DuPont

Tedlar®

polyvinyl fluoride film

FRP Continuous Lamination Guide

Introduction

This guide provides technical information to the fiberglass-reinforced polyester panel (FRP) manufacturer who wants to laminate *Tedlar*® PVF films in a continuous process. Because there are many variations of the FRP lamination process, this guide only reviews the technology necessary to bond *Tedlar*® film to polyester resin.

For over 30 years *Tedlar*® film has been successfully laminated to fiberglass panels. It has substantially improved panel life in high humidity, high ultraviolet light, and corrosive environments. The FRP markets that *Tedlar*® films serve include signs (commercial and traffic), architectural components and structures (modular buildings, roof and wall systems, solar collectors, farm buildings, and garage doors), and industrial structures (greenhouses and factories). To meet these needs, *Tedlar*® film is manufactured in transparent, translucent, and opaque formulations.

Safety

Tedlar® film is not hazardous as shipped. Laboratory studies by DuPont and experience by DuPont and processors have shown that *Tedlar*® film, itself, presents no health hazards. At temperatures above 204°C (400°F) or upon prolonged heating, film discoloration and evolution of small amounts of hydrogen fluoride (HF) vapor may occur. The time-weighted average concentration of HF should not exceed 3 ppm vapor in air by volume, as prescribed by OSHA regulations (29 CFR 1910.1000). Further safety information can be found in the DuPont bulletin "Materials and Processing Information Safety Considerations" for *Tedlar*® film.

Processing and Materials

Process

Although panel manufacturing processes will differ somewhat, they typically have the common elements illustrated in **Figure 1**. They are: top and bottom film unwind stands with provisions for tension adjustment and preheat; resin and catalyst systems tailored to process needs; one or more feed lines to deposit catalyzed resin onto a heated lay-up table; an adjustable doctor blade that spreads and meters the resin on the carrier film; glass roving fed into a glass chopping system that randomly distributes glass fibers onto the resin; wet-out rolls to mix resin and glass; a nip roll to combine the top film with the glass/resin mix and bottom film; a hot air oven with three or more heating zones to control resin gel and cure points; tooling fixtures inside and outside the oven to gather and form the lay-up into the required configuration; a panel cooling zone; and a panel pulling and cutting system.

Operating conditions such as line speed, oven temperatures, and panel temperatures will differ with the process, the resin, and the panel weight and configuration. In general, experience has revealed that good laminates are produced when the resin gel temperature is 80–90°C (176–194°F) and the peak exotherm temperature is 150–165°C (302–329°F) just prior to exiting the oven. A typical panel temperature profile is indicated in **Figure 2**.

Handling the lay-up through the gathering and forming zones is generally the same as the production of a panel without *Tedlar*® film. Some adjustments in line speed, gathering and forming techniques, control of the gel position, and control of the panel temperature as it cures may be required. Gathering the lay-up early so that minimal contact with the tooling is needed near the gel point works well. The gel point position will vary somewhat with the panel weight and configuration. The optimum gel point position for a *Tedlar*® film panel is usually just inside or just outside the last top fixture, possibly a little further downstream than normal.

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Figure 1. FRP Process Diagram

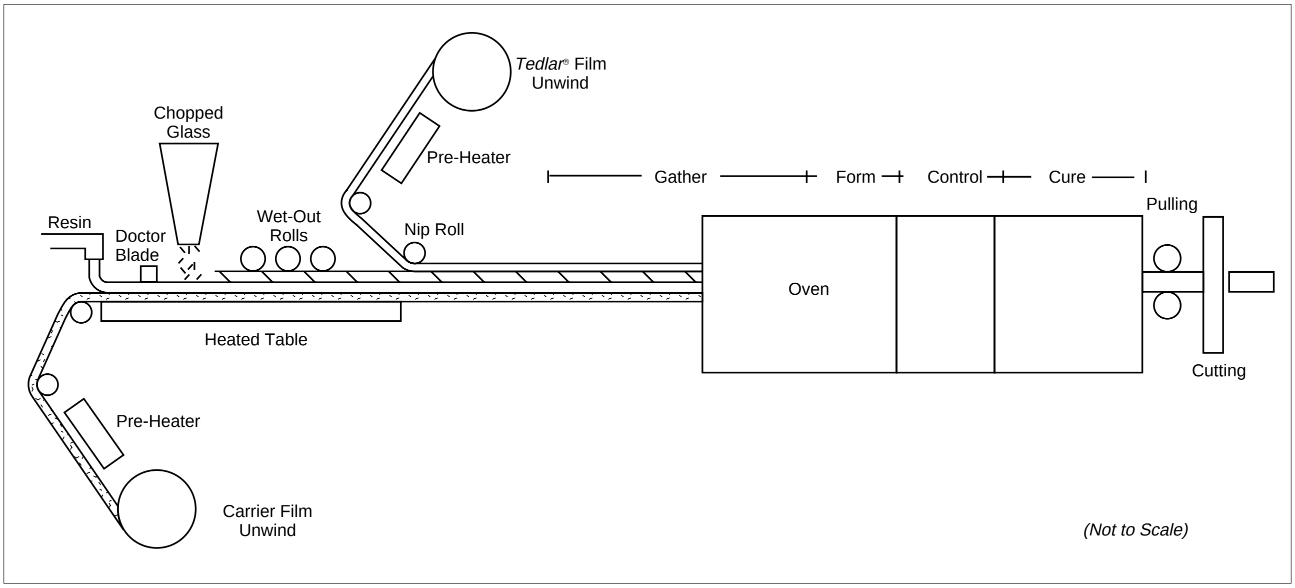
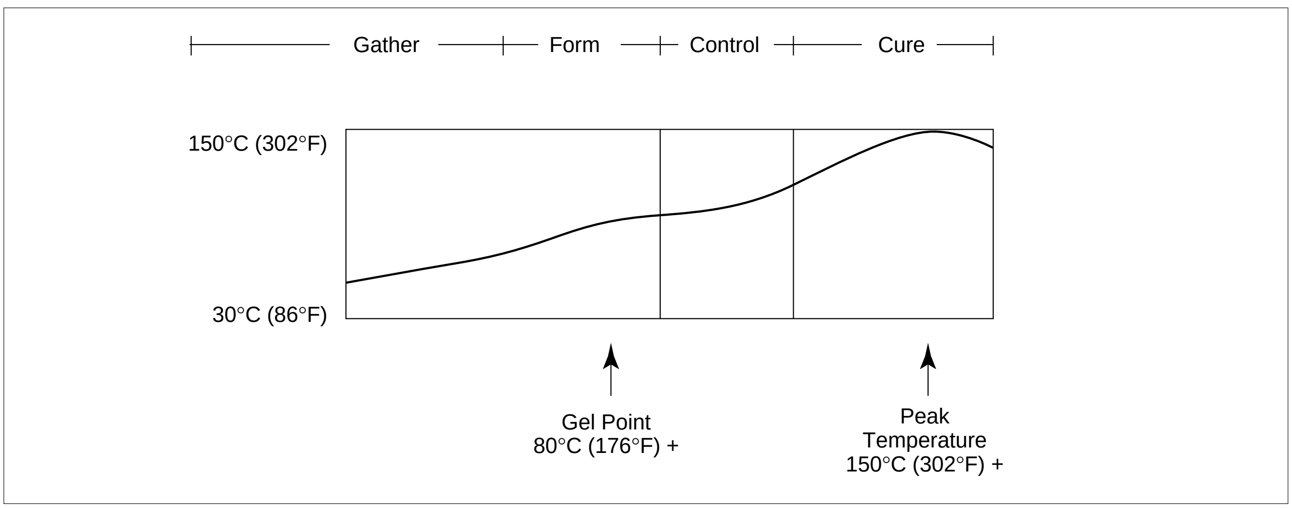


Figure 2. Typical FRP Panel Temperature Profile in Oven



The best quality laminate is produced when very little shrinkage and thermal stress exist between resin and glass and between resin and film. Panels produced with a proper balance of catalyst and heat, using the full length of the oven, have the best properties. Configuration problems, blistering, fiber prominence, discoloration, and a weakened *Tedlar*® film bond may occur if this balance is not achieved. Aggressively forcing the cure with heat can compromise panel quality when compared with panels made with less heat and an added second catalyst that kicks in as gel occurs. The reaction should carry itself as much as possible by its own exothermic heat, especially at the stage in the process just past the gel point. To ensure a complete cure, the temperature of the last oven should be as hot or hotter than the peak exotherm temperature.

Materials

Under the right conditions, most unsaturated polyester resins will bond well to *Tedlar*® film in the continuous FRP process. Panel resins generally have about 40% reactive monomer. Resins with styrene as the only monomer form a good bond to *Tedlar*® film, but do not weather as well (gradual color change and internal fiber prominence) as a resin that contains 10% or more acrylic monomer. Limited flammability (LF) resins contain halogenated compounds and do not typically weather as well as panels made from general-purpose resins. Opaque *Tedlar*® films bond well to these LF systems and protect them from weathering elements.

Tedlar® film FRP laminates are produced with two basic catalyst systems: 1.) a methyl ethyl ketone (MEK) peroxide or methyl isobutyl ketone (MIBK) peroxide catalyst with a cobalt compound promoter (i.e., cobalt naphthenate) and benzoyl peroxide, or 2.) a cumene hydroperoxide (CHP) catalyst with quaternary amine salt promoter, with or without a second catalyst. The catalyst initiates cross-linking of the polyester resin by the monomer to yield a solid material. The first curing system appears to have a narrow window of operability for good adhesion to *Tedlar*® film, while the second system is more robust. This seems to be related to their different viscous gel temperatures. The CHP system has a viscous gel temperature of ~80°C (176°F) and tends to be more effective in wetting-out the glass and *Tedlar*® film. The MEK peroxide system has a viscous gel temperature of ~70°C (158°F), gels quickly, and does not provide as good of a bond to the film and glass.

Many different types of carrier sheet have been used in the FRP business (i.e., cellophane, PVA, and polyester). There are no known restrictions for carrier sheets run with *Tedlar*® films. However, the thinner the carrier sheet the more difficult it is to handle a lay-up. For this reason, a thicker gauge of release film is recommended until one is comfortable with laminating *Tedlar*® film in a continuous FRP process.

Generally, the type of glass fiber selected is based on resin needs, product availability, and price. While glass type is not usually critical to adhesion, there is a possibility that the glass sizing or binder will influence adhesion to *Tedlar*® film. Variation in glass distribution across the sheet can also affect adhesion.

There are three *Tedlar*® film formulations made specifically for the FRP panel market—TUT10BG1 (transparent), TUW10BG1 (translucent white), and TWH10BS1 (opaque white). Light transmission data is plotted in **Figure 3**. Note that light transmission for TWH10BS1 is not depicted, as it is less than 0.1% across the represented wavelengths. The surface treatment of *Tedlar*® films for FRP applications has been optimized to give good adhesion to cured polyester resin in humid environments.

All three films are nominally 1 mil thick and are manufactured to have no transverse direction expansion at 60°C (140°F) and approximately 1% transverse direction shrinkage at 80°C (176°F). The machine direction shrinkage of *Tedlar*® film is greater than the transverse direction shrinkage at lower temperatures. See **Figure 4** for typical shrinkage of an unrestrained *Tedlar*® film designed for lamination to FRP panels. Film shrinkage is required to flatten the sheet and to allow the film to adjust to the shrinkage requirements of the particular system.

FRP Panel Evaluation

Achieving a suitable bond between the *Tedlar*® film and the FRP panel is a primary concern in the lamination process. A water soak test can be employed to evaluate the quality of *initial* adhesion. This test involves soaking segments of FRP panels clad with *Tedlar*® film in a 60°C (140°F) water bath for 4 hr, and in a boiling water bath for 24 hr. After each of these time frames, the samples are removed from the bath and cooled in a room-temperature water bath.

Figure 3. Spectral Transmission of TUT10BG1 and TUW10BG1 *Tedlar*® Films

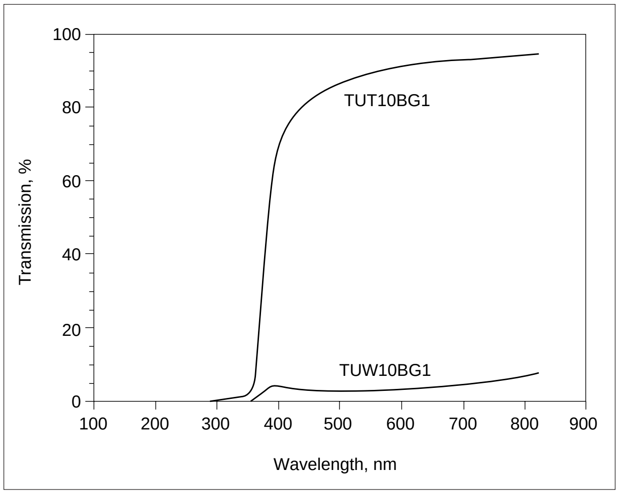
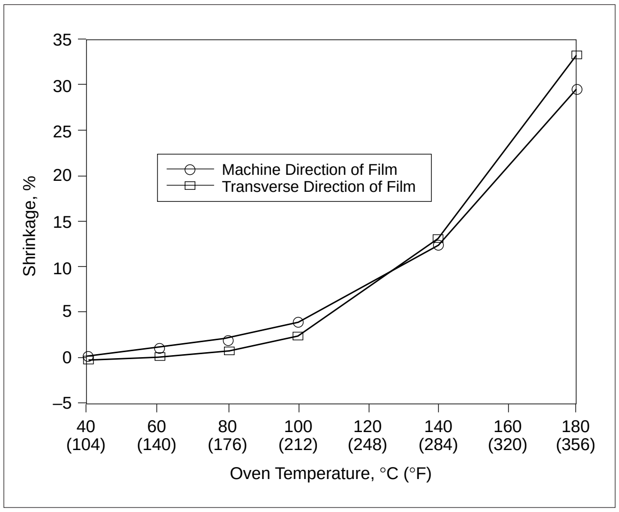


Figure 4. Typical Shrinkage of TUT10BG1 *Tedlar*® Film Designed for Lamination to FRP



While still wet, the samples are scored on the *Tedlar*® film side with a knife. A set of parallel lines, about 3 mm (1/8 in) in width, is cut in the machine direction of the panel. A second set of parallel lines (not intersecting with the first set of lines) is cut in the transverse direction of the panel. An attempt is made to pry the film up from the resin in these two areas. If the film will not separate from the resin, or if the film separates but breaks before more than 3 mm (1/8 in) of film have been peeled away, the initial bond is considered acceptable. It is recommended that several samples be cut out across the width of the panel and tested to ensure uniform adhesion from one edge to the other. It is also advisable to check adhesion of the slopes, peaks, and valleys of corrugated panels.

If initial adhesion is unacceptable, refer to the Troubleshooting Guide in **Table 1** for suggestions on improving the film-to-resin bond.

Long-term adhesion between the *Tedlar*® film and the FRP panel in the field is dependent on a number of variables, which include the previously mentioned manufacturing process and materials, as well as environmental conditions and installation factors.

Thermal history and intensity of light radiation play a large role in the performance of an FRP panel. Ambient temperature, moisture, exposure location, exposure angle, and exposure direction can impact the life of a laminate surfaced with *Tedlar*® film. Elevated temperatures, high altitudes, close proximity to the equator, and horizontal or near-horizontal surfaces constitute harsh exposure conditions.

Accelerated weathering can be a useful technique in assessing the potential life of an FRP panel surfaced with *Tedlar*® film. Ideally samples are weathered in a machine that emits wavelengths of light similar to those found at the earth's surface. An example of such a machine is one equipped with a xenon arc energy source that provides both moist and dry cycles. Accelerated weathering can take some time to complete; therefore, it is more often used as a tool to evaluate new products, or products in which a significant process or material change has been made.

Table 1
Troubleshooting Guide—Continuous Lamination of *Tedlar*® Film to FRP

Problem	Causes	Solutions
Poor initial film adhesion	Contamination of *Tedlar*® film	Check process for contaminated rolls, guides.
	Cure between resin and film is not optimized	Check the cure characteristics of the resin. Adjust time from gel to peak exotherm and location of peak exotherm as needed.
		Adjust resin gel temperature (near the last forming tools) to ~80 to 90°C (176 to 194°F) by changing oven temperature or line speed.
		Ensure that the panel temperature does not rise too quickly just past the gel point. Locate peak exotherm temperature just inside the oven exit. If a higher panel temperature is necessary to fully cure resin, consider adding a second catalyst; adjust oven temperature in last zone accordingly.
		Check that there is no scuffing or lifting of the film. If there is, move the gel point further downstream by increasing line speed or reducing oven temperature so that the panel does not snag on the forming tools; use fewer tools.

Table 1 *(continued)*
Troubleshooting Guide—Continuous Lamination of *Tedlar*® Film to FRP

Problem	Causes	Solutions
Blisters	Monomer flashing	If blistering is near the gel point, reduce panel temperature by decreasing oven temperature in the forming zone or by increasing the line speed. This will move the gel point further downstream. If blistering is in the control zone, decrease the temperature in this zone and adjust the temperature in the forming zone to move the gel point upstream. Raise the temperature in the cure zone after lowering the control zone temperature if the cure does not progress as needed.
Scuff marks	Upper tooling fixtures located too far past forming stage	Relieve pressure between tooling and panel by raising tooling in area of scuffing. Move the gel point further downstream if necessary.
Peaking	*Tedlar*® film shrinking too much in oven	Increase the *Tedlar*® film preheat. If the gel point is correct, lower the temperature of the hottest forming zone and raise the temperature of a cooler zone to compensate. If the gel is too tight (curing too early), lower the temperature of the hottest forming zone.
	Release film not shrinking enough in oven	Reduce the release film preheat.
Puckers (wrinkles in *Tedlar*® film surface only)	*Tedlar*® film preheat too high	Reduce *Tedlar*® film preheat.
	Tedlar® film not shrinking enough in oven	Increase temperature of oven zone where pucker marks first appear.
Resin beads (thick linear wrinkles on one or both sides)	Gathering problems	If bead occurs before the gel point, relieve pressure between the tooling and the panel. If necessary, tighten gel by decreasing line speed and decrease heat in gathering zone.
	Glass-to-resin ratio is on the resin-rich side	Increase the glass cutter speed, adjust line speed, and/or decrease the wet-out roll pressure.
	Tedlar® film or release film shrinkage is out of balance	See "Peaking" solutions.
Diagonal wrinkles	Friction between *Tedlar*® film and tooling fixtures	Look for small resin pockets trapped on upstream side of tooling. Reduce heat in the zone where the pockets are forming, increase gathering, check tooling alignment, and/or increase film tension.

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