ADVANCED DESIGN OF GLASS STRUCTURES

Lecture 3 – Laminated glass and interlayers

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European Erasmus Mundus Master Course

Sustainable Constructions

under Natural Hazards and Catastrophic Events

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Laminated glass introduction

- Glass strengthening methods improve the structural behaviour of glass and reduce the time dependence of the strength, but glass still exhibits brittle behaviour.

- Lamination of glass overcomes that drawback, up to some extent, since it enables significant improvement in the post-breakage behaviour.

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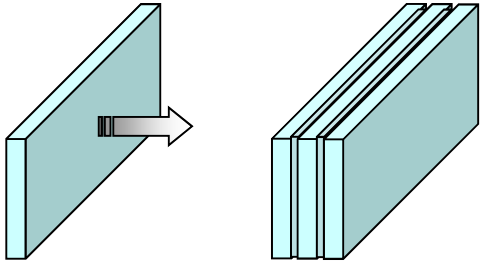
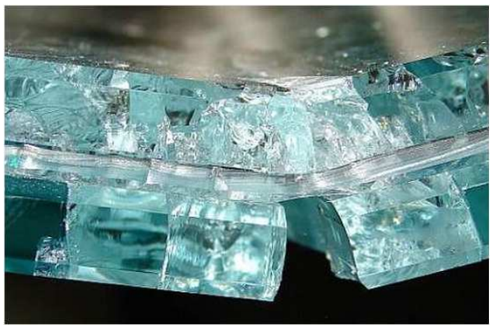
Laminated glass introduction

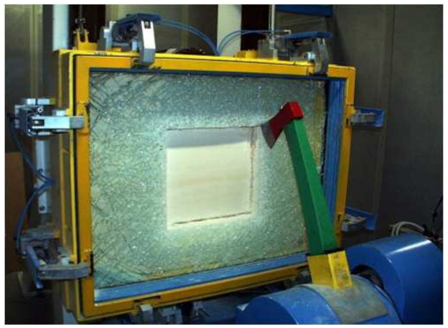


Two or more panes bounded together by some transparent plastic interlayer.

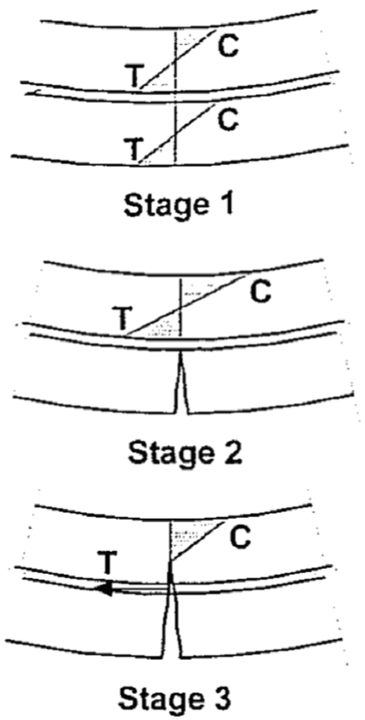
Glass panes may have identical thickness and heat treatment or different ones.

After breakage the glass fragments adhere to the film/interlayer so that a certain remaining structural capacity is obtained as the glass fragments “arch” in place.





Laminated glass structural behaviour



Both sheets are intact and carrying load

Bottom sheet has fractured and the top sheet is carrying all the load

Both sheets have fractured but the fragments in the top sheet lock together in compression and combine with a tensile stress in the interlayer to provide extra post-breakage resistance. It depends on the interlayer material and on the type of glass used on the top sheet.

Global structural behaviour of the laminated element depends on the structural behaviour of both the glass panes (upper and bottom layers) and the foils.

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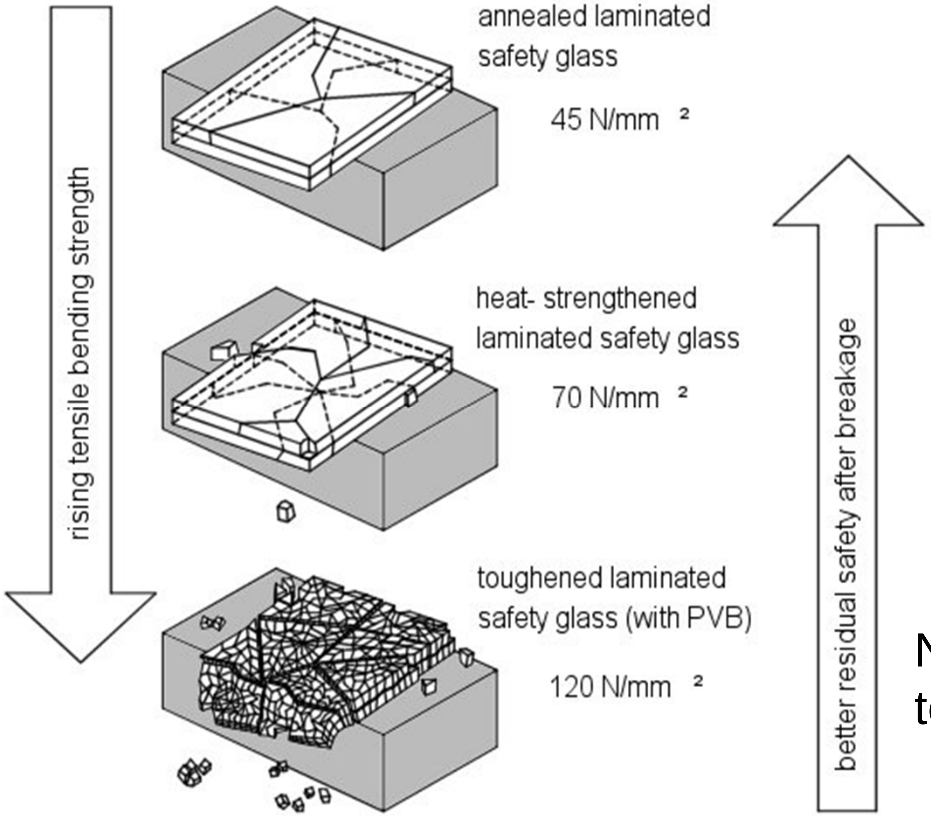
Laminated glass structural behaviour

influence of the structural behaviour of the glass panes

Part of the remaining structural capacity depends upon the fragmentation of the glass and increases with increasing fragment size.

The fragment size is inversely proportional to the energy strored in the glass.



No arch effect | wet towel deformation

Laminated glass chemistry of adhesives

Adhesives are polymer materials. They can be classified according to their thermo-mechanical properties, which are controlled by the molecular structure.

Molecular structure of polymers

Thermoplastics: Relatively weak intermolecular forces hold molecules together in a thermoplastic. The material softens when exposed to heat, but returns to its original condition when cooled. Can be repeatedly softened by heating and then solidified by cooling, for improved performance. (linear and slightly branched polymers)

Elastomers: Rubbery polymers that can be stretched easily to several times their unstretched length and which rapidly return to their original dimensions. (cross-linked with low cross-link density)

Termosets: Solidify or "set" irreversibly when heated and further heating cannot reshape the material. (3D networked polymers with high degree of cross-linking)

Polymer adhesives

Thermoplastics	Elastomers	Thermosets
Linear or branched polymer chains	Long cross-linked polymer chains	High cross-linked polymer chains
PVB	Silicone (inorganic) Polyurethane (organic)	Acrylic adhesive Polyester resin, Epoxy

Laminated glass deformability of adhesives

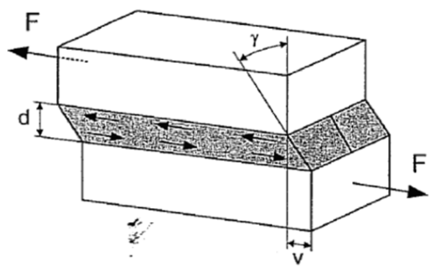
The deformation of a polymer under external forces, is the result of the superimposition of three different deformation types:

Spontaneous elastic deformation

Time dependent viscoelastic deformation

Time dependent viscoplastic deformation

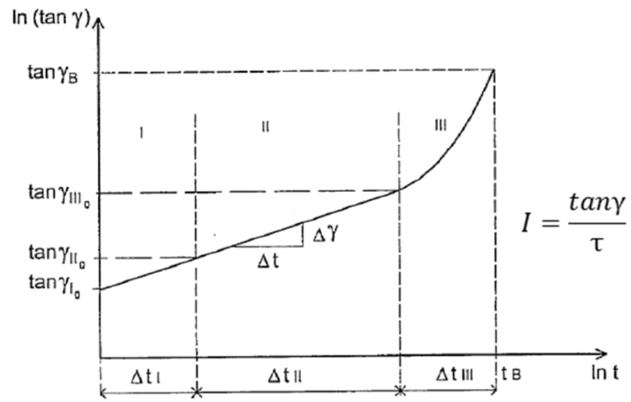
Behaviour under short-term loads (small strains)



$$tan\gamma = \frac{v}{d}$$

$$G = \frac{\tau}{tan\gamma}$$

Behaviour under long-term loads (small strains)



$$I = \frac{tan\gamma}{\tau} = B.t^{\alpha}$$

Region I Creeping is due to the stretching of molecular chains

Region II Creeping is due to the sliding of the molecular chains

Region III The lost physical bonding become prevalent and the connection breaks

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Interlayer materials commercial offer

Types of interlayers:

- Polyvinyl butyral (PVB)
- Ionoplast Polymers
- Ethylene Vinyl Acetate (Cross-Linked EVA)
- Cast in Place (CIP) liquid resin
- Thermoplastic polyurethane (TPU)

Interlayers for:

- Automotive industry
- Architectural industry
- Photovoltaic panels
- Decorative and specialty market
- Fire resistance

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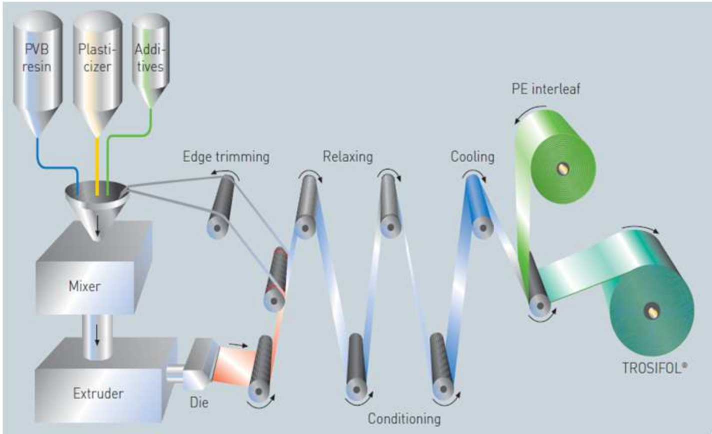
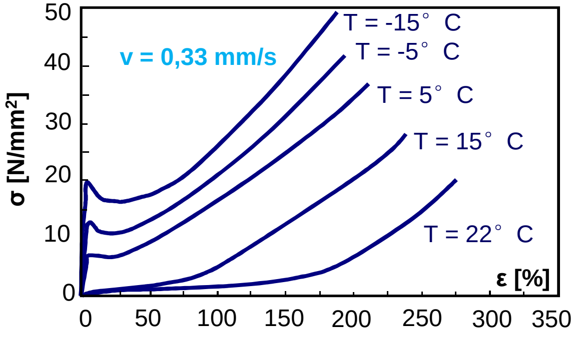
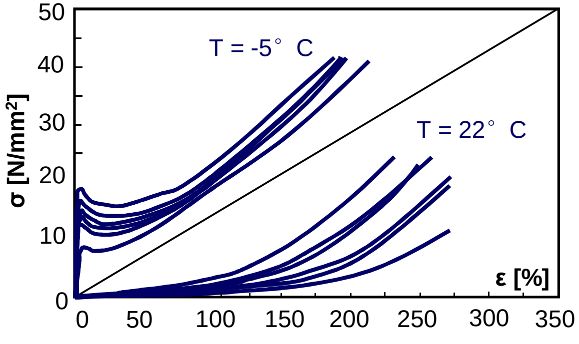
Interlayer materials Polyvinyl butyral (PVB)

- The reference since the 1960's (most specified WW)
- Blocks UV almost completely
- Interlayer = 2 or 4 foils (1 foil= 0.38mm)
- Autoclave or non autoclave
- Requires special storage climate controlled conditions
- Can be used with other interlayers and colors
- Viscoelastic (properties depend on the temperature and load duration)
- Best performance at low temperatures and for short loading times (if not, shear resistance is greatly reduced)

Density	ρ	Kg/m^3	1070
Shear modulus	G	GPa	0 - 4
Poisson's ratio	v	-	≈ 0.50
Coef. thermal expansion	α_T	K^{-1}	80.10^{-6}
Tensile strength	f_t	MPa	> 20
Elongation at failure	ε_t	%	> 300







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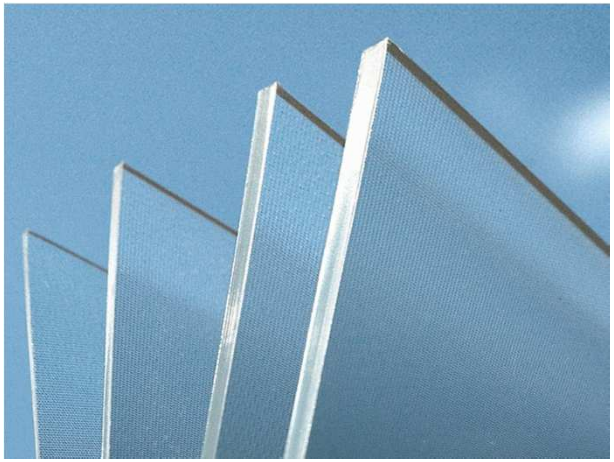
Interlayer materials Ionoplast Polymers

- Ionomer (copolymer) is derived from ethylene and metha-crylic acid
- Most common: SentryGlas®Plus (SGP) and is produced by DuPont
- SGP offers five times the tear strength, 100 times the rigidity of conventional PVB interlayer's … yes but not at all temperatures
- Retains its clarity – even after years of service
- Transparency with low haze index
- Much less vulnerable to moisture exposure or yellowing over time
- Good impact strength/toughness over broad range of temperature
- Higher adhesion on tin versus air side
- Excellent adhesion on metal coated glass surface



- high price of SentryGlas® versus conventional PVB
- Can not be used with other interlayers
- Can be difficult to trim after cure

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Interlayer materials

Ethylene Vinyl Acetate (EVA Cross-Linked)

- EVA is the copolymer of ethylene and vinyl acetate, typically contains 26% Vinyl Acetate.
- Very good sound <u>insulating</u> properties in the high frequency range.
- It is the dominant <u>photovoltaic encapsulant</u>.
- Highly adhesive to materials other than glass, thus it is used for <u>connections</u> and glued supporting structural details, such as point fixed glazing systems.
- Outstanding heat, humidity and ultraviolet ray durability and long-term reliability
- Today's EVA films provide optical quality that can rival PVB

Weller et al. (TU Dresden)

- Haze level worse than PVB
- Higher Yellowness Index (YI) than PVB
- Lower impact performance than PVB (< 50% of PVB strength of the same thickness)

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Interlayer materials

Cast in Place (CIP) liquid resin

- Typical base polymers for this type of lamination are acrylics, polyurethanes and polyesters
- Belong to the Thermosetting Plastic family (polymer material that cures irreversibly).
- The cure may be done through: (i) heat, generally above 200ºC; (ii) a chemical reaction (two-part epoxy, for example); (iii) irradiation, such as electron beam processing and/or UV exposure
- Allows for a wide variety of thickness and designs
- Can be colored with dyes or pigments, although pigmented versions have higher haze than PVB
- Low capital investment (relative to autoclave lamination)
- Free flowing – can adapt to most shapes (bent/curved glass)
- Excellent edge compatibility with sealants

Weller et al. (TU Dresden)

- Poor optics due to variations in glazing thickness
- Poorer low temperature impact versus PVB laminates
- Chemical handling requires permits
- Edges retain tape and must be cut off if exposed
- Cannot provide BOTH good acoustics and impact
- Lower output / Productivity - High manufacturing costs

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Interlayer material comparison (material properties)

	Test Methods	Units	Standard PVB	Acoustic PVB	Structural PVB	Ionoplast SentryGlas	EVA Cross-linking
Tensile strength	ASTM D 412 JIS K6771 DIN53455-4-5 ISO 527-3	Kg/cm² Kg/cm² MPa MPa	226 250 20.8 20.8	- 10 8.7 8.2	300 330 - -	345 - - -	- - 20.8 -
Elongation @ failure	ASTM D 412 JIS K6771 DIN53455-4-5 ISO527-3	% % % %	- 190 250 313	- 350 330 -	160 190 - -	400 - (ASTMD63) -	- - 415 -
Glass Transition (Tg)	From “Tan delta vs. Temp°” curves	°C	28-32	16-18	40-45	50-55	-
Tear Resistance	ASTM D1004 DIN 53363 DIN 53363	N/cm 50C N %	112 - -	- 9.5 157	- - -	- - -	- - -
Poisson ratio			~0.5	~0.5	~0.5	~0.5	-

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Interlayer material commercial sizes

Type	Presentation	thickness	width	length	weight	Brand
PVB	Standard roll	0.38 0.76 1.14 1.52	<1.0→3.2			Saflex®
	Magnum roll	0.38 0.76	3.22 3.3	1500 790	2004 2154	
Ionoplast	Flat sheet	0.89 1.52 2.29 3.05				SentryGlas®
	Roll	0.89	1.21 1.52 1.83	200		
			1.52	50		
EVA Cross-linking		0.2 0.4	0.955 1.260	170 130		Asahi-Bridgestone (AB)“EVASAFE” DuPont “Elvax” Tosoh “Methylene-G” Sekisui “EN-film” Takeda-Dumiran

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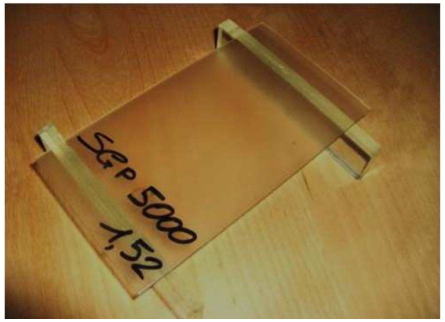
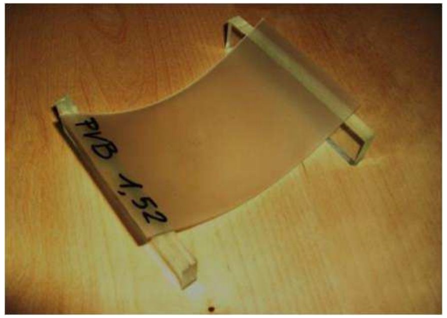
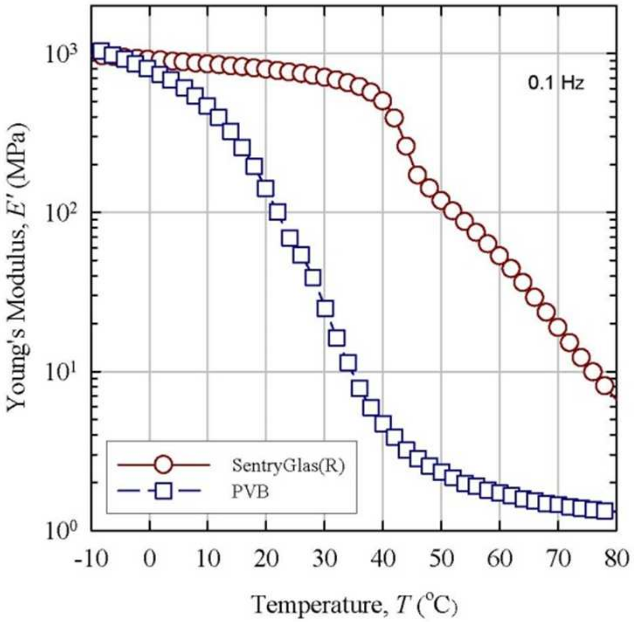
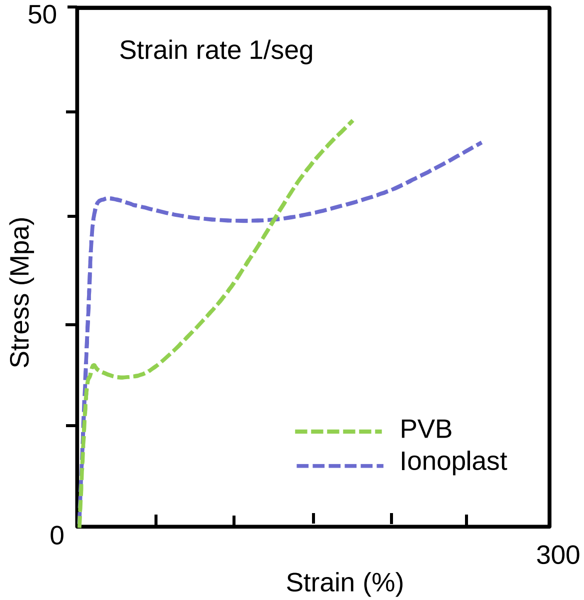
Interlayer material PVB *vs* Sentryglas









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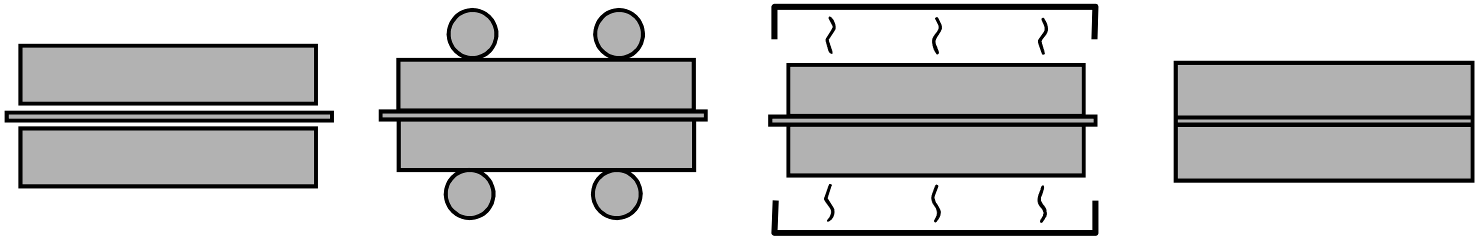
Lamination cure processes

- Lamination cure processes
  - Light
  - Addition of chemical catalysts
  - Heat
  - UV
  - Autoclaving

- The most common lamination process is autoclaving.
- It is used to cure PVB, Ionoplast and EVA (Crosslinking) based laminates.
- Non Autoclave or alternative processes are available for PVB, Ionoplast and EVA for photovoltaic panels; EVA for decorative market and CIP for security or acoustic or decorative.

Lamination process with PVB

- Two or more glass panes bonded by a transparent interlayer (up to 25 layers, thickness up to 100 mm); float glass, tempered glass, polycarbonate, bent glass.
- Largest size of pane 6,0 x 3,21m.



positioning and layering | *prelamination by calender* | *autoclave* | *finished laminated glass*

Glass panes are washed and foils are layered

The assembly is heated (70ºC) and pressed by roller process to squeeze out the air or blisters

The assembly is heated to 140ºC under a pressure about 0.8MPa

http://www.glasswebsite.com/video/laminating.asp

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Lamination process with autoclave

Interlayer

Glass

Nip-Roll

Pressure

Encapsulation

Powered pressure rolls
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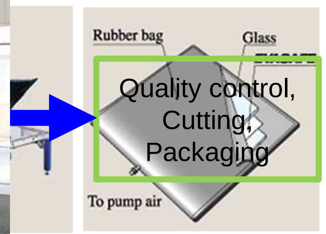

Quality control, Cutting, Packaging

(car w
photovoltaic panels…)

polymer on its border through a framing mold.

Processes used to impose pressure onto the laminated set so that it can be squeezed out of any air bubbles or blisters that might cause a defective bond.

Autoclaving

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Lamination process with Ionoplast

- Similar to PVB, but…
- Direct adhesion to glass by heat lamination is feasible since autoclaving of laminate is not mandatory (depending on the preheat capability of the flat laminate production line)
- Stability in dimensioning (zero snap back during ACV).
- No special conditioning of temperature or humidity is require for sheet storage and use.
- Preferably require cutting SentryGlas® sheet to size prior lay-up to avoid post trimming. Post prepress/ACV cutting results in trimming difficulties.
- Require saw cutting tools or heating wired, since conventional methods of cutting PVB laminates will not work. SentryGlas laminate may get scored, resulting in small chips on the edges and/or the laminate may break easily during cutting.

Lamination process with EVA

•Same as PVB but ....

•No special conditioning of temperature or humidity is require for sheet storage and use.

•Adhesion to glass occurs at lower temperatures and pressures than traditional PVB

•Alternative process using low-cost equipment (Vacuum bag de-airing …)

European Norms list

Laminated and safety glass: EN ISO 12543

Safety – Impact resistance: EN 12600

Safety in case of fire:

•Resistance to Fire: EN 13501-2

•Reaction to Fire: EN 13501-1

•External fire behaviour : prEN 13505-1 (CR 187)

Security

•Burglar Resistant: EN 356

•Bullet Resistant: EN 1063 (1999)

•Explosion: EN 13541

Mechanical Strength

•prEN 13474-1:2005 - General basis of design - Design for uniformly distributed loads and triangular loads

•prEN 13474-3: June 2008 - Design for line and concentrated loads.

•prEN vwxyz_N255E:June 2008 - Determination of interlayer shear transfer coefficient

•prEN…_N249a:2008 - Effective thickness concept

Sound attenuation:

•N 12758-1(2008-Rev7)

•ISO DIS 16940: “MIM” test method

Light & Energy Transmission, Thermal Insulation:

•EN 410: Determination of luminous and solar characteristics

•EN 673: Determination of the U-value

Assembly Rules:

•EN 12488

Evaluation of conformity (CE Marking)

•EN 14449

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European Norms definitions

Definition according to EN ISO 12543- Part 1:

Laminated Glass: assembly consisting of one sheet of glass with one or more sheets of glass and/or plastics glazing sheet material joined together with one or more interlayers.

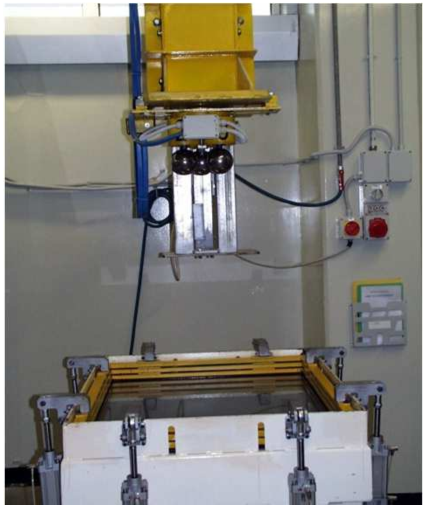
Laminated Safety Glass: laminated glass where in the case of breakage the interlayer serves to retain the glass fragments, limits the size of opening, offers residual resistance and reduces the risk of cutting or piercing injuries.

Laminated safety glass is distinguished from laminated glass by the pendulum impact test and its requirements. In CEN member states, laminated safety glass shall be classified in accordance with EN 12600. The ball drop impact test and its requirements according to EN 356 may apply too.

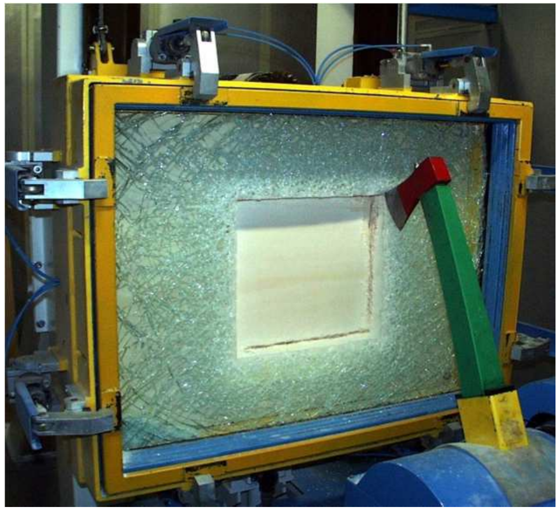

Pendulum Test EN 12600

European Norms resistance tests

Ball drop impact test
EN 356



Axe & Hammer Test
EN 356



Lecture 3

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This lecture was prepared for the 1st Edition of SUSCOS (2012/14) by Prof. Sandra Jordão (UC).

Adaptations brought by Prof. Viorel Ungureanu (UPT) for 2nd Edition of SUSCOS

Thank you
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