Driving Innovation: Bringing Thin, Lightweight Glass to the Automotive Industry

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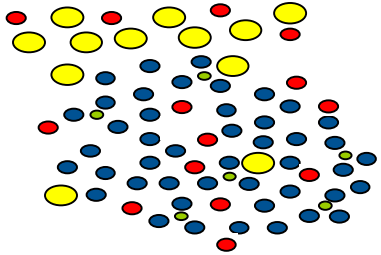
Corning® Gorilla® Glass can enable multiple benefits for automotive windows

Lighter	Tougher	Better Optics
• Up to 30-40% lower weight than conventional windows • Up to ~30% faster defrost/defog time • Up to 1.2” lower center of gravity, which can enable better handling	• 2x better rock-strike performance • Potential reduction in windshield replacements • Significantly more resistant to interior cabin spall	• 3x larger HUD image • Draw-line free glass • Virtually “ghost-free”

What is Corning® Gorilla® Glass?
Gorilla Glass combines two unique technologies

Fusion Process

Glass Composition + Strengthening



Gorilla Glass has virtually no draw line distortion

Photos with point light source at 60 degrees

**Note the vertical distortion lines*

Gorilla Glass retains its strength after abrasion*

Construction	B10: Failure Load (N)		Result
	Before	After	
0.7mm ASLG – single ply	188	73	61% strength reduction
0.7mm Gorilla Glass – single ply	1458	1326	9% strength reduction (18x > ASLG)

*Abrasion with ISO-12103-1 A4 Test Dust

Motivation: Light weighting matters
Lightweight glazing provides unique benefits

1

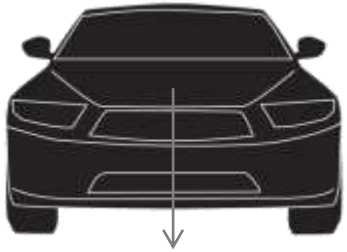
Better Fuel Economy
Less fuel consumption

Lower Emissions
Lower CO_2 release

2

LIGHTWEIGHT

3



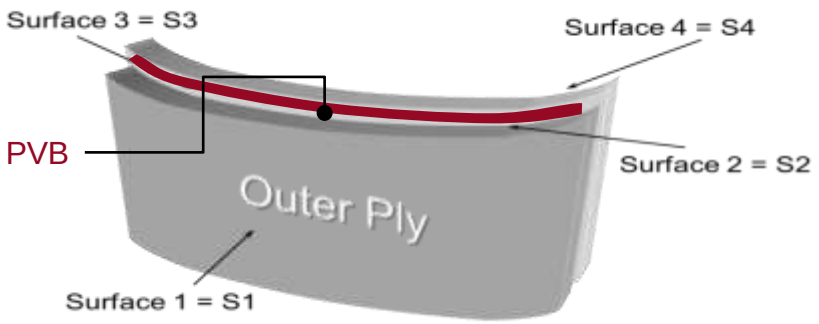
Lower Center of Gravity
Improved stability

Glazing Performance
Faster defog/defrost

4

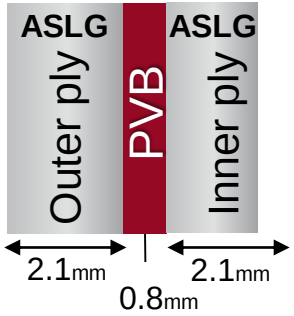
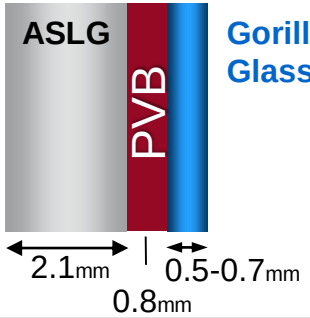
Purpose: Evaluate impact performance of Gorilla hybrid windows over a wide range of impact conditions

Typical Windshield Construction



2 Glass Plies + PVB

Standard vs. Gorilla Hybrid Windshield

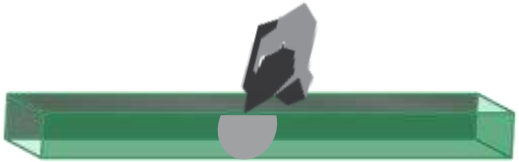
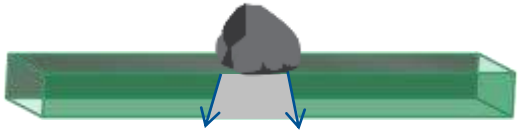
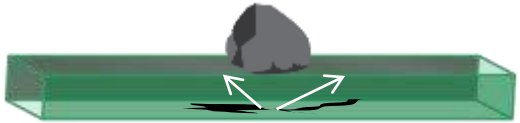
Standard	Lightweight Concept*
	
Total 4.5 mm 11.3 kg/m²	**Total 3.4 mm 7.3 kg/m²**

* ASLG - Annealed Soda Lime Glass
PVB - Poly Vinyl Butyral Laminate Interlayer
Corning® Gorilla® Glass for Automotive

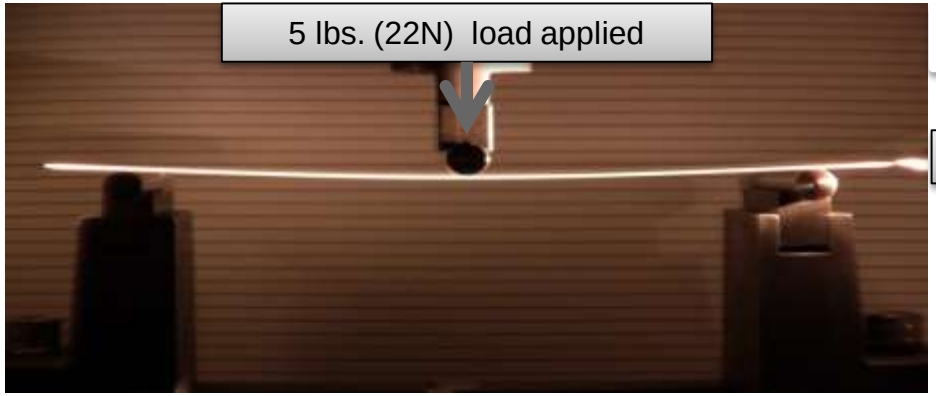
Stone impact is #1 failure mode.
Will thinner laminates perform adequately?

~4.9 kg weight saving
for typical windshield

Stone impact is the #1 cause for windshield replacements
What are the fracture mechanisms?

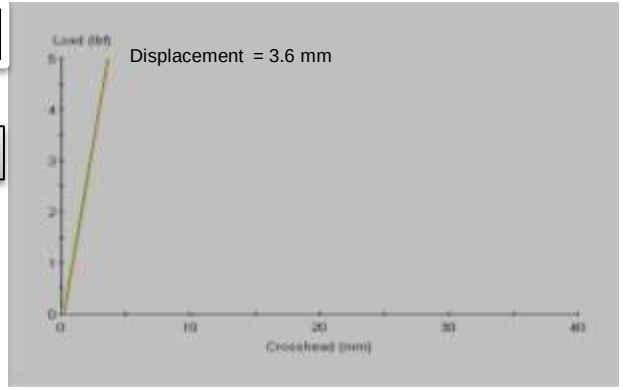
Event: **Sharp Impact**	Event: **Blunt Impact**	Event: **Biaxial Flexure**
		
		
Mechanism: Sharp impact **creates new damage** from S1 through thickness to S2 and propagates on S2 = “Through Crack”.	**Mechanism:** Elastic contact up to failure. Radial stress activates flaw on S1 initiates cone crack. As cone exits S2, radial cracks may form.	**Mechanism:** High energy impact creates flexure that places S2 and S4 in tension. Radial/median fractures created.

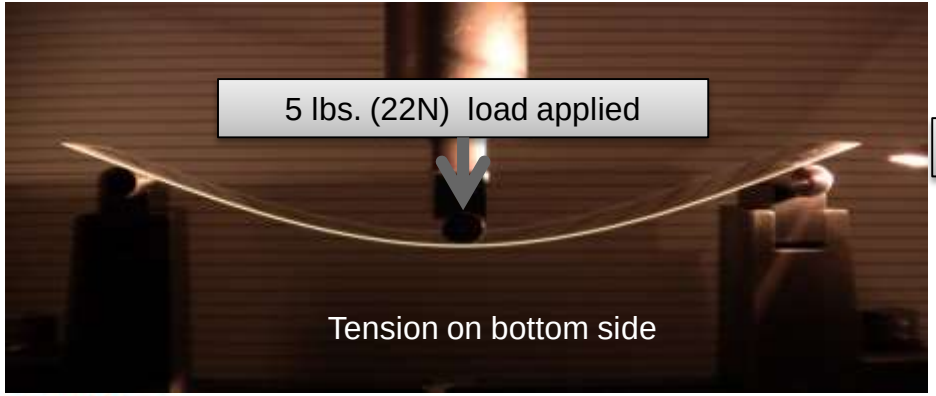
Fundamentals: Thinner materials experience greater deflection for a given load



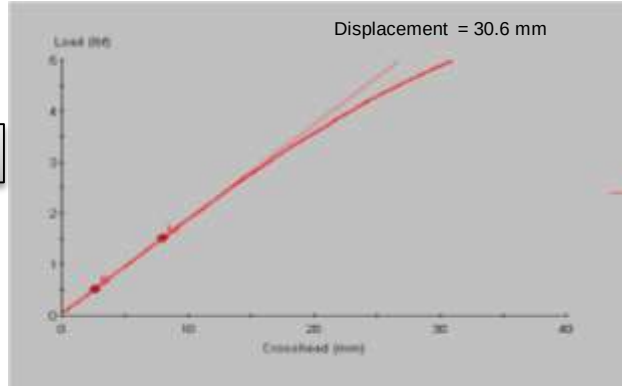
Monolith

2 mm Glass





1 mm Glass



Fundamentals: More deflection equals more stress on the backside. Flaw distribution becomes more critical.

$$Rigidity\ (D) = \frac{Et^3}{12(1-\nu^2)}$$

E = Young's modulus; t = thickness; v = Poisson's ratio

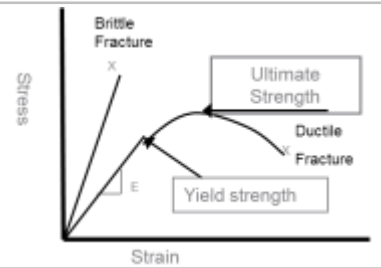
$$Critical\ Flaw\ Size\ (ac) = \left(\frac{K_{IC}}{Y\sigma_f}\right)^2$$

K_{IC} = fracture toughness; Y = flaw shape parameter
σ_f = failure stress

$$\sigma_f = \left(\frac{3LW}{bt^2}\right)$$

L = applied load; W = geometric constant; t = thickness
b = width

Lower Rigidity =
More Deflection =
More Strain =
More Stress =
Higher risk of fracture



$$Hooke's\ Law: \sigma = E\varepsilon$$

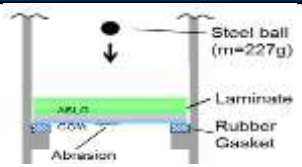
E = Young's modulus; σ = stress; ε = strain

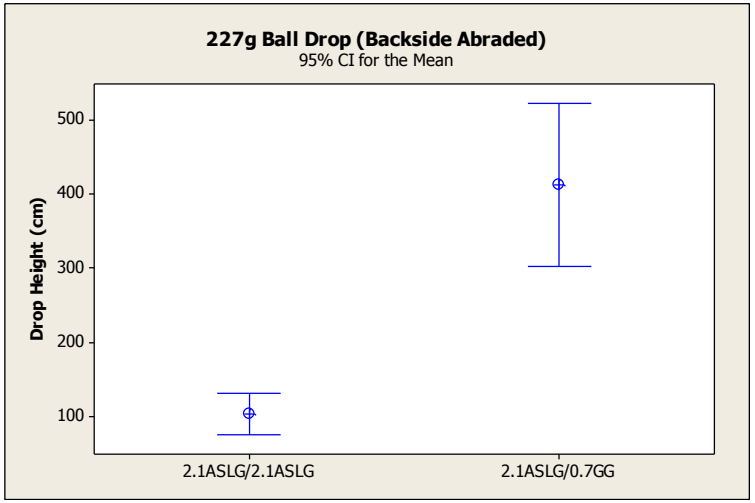
Critical flaw size is proportionate to thickness raised to the 4th:

$$a_c = \left(\frac{b^2t^4}{9Y^2L^2W^2}\right)$$

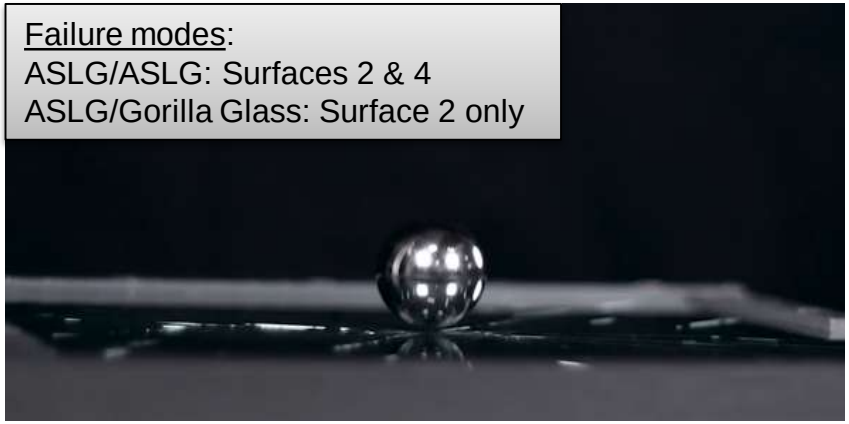
Reduction in thickness makes laminates *very sensitive* to flaw population

Thin Gorilla hybrid windows are more resistant to large, blunt force damage than thick SLG windows

Flexure induced by a large blunt force	Corning analyzed and simulated in the lab
Examples: Hail or large stones 	227g Ball Drop  • Flat samples • Dust abrasion on S4 • Impact on S1 • Record drop height for fracture

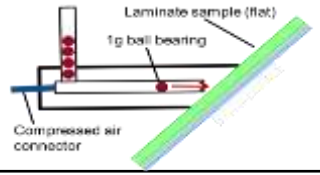


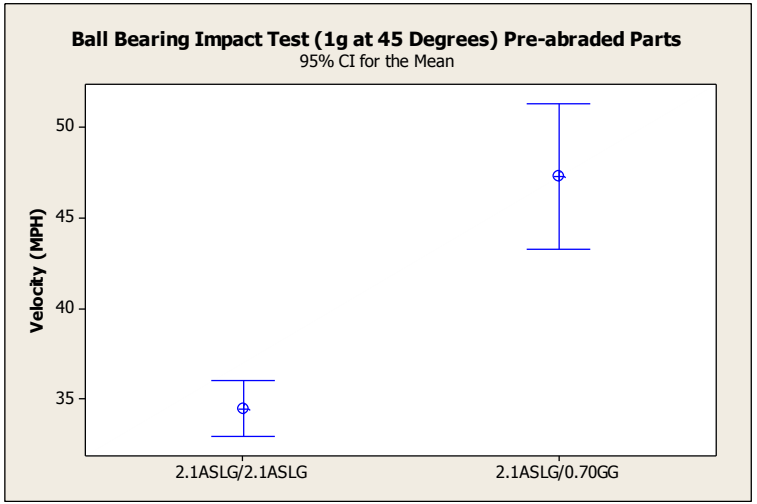
Failure modes:
ASLG/ASLG: Surfaces 2 & 4
ASLG/Gorilla Glass: Surface 2 only



Results: Gorilla hybrid windows have ~4X higher drop height than conventional SLG windows

Concept evaluation – Impact performance
Simulated stone impact test

Hertzian stress due to small blunt force	Corning analyzed and simulated in the lab
 	1g steel ball 45º impact angle  • Flat samples • AZ dust abrasion on S1 & 4 • Record failure velocity & mode



Results: Gorilla hybrid windows have >1.25X more impact resistant than conventional SLG windows

During BB impact tests, it was observed that thin ASLG laminates tended to break the inner ply (S4); Gorilla hybrid windows do not

- Parts abraded on S1 & S4
- Parts stored at temperature over 4 hours
- Parts impacted w/ 1g BB at angle of 45 degrees

Category	Construction	Inner Ply Breakage Rate		
		"Hot" (40 °C)	Room Temperature (23 °C)	"Cold" (-20 °C)
Standard ASLG	2.1/2.1 ASLG	0%	12%	0%
	2.1/1.6 ASLG	No data	40%	No data
Thin ASLG	1.8/1.4 ASLG	30%	58%	75%
	1.6/1.6 ASLG	20%	88%	95%
	2.1/1.0 ASLG	45%	50%	100%
Thin Gorilla Hybrid Windows	2.1/0.7 Gorilla Hybrid	0%	0%	0%
	2.1/0.55 Gorilla Hybrid	0%	0%	0%
	1.8/0.4 Gorilla Hybrid	0%	0%	0%

Gorilla hybrid windows: Strong, damage resistant inner-ply survives high flexure stress

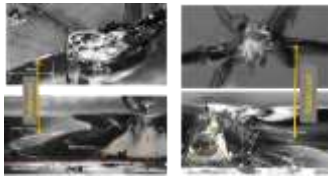
Corning® Gorilla® Glass enables thin laminates ≤ 4.5mm for automotive windshield applications

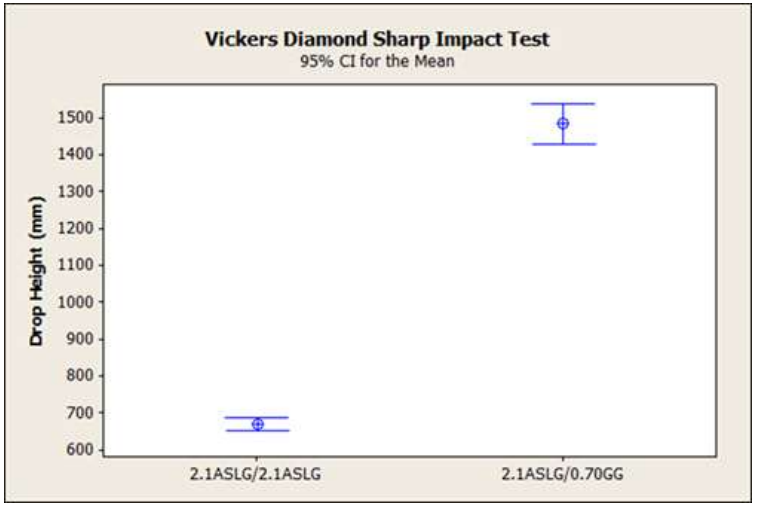
Automotive Windshield Lightweight Journey

Thick SLG/SLG
Conventional
Windshields

Thin SLG/Gorilla Glass
Hybrid
Windshields

Sharp impact is primary cause for replacements of conventional thick windshields

Not all stones are blunt	Corning analyzed and simulated in the lab
	Vickers Diamond Indenter 90º impact angle • Height increased until radial fractures (star-cracks) >10mm diameter are observed 



ASLG/ASLG

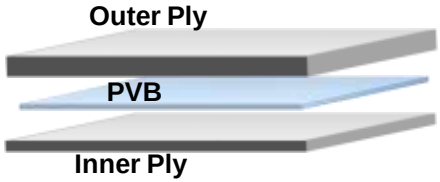
ASLG/Gorilla Glass

Results: Gorilla hybrid windows ~2X higher impact energy than conventional SLG windows

Vickers Sharp Impact Test

Crack Propagation

Thin Gorilla hybrid windows are advantaged for stone impact, they survive flexure stresses and dissipate impact energy

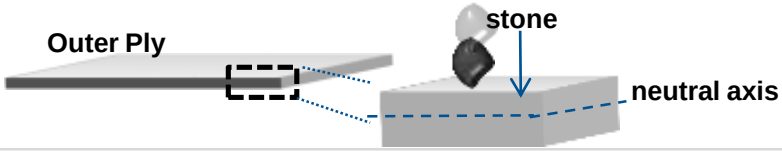


Our testing shows that for sharp impacts, survival is highly dependent on:

- Outer ply thickness: **Thicker** is better
- Inner ply thickness: **Thinner** is better

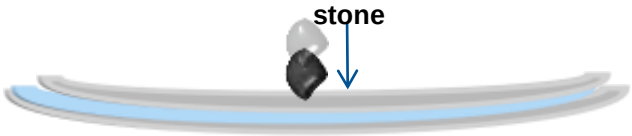
Thick Outer Ply Role:

- To avoid fracture damage must penetrate <½ thickness of outer ply
- Thicker outer = more damage resistant



Why thinner inner ply?

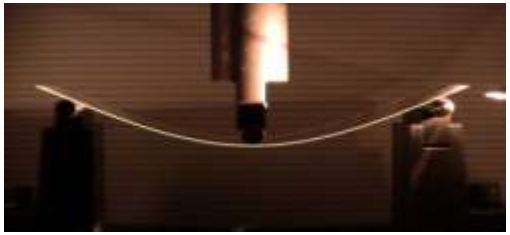
- Conservation of energy:
  Impact KE = $E_{bend} + E_{fracture} + E_{rebound}$
- Energy of impact is dissipated in flexure (bending) instead of cracking



High flexure dissipates impact energy thus reducing fracture of outer-ply, but results in high stress on inner-ply: need tough inner ply such as Gorilla Glass

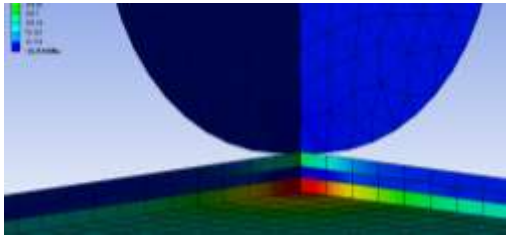
Gorilla hybrid windows is a lightweight glazing solution with added benefits

1. Thin laminates flex more



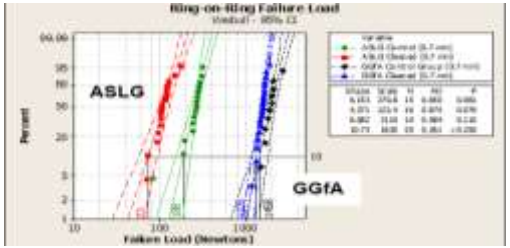
2. High stress on S2 & S4:

Area under stress: S4>>S2



3. Damage introduced in-service on S4:

ASLG loses >50% strength; Gorilla Glass retains its strength



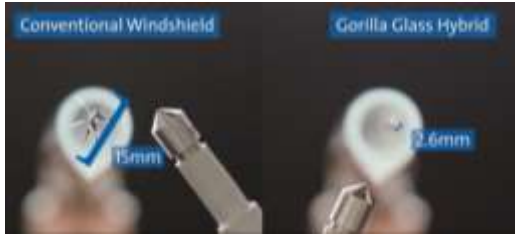
4. Fracture & particle ejection risk for thin ASLG

Thin Gorilla Glass hybrid window have higher resistance

5. Thin Gorilla Glass hybrid windows:

Additional flexure reduces impact contact stresses.

Superior sharp impact performance results.



Gorilla Hybrid Windows:

- **Thinner (<4 mm)**
- **Lighter (~30% weight reduction)**
- **Tougher (~2x better sharp stone impact)**

THANK YOU

Questions?