
Float Glass (t ≤ 12 mm)	35	40	45
Float Glass (15 mm ≤ t ≤ 19 mm)	30	35	40
Float Glass (t = 25 mm)	26	30	35
Laminated Glass	Smallest Value of the Component Panes		
Patterned Glass	26	26	26
Wired Glass (All Types)	22	22	22
Heat Strengthened Glass (All Types)	100	100	100
Thermally Toughened Glass (All Types)	200	200	200

ALLOWABLE TEMPERATURE DIFFERENCE (NF DTU 39-3)

NF DTU 39 P3 provides several factors depending on framing, edgework, installation and glass type.

FRAME INERTIA

The standard provides a factor (k_t) to modify the level of thermal stress generated dependent upon the thermal inertia of the rebate, as below;

Table 2 – NF DTU 39-3 Rebate Thermal Inertia Factor

Rebate Thermal Inertia	Factor, K_t
Low/Structural Glazing	0.9
Medium	1.0
High	1.1

EDGEWORK

NF DTU 39 Part 3 provides factors (k_v) to modify the permissible stress limit of glass based on the edgework, applicable only to annealed glass types.

Table 3 – NF DTU 39-3 Edgework and Glass Type Factor

Glass Type		Edgework		
		Saw Cut	As-Cut/ Arrissed	Ground/ Polished
Monolithic		---	1.00	1.20
Symmetrical Laminate	(t ≥ 4mm)	0.75	1.00	1.20
	(t ≤ 3mm)	---	0.75	1.00
Asymmetrical Laminate		0.70	0.75	1.00
Wired		---	0.80	---
Patterned		---	1.00	1.00

A laminated glass is considered symmetrical if the difference between pane nominal thickness (t) is less than or equal to 2 mm ($t \leq 2$ mm).

GLASS TYPES

The allowable working stresses (σ_{vm}) for glass types are provided by NF DTU 39 Part 3, and are based on the stresses provided in the relevant manufacturing standards, to which safety factors are applied.

Table 4 – NF DTU 39-3 Permissible Glass Edge Stress

Glass Type		Allowable Stress (MPa)
Annealed		20
Wired Glass		16
Strengthened		35
Toughened		50
Enamelled Toughened		35
Patterned Glass	Annealed	18
	Toughened	40
	Enamelled Toughened	30
	Wired	16

INCLINATION

Glazing installed at angles will be subjected to its own weight, as well as any thermally induced stresses. This is factored (k_a) into the glass strength by NF DTU 39 P3, and is also dependent on the level of edge support.

Table 5 – NF DTU 39-3 Edge Support Factor

Angle from Horizontal, β	Fully Supported	Partially Supported
β≥60	1.00	0.80
30≤β<60	0.90	0.65
β<30	0.80	0.50

Glazing at a steeper angle, will to an extent already be pre-stressed by its own weight. The closer the pane is to horizontal, the greater the influence of self-weight.

ALLOWABLE TEMPERATURE DIFFERENCE

Based on the properties of the glass and the various factors, the allowable temperature difference for the glass types (ΔT_{adm}) can be calculated based on the following equation;

$$\Delta T_{adm} = \frac{k_v \cdot k_a \cdot \sigma_{vm}}{k_t \cdot E \cdot \alpha}$$

Therefore, for a low thermal inertia rebate, and glazing above 60º from horizontal, the following safe temperature differences apply;

Table 6 – NF DTU 39-3 Permissible Temperature Difference

Glass Type		Allowable Temperature Difference, Δt_{adm}		
		Saw Cut	As-Cut/ Arrissed	Smooth Ground/ Polished
Float Glass		---	35	42
Symmetrical Laminate	(t ≥ 4mm)	26	35	42
	(t ≤ 3mm)	---	26	35
Asymmetrical Laminate		25	26	35
Patterned Glass		---	32	32
Wired Glass (All Types)		---	23	23
Heat Strengthened Glass		---	150	150
Thermally Toughened Glass	Float	---	215	215
	Patterned	---	170	170
	Enamelled	---	150	150
	Patterned Enamelled	---	130	130

REFERENCES

[1] M. Haldimann, A. Luible and M. Overend, *Structural Engineering Document 10 - Structural Use of Glass,* IABSE, 2008.

[2] CSTB, *NF DTU 39 P3 - Travaux de vitrerie-miroiterie - Partie 3: Mémento calculs des contraintes thermiques,* CSTB, 2006.

[3] M. Vandebroek, J. Belis, C. Louter and G. Van Tendeloo, “Experimental validation of edge strength model for glass with polished and cut edge finishing,” *Engineering Fracture Mechanics,* vol. 96, pp. 480-489, 2012.

SAINT-GOBAIN