CORNING

Comportement Mécanique du Verre
&
Application Automobile

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Technology Director

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At a glance

50,000+

employees across 40+ countries

75+

manufacturing sites

10

R&D facilities

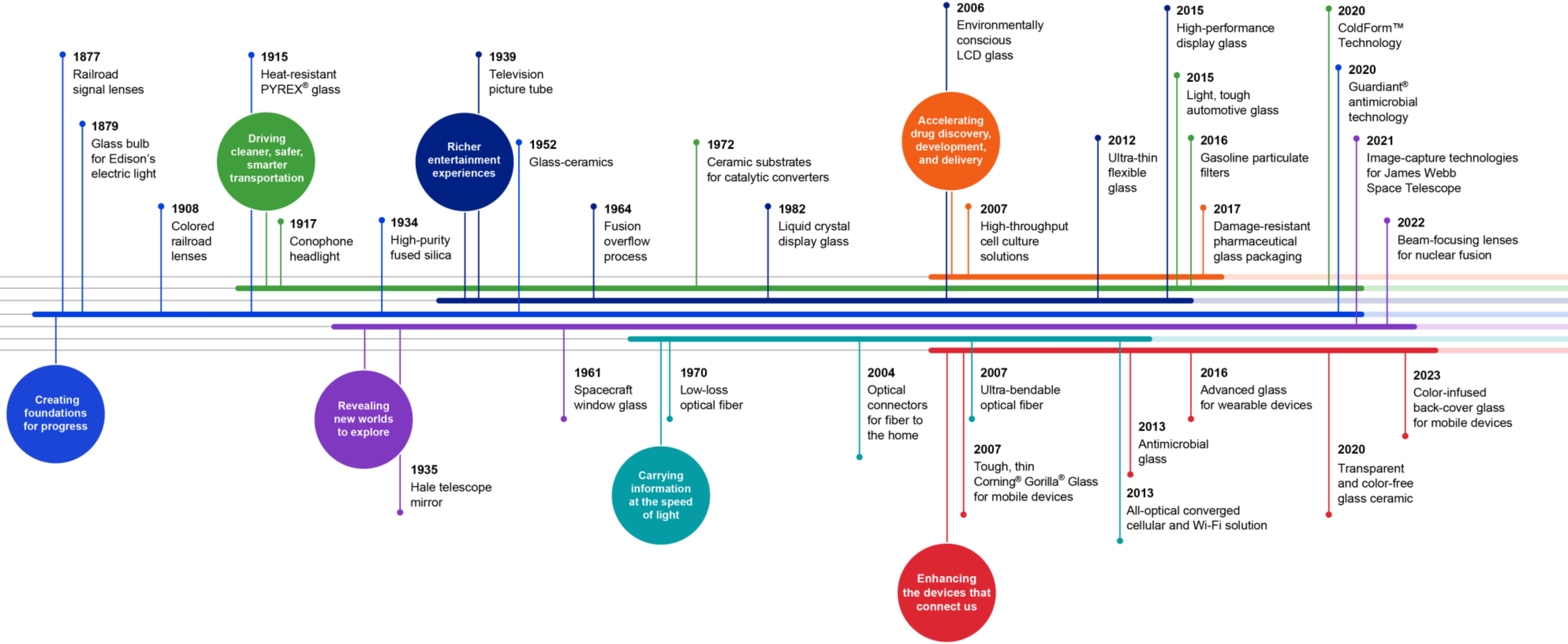
Fortune 500 Ranking:

263

Core Sales 2022:

$14.8 billion

Advancing the way to work, learn, and live for nearly 200 years



Featured on more than

6,000,000,000

devices *worldwide*

Agenda

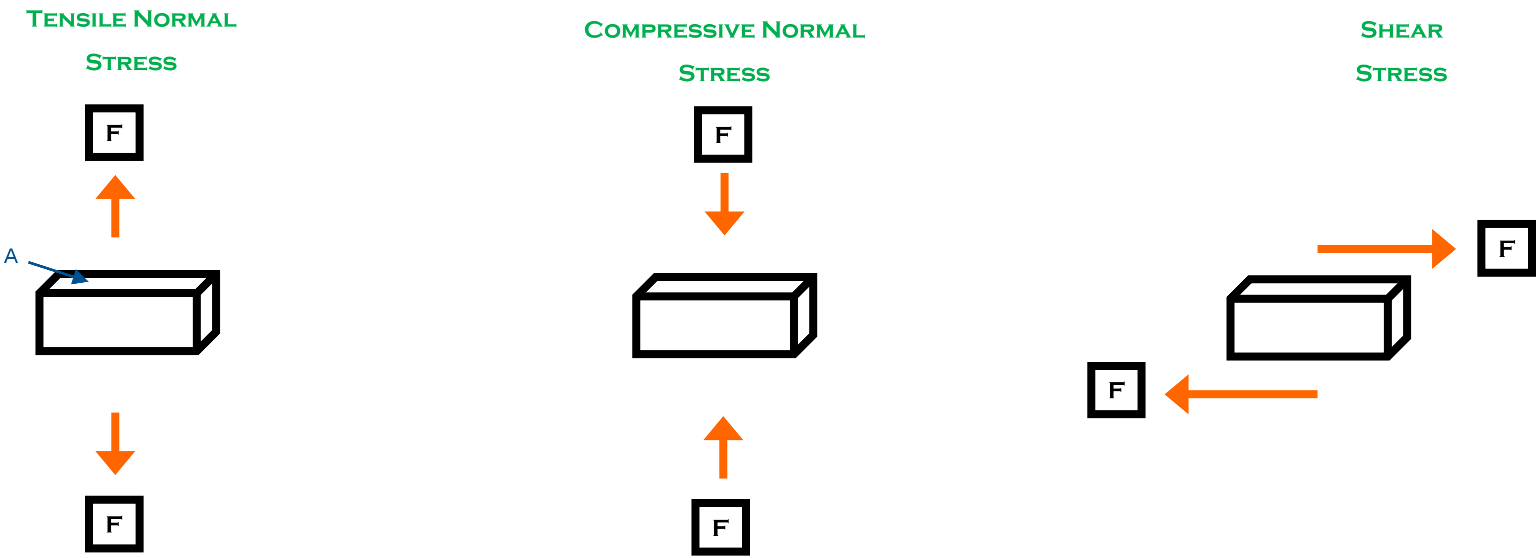
- Stress-Strain Fundamentals
- Glass Strength
- Glass Strength Statistical Behavior
- Glass Strength Measurement
- Glass Fractography
- Glass Strengthening Techniques
- Automotive application example #1: Headform Impact Test & Retained Strength
- Automotive application example #2: 3D ColdForm™ Technology
- Concluding Remarks

Stress-Strain Fundamentals

Fundamentals - Stress

Stress represents an applied force over an area

- Definition: Stress = force/area $\sigma = F/A$
- Units: pound per square inch (psi), or $MN/m^2 = N/mm^2$ (MPa)
- Normal Stresses are caused by the part of the force which is perpendicular to the plane.
- Shear Stresses are caused by the part of the force which is parallel to the plane.



Fundamentals - Strain

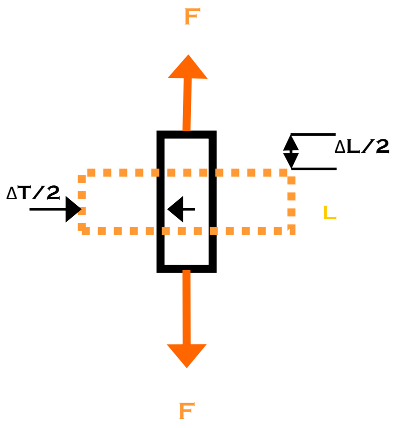
Strain represents deformation in the material resulting from stress

- **Strain**:
  - When a stress is applied to a material, the material changes size.
  - Strain (ε) is the unit change in size (deformation).

$$\varepsilon = \Delta L/L$$ (units: in./in., m/m, or dimensionless)

- **Poisson's Ratio:**
  - The material changes size along the direction of the applied stress (primary strain ε_l) and perpendicular to the applied stress (secondary strain ε_a).
  - The Ratio of secondary strain to the primary strain is called the poisson's ratio (ν):

$$\nu = -(\varepsilon_a/\varepsilon_l) = (\Delta T/T)/(\Delta L/L)$$ (Units: dimensionless)

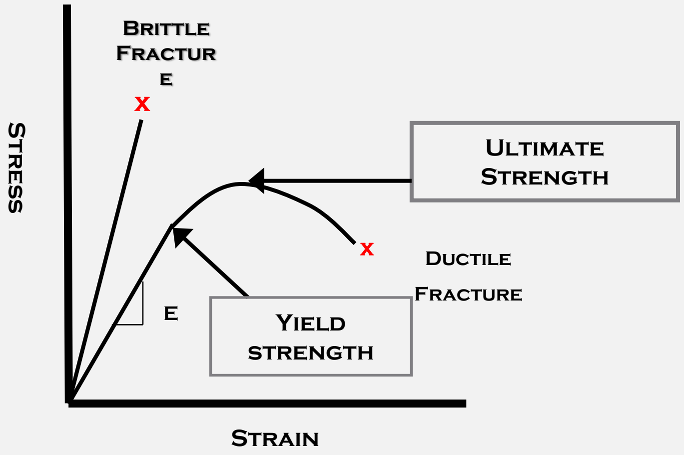


Fundamentals – Stress-Strain Relationship

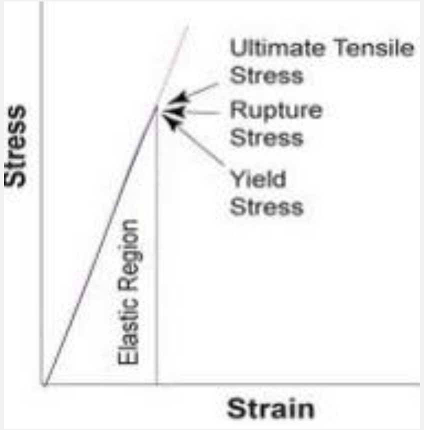
Glass is a linearly elastic material

- For linearly elastic, isotropic & homogeneous materials, "Hooke's law" states that Stress is directly proportional to Strain:
  - Hooke's Law: stress = constant x strain → $\sigma = E\,\varepsilon$; "E" is the material's Modulus of Elasticity or Young's modulus

Stress-strain diagram in general



Stress-strain diagram for glass



- Fractures without warning
- Linear elastic up to fracture, no yielding or stress redistribution
- Fracture stress determined by fracture mechanics
- Fracture is statistical in nature

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Glass Strength

Basics of Glass Strength

How Strong is Glass?????

Strength: The value of applied stress which causes fracture.

Answer: It depends!!!

Basics of Glass Strength

- Strength of glass is essentially an *Extrinsic* property:
  - It is dependent on chemical composition, surface conditions, test environment, test method, etc.
  - In comparison: *Intrinsic* properties are those that are dependent only on chemical composition of the glass. For example, thermal expansion coefficient.

Basics of Glass Strength

Theoretical Strength

- Theoretical Strength is based on stress needed to break atomic bonds of the Si-O-Si tetrahedron.

$$\sigma_F = [(E\ \gamma)/a_o]^{1/2}$$

σ_F = failure stress

E = Young's Modulus

γ = Surface Energy of new surfaces

a_o = lattice spacing of molecules

- For SLS glass is equal to approximately 1 million psi (~7 GPa)!
- Such strengths do not exist in usable commercial glass form!

Basics of Glass Strength
Practical Strength

- Practical, or *extrinsic*, strength of glass (as experienced in daily use) is many orders of magnitude lower

- Dictated by surface imperfections, or flaws, induced by manufacturing and routine handling of glass.

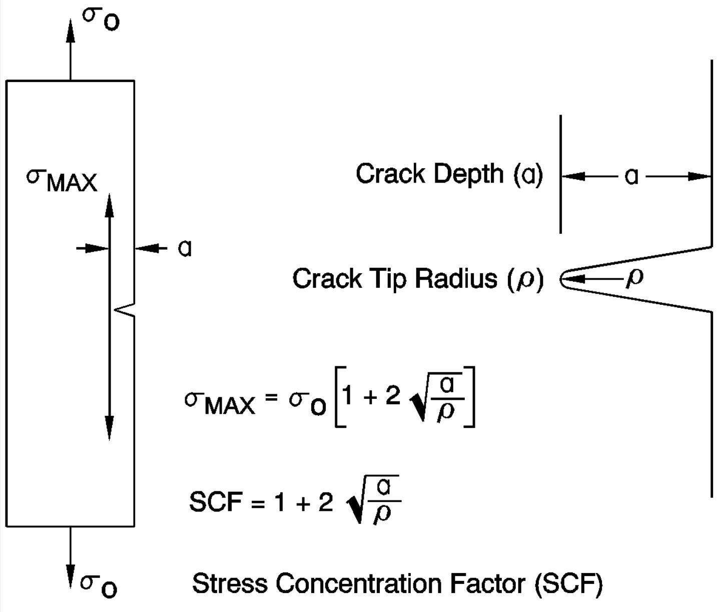
Basics of Glass Strength

Practical Strength – Inglis model

- In brittle materials (ie, ceramics, glass, glass-ceramics), any surface flaw (microcrack or other discontinuity), no matter how small, will act as a *"stress concentrator"* such that tensile stresses at the crack tip will be orders of magnitude higher than the nominal stress corresponding to the applied load.

- If the concentrated local stress at the tip of a critical flaw reaches the bond-strength of the material, the material will fail at a nominal load stress far below its intrinsic strength.

Inglis model



$$\sigma_{MAX} = \sigma_O \left[1 + 2\sqrt{\frac{a}{\rho}}\right]$$

$$SCF = 1 + 2\sqrt{\frac{a}{\rho}}$$

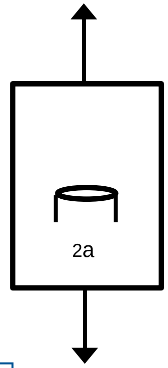
SCF for a hole in glass in uniaxial tensile stress is approximately 3x.

Basics of Glass Strength
Practical Strength – Griffith Model

- Practical strength of glass is much lower due to the stress concentration effect of surface flaws.
- Griffith Model:
  - Thermodynamic (energy balance) model that accounts for stress concentration.

$$\sigma_F = [(2E\,\gamma)/(\pi\, a)]^{½}$$

- E = modulus of elasticity
- γ = (fracture) surface energy
- a = half of crack length



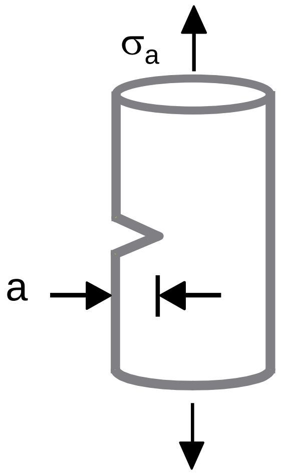
Crack propagates when decrease in stored elastic energy is greater than surface energy of new surfaces created by crack extension.

Fracture mechanics describes the relationship between the stress intensity factor and the applied stress

- Stress intensity factor (K_I)

$$K_I = Y\sigma_a\sqrt{\pi a}$$

Y = Geometry parameter
σ_a = Applied stress
a = Flaw depth



- Fracture occurs when K_I exceeds the fracture toughness K_{IC} we typically measure the strength, σ_c

$$K_{IC} = Y\sigma_c\sqrt{\pi a_c}$$

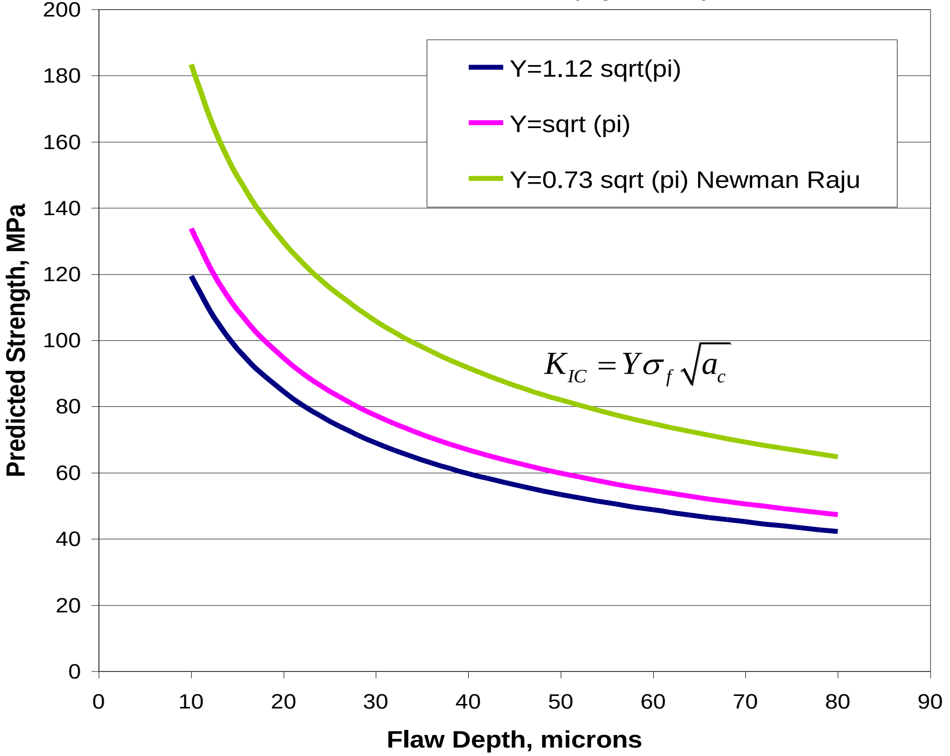
Extrinsic
Intrinsic

$$\sigma_c = \frac{K_{IC}}{Y\sqrt{\pi a_c}}$$

Glass strength decreases with increasing flaw depth

One application is importance of good edge finishing for high strength glass

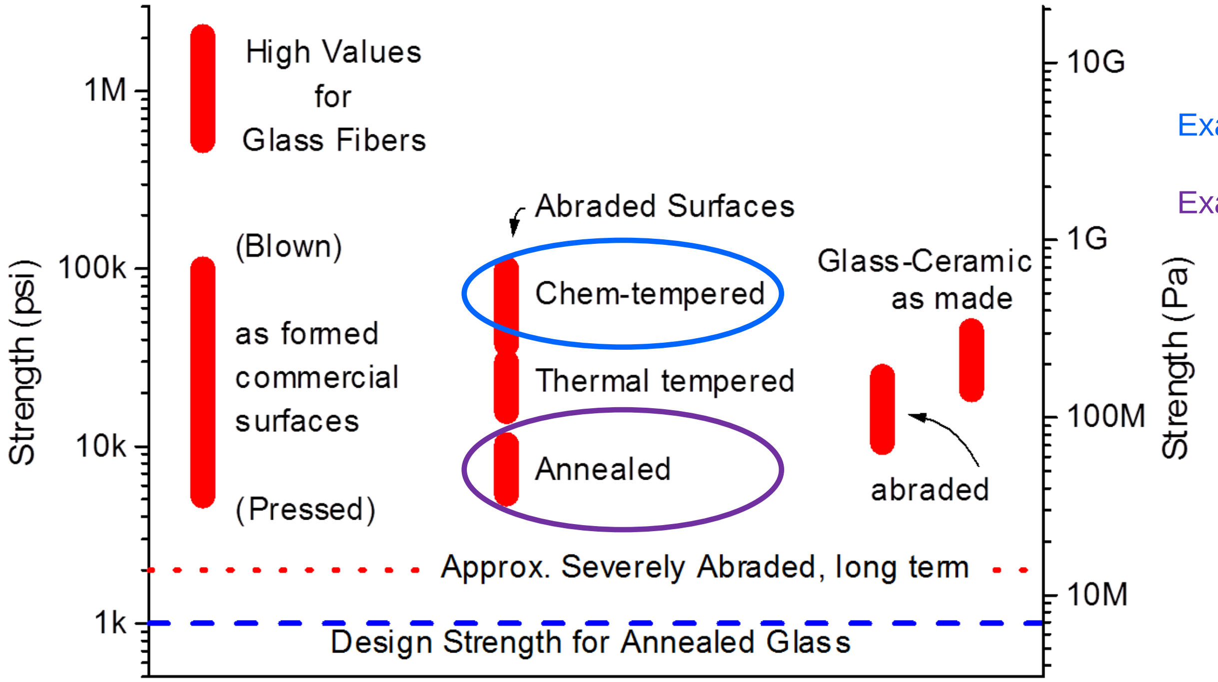
Y = flaw tip geometry factor ~ 1.2 for surface flaws



$$K_{IC} = Y\sigma_f\sqrt{a_c}$$

$$\sigma_f = \frac{K_{IC}}{Y\sqrt{\pi a_c}}$$

Glass strength varies by orders of magnitude upon process, protection and handling conditions



Example: Corning ® Gorilla® Glass

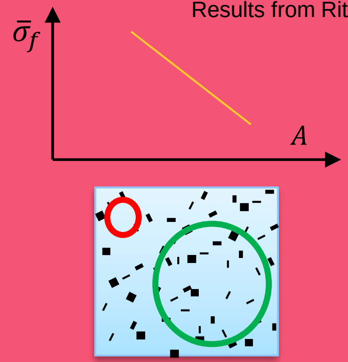
Example: Window Glass

Basics of Glass Strength
Factors affecting strength values

1. Size of Part

1. Effect of size of stressed surface

Results from Ritter:

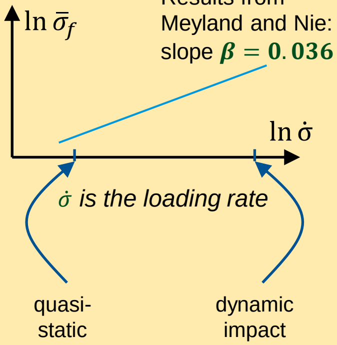


Larger sizes = lower strength

2. Load Rate & Duration

2. Effect of the speed (strain rate)

Results from Meyland and Nie: slope $\boldsymbol{\beta} = \mathbf{0.036}$



Slower load rate = lower strength

3. Environment

3. Effect of temperature & humidity

Higher humidity = lower strength

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Glass Strength Statistical Behavior

Glass Strength Statistical Behavior

- The quantification of strength of glass is statistical in nature, and depends on size of the specimen, surface quality, pH, humidity, temperature, load rate, flaw distribution (size and orientation) etc.

- Fracture occurs when: a sufficiently large applied stress encounters a sufficiently large flaw in the correct orientation with moisture present.

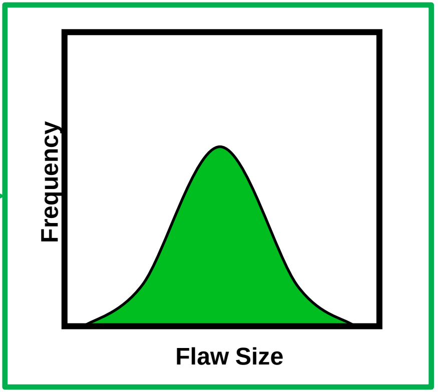
- The question of strength: What is the probability that an applied stress will encounter a sufficiently large flaw in the correct orientation to create failure???

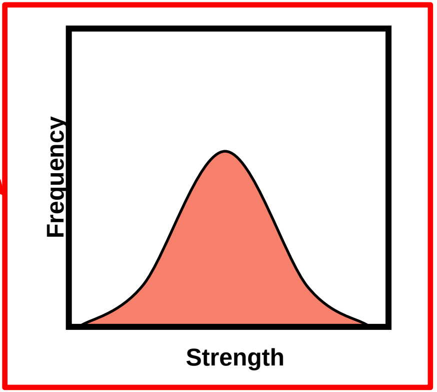
Glass strength has the same distribution as that of flaw sizes

$$K_{IC} = Y\sigma_c\sqrt{\pi a_c}$$

Glass	MPa-m$^{1/2}$	kpsi-in$^{1/2}$
61 % Lead silicate	0.62	0.57
TiO_2 doped silicate	0.70	0.63
Fused silica	0.74	0.67
Soda-lime silicate	0.75	0.68
Borosilicate	0.76	0.69
Aluminosilicate	0.85	0.77
Borosilicate crown	0.86	0.78
LCD - 1737	0.83	0.76

ref: ASTM STP 745





Glass Strength Statistical Behavior well described by Weibull distribution

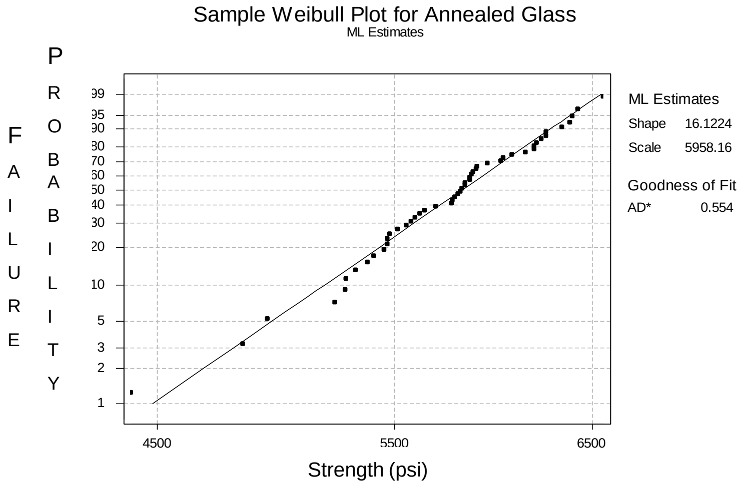
- To project the probability of failure at a given service stress, a Weibull Analysis is used.
- Note that even at the lowest levels of stress, there is still some risk of failure due to the nature of brittle materials.

Glass Strength Statistical Behavior

What is a Weibull Analysis?

- Definition:
  - Analogous to a "weakest link model".
  - Failure probability model which is based on the fact that strength of a brittle material is dictated by randomly distributed flaws and that failure is controlled by the largest, most severely stressed flaw.
- Process:
  - Strength data is gathered on a population of 20 or more samples.
  - Data is then ranked from lowest to highest strength
  - Converted to a failure probability
  - Plotted on special axis (Y-axis is Cumulative Failure Probability & X-axis is Ln strength).
- Outputs:
  - Plot should yield a straight line and from this plot two key parameters are determined:
  - The Weibull Modulus (M) or "Shape": this characterizes the scatter of the strength distribution and is a key component in assessing failure probability.
  - The characteristic strength (σo) or "Scale": this indicates the overall location of the strength distribution (based on the mean of a Gaussian distribution, occurs at the 63.2% probability point).

$$F = 1-\exp\{[-(\sigma/\sigma o)^m]\}$$



F = Failure Probability

m= Weibull Slope or "Shape"

σo = Characteristic Strength or "Scale"

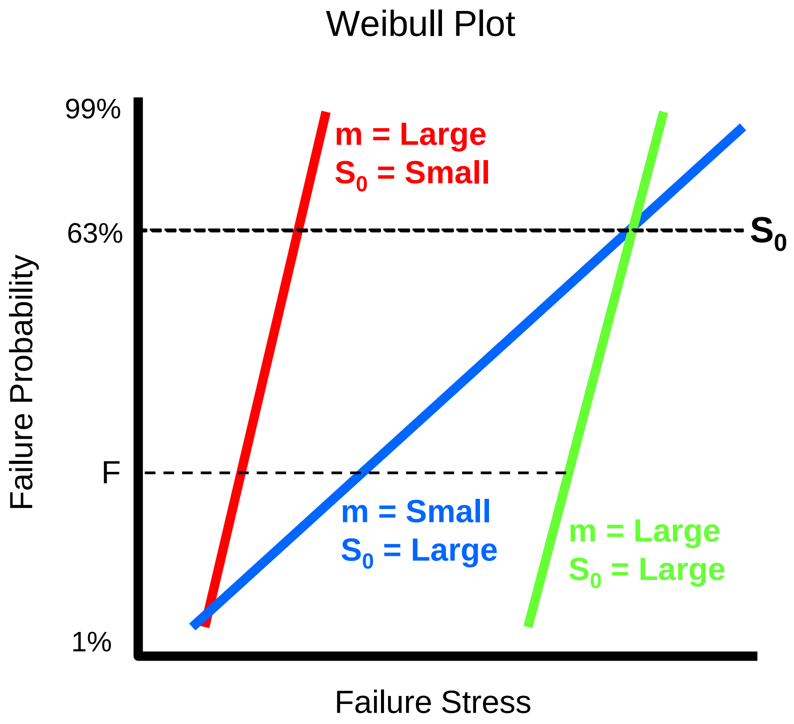
Glass strength is best characterized by the Weibull distribution due to its statistical nature

- Surface flaws from handling-induced damage are the most common
- Strength is primarily determined by the glass object's handling history
- Strength is more likely to go down than up during the life of an object

S_o = characteristic strength

m = Weibull Modulus

- high value = tight distribution
- low value = wide distribution

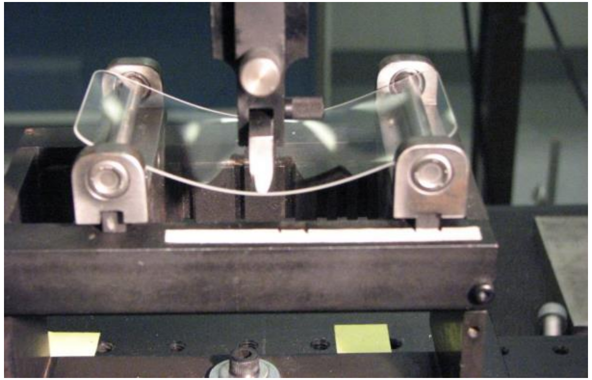


Glass Strength Measurement

Edge Strength Testing

- Adequate edge strength is important in order for parts to survive Shipping, Handling & Decking into the vehicle. Once Parts are decked, parts will typically experience use case and abuse case stresses.

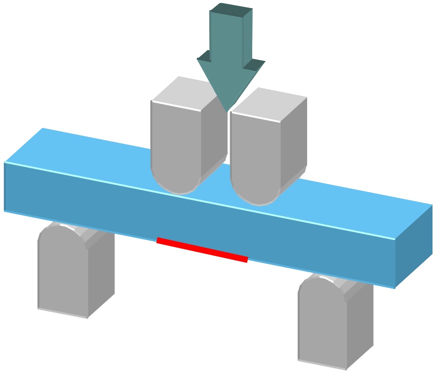
- Edge Strength is measured by uniaxial flexure tests.

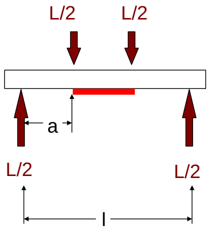


Edge Strength Testing

4-Point Bending effectively tests only 2 bottom edges

- Samples: 50 mm x 100 mm
- Tested in: 4-point Bending
- Support Span: 36 mm
- Load Span: 18 mm
- Load Rate: 5 mm/minute





Discard data with origins outside of load points or not from edge.

- Maximum stress in region between loading points
- Edges are often weaker than surface
- ***Effectively tests only two bottom edges***

- 4-point bending (ASTM C158)

$$\sigma_f = \frac{3La}{bh^2}$$

σ_f = Failure Stress (Modulus of Rupture)

L = Applied Load

a = distance between support and load points

b = width of bar

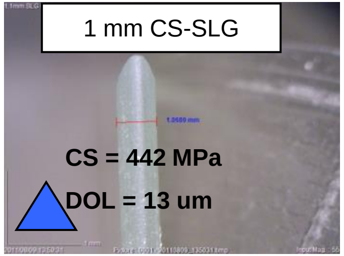
h = thickness

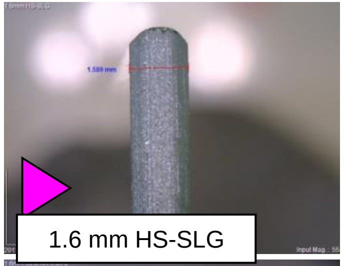
- Assumptions:
  – Elastic
  – Homogeneous
  – Isotropic
  – Small Deflections

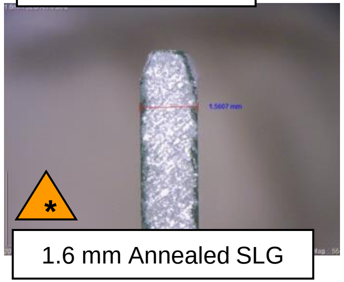
Edge Strength Testing

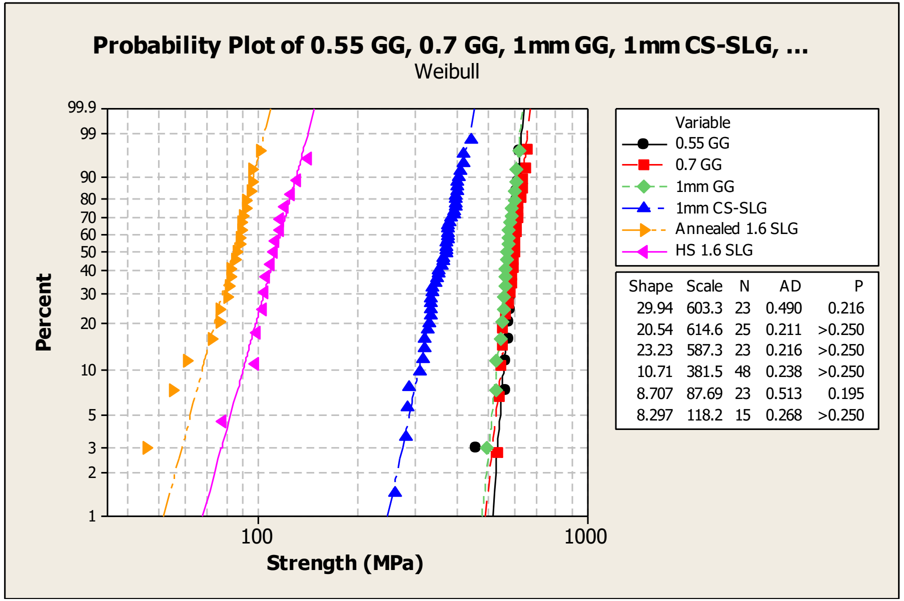
Edge Strength depends also on glass strengthening (CS/DOL values)

SLG

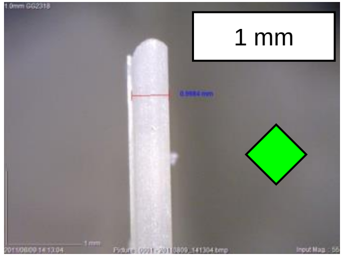


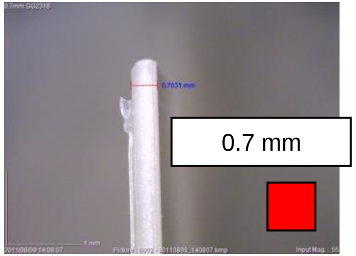


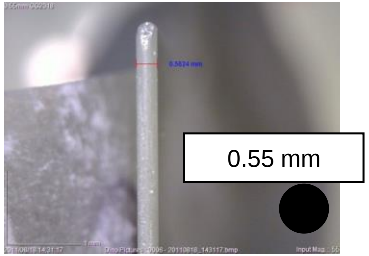




Gorilla Glass

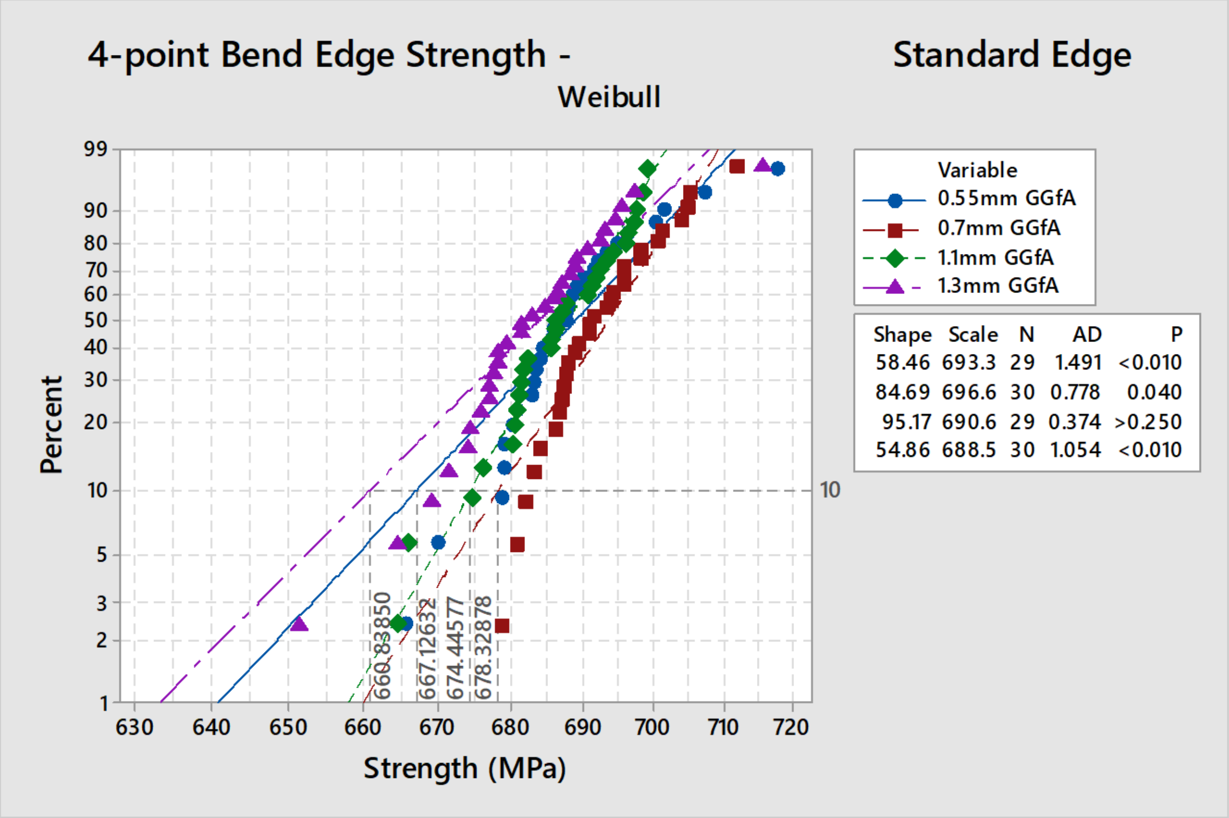






Edge Strength Testing

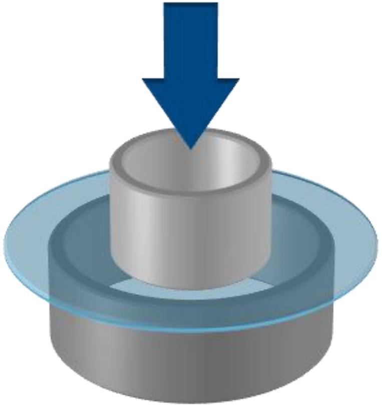
Edge Strength of Gorilla Glass for Auto indicates small impact of glass thickness (2018 Data set)

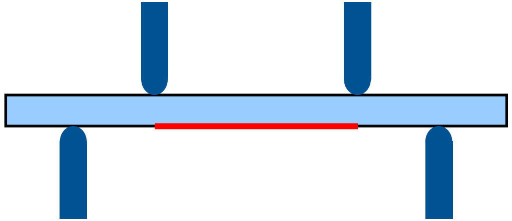


Surface Strength Testing

Ring-on-Ring - measurement of glass surface strength

- Ring-on-Ring test (ASTM C1499)
  - Maximum stress in area defined by inner ring (on other side)
  - Teflon film used between glass and loading rings (friction)
  - ***Tests only bottom surface***
- Limitations: Thin glass (with deflection greater than half thickness at failure) shows significant non-linear effects





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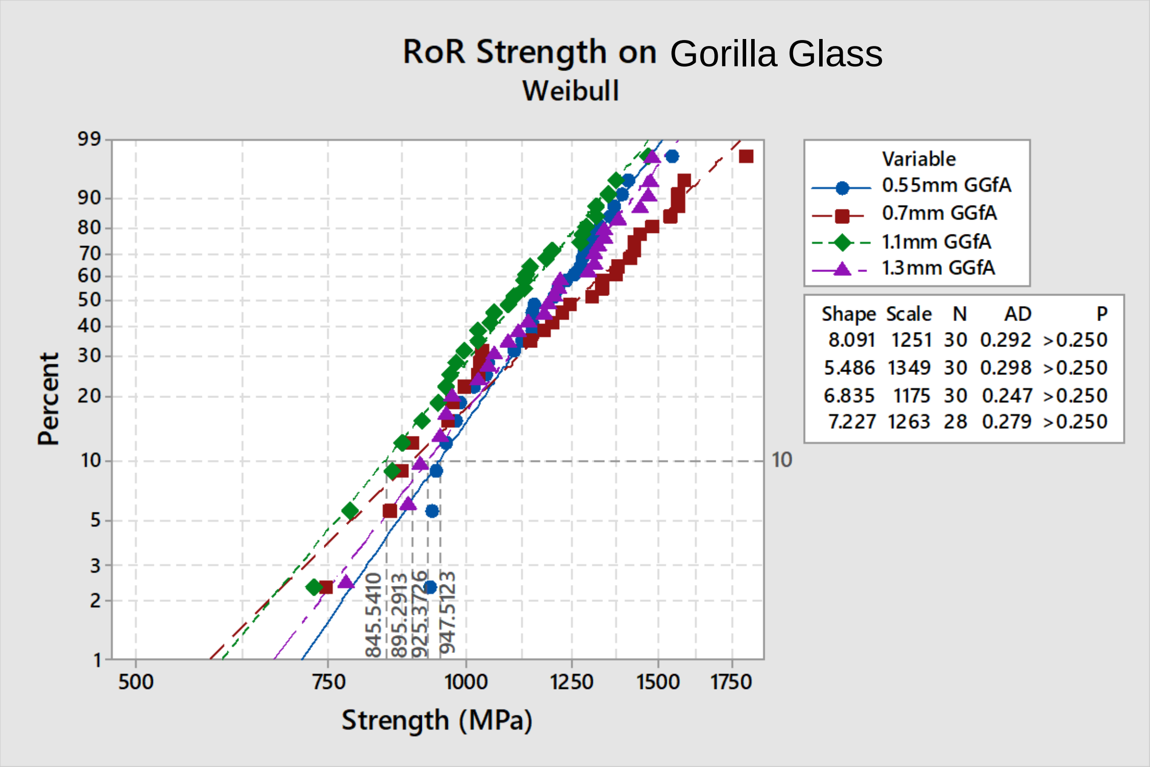
Surface Strength Testing

Surface Strength of Gorilla Glass for Auto indicates small impact of glass thickness (2018 Data set)



Glass Fractography

Fractography is a practical tool to analyze glass failure origins and to estimate failure stress (glass strength)

$$Strength = \sigma_f = \frac{A_m}{\sqrt{R_m}} = \frac{K_{IC}}{\beta\sqrt{a}}$$

A_m = mirror constant for glass (determined experimentally)

R_m = mirror radius

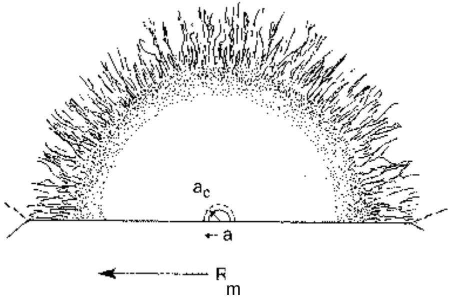
a = flaw depth (measured)

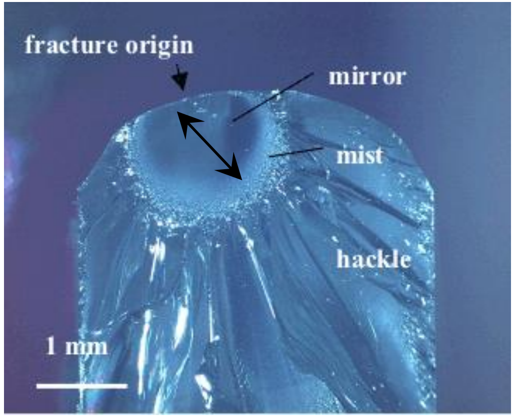
a = $0.1R_m^{0.5}$ (approx.)

For soda lime glass the mirror constant measured at Corning is:

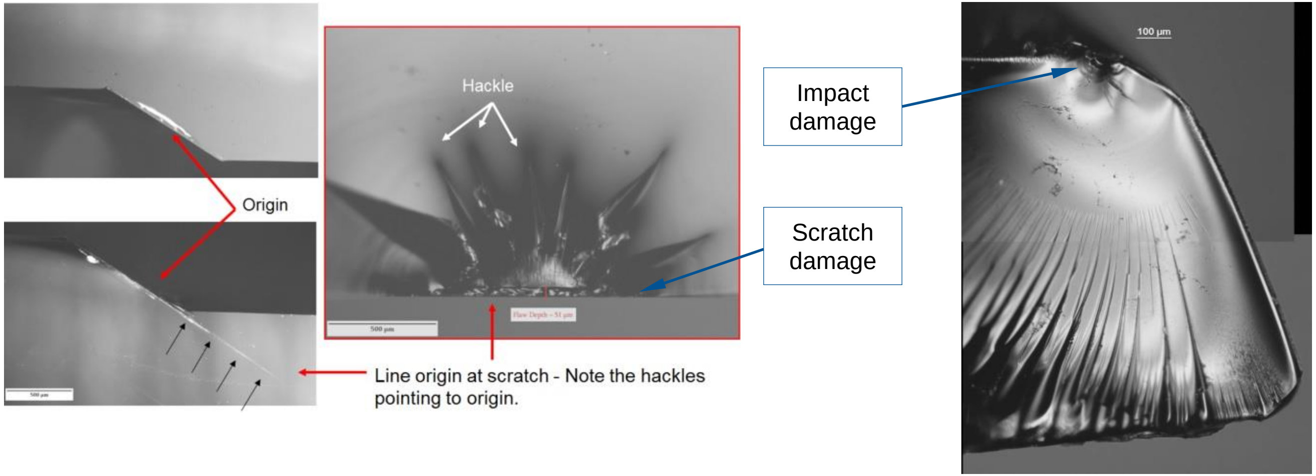
$$A_m = 1.86 MPa\sqrt{m} = 1695 psi\sqrt{in}$$

Best Practice: use mirror constants generated by the individual measuring the mirrors





Fractography is widely used in Corning for use-case study and process/handling damage prevention



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Glass Strengthening Techniques

Glass Strengthening Techniques

The strengthening of glass may thus be considered in three broad areas:

- Raise the intrinsic strength of glass
  - This value is fixed by the strength of the glass former (Si-O-Si) molecular bond. Little room for improvement.

- Prevent or eliminate flaws
  - Protect surface with coatings etc. For most applications coatings are not practical until after the glass is processed into a new shape/form which necessitates handling of glass.
    - Parts in-service get contacted and flaws are introduced.
  - Remove flaws with acid etching

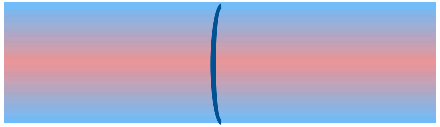
- Counteract the effect of surface flaws by compressively pre-stressing the surface such that growth of these imperfections is impeded, and the strength-reducing effects of the flaws are partially offset.

Annealed Glass

- Annealed glass is cooled slowly so as to reduce the internal stresses.

- This results in a relatively weak glass in terms of load bearing capability, but one that is fairly tolerant to damage.

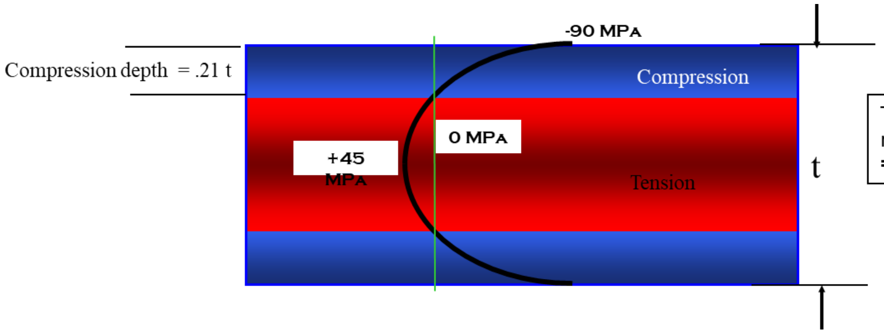
- There is no internal stored energy to make damage propagate.



Very low stress

Thermally Strengthened glass has a depth of compression of 21% of its thickness & magnitude is driven by thickness[2]

<u>Thermal Tempered Strengthened Stress Profile Example</u>



Typical part thickness 2.8 to 6 mm so depth of compression **= 0.588 – 1.260 mm**

Center tension (σ_{CT}) is a function of thickness squared:

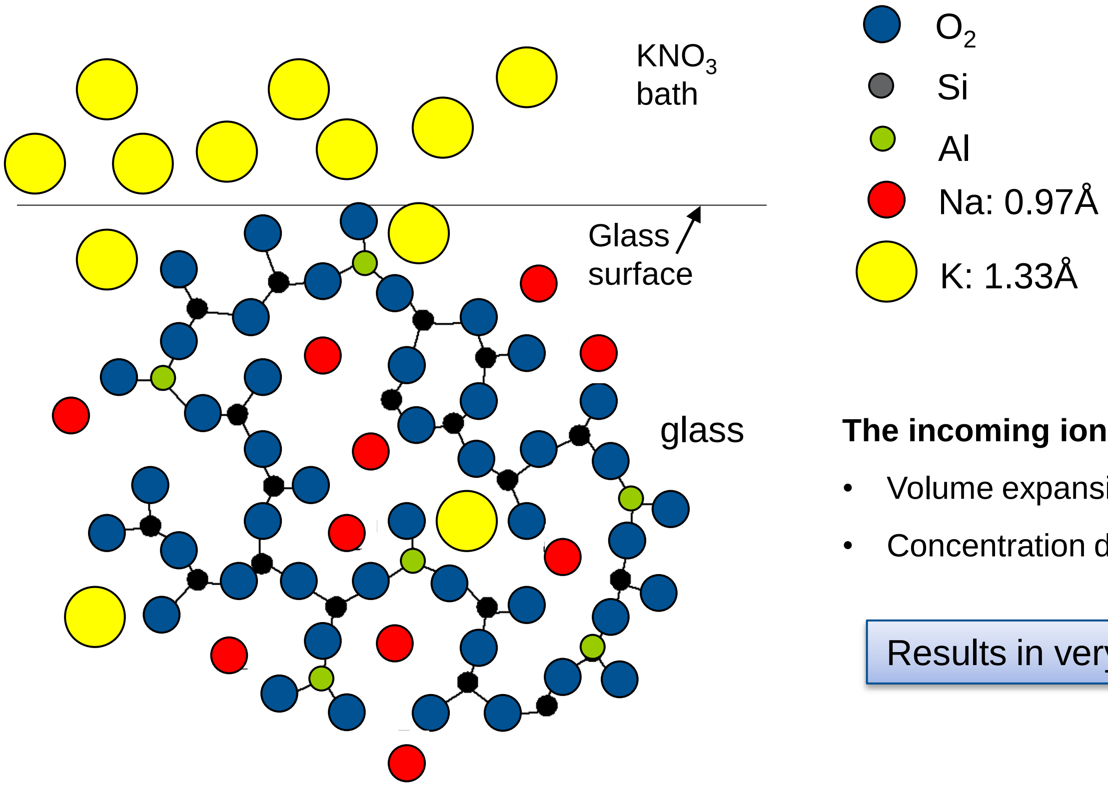
$$\sigma_{CT} = \frac{E * \acute{\alpha} * t^2 * R}{24K * (1-v)}$$

E = Young's modulus
ά = Coef. of thermal expansion in transformation range
R = cooling rate
t = thickness
K = thermal diffusivity of glass
v = Poisson's ratio

Surface compression (σs) = -2* σCT

Chemically strengthened Glass (AKA Ion exchange)

A chemical salt bath is used to exchange small ions for bigger ones

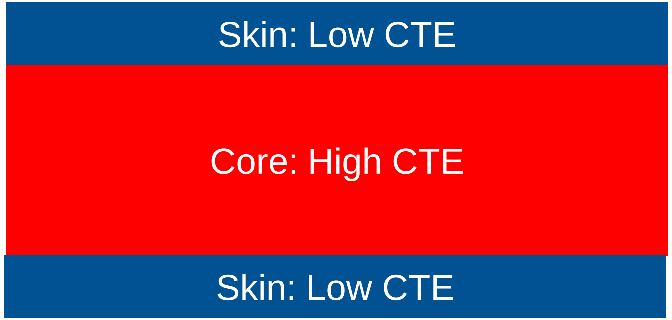


The incoming ion (K^+) and its larger volume produces:

- Volume expansion → compressive stress on the surface
- Concentration distribution resulting in a stress profile

Results in very high surface compressive stress

Mechanically strengthened by CTE mismatch



$$\sigma_s = \left(\frac{E_c}{1-\nu_c}\right)\frac{(\alpha_s-\alpha_c)(T^*-25)}{\left[\frac{t_s}{t_c}+\frac{E_c}{E_s}\left(\frac{1-\nu_s}{1-\nu_c}\right)\right]}$$

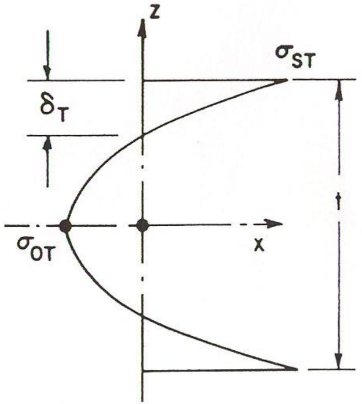
$$\sigma_s t_s = -\sigma_c t_c$$

Surface compressive stress created by the center layer contracting.
Surface compression is of uniform magnitude throughout its thickness

Example in use: Corelle dishware

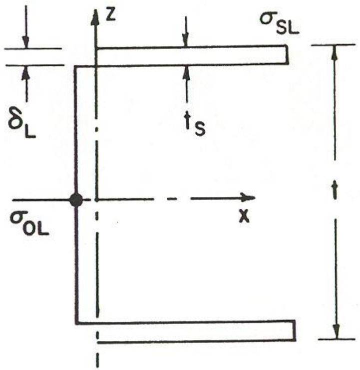
Stress Profiles for Different Strengthening Techniques

Parabolic stress profile



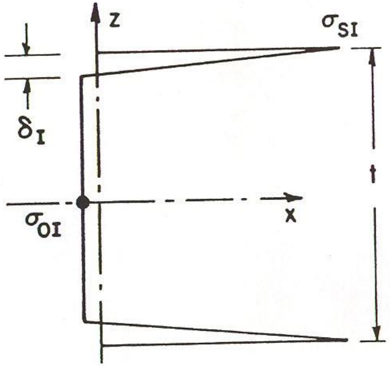
Magnitude & depth of CS controlled by thickness and thermal diffusivity.

Square stress profile



Magnitude & depth of CS controlled by thickness ratios of skin/core and their CTE’s

Error function stress profile



Magnitude & depth of CS Function of glass composition, IOX parameters (chemistry, time, temp)

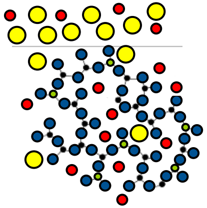
With 2 core Corning technologies, Corning has designed Gorilla® Glass for automobile interior applications

Fusion Process

Proven Properties

- Thin *(without grinding/polishing)*
- Excellent surface quality
- Scalability
- Reliability

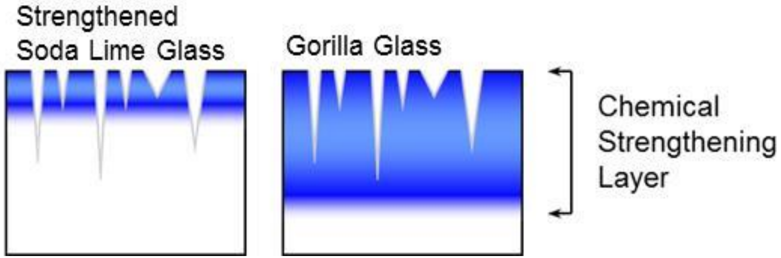
Innovative Glass Composition



Proven Properties

- Optimized for chemical strengthening
- Scratch & damage resistance

Corning® Gorilla® Glass



Application Automobile #1

Headform Impact Test
&
Retained Strength

Today's market trends are challenging industry requirements

Corning's extensive analysis led to considering "Retained Strength" as relevant metric

Auto Interior Displays are Evolving

Glass

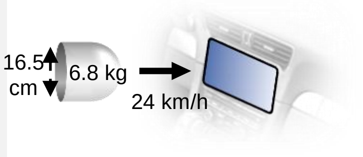
Size

Slim

Shape

Industry Requirements and Today's Solutions

Headform Impact Test (HIT):



".. Cover must not contain any dangerous roughness or sharp edges likely to increase the risk of injury.."

When glass is used, it must not break <u>or</u> must have protective film

Preferred material: **Glass**

	Plastic	Soda-Lime	AlSi
HIT Performance	Green	Red	Yellow/Green
Damage Resistance	Red	Yellow	Green
Advanced Optics	Red	Green	Green
Authenticity	Red	Red (*requires film*)	Green

Corning's Approach

Corning has performed extensive analysis, simulations & testing to investigate HIT and its impact on Glass Attributes

- 50+ Platforms Studied
- 70+ Frame Teardowns
- 1.7k HIT Tests Done
- 20k Total Lab Hours

Evaluation of auto display modules

>90% of market designs

↓

"Retained Strength" proposed as relevant metric

Corning built Headform Impact Test capability to investigate impact on glass attributes

Standards

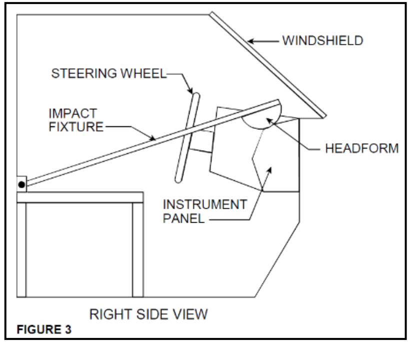
- FMVSS201 (USA)
- ECE-R21 (EU)
- GB 11552 (CN)

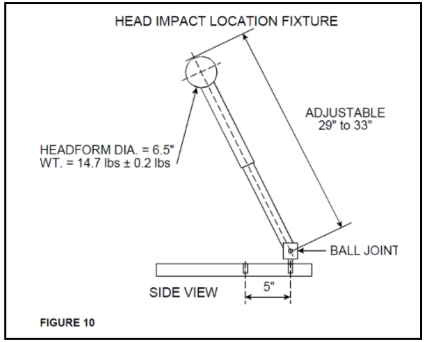
Test Conditions

– Headform diameter	6.5” (165 mm)
– Headform mass	6.8 Kg
– Impact velocity	6.69 m/s
	5.36 m/s with airbag
– Calculated impact energy	152 J

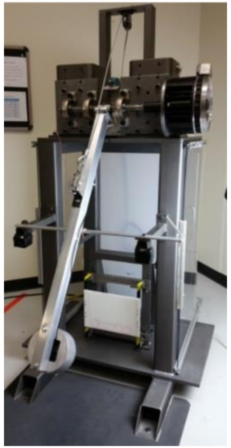
Success Criteria

- Deceleration of head must not exceed 80 g for more than 3 ms
- “..Cover must not contain any dangerous roughness or sharp edges likely to increase the risk of injury..”
    - Many OEMs require No Glass Breakage





Source: Laboratory Test Procedure for FMVSS201, TP-201-02, National Highway Traffic Safety Administration



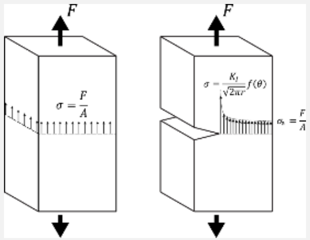
Glass strength is controlled by flaws and is not an intrinsic property

Science of Glass Breakage

Stress intensity factor (K_I)

$$K_I = Y\sigma_a\sqrt{a}$$

(Y = geometry parameter ; σ_a = applied stress ; a = flaw depth)



During loading

increase of applied stress ⇨ Increase of K_I

Failure occurs when

$$K_I \geq K_{Ic} \Rightarrow \sigma_a \geq \frac{K_{Ic}}{Y\sqrt{a}}$$

(K_{IC}= Fracture toughness)

In case of IOX glass ⇨

$$\sigma_a \geq \frac{K_{Ic}}{Y\sqrt{a}} + \sigma_{compression}$$

Glass composition

Applied stress

Supply Chain Flaws

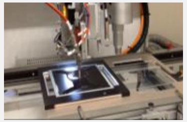
Key Parameters

① Supply chain flaws

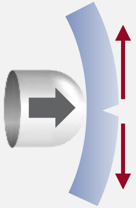
Glass Packing

Glass Handling

Assembly Process

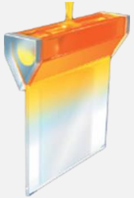


② Stress during HIT

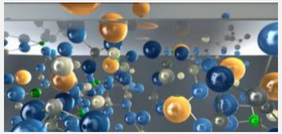


Applied Stress

③ Glass composition



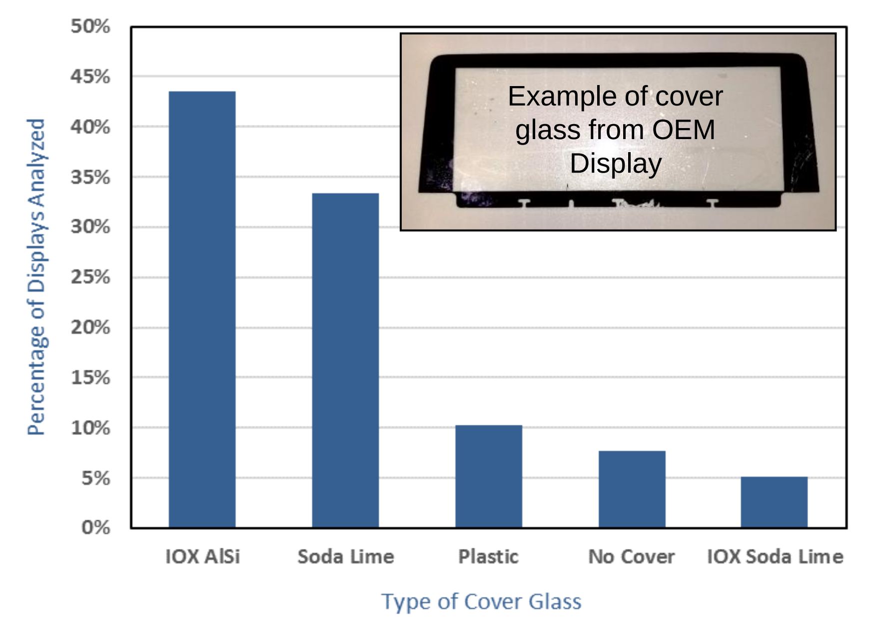
Fusion Draw Processes invented by Corning



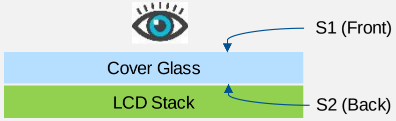
Gorilla® Glass IOX processes invented by Corning

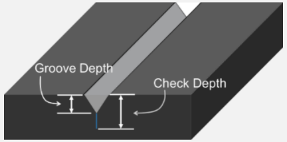
Based on in-field displays, flaws from supply chain are ~ 5 microns

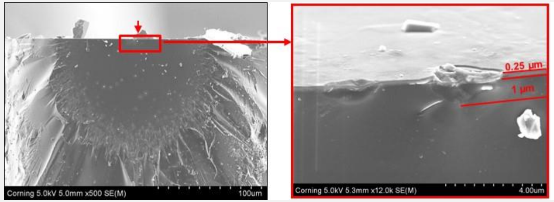
Teardown of Display Modules from field

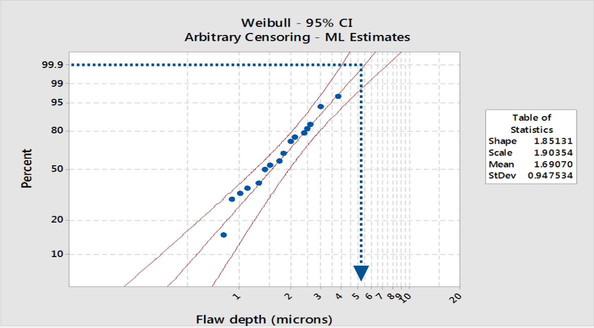


Flaw size (S2)



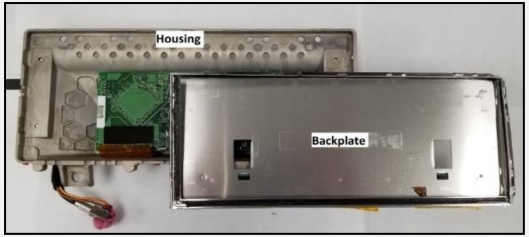






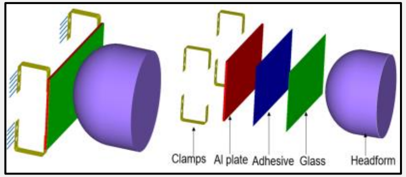
Extensive study of modules design provided stress distribution on cover glass during HIT
Max stress = 900 MPa

In-field modules teardown

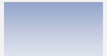


Stress Modeling and Measurement

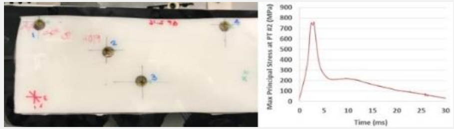
Surrogate design Modeling



Commercial design Modeling



Stress measurement



Commercialized product CAD analysis

Source: http://k.sina.com.cn/article_6431948680_17f5fbf8800100pox8.html?from=auto

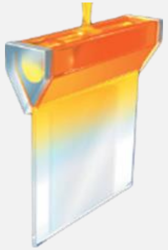
Distribution of stress on cover glass across system designs

Target to survive HIT

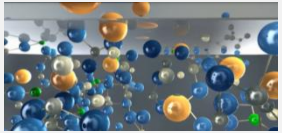
Corning developed glass compositions optimized to exhibit high Retained Strength

Corning's Technology

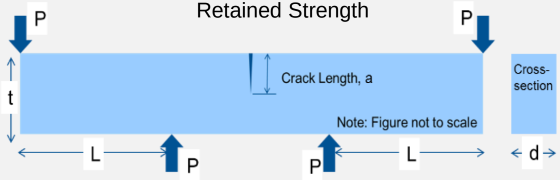
Fusion Draw Processes invented by Corning



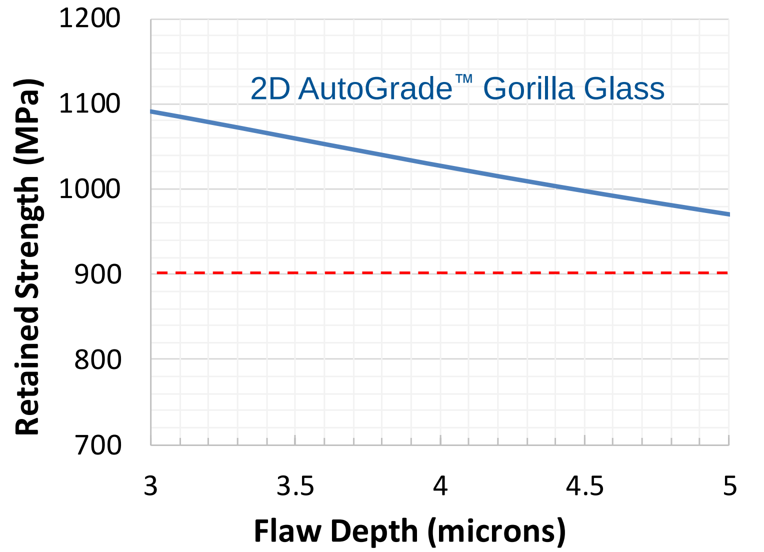
Gorilla® Glass IOX processes invented by Corning



Finite Element Modeling of Retained Strength



Invented AutoGrade™ Corning Gorilla Glass for Interiors with Retained Strength ≥ 900 MPa

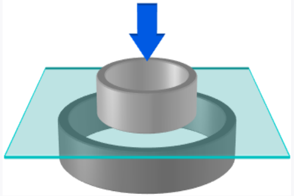


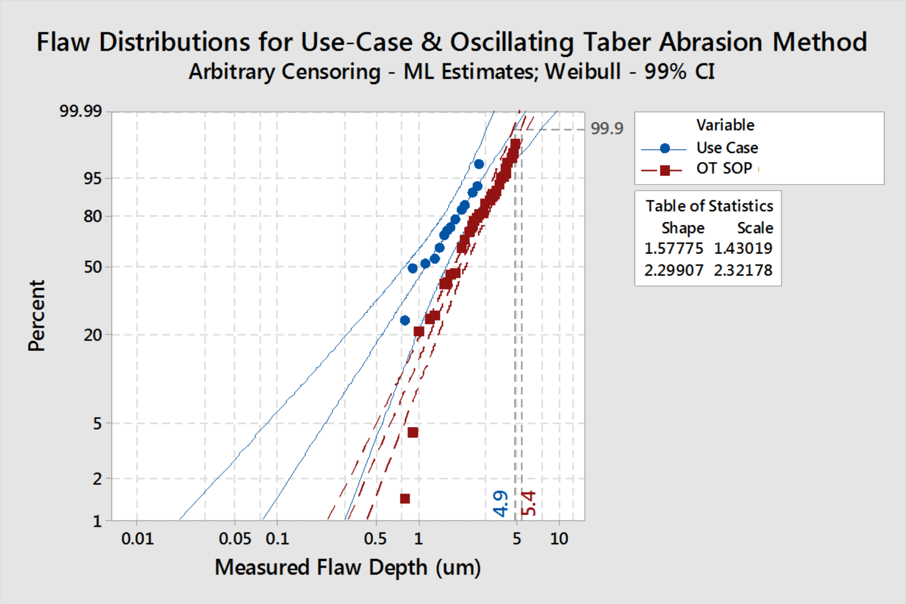
Modeling data

Next step is to validate experimentally Retained Strength and HIT performance!

Damage introduction methodology developed for reproducing use-case flaw distribution (99.9% = 5 microns)

Based on ASTM F735	*Based on ASTM F735*	*Based on ASTM C1499*
Oscillating Taber w/ specimen tray	6/9 quartz silica 600 cycles *& more*	Both sides taped, ROR, ½" / 1" rings





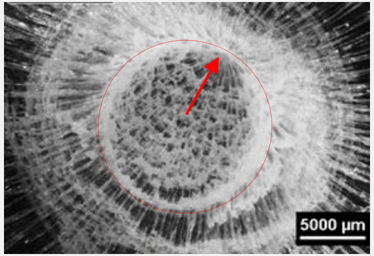
Ring-on-Ring Testing to measure Retained Strength

Large deflection and failure location taken into consideration

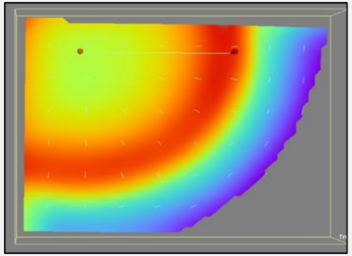
Stress Distribution Experimentally

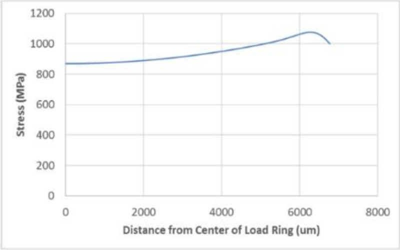
Ring-on-Ring

Failure Location

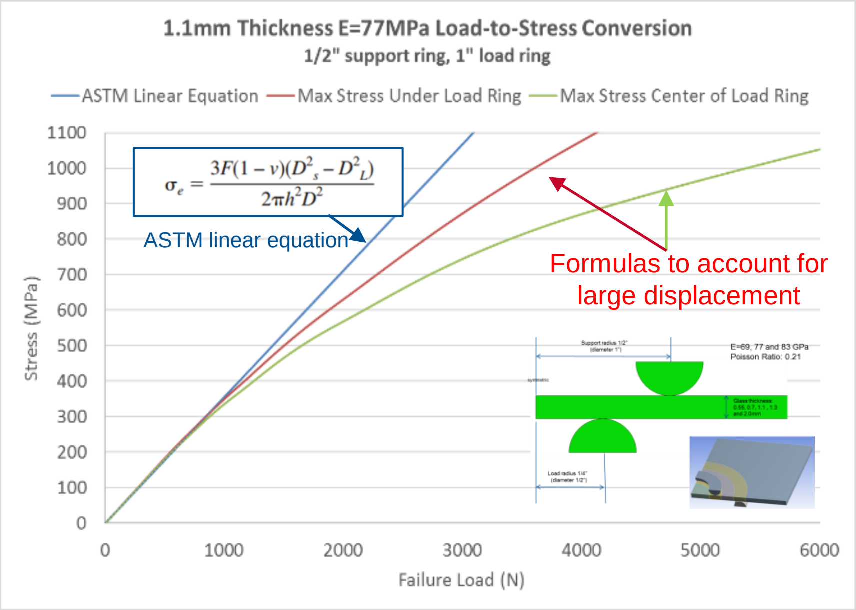


Digital Image Correlation



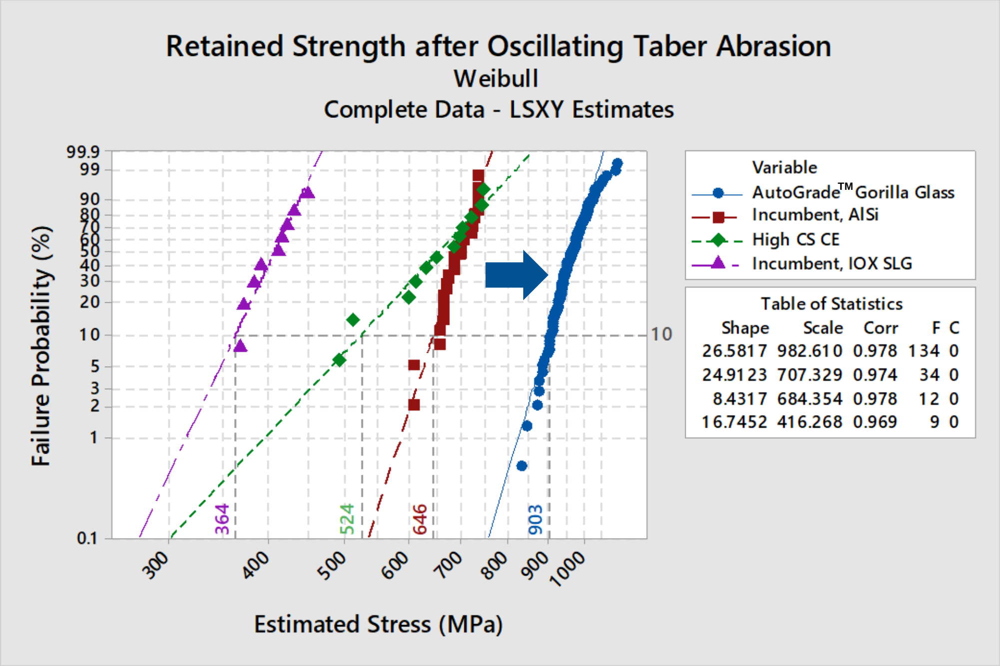


Stress Distribution by Finite Element Modeling



F = Applied load [N ; D = Diameter [mm] (S=Small;L=Large) ; h = Glass thickness [mm] ; v = Poisson ratio

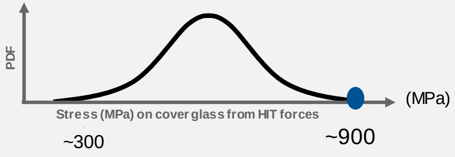
Corning AutoGrade™ Gorilla Glass exhibits Retained Strength greater than 900 MPa

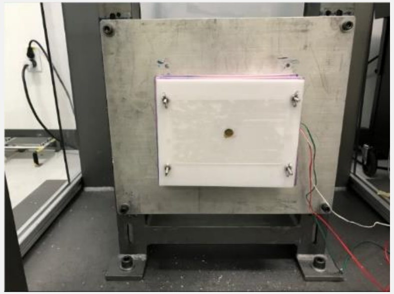


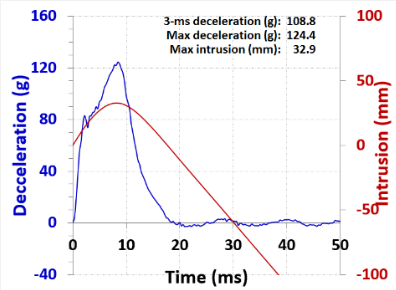
Surrogate module test designed to validate HIT performance of AutoGrade™ Gorilla Glass

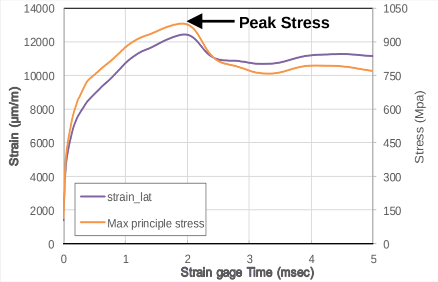
HIT Surrogate Module

- Designed to represent aggressive biaxial bending cases during HIT
  - 3ms 110G vs. 3ms 80G
  - Stress slightly above 900 MPa



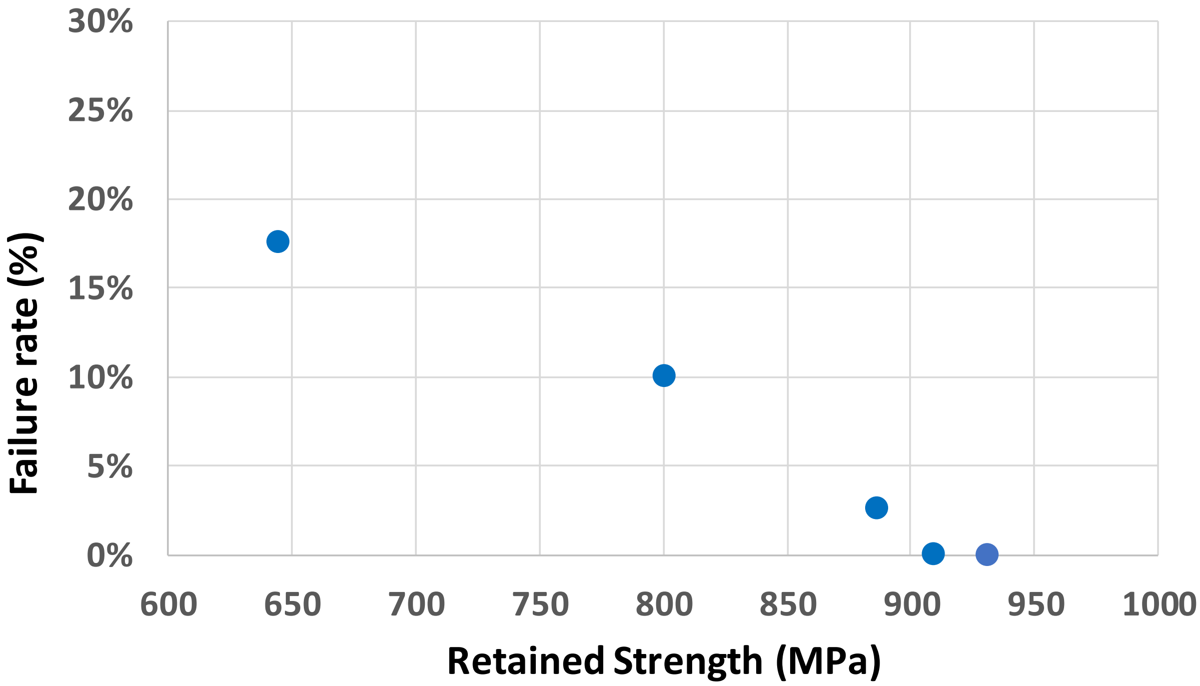






AutoGrade™ Gorilla Glass survives extreme HIT conditions without failure

Correlation confirmed between Retained Strength and HIT survivability



Retained Strength ≥ 900 MPa needed to survive HIT

Conclusion

- Retained Strength proposed as an accurate metric for HIT survivability in auto interior applications.
- Methodology developed to experimentally measure Retained Strength, taking into account supply chain flaws.
- Both experiments and modeling indicate a Retained Strength required minimum value of 900 MPa for cover glasses for use in automotive interior applications.
- Corning developed AutoGrade™ Gorilla Glass, which provides Retained Strength higher than 900 MPa.

References:

K. Layouni, T. Gross, SID-2019, "Retained Strength for AutoGrade™ Cover Glass"

https://www.corning.com/gorillaglass/worldwide/en/applications/automotive/technology-resources.html

https://www.youtube.com/watch?v=857g76Gw1Nw

CORNING

Application Automobile #2

3D ColdForm™ Technology

Corning® ColdForm™ Technology
Started mass production in 2019

+50 granted product and process patents covering ColdForm™ Technology

Europaisches Patentamt
European Patent Office
Office européen des brevets

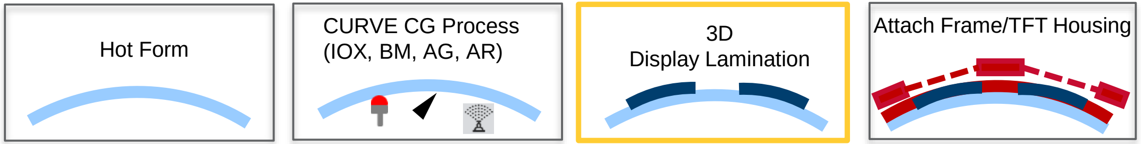
JPO JAPAN PATENT OFFICE

특허청
Korean Intellectual Property Office

CNIPA
China National Intellectual Property Administration

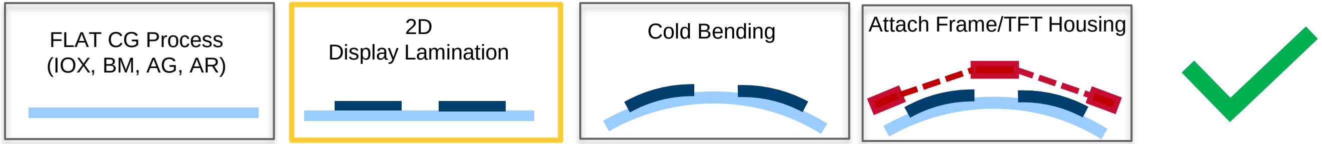
IPO
Intellectual Property Office

“Bend last” during ColdForm™ Technology process enables significant yield advantage and economic savings versus hot forming

Bending	Process Sequence
Hot Form (Bend First)	

With ColdForm™ Technology we can overcome challenges from hot-formed glass:

- ✓ Hot forming economics
- ✓ Poor dimensional tolerance
- ✓ Poor surface uniformity
- ✓ Optical coatings with high color shift
- ✓ Optical distortion
- ✓ 3D decoration

ColdForm Tech (Bend Last) *“One Step Bend”*	

https://m.youtube.com/watch?v=YJ83p1NQwQc&feature=share

Display Lamination Step

Corning ColdForm™ Technology

Better economics, performance, and more sustainable

1 Better Economics

up to **40% Lower BOM**

up to **20% Module Savings**

Validated through industrialization partners and series production models

Continental The Future in Motion · LG Electronics · Visteon · ALPSALPINE · AUO · BOE · VARITRONIX · INNOLUX · NIPPON SEIKI · TIANMA · SHARP · BHTC · faurecia clarion · VIA optronics · ECi · TOLYY

15 Active Partners

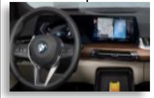
Design-ins validated technology advantage


V-Shape –


J-Shape –


V-Shape –


C-Shape long axis


C-Shape – '22


EU OEM
Dual Display C-Shape


US OEM
Large Multi-Shape


EU OEM
Large Multi-Shape


EU OEM
C-Shape

2 Better Performance

- ✓ Better **shape uniformity** ±0.3mm
- ✓ Best **part-to-part consistency (cosmetic / dimensional)**
- ✓ Superior **optics performance** (AR coating uniformity)
- ✓ **+99% yields** (first pass) for >80,000 series production parts on **automated ColdForm line**

3 Better *for the* Environment

min. **25% Lower environmental impact** *

1M sqft of curved glass is produced using ColdForm Tech instead of hot form technology:

- **14.5M** kg CO_2 are reduced
- **43.4M** kWh are saved
- **$6.1M** are saved

**Based on ColdForm™ vs Hot Form "Lifecycle Analysis" (LCA)done by an independent 3rd party*

Concluding Remarks

Concluding remarks

- Glass strength is essentially an extrinsic property with a statistical behavior.
- The choice of mechanical test depends on use-case application.
- Fractography is a powerful tool for root cause analysis and/or test validation.
- The best choice of glass material depends on the use case: Consumer Electronics, Automotive (Interior/Exterior), Architecture, etc…
- Corning's long history of innovation is pushing the boundaries of glass strength, enabling new forming technologies and new applications.


CORNING