3M Renewable Energy Division
Laminated Glass Processing Guide for 3M Architectural Glass Films
Technical Bulletin

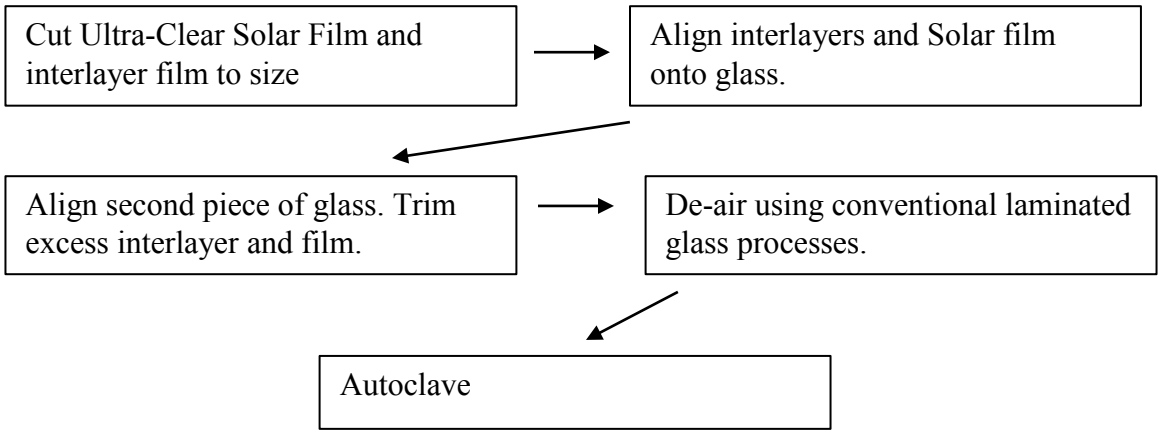
Architectural Glass Solutions

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

3M supplies two types of film for laminated glass constructions: Ultra-Clear Solar Film and two colors of Dichroic Film. Both films are based on 3M's non-metallic, multi-layer film technology that reflects infrared solar radiation while transmitting visible light. These films can be laminated into structural and non-structural architectural glazing applications.

This document provides an overview of the recommended processing techniques that should be employed to successfully incorporate 3M film into architectural glazing. The general recommendations in the main body of the document are applicable for both types of film. The appendix at the end of the document provides additional guidance regarding processing the Dichroic Films, which are thinner and for this reason require extra handling precautions. This document is not intended to be an exhaustive document, and laminators will find that they need to modify the processes herein to suit their needs.

Overall process flow diagram

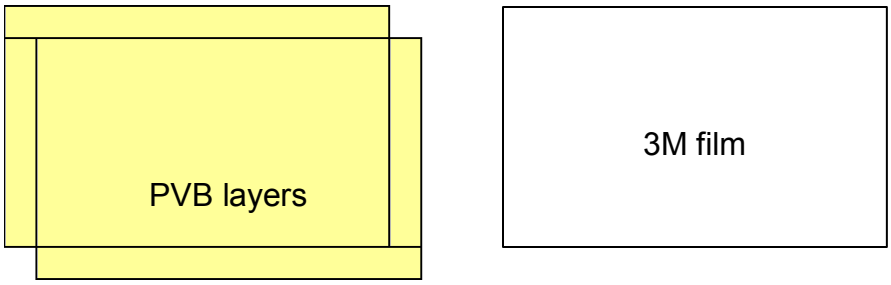


Notes:

1. The following instructions assumes some familiarity with the glass lamination process; for example, proper storage and handling of interlayer materials is not covered
2. In this document, "PVB" is at times used generically as the interlayer/adhesive material in the following procedure. 3M™ Ultra-Clear Solar Film has also been successfully laminated with other interlayer materials, including SentryGlas® from Dupont™ and Bridgstone's EVASafe®™. Contact 3M for a list of interlayer materials that have been tested. All constructions should be tested by the glass laminator to insure ultimate compatibility.

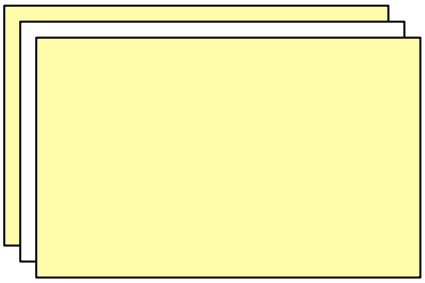
Step 1: Prepare films

- All laminations will require two sheets of interlayer material and a sheet of 3M film.
    - When making laminations with flexible interlayer materials up to 0.030" (0.76 mm) thick, it is usually acceptable to cut the interlayer and sheets so that they are slightly larger than the glass. Then all three layers can be cut so that they are flush to the edge of the glass.
    - When working with more rigid interlayer material like SentryGlas®, or with thicker interlayer material, it is best to pre-cut the interlayer material to the glass dimensions or to a size just slightly smaller than the glass.
- Care should be taken when handling the 3M film and PVB. To avoid aesthetic defects, the film should be handled on the edge as much as possible and should not be handled with bare hands – any fingerprints will be evident in the final lamination. The best practice is to wear gloves when handling UCSF. Avoid cleaning 3M film with solvents and tacky/adhesive coated rolls or cloths. Avoid cleaning with abrasive rubbing. 3M film may be cleaned lightly with lint-free, adhesive-free cloths or rollers. Compressed air may also be used to remove light debris. The source of compressed air should be oil-free.
- We have found that minor physical defects such as creases and dimples which are in the film will often be removed by the pressure and heat in the autoclave. However, it is still important to minimize defects of this type in order to assure a high-quality finished product.



Steps 2 & 3: Align interlayer films onto glass (PVB/3M film/PVB). Align second piece of glass

Apply the interlayer/3M film/interlayer in the same manner as you would PVB-only laminations. Trim all excess film or film and interlayer material to the edge of the glass. Ultra-Clear Solar Film will shrink slightly but in most cases this will not be noticeable so a good starting point is to trim the PVB and film to the same dimension. See the troubleshooting section at the end of this document for additional comments with regards to trimming excess PVB and solar film.



When trimming excess PVB and film, it is critical to make as a clean a cut as possible, and to change knife blades frequently. Particular care should be taken at the corners. If the 3M film or interlayer is pulled during the trimming process, then this will stress the film and this will act as a starting point for the film to wrinkle during the cure process.

Step 4. De-air

The glass/interlayer/3M film/interlayer/glass construction requires de-airing prior to autoclaving. The purpose of de-airing is to remove trapped air from within the lamination. In general, the same procedures can be used to remove air as is currently used in laminations that do not incorporate 3M films. De-airing methods include nip rolling, vacuum ring, and vacuum bag. Following is an outline of the most important de-airing processes:

Nip Rolling (Calender) Process

The loose sandwich of glass, interlayer, and film is first pre-nipped to remove most of the air within the laminated construction. This step can be done at either room temperature or after heating to approximately 35°C (95°F) in a short heating tunnel. The sandwich is then passed through a second, longer heating tunnel where the glass surface is heated to 60-75°C (140 – 167°F). At the end of this tunnel there is a second nip roll, which forces the glass/interlayer/film/interlayer/film sandwich firmly together. The laminated glass should have a slightly striped gray structure distributed uniformly over the entire area of the sandwich after this step. Also, a narrow zone around the perimeter of the assembly should be transparent. At this point, the edge of the glass is sealed and it is not possible to remove air from the sandwich.

Factors which influence de-airing include the flow properties and the surface roughness of the PVB, the flatness of the glass, the glass thickness, and whether the glass being laminated has a color or a coating. It may be necessary to modify the above temperatures or experiment with different nip pressures in order to achieve a lamination with securely-bonded edges with most of the entrapped air removed. If the interlayer manufacturer suggests specific procedures for nip rolling, it is best to follow these suggestions.

Vacuum Bag or Vacuum Ring Process

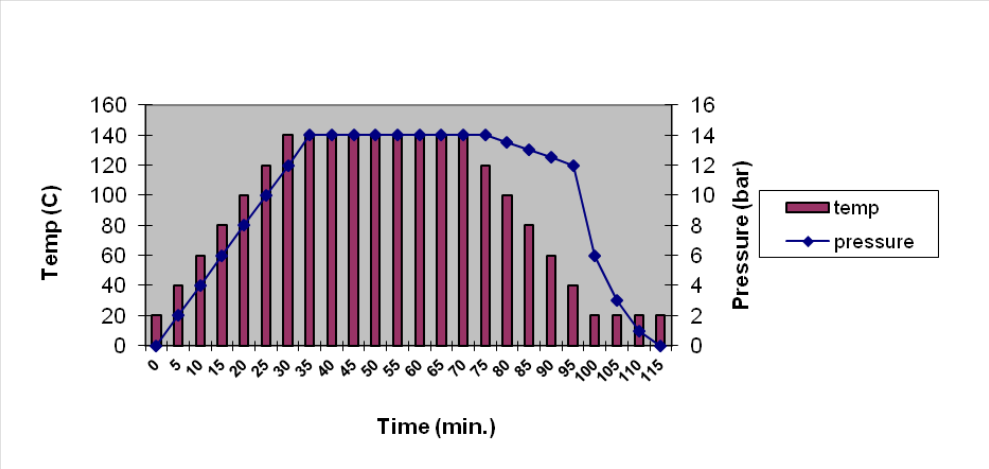
The overall concept is the same as for nip rolling, but vacuum is used to remove air. Vacuum is applied to the lamination before the laminate is heated in order to evacuate the air before the edges of the lamination begin to seal. This evacuation step should be a minimum of 10 minutes. Vacuum of 0.1 to 0.2 bar (1.5 to 2.5 psi) is maintained as the glass is heated to a surface temperature of 95 to 105°C (203 to 221°F). Pre-laminates made using the vacuum process are typically clearer than those done by the nip rolling process.

Some interlayer manufacturers recommend specific grades of their material where vacuum de-airing is used. As with the calender process, it is always advisable to follow the manufacturer's procedures when de-airing glass laminates.

Step 5: Autoclave

In the autoclave, the pre-laminations are heated under pressure to melt/cure the interlayer material, and to dissolve the remaining air in the material. The actual autoclave cycle used will depend upon the equipment itself, the interlayer material which is being used, the amount of glass in the autoclave, and the size of the glass laminates. In our experience, it is seldom necessary to change the standard autoclave process when running glass with UCSF. There are a few key guidelines which have proven to be successful for making laminations with 3M films:

- Shorter pressure ramp-up time seems to have a positive effect, "fixing" the UCSF in place, resulting in less film shrinkage and wrinkling.
- Ultimately, a holding temperature between 135 and 145°C (275 to 293°F) and a holding pressure of 12 -14 bar (175 – 200 psi) must be achieved in order to produce a well-adhered, wrinkle-free, and bubble-free lamination. Temperatures in excess of 160°C (320°F) should be avoided or excess film edge flow or yellowing at the edges of the lamination may result.
- As with laminations that do not contain solar film, it is important to allow the glass surface to cool to below 40°C (104°F) before releasing the autoclave pressure.



Above is an example of a typical autoclave pressure/temperature/time cycle. Actual pressures and temperatures can vary to some degree, but the shape of the curve will be similar in close to 100% of the cases.

Step 5A: Vacuum Kiln Process

Certain interlayer materials do not require pressurization in an autoclave in order to achieve their final properties. But the overall curve is similar in that the laminated glass goes though a ramp-up and hold period. In this process, the laminate remains under vacuum and a typical hold temperature is 115 to 135°C (239 to 275°F).

Troubleshooting Information
The following is intended as an introduction to resolving some of the more common defects in constructions laminated with 3M Ultra-Clear Solar Film. Contact 3M to discuss other possible troubleshooting suggestions.

- Orange Peel (also called Applesauce)
  - This is defined as a wavy blue/purple appearance within the laminate which is noted in reflection
  - The most common cause of this is the surface roughness of the PVB; if the de-airing process does not allow the PVB to flow into a uniform layer, the orange peel appearance will be evident.
    - This is more likely to occur when grades of interlayer material with high Rsm factor; that is, with larger areas between individual peaks in the interlayer.
    - Most grades of PVB have not proven to have a problem with orange peel, but if orange peel occurs consider a switch to a different grade of PVB. Contact 3M for suggestions.
    - Thicker PVB (0.76 mm or 0.030 in.) appears to be more resistant to orange peel formation.
- Wrinkles
  - Wrinkling can occur under the following autoclave conditions
    - Temperature too high (>145°C/293°F)
    - Pressure too low (< 11 bar/160 psi)
    - Hold time too short – as noted above, it is important to return the laminate to a temperature below 40°C (104°F) before relieving pressure
  - As noted previously, wrinkles are often the result of stress created in the film as it is trimmed. A sharp blade is the best defense against this. It is also important to cut smoothly through the corners of the lamination when trimming as this is the most likely place for wrinkles to begin.
  - There is a common phenomenon that takes place at the intersection of the glass and the rack. Because PVB is unable to expand in this area the film it puts some additional pressure on the solar film. The result is a slight color distortion in this area. In most cases, this distortion will be hidden after the glass is installed. For projects where no edge distortion is essential, please contact 3M for potential solutions.

Appendix: Best Practices - Preparing Laminated Glass with 3M Dichroic Films

1. The best appearance will be realized when laminating with SentryGlas® interlayer from DuPont. This has been found to give the flattest, most "mirror-like" final results. Some users have found acceptable results with EVASafe™ interlayer from Bridgestone, or with PVB. However, these interlayer materials will result in a lamination with "waves" present throughout the surface. 3M recommends that all processors test adhesion of the final construction in order to determine if the needs of the particular project, including safety requirements, can be met.

2. It is more critical to minimize the stress on the dichroic film during the laying-up and trimming process than with Ultra-Clear Solar Film. Stress is introduced from pulling or tugging on the dichroic film as it is being trimmed. Following are some techniques that have been used successfully to prepare laminations.

3. Preparing laminations:
    a. If it is desired to flush-cut the interlayer and film before the nip oven, the best practice is to pre-cut the interlayer material to the exact size of the glass before laying up the film. This is especially important when preparing laminations with SentryGlas®: It is impossible in our experience to cut through two layers of SentryGlas® and the film without pulling on the film. Some users have found that they can trim EVA/film/EVA or PVB/film/PVB successfully without pulling on the film, but our recommendation is to pre-cut to size when using these interlayers as well.
    b. After the interlayer is prepared, cut the dichroic film so that there is an excess of material around all the edges of the lamination. Lay up the lamination, then trim off the excess film using a very sharp blade, being careful to minimize any pulling on the film. Film should be trimmed flush with the glass edge. If vacuum de-airing is to be used, this is absolutely critical. If nip de-airing is used, then there is an opportunity to trim after the de-airing oven.
    c. An alternative trimming method when using the nip oven de-airing process is to wait to trim film until after the oven. There are two advantages to this. First, the glass/interlayer/film lamination is more tightly held after the nip oven, which reduces the opportunity for the film to slip while it's being trimmed. Second, any excess interlayer material which flows out of the lamination can also be trimmed away at this time.

4. De-airing
    a. Vacuum-bag de-airing: Trim the excess dichroic film so it is flush to the glass edge. Any overhanging material will be pushed on by the vacuum bag and a wrinkled area will likely form in the lamination. If tape is being used to hold the glass together prior to de-airing, it is especially important to trim the film flush in the taped areas.
    b. Nip/heated oven de-airing: Run the laminations so the glass surface temperature at the oven exit is approximately 60°C (140°F). In general, laminations with film should be run at a slightly cooler temperature than

laminations with no film. Thicker glass (>1/4" or 6 mm) will typically have better results with a hotter glass surface temperature.

5. Autoclaving
    a. **The key to success when autoclaving is to create a condition where the film is fixed in place prior to when it is exposed to high temperatures.** In practice, this means that final autoclave pressure should be reached before the desired soak temperature is reached. This can be accomplished in a couple of different ways:
        i. If the compressor on the autoclave is very efficient, then the ramp-up time for pressure will be short, and full pressure will be reached before the large mass of air and glass in the oven reaches a temperature of 90°C or 195°F.
        ii. If the pressure ramp-up cannot be accomplished before the autoclave temperature reaches 90°C (195°F), then the autoclave temperature should be set at 90°C (195°F) during the pressure ramp-up cycle. After final processing pressure is reached, then the temperature can be re-set to the final soak temperature.
    b. Follow the interlayer manufacturer's recommendations for processing pressure, soak temperature, and soak time.

6. Processing of tempered glass laminates
    a. Tempered (or heat strengthened) glass poses special challenges when laminating dichroic films because of the relative non-flatness of these glasses compared to annealed float glass.
    b. It is often necessary to use thicker interlayer sheets in order to "fill in" the waviness of the glass surface.
    c. If thicker interlayers are used, then the de-airing method will need to be changed to ensure that the interlayers flow adequately to insure a good seal around the edge of the lamination. This may mean that the glass surface will have a hotter temperature than the 60°C figure mentioned above.

7. Other considerations
    a. It is typical to see a slight waviness in the appearance of the final construction where the edge of the glass was in contact with the autoclave racks. This is caused by the rack restricting the flow of the interlayer material, which puts a slight amount of pressure on the film in this area. Following are two suggestions to reduce this:
        i. Use v-shaped supports under the glass edge
        ii. When preparing the interlayer, cut so that its area is just slightly less than the area of the glass, to allow some "room" for it to flow.
    b. We have seen in practice that small creases in the film will not be visible after the autoclave. But it is still important to avoid adding creases, dimples, or other defects when handling 3M dichroic films.

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98-0150-0274-8

Issue Date: 02/13