# Heat Treatment of Glass

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## Structure of Glass

Glass is amorphous:

- No long-range atomic order
- No traditional phase transformation
- Mechanical properties strongly dependent on thermal history

Glass is brittle and weak in tension.

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## Glass Transition Temperature (Tg)

At Tg:

- Glass transitions from rigid solid to viscoelastic state
- Atomic mobility increases

Below Tg:

- Structure is “frozen”

Above Tg:

- Stress relaxation possible

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## Annealing of Glass

Purpose:

- Remove residual internal stresses from forming

Process:

- Heat slightly above Tg
- Slow controlled cooling

Residual stress relaxation occurs via viscous flow.

Improper annealing → spontaneous fracture.

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## Tempering of Glass

Thermal tempering process:

1. Heat glass to 600–650°C
2. Rapid air quenching

Surface cools first → contracts → becomes rigid

Core cools later → attempts to contract

Result:

Surface → compressive stress

Core → tensile stress

Residual stress profile:

Compression (surface)

Tension (interior)

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## Strengthening Mechanism

Cracks initiate at surface.

Surface compression suppresses crack opening.

Effective tensile strength increases 4–5 times.

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## Stress Distribution

Residual compressive stress magnitude:

100–200 MPa (typical)

Surface compression depth:

~20–40% of thickness

Failure occurs when internal tensile stress exceeds fracture strength.

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## Heat-Strengthened vs Fully Tempered Glass

Heat-strengthened:

- Lower residual stress
- Larger fragments

Fully tempered:

- Higher residual stress
- Small cube-like fragments
- Safety glass

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## Nickel Sulfide Inclusions

NiS inclusion undergoes phase change:

High-temperature phase → low-temperature phase

Volume expansion → delayed fracture

Important in façade systems.

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## Laminated Glass

Thermal treatment combined with polymer interlayer.

Improves:

- Impact resistance
- Post-fracture integrity

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## Thermal Shock Resistance

Thermal shock resistance depends on:

$$R = \frac{\sigma_f k}{E\alpha}$$

Where:

- k = thermal conductivity
- α = expansion coefficient

Tempered glass has improved thermal shock resistance.

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## Comparison with Steel

Steel:

- Strength from phase transformation.

Glass:

- Strength from residual stress engineering.

Ceramics:

- Strength from densification and flaw control.

Different mechanisms — same thermodynamic control philosophy.

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## Summary

Heat treatment of glass controls:

Temperature → Viscous flow → Stress redistribution → Surface compression → Structural safety.

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