UV Curable Glass Lamination for Acoustical Performance

Carol Vargas
Scientist I
TS&D Industrial Coatings-Radcure
Cytec
Smyrna, GA USA

Introduction

From about the time the first window was broken, glass manufacturers have looked for ways to improve the properties of this useful but brittle material. Of key concern was how to make glass safer and more versatile. One way to achieve this is to laminate two or more pieces of glass together with a bonding interlayer. The multi-layer system provides impact resistance and versatility, and if the glass is broken, the bonding layer holds the resultant shards together. The interlayer can also be designed to resist puncture or penetration upon impact. Glass lamination thus makes for a more valuable product for window and door manufacturers, designers, and architects. Laminated glass can provide hurricane resistance, safety, security, sound control, and other benefits. This paper will discuss how glass is laminated with UV technology and some of the benefits of this technology. In particular, we will focus on the benefits of UV glass lamination for sound control.

Technology of Glass Lamination

There are several methods by which two or more layers of glass can be bonded together. The traditional method is through the use of a film such as PVB (polyvinyl butyral). PVB film has been used to laminate glass since the 1930s.[1] First the film is placed between the glass, and the air is removed from between the film and the glass by a vacuum. Then controlled heat and very high pressure is used to bond the layers together. This process takes place in an autoclave, which requires a high capital investment, and has high energy consumption. With this process, large sheet pieces of laminate are made that are then cut down to the desired size for different window types, or laminates are made-to-size for high volume production, such as car windshields.

Another method of glass lamination is through the use of a liquid system. This method does not require an autoclave, and typically represents a much lower investment for the laminator. In addition, the glass can be cut to the desired size before lamination, which reduces waste. The liquid is pumped between the glass layers, where a double-sided tape provides the dam to hold the liquid in and establish the interlayer thickness. Upon controlled exposure to heat or light, a chemical reaction occurs that allows the liquid to form a solid polymer that then bonds with the glass. UV technology is ideally suited to this type of lamination, and allows for a simple, energy efficient process. Because the liquid does not start cure until it sees UV light, it is a one component system that requires no mixing. UV curing has been used in the glass lamination industry for over 25 years, especially in Europe.[2] It has found increasing use here in the United States with systems that are designed for hurricane resistance. There are four basic steps used to laminating glass with UV:

1. Wash the glass: The glass must be cleaned and dried to provide a surface that is free from dirt, oils, or any material that can interfere with the bonding of the interlayer material to the glass. This is generally performed by an industrial glass washer equipped with deionized water.

2. Assemble the glass pieces: A double-sided tape is applied around the perimeter of one piece of glass. The tape sets the interlayer thickness and contains the liquid between the two pieces of glass. The second piece of glass is placed on top, creating a pocket into which the liquid will be pumped.
3. Fill with the liquid: A metering pump system will fill the pocket with the proper amount of liquid. This is done with the glass at about a 45-75° angle to the horizontal. When pumping is complete, the glass is laid horizontal, and the low viscosity liquid will push the air out from between the glass and completely and evenly fill the interlayer space. The piece is then sealed with hot melt glue at the small openings where the air was allowed to escape.
4. Cure: The piece is now placed under a bank of low intensity UV lights and cured for 20 minutes. The cure area must be completely level and flat, and the lamps should be checked to make sure they are giving the proper dose to the laminate to cure in the allotted time. The top piece of glass must be transparent to the UV wavelength range needed to activate the photoinitiators that are used in the system.

UV Coating vs. UV Glass Lamination

While there are some similarities between UV coating and UV glass lamination such as energy savings, there are also some significant differences. The table below compares the two:

Table 1. UV Coating vs. UV Glass Lamination

	UV Coating	UV Glass Laminate Interlayer
Key Properties	Scratch, abrasion, adhesion, some weatherability, some impact resistance	Flexibility, elongation, impact resistance, adhesion, non-yellowing, clarity, sound damping
Typical Thickness	1 mil or less	30-120 mils
Cure Speed	Very fast (< 1 second)	Can be much slower (minutes)
Type of lamps	High intensity UV	Low intensity UV (black lights)
Oxygen Inhibition	For free radical - yes, unless there is a nitrogen blanket	No, no air present
Type of Process	Often continuous or semi-continuous moving lines	Always batch, laminates do not move during cure
Key Benefits	Low to no VOCs Energy savings Superior scratch, abrasion	Low to no VOCs Low capital investment Energy savings Reduced waste Process flexibility, simplicity

So while a UV coating is often designed to be hard, scratch resistant, and fast curing, a UV glass laminate interlayer is designed to be very flexible, softer, and slower curing. The laminated glass must remain completely bonded together, must not noticeably discolor or weather over time, and must be shown to meet the requirements for its particular application.

Performance of UV Laminates

UV laminates have been shown to meet the same types of performance criteria as traditional laminate systems. Table 2 shows the impact performance of UV acoustic glass laminates in safety impact tests. In these types of tests, a soft body impactor, in the form of a large shot bag or tire, is used to simulate a person falling against a safety glass.[3] The glass can break, but the pieces must be held together by the interlayer. The configurations shown below all passed the given test for safety.

Table 2. Performance of UV acoustic laminates in pendulum safety tests*

Standard	Impactor Type	Drop Height (m)	Composition glass/interlayer/glass (mm)
ANSI Z 97.1 adapted	Bag – 50 kg	2.0	5 / 2 / 4
ANSI Z 97.1 adapted	Bag – 45 kg	1.3	5 / 1 / 6
NFP 08.301 M 50 adapted	Bag – 50 kg	1.8	4 / 1 / 4
EN 12600, Class 1B	Twin tire – 50 kg	1.2	4 / 1 / 4

* Tested by Institut für fenstertechnik, Rosenheim Germany, Institut (Scientifique) du Verre, Charleroi, Belgium, and Centre Experimental de Recherches et d'Etudes du Batiment et des Travaux Publics, St. Remy les Chevreuse, France

In addition to safety, the impact resistance of glass laminates also provides security by making it more difficult for a thief or vandal to break through a window and steal or damage goods inside a building. Tests for security involve different types of impact, such as a standardized ball drop test. Table 3 shows the impact performance of UV acoustic glass laminates in falling ball security impact tests. In this test from Europe, a steel ball of 4.11 kg is dropped from a standardized drop height onto a horizontally positioned test panel. The test simulates impacts that a window can undergo in cases of vandalism, burglary, or manual attack.

Table 3. Performance of UV acoustic laminates in falling ball impact tests*

EN 356 Category	Drop Height (m)	Number of Drops	Composition glass/interlayer/glass (mm)
P1A	1.5	3	3 / 1 / 3
P2A	3.0	3	3 / 2 / 3
P3A	6.0	3	4 / 2 / 4

* Tested by Institut für fenstertechnik, Rosenheim Germany and Institut (Scientifique) du Verre, Charleroi, Belgium

Laminates made with UV interlayers have also shown excellent stability to heat and accelerated aging. This is of obvious importance, as this type of glass will likely be exposed to natural sunlight and extremes of temperature, depending on the climate where the window is located. Table 4 shows the performance of the UV cured glass laminates in different types of stability tests.

Table 4. Accelerated aging of UV acoustic laminates

Resistance	Test	Standard	Performance
Heat	Oven Aging at 60°C		4 / 1 / 4 mm laminate: no defects after 1500 hours, $\Delta E = 0.9$
Temperature Cycling	-30° C to 80°C	DIN 52344 adapted	No defects
Heat + moisture	Boiling water test, extended to two days	EN 12543 adapted	No defects
UV	Q panel aging at 351 nm continuous UV irradiation	ASTM G53	4 / 1 / 4 laminate: no defects after 5000 hours, $\Delta E = 0.33$
UV	Florida natural weathering, 5° orientation, 45° South	ASTM G7	No defects after 24 months, $\Delta E = 0.47$

Sound Propagation

One application where laminated glass can provide a benefit is in the area of sound control. Sound is manifested as the vibrations in the air that can be detected by the human ear. Sound travels through air through the propagation of variations in air pressure when something vibrates. This can happen when a person speaks, when one object strikes another, or when an object such as a car moves along the ground. There are two important components of sound. Sound has a frequency, the number of wavelength cycles per second, and an amplitude, which is related to its loudness. The frequency is measured in Hertz (Hz), while the amplitude is represented by its Sound Pressure Level (SPL), measured in decibels (dB). The frequency is what gives a sound its pitch, with high pitched sounds such as a whistle having a high frequency and short wavelength, and low pitched sounds such as a fog horn having a low frequency and long wavelength. The average human ear can detect sounds in a frequency range of 20 to 20,000 Hz. For the Sound Pressure Levels, the human ear is sensitive to a range of between 0 and 130 dB, from the threshold of audibility to the threshold of pain. The SPL follows a logarithmic scale, so an increase of 10 dB would be approximately double the loudness, while a decrease of 20 dB would be about one quarter of the loudness[4]. Table 5 shows some typical sounds and their corresponding SPL rating.

Table 5. Relationship Between Typical Sounds and Their Sound Pressure Level[5]

Typical Sound	SPL (dB)
Thunder Clap	120
Nearby Riveter	110
Loud Street Noise	90
Noisy Office	80
Average Street Noise	70
Average Office	60
Restaurant Chatter	50
Private Office	40
Quiet Private Room	30
Whisper	20
Normal Breathing	10
Audibility Threshold	0

Testing for Sound Transmission

In a laboratory, sound transmission is measured with two chambers separated by a filler wall, into which the test specimen is placed. The first chamber is the source room, where the test sounds are generated, and the second chamber is the receiving room, where the sound is measured. For testing sound transmission through a building component such as a window, the test chambers must be designed to acoustically isolate the given test specimen. This assures that one is measuring mainly the transmission through the window, and not through the surrounding wall, floor, ceiling, or other building component. The ASTM sound transmission loss (TL)[6] is calculated as:

$$TL = L1 - L2 + 10 \log S/A$$

Where:
L1 = the average sound pressure level in the source room (dB)
L2 = the average sound pressure level in the receiving room (dB)
S = the area of the test specimen (ft^2 or m^2)
A = absorption of the receiving room

When comparing different components, the building materials with better acoustical performance are those that have less noise transmitted through them. In order to more effectively compare different building materials, single number rating systems were developed that incorporate the sound reduction characteristics across a given sound spectrum.

In North America, a rating system was introduced in 1970 under ASTM E 413 "Classification for Rating Sound Insulation." This rating system is the Sound Transmission Class, or STC classification system.[7] In general, test specimens with higher STC ratings will have better acoustical performance than those with lower ratings.

It is based on a "standard household noise" spectrum. This spectrum emphasizes the mid- or high-frequency sound energy levels found with such noises as live speech, radio and television noise, vacuum cleaners and household appliances, and other household noise.[8] It is less appropriate for lower frequency noises such as car traffic, airport noise, trains, and industrial processes.

Reduction of Noise Transmission through Windows

There are several ways that one can reduce the sound transmission through a window. An increase in glass thickness will reduce the sound transmission and increase the STC value for the window, based on the Mass Law:

$$TL = 20 \log(m_s \times f) - 47$$

Where:
TL = transmission loss across the barrier (dB)
m_s = mass per unit area of the barrier
f = frequency of the incident sound wave

Therefore, if the mass per unit area is doubled, the Mass Law states that the difference between the transmission loss for a fixed frequency will be 6 dB. In real life, however, the Mass Law is not always followed. In some cases doubling the glass thickness will only yield a three to five unit improvement in the STC rating.

One reason for this is the "coincidence effect."[9] This occurs because glass will resonate or vibrate at a particular frequency. When this frequency matches that of an incoming sound wave, the sound will not be blocked significantly by the material. In a graph of sound transmission loss vs. frequency for regular annealed glass, this effect can be seen in a significant "coincidence dip" towards the higher frequency region.

The "coincidence dip" will move to lower frequency as the glass thickness is increased, more towards the region where the human ear will have increased perception. This becomes a serious problem when trying to improve the acoustical performance of the window, since the STC ratings are calculated to correlate with the human ear's perception.

The other drawback to increasing glass mass is the obvious increase in weight and thickness for a window. One would not want to have to use a 1" thick piece of glass for a simple window to achieve a desired STC rating, especially if the thicker glass means that the window now weighs hundreds of pounds! For this reason, increasing glass mass is not seen as the most effective way to improve the acoustical performance.

For insulated glass units, sound transmission reduction can be improved by increasing the air space. One obvious drawback of this approach is that there may not be enough room to accommodate the increased space. For instance, a double hung window made with ¼" annealed glass and a ½" air space may have an STC rating of 33. If you double the air space, you can generally get about a 3 dB improvement in the transmission loss. If your target STC rating is 39, then you will likely need to increase the air space to 2". If your system only allows 1 ¾" total window thickness, you would not be able to achieve this STC rating by increasing the air space alone. Doubling the mass of glass may also be impractical. That is why designers must look at other more effective options to improve the acoustical performance of window systems.

Laminated Glass for Sound Control

With glass lamination, the interlayer between the glass can provide improved safety and security performance by holding the glass together and keeping glass shards in place after breakage. In addition, the plastic interlayer can provide acoustical performance benefits. As mentioned before, glass will vibrate at a particular frequency, allowing sound waves to penetrate through the window without significant attenuation. The presence of a plastic interlayer between the two lites of laminated glass has a damping effect that reduces this vibration and thus reduces sound transmission. Sound waves can be absorbed by the plastic interlayer so they are not transmitted to the second lite of glass, and therefore not transmitted to the receiving room. In this way the two lites of glass have been "decoupled," so that you have the acoustical benefits of the additional mass of glass, but not the drawbacks caused by the shift in the "coincidence dip" towards the lower frequency sound waves.

Performance of Acoustic UV Interlayer in Different Window Systems

Table 6 shows the STC ratings for different glass configurations, and can give a general guideline on how much improvement can be obtained with each type of change to the system.

Table 6. STC Ratings for Acoustic Interlayer Laminate Configurations*

Configuration – mm	STC
6 mm monolithic	31
12 mm monolithic	35
3 / 0.8 / 3 – 6.8 mm total laminated	36
6 / 0.8 / 3 – 9.8 mm total laminated	37
6 / 0.8 / 6 – 12.8 mm total laminated	39
10 / 0.8 / 6 – 16.8 mm total laminated	41
3 / 0.8 / 3 / 13 AS / 6 – 25.8 mm total insulated glass	40
3 / 0.8 / 3 / 102 AS / 5 – 113.8 mm total insulated glass	50

* Testing performed at Riverbank Acoustical Laboratories, Geneva, IL

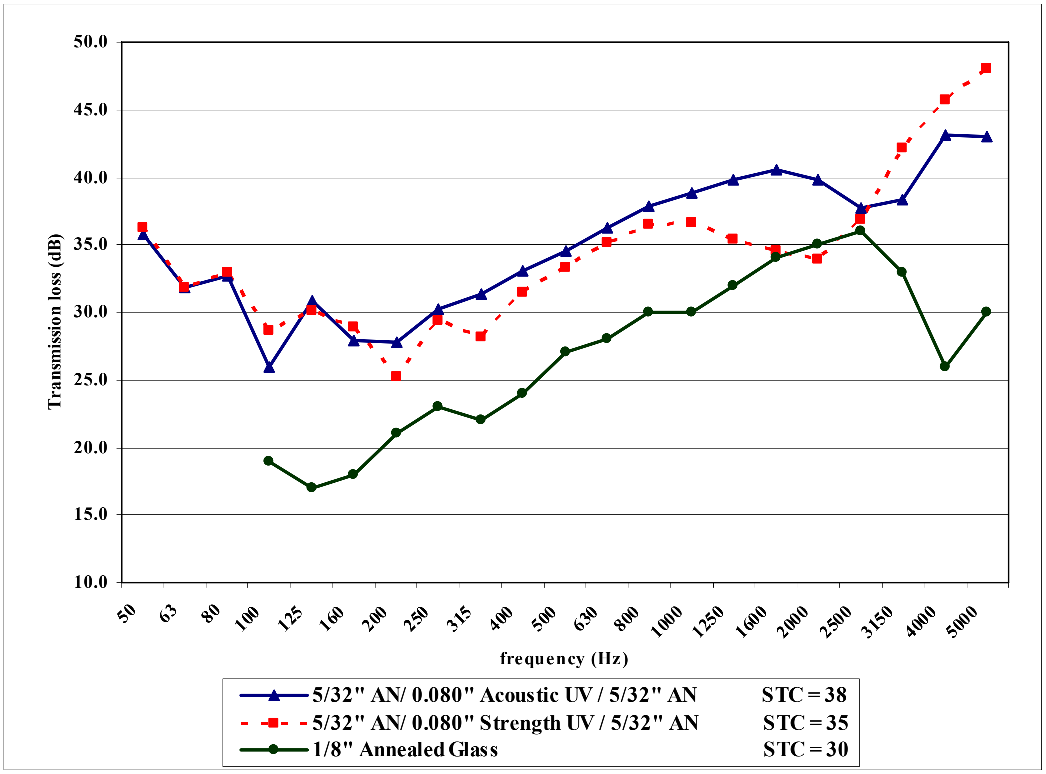
One can see the increase in STC rating with the use of laminated glass vs. monolithic glass, and the improvement with increased glass thickness for laminates. One can also see the improvement with increasing the air space in an insulated double glazing.

The Effect of Laminate Interlayer Type on Acoustical Performance

As one would expect, different types of laminate interlayers can have different acoustical performance. In general, a softer, more pliable interlayer will have better performance than a stiffer interlayer because it can more effectively dampen sound vibrations. This can be seen when we compare the acoustic performance of two types of UV curable interlayers.

One type is designed for safety and security performance, so it is a more rigid material. The other is a more pliable interlayer designed specifically for acoustic applications. Both materials are supplied in liquid form and pumped between two lites of glass. They are then cured under UV black lights for the same period of time to form a solid plastic interlayer. Figure 1 shows the sound transmission loss for the two different types of interlayers, in comparison to ⅛" annealed glass.

Figure 1. Transmission loss (dB) vs. Frequency for Laminated and Annealed Glass



It can be seen that both laminated pieces have much higher STC ratings than the single lite of ⅛" annealed glass. This is due to both the increased mass and the presence of the plastic laminate interlayer. For the strength interlayer, one can see the presence of the "coincidence dip" in the transmission loss curve between frequencies of 1000 and 3000 Hz. For the acoustic interlayer, the transmission loss is mostly higher than that of the stiffer strength laminate, and the "coincidence dip" has shifted up to 1600 to 4000 Hz. The dip is closer to that of the single ⅛" lite, but is less pronounced. This results in a higher STC rating of 38 for acoustic laminate, compared to the STC rating of 35 for the strength laminate.

It is up to the window designer to determine how best to achieve the desired acoustical performance, whether it is by increasing glass thickness, using laminated glass, using different types of laminate interlayers, and/or using an insulated unit with an increased air space.

Other design considerations, including the type of edge sealing, gasketing, insulated glass (IG) spacer systems, or the type of gas used to fill the IG will also play a role in determining how much noise attenuation can be achieved.

The use of laminated glass, however, has several advantages that make it an attractive option for noise reduction:

- Reduced space requirement
- Reduced weight
- Additional benefits from lamination: safety performance, security performance
- Reduction in the “coincidence dip”
- Maintain clear visibility

For these reasons, the incorporation of laminated glass in window systems for good acoustical performance is often seen as not just an option, but as a requirement. As we have seen, the glass laminated with a UV cured interlayer has excellent sound damping properties. In addition, this type of lamination has additional benefits of safety and security performance, along with a simple, cost effective method of production.

Conclusions

Glass lamination is one method by which manufacturers make stronger, more high-value windows and doors. While there are a number of methods in the industry for producing laminated glass, UV curing is one technology that can be used, and has been used for over 20 years. The process for making glass laminates with UV cured interlayers can be broken down into four simple steps: cleaning, assembly, filling, and cure.

Glass laminates made with UV cured interlayers pass a number of important national and international standards, including safety impact resistance, security impact, and weatherability. In addition, these types of laminates can be used in the area of noise control. The presence of a UV cured interlayer between two layers of glass can act as a barrier to noise by decoupling the two glass pieces and attenuating sound waves. This results in glass laminates with much higher sound transmission classification (STC) ratings, and therefore, superior sound control.

This gives glass laminators an additional benefit and a more valuable product. It is one more way that UV technology is used to make superior, high-end products.

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