

FUNDAMENTALS OF LAMINATING PROCESS AND QUALITY REQUIREMENTS

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ABSTRACT

Abstract: Fundamentals of Laminating Process and Quality Requirements.

As we review the previous decades, we are impressed with the technological accomplishments of the worldwide laminated architectural glass manufacturers especially in the areas of product diversification. Keeping up with it has been challenging for all of us and, as we are entering a new century, we see even more diversifications and greater challenges for PVB-based laminated glass.

As might be expected, past diversification and growth have led up to some confusions and, to a lesser extent, some misunderstandings in the market place about laminated glass products and performances.

From the CEN/TC129/WG3 "Glass in Building" prEN 12543-1 to 7 draft documents, we are getting a clear understanding of what is laminated glass and laminated safety glass, as well as, what is expected of these products in terms of performances, overall visual quality and durability. An in-depth knowledge of the laminating glass process fundamentals combined with the legendary "know-how" of the professionals should minimize or better eliminate industry wide problems and assess definitively the credibility of these products.

1. INTRODUCTION

Laminated glass and laminated safety glass - with or without fire resistant properties - are covered by several European Standards drafts and, in particular, by prEN 12543-1 to 7. They incorporate by dated or undated reference, provisions from other publications. These standards are interrelated and unable the user to find out which glass product or test method standards should be referred to when considering a particular product property related to the use of

glass in building - Construction Products Directive (CDP) 89/106/EEC: Official Journal L 40, 11.2.1989, p.12 - and to the six Essential Requirements - Interpretative Documents (ID's): Official Journal C 62, 28.2.94, p.1 - laid down in the CDP. This clearly indicates that the evaluation of conformity, including initial type testing of the essential characteristics, initial type of testing if the product belongs to the intended product group, and the organization of the factory production control, is in line with the attestation of conformity. To achieve this objective, an in-depth knowledge of the laminating process (es) and product requirements is essential. The following will give you an overview on how to master the laminating processes to fulfill the expected quality requirements.

2. PRODUCT DESCRIPTION

The prEN ISO 12543-1 defines terms and describes component parts for laminated glass and laminated safety glass for use in building.

2.1 Laminated glass:

An 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.

2.2 Laminated glass with fire resistant properties:

Laminated glass which does not achieve its fire resistance by means of interlayers which react to high temperatures.

2.3 Fire resistant laminated glass:

Laminated glass where at least one interlayer reacts to high temperature to give the product its fire resistance

2.4 Laminated safety glass:

Laminated glass where in 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 glass can be made from most combinations of all types of glass, plastics glazing sheet material (polycarbonate or acrylic) and interlayers in solid form (film) or liquid form (resins) such as:

- ◆ Film: - polyvinylbutyral (PVB)
- ethylvinylacetate (EVA)
- polyurethane (PU)
- ◆ Liquid: - one-component resins
- multi-component resins
- intumescent gels

3. PROCESS DESCRIPTION

One can distinguish two main lamination processes

3.1 Folio lamination process

This lamination process is the most widely used process where the interlayer is a solid film such as PVB. The process flow diagram is divided into 4 main steps:

- ◆ glass and film preparation
- ◆ assembly step
- ◆ deairing step either by calendring or under vacuum
- ◆ autoclaving under heat and pressure

For more details, please refer to Mr. Van Russelt's paper "How to Make a Good Laminated Safety Glass" - Automotive Session 9.

3.2 Cast-in place lamination process

Commonly used where the interlayer is a liquid resin. Lamination is done by pouring a liquid between the plies of glass or plastics glazing sheet material. The assembly is then chemically, UV-cured to produce the final product. The process flow diagram is:

- ◆ glass and liquid preparation
- ◆ assembly step
- ◆ curing step

4. REQUIREMENTS

4.1 Conformity to the definitions

Products intended to belong to the product group laminated and laminated safety glass units shall be conform with the definition of laminated and laminated safety glass defined by National and/or European Standards (prEN 12543-1/2/3). On that basis, the laminated glass shall resist the durability tests: high temperature, humidity and radiation tests (prEN 12543-4). Additionally for laminated safety glass, it shall be tested and catalogized conform with the human impact pendulum test (prEN 12600).

4.2 Performances of the characteristics:

The performances of the characteristics listed below shall be determined when required

Nr Performances

- 1 Fire resistance
- 2 Reaction to fire
- 3 Light transmittance and reflection
- 4 Solar energy characteristics
- 5 Wind, snow and/or permanent load resistance
- 6 Human impact resistance
- 7 Explosion resistance
- 8 Sound reduction
- 9 Energy saving
- 10 Bullet resistance
- 11 Burglar/vandalism resistance
- 12 Release of dangerous substances

For each of above performances there do exist a corresponding National and/or European Standard.

4.3 Optical and visual quality

National and/or European Standard (prEN ISO 12543-6) specifies defects of finished sizes and test methods with regard to the appearance when looking through the glass.

4.4 Dimensional tolerances

National and/or European Standard (prEN ISO 12543-5) specifies dimensions, tolerances and edge finishes.

5. CONFORMITY

The evaluation of conformity is based on:

5.1 Factory production control

5.2 Inspection of samples taken at the factory

- ◆ on-line quality control
- ◆ off-line quality control

5.3 Continuous monitoring and assessment of the factory production control

It becomes obvious that laminated glass and laminated safety glass process(es) is an INDUSTRIAL process carried out by HIGHLY PROFESSIONAL PEOPLE. The fundamentals of the laminating glass and quality requirements have to be clearly understood and are the key success of the product performances, durability and credibility.

6. FUNDAMENTALS AND REQUIREMENTS

This part focuses on laminated safety glass based on PVB interlayers only. Indeed more than 90% of the laminated glass consumption in the building industry are PVB-based laminated safety glass.

The importance of accurate record keeping cannot be overstressed when it comes to

troubleshooting process or product performance deviations. The final laminate performance properties include impact, adhesion and durability/ageing tests. Processing observations include bubbles, trapped air penetration and delamination. The format for discussion of each property incorporates:

- ◆ Statement deviation
- ◆ Potential cause list
- ◆ Action steps

6.1 BASIC RELATIONSHIPS

Impact, adhesion to glass, moisture content of the PVB interlayer, thickness of the PVB, float glass orientation, glass treatment (metal coated, chemically tempered, color), residual salts on the glass surface, glass surface contamination, are all important variables that control final performance:

- ◆ For a given glass type and thickness, impact levels will vary inversely with adhesion:
($\text{impact} = f(1/\text{adhesion})$)
- ◆ The thicker the PVB the higher the impact:
($\text{impact} = f(\text{PVB thickness})$)
- ◆ Moisture in the PVB interferes with the glass/PVB bonding mechanism. Thus as moisture content increases, the adhesion drops and the impact improves:
($\text{Adhesion} = f(1/\% \text{moisture})$)
($\text{impact} = f(\% \text{moisture})$)
- ◆ Too high moisture content may result in bubble formation and/or delamination with time.
- ◆ The placement of the air side of the float glass against the PVB will result in higher adhesion than the tin side
- ◆ High residual salt concentration on the glass surfaces at lamination, interferes with bonding and lower the adhesion.
- ◆ Adhesion to metal coated glass depends on the coating and requires to be studied case by case.
- ◆ Any glass surface contamination at the assembly step may result in unacceptable visual and/or optical quality.
- ◆ Unadequate deairing steps and/or autoclave cycle may result in trapped air penetration and consequently delamination or bubble formation even if not directly visible at the inspection.

These basic relationships are important to keep in mind when identifying the cause(s) of performance deviations and testing the cause(s)

6.2 Impact performance properties

6.2.1 Deviation

- ◆ Increase or decrease in tested impact level

6.2.2 Potential Cause list:

- ◆ Change in the glass/PVB adhesion level
- ◆ Change in the interlayer thickness
- ◆ Glass thickness change
- ◆ Wrong interlayer product type
- ◆ Change in impact test conditions or procedure
- ◆ Glass treatment

6.2.3 Action steps

- ◆ First check adhesion (see next session)
- ◆ If OK then check the test conditions, observe the impacted specimen in terms of dimension, break pattern, interlayer used, and laminate thickness.

6.3 Adhesion performance properties

6.3.1 Deviation

- ◆ Increase or decrease in adhesion level

6.3.2. Potential cause list

- ◆ Change in moisture content of PVB in laminate
- ◆ Different residual salts on the glass
- ◆ Change in detergents or glass washing conditions
- ◆ Glass type/composition
- ◆ Float glass orientation (air vs tin)
- ◆ Incorrect autoclave cycle
- ◆ Contamination
- ◆ Change in adhesion test conditions or procedure

6.3.3 Action Steps

- ◆ Identify any water supply changes (glass washing/rinsing machine)
- ◆ Review washer performance and records (changes in detergents, line speed, air blow-off system, water temperature, brushes worn out)
- ◆ Review adhesion tests conditions and samples
- ◆ Review autoclave cycle, probes, gauges and recorders for accuracy. Low temperatures and short hold times may not allow for PVB to flow and intimate contact with the glass
- ◆ Check laminates for contamination
- ◆ Check PVB type

6.4 Moisture performance properties

6.4.1 Deviation

- ◆ Moisture higher or lower than expected

6.4.2 Potential cause List

- ◆ Incoming PVB moisture content level
- ◆ Unsealed PVB storage
- ◆ Relative humidity storage and lay-up room
- ◆ Moisture test conditions and procedure
- ◆ Moisture standards

6.4.3 Action steps

- ◆ Review production records
- ◆ Check incoming PVB moisture
- ◆ Check %RH in lay-up room
- ◆ Check moisture analyser calibration
- ◆ Check moisture standards

6.5 Durability performance properties

Process conditions have to be set in a such way that they shall prevent from air penetration, trapped air (inside air pocket or bubbles), delaminations, edge bubbles, product yellowing or discoloration (PVB degradation)

6.5.1 Deviation

- ◆ Failure during high temperature tests (boil and/or bake test)
- ◆ Failure during humidity test (with or without condensation)
- ◆ Failure in radiation test

6.5.2 Potential Cause list

- ◆ Excessive moisture content thus low adhesion
- ◆ Trapped air
- ◆ Contaminations
- ◆ Poor edge sealing
- ◆ Localized interlayer thinning
- ◆ Glass flatness (tempered glass)
- ◆ Glass mismatch
- ◆ Premature edge sealing
- ◆ Improper autoclave cycle
- ◆ Folded PVB
- ◆ Interlayer heat/light stability
- ◆ Test conditions and procedure

6.5.3 Action steps

- ◆ Test moisture content. High moisture (>0.8%) can create bubbles upon boiling/baking
- ◆ Test adhesion level: if below 3 Pummel units, can cause delamination in conjunction with glass stresses

- ◆ Check line for deairing. Look for pockets of trapped air and premature (or lack of) edge sealing. Are there large patches of cloudy appearance?
- ◆ Review autoclave cycle:
 - (Too fast or too slow pressurisation before heat-up can allow edge defects due to air penetration.
 - (Temperature at pressure release point should be at or below 50°C to avoid bubbles formation along the edges of the laminate.
 - (Fast heat-up prior to pressurisation can expand residual entrapped air
 - (Low temperatures and short hold times reduce adhesion and further may initiate delamination
 - (Too high temperature (>160°C) combined with too long hold time may initiate the degradation of the PVB. The radiation test will amplify this phenomena
- ◆ Measure glass match: does defect align with? Gaps greater than 10% of the PVB thickness are suspect
- ◆ Measure PVB stabiliser content or ask the interlayer supplier the quality control data. A too low UV/anti-oxydant concentration may induce the change in light transmittance
- ◆ Review boil/bake/humidity/Radiation test conditions

CONCLUSIONS

The above fundamentals in laminating glass and related quality performance requirements are based on decades of research experimentation, process troubleshooting and process optimisation. Laminated safety glass based on PVB interlayer has been tested and proven since more than 50 years in the automotive industry (windscreen) and about 30 years in architectural buildings. When manufactured according to the PVB supplier recommendations, the product performances characteristics listed above (see § 4 - requirements) will last, subject to normal maintenance and actions which are foreseeable, for an economically reasonable working life. From field experiences we have learned to trust in laminated safety glass based on PVB for its reliability in terms of product durability, ageing, and multi-function performances.