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Multilayer Lamination Methods for PTFE-Based PCBs

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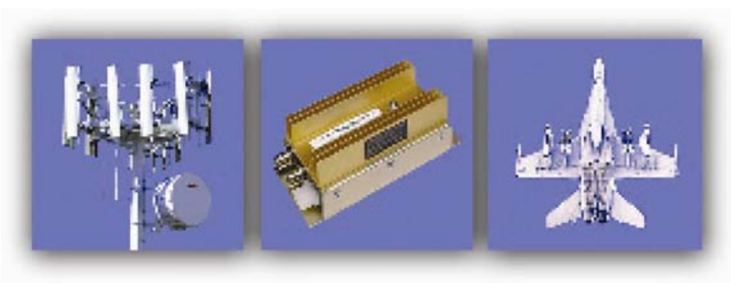

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Introduction
Teflon® (PTFE) microwave laminates are increasingly being used in both RF and digital designs. Higher frequencies and data rates require material with a very low electrical loss, consistent dielectric constant, and tight thickness tolerance. PTFE laminates have all of these characteristics and offer superior performance in many applications. Board designers are continually looking for ways to save weight and space in their applications and are moving toward higher count multilayer designs to solve these issues. Historically, PTFE multilayer designs have limited the number of layers within the design due to the ability of board shops to laminate PTFE designs with high layer counts. This article will review the different types of applications, bonding films and prepregs, equipment needs, and bonding methods that can be used to produce low and high count PTFE multilayer boards.

There are four general types of PTFE multilayers:

- Single lamination, all PTFE based laminates
- Single lamination, mixed dielectrics
- Sequential lamination, all PTFE based laminates
- Sequential lamination, mixed dielectrics

The most basic type of RF multilayer application is a simple three layer RF board that uses PTFE laminates throughout the build and is bonded together with a bonding film or fusion bonded in a single lamination. This type of board has been produced for many years, but not in what would be considered medium or high volume. Another type of board that has been developed in the last ten years is a mixed dielectric where the high frequency circuitry is printed on the PTFE laminate and is bonded to an epoxy laminate that handles the lower frequency signal or digital signal. The advantages of this type of multilayer are the space that it saves and the ability to bond with standard epoxy prepreg that is commonly used in most board shops.

Other designs may utilize combinations of PTFE laminates along with other types of laminates to produce a board with four or more circuit layers and usually requires the board to go through multiple, or sequential, laminations. Sequential lamination is relatively simple and has been used for years with thermoset epoxy-based laminates. A typical sequential lamination would be a several layers bonded together and then drilled and plated before having more layers bonded to it. With thermoset epoxy boards, the bonding, drilling, and plating sequence can be done as many times as needed until the board is completed.

Until recently, PTFE laminates have been limited to low layer count multilayer designs because of the difficulty of sequential lamination. The difficulty lies in the fact that the bonding films used to bond PTFE laminates together are thermoplastic, and any thermal excursions (another lamination cycle) above the melt point of the bond film will usually cause delamination. Some designs have been built using a two-step sequential bond by using a higher melt point bonding film for the first lamination and then using a lower melt point bond film for the second. However, for three or more sequential bond cycles, the best methods for sequential bonding utilize a thermoset bond ply or fusion bonding. Fusion bonding is a high temperature lamination of the PTFE resin system. Lamination temperatures are approximately 700° F [371° C] that exceeds the capability of most lamination presses in the industry, but it is an effective method for bonding PTFE laminates. In some cases, a skived film of PTFE is used at the bond line to enhance the fill capability around internal circuitry.

Equipment

The equipment needed to laminate multilayer printed circuit boards (PCBs) includes:

- Lamination press
- Press padding
- Separator plates
- Carrier plate (sometimes knows as caul plate or tooling plate)

Other peripheral equipment such as loaders/unloaders and separator plate cleaners are not discussed here.

Lamination Press

Lamination presses apply heat and pressure to the material being bonded in order to activate the mechanism that causes the inner layers to bond together. There are three basic types of presses in use today. The most basic press uses hydraulic cylinders to apply pressure to the press platens. The platens are heated by steam, hot oil, or electrical elements. A second type of press is basically the same except that it also has a vacuum chamber around the platens that assists in removing oxygen and volatiles prior to and during the press cycle.

A variation to both these presses is the addition of a transfer cooling press. The transfer cooling press is used when the bonded multilayer laminates are cooled below the melt temperature of the bond film or ply being used. The laminates are transferred to the cooling press to finish the cooling process under pressure. Water is sent through the platens of the transfer cooling press and cools the laminates to room temperature. The use of a transfer cooling press allows for greater throughput.

The third type of press is really not a press at all. It is called an autoclave and uses gas pressure and heat to bond the layers together. Very few autoclaves are in use in the printed circuit manufacturing industry; however, they have the advantage of applying more even pressure on the bond package.

Both the hydraulic and the vacuum assisted types of presses can be heated by the several methods mentioned above. Steam heat is rarely used in today's processes. Hot oil heating requires a boiler to heat the oil that is then pumped into the platens. Hot oil presses generally have better heat distribution than electrically heated presses but usually take longer to reach maximum temperature and to cool down to room temperature. Even so, hot oil presses are considered by many to provide more consistent bonding and are preferred. Maintenance of an electrically heated press is usually less complicated since the press does not need the separate boiler, pumps, or piping that the hot oil press needs.

The characteristics of the lamination press depend on the type of material and the size of the multilayer that is being bonded. Presses used for bonding epoxy based laminates or multilayer boards are usually vacuum assisted and often limited in temperature to a maximum around 400° F (204° C). This temperature is not high enough to utilize bond films such as CTFE or FEP, which are commonly used in bonding PTFE laminates, and is not nearly high enough to fusion bond PTFE. In order to bond PTFE using thermoplastic bond film or fusion bond, the press platens should be able to reach temperatures shown in the table below. The crystalline melt temperature of the bond film is slightly lower than the temperatures shown below. The actual melt temperatures are given in the data sheets listed later in this paper.

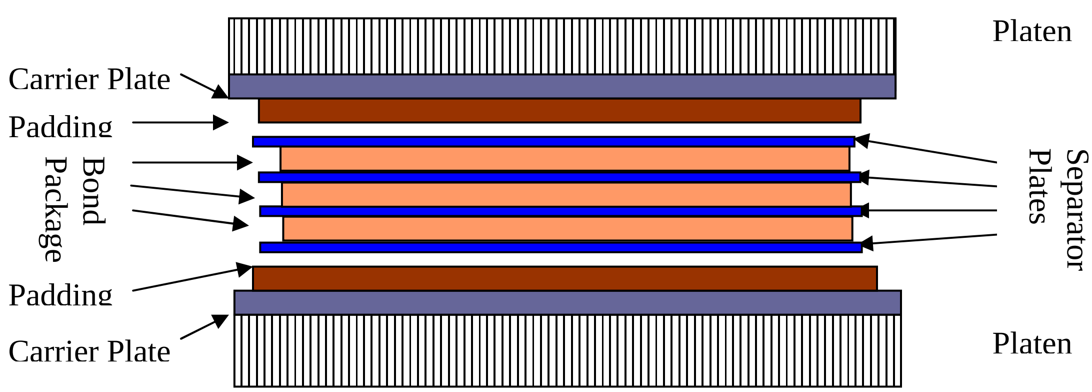
	Bond Film Type		
	CTFE	FEP	Fusion (direct, no film)
Press Capability Temperature	425° F (218° C)	525° F (274° C)	720° F (382° C)

The size of the laminate or multilayer being pressed determines the amount of pressure capability that the press must have. Most printed circuit board shops laminate a maximum size of 18" x 24" (457 mm by 610 mm). Bonding with CTFE or FEP bond films require the pressure to be from 100 psi to 200 psi (7 bar to 14 bar).

Fusion bonding can be done with pressures akin to thermoset prepregs namely 300 psi – 500 psi (21 bar to 34 bar) although for "delicate" work (perhaps boards with buried vias), lower pressures can be used (say 100 psi [7 bar]).

Most lamination presses currently used in printed circuit board facilities could be converted to achieve the high temperatures of fusion bonding; however, conversion to higher pressures needed for fusion bonding may not be possible or practical. The board size can always be reduced to effectively increase the pounds per square inch to the board, but at high pressures it may cause imprint damage to the platens, rendering them useless for larger laminates.

Multilayer bonding also requires a carrier plate, separator plates, and press padding. The carrier plate is a thick (1/4" to 1/2") steel plate that the multilayer stackup rests upon in the press as shown in the graphic below.



The separator plates separate the individual multilayer packages and provide a smooth surface against the copper foil of the multilayer board. It is imperative that the separator plates be cleaned and inspected for scratches and pits prior to lamination. Any surface defects on the plate will transfer to the copper foil of the multilayer board and may result in a rejectable condition. Separator plates are normally sent through a plate cleaner after every use and separated with a heavy paper when stacking for storage.

An important part of the lamination process is the padding used in the bond package. The purpose of the padding is to compensate for conditions such as unparallel platens, slightly bowed or warped platens, or thickness differences in the separator plates or carrier plate. The choice of padding depends on the melt or cure temperature of the bond film or prepreg being used. If the temperature of the press does not exceed approximately 450^{o} F (232^{o} C), the padding of choice is usually several plies of thick Kraft paper. For higher temperature applications, silicone rubber can be used as long as the temperature does not exceed its melt point. For very high temperatures, either a graphite-based or woven stainless steel pad must be used. (Taconic can supply high temperature press-pads, please contact Customer Service for further details).

Whichever padding material is used, its ability to compress and compensate will degrade and it will have to be replaced periodically. Padding may also slow the heat rise of the bond package and should be taken into consideration when deciding how much padding to use.

Bond Film/Prepreg Materials

For the purposes of this paper, a bond film is defined as thermoplastic film. A prepreg is a fiberglass-reinforced thermoset resin or a fiberglass-reinforced or -unreinforced thermoplastic resin combined with a thermoset resin to form a bonding sheet. The choice of a bonding film or prepreg is dependent on the application requirements. Thermoplastic bond films generally have a lower dielectric loss tangent and dielectric constant but cannot be easily used in sequential lamination or high temperature applications due to possible delamination of the package when reheated above their crystalline melt point. Thermoset prepregs are very suitable to sequential lamination given that they do not remelt once cured. The primary disadvantage of thermoset prepregs is the relatively high loss tangent. In recent years, two products have been developed to address these issues in order to design a product with the advantages of low loss tangent and suitability for sequential lamination. They will be discussed later.

Thermoplastic Bond Films

It is important to note that bonding films and prepregs are designed to flow into the structure left on the surface of the inner layers after the copper foil has been etched off, and therefore the bond is primarily mechanical in nature. Fusion bonding of PTFE does not rely on a mechanical bond, since it fuses the PTFE molecules together, and is a good method for sequential lamination. Several thermoplastic bond films are available for use in printed circuit board applications and include ChloroTriFluoroEthylene (CTFE), Fluorinated Ethylene Propylene (FEP), PolyTetraFluoroEthylene (PTFE), and Polyethylene. CTFE has been used for bonding PTFE multilayers since the mid 1970s and is more commonly known as Taconic Tacbond HT1.5, Arlon 6700, or Rogers 3001.

The melt temperature of CTFE is approximately 380^{o} F (193^{o} C) and therefore is usually not suitable for multilayer boards that will see processes with higher temperatures such as hot air solder leveling. FEP has a melt point of approximately 500^{o} F (260^{o} C) and is capable of handling hot air solder leveling temperatures. Using FEP in conjunction with CTFE allows limited sequential lamination. PTFE or skived, film is sometimes used in fusion bonding to improve flow around the traces of the multilayer board. The melt point of PTFE is above 630^{o} F (332^{o} C), so it will survive subsequent high temperature processes. With fusion bonding, no PTFE bond film is needed for ½ ounce (18 µm) or one ounce (35 µm) copper traces, but may be required if the trace thickness exceeds 2 mils [0.050 mm]. Polyethylene is used as a bonding film in very limited applications. The melt temperature of polyethylene varies from approximately 190^{o} F to 250^{o} F (88^{o} C to 121^{o} C), depending on the density of the resin and whether the film has seen irradiation treatment to increase cross-linking of the molecules.

The primary advantage of using thermoplastic bonding films is their low electrical loss factor. PTFE multilayer boards are well known for their excellent electrical properties, and using a high loss epoxy-based prepreg would defeat the purpose of the PTFE. Although the bonding films may not be available in dielectric constants to exactly match the laminate, the effect of any difference is negligible, or the board can be designed to take the difference into account.

Thermoset Prepregs

The advantages of thermoset prepregs are the ability to build sequentially laminated boards and a broad industry capability to laminate at their cure temperature. As mentioned previously, the primary disadvantage of thermoset prepregs is a relatively high electrical loss. The ideal prepreg would have low loss and the ability to survive multiple laminations without the concern of multilayer delamination.

Two products have been developed to take advantage of the thermoset properties for sequential lamination and the low loss properties of a PTFE-based material. W. L. Gore developed Speedboard® C as a low loss thermoset prepreg for bonding PTFE laminates together. Basically, Speedboard C is an expanded PTFE with a thermoset epoxy resin filling in the air pockets left after the PTFE expansion process. Speedboard C offers a lower dissipation factor than standard epoxy thermoset prepregs and thermosetting properties that enable sequential lamination of multilayer printed circuit boards. Speedboard C is relatively very expensive compared to other prepregs or bonding films.

Taconic has developed TacPreg® as a low loss prepreg for RF and digital applications. Unlike Speedboard C, the thermoset resin is coated on the surface of a PTFE prepreg. At the time of this writing, TacPreg is available with a dielectric constant of 3.2 or 3.4. However, the process of coating the epoxy resin on the PTFE prepreg can be done on prepregs with different dielectric constants, meaning that it is possible to have the prepreg closely match the dielectric constant of the core laminates within the multilayer printed circuit board. The BT epoxy resin on the surface of the prepreg enables multiple, or sequential, lamination at a lamination temperature and pressure within reach of most board shops. TacPreg is priced relatively inexpensive compared to conventional bonding films normally used to bond PTFE multilayers and is very inexpensive compared to Speedboard C.

Lamination Process

Successful lamination begins with the selection of the proper materials. As previously discussed, several bond films and prepregs are available to facilitate bonding of PTFE cores together. Preparation of the inner layers is critical to good bond strength. Inner layer cores should be ordered with copper foil on both sides even if foil is only required on one side. The reason for this is that a good structure on the surface of the core is necessary for the bond film or prepreg resin to flow into under heat and pressure and create a mechanical bond. The structure is created when the copper foil is laminated to the core by the laminate supplier. Once the copper is etched off, the dendrites that held the foil to the laminate are also etched and leave small indentations in the PTFE in which the bond medium flows. Subsequent processes or handling that disturbs the textured surface of the PTFE will result in poor bonding and possible delamination. If the copper foil circuitry needs to be cleaned, it is recommended that only a chemical cleaning process is used.

Variables that will affect the heat rise of the lamination package include the stack height, amount of padding, initial press temperature, and thermal input capability of the press. For lamination packages using a thermoplastic bond film or fusion bonding, the heat rise is not critical. For packages using TacPreg or other prepregs with a thermoset resin, heat rise is critical and the manufacturer’s recommendations should be closely followed. The number and thickness of bond packages within each opening should be identical in order to facilitate even heating of each package. The type and amount of padding used should be consistent and will affect the amount of heat transfer. If heat rise is critical, experiments should be done to determine how many laminates per opening and how much padding is necessary to achieve the desired heat rise.

Another important factor in lamination is the initial press temperature. Generally speaking, lamination packages using a thermoplastic bond film or fusion bonding will be successful when the initial press temperature is above ambient. For some thermoset prepregs, the initial press temperature must be kept to a minimum in order to prevent resin cure before desired. Consult the manufacturer’s recommended lamination procedure. In all lamination processes, it is important that a thermocouple be placed in the middle laminate of the middle opening of the press in order to monitor heat rise, dwell time, and cool down rate, given that it is the last laminate to reach temperature. Platen temperatures do not accurately reflect laminate temperatures. For high volume lamination that uses consistent stack height, padding, and laminate thickness and cure temperatures, the laminate thermocouple data and the platen temperature data can be correlated and the platen thermocouple used to control the heat rise, dwell time, and cool down rate.

There are various methods of bonding PTFE laminates to themselves or other laminate types. The bonding method of choice depends on the complexity of the PCB design. High layer count PCBs with buried or blind vias may require one method while a simple three-layer tin plated board will require another, which may be different than a three-layer board with a hot air solder level finish. It is important that the designer and printed board shop engineers understand the capabilities of the board shop and the complexity and final finish of the board prior to choosing the bonding method.

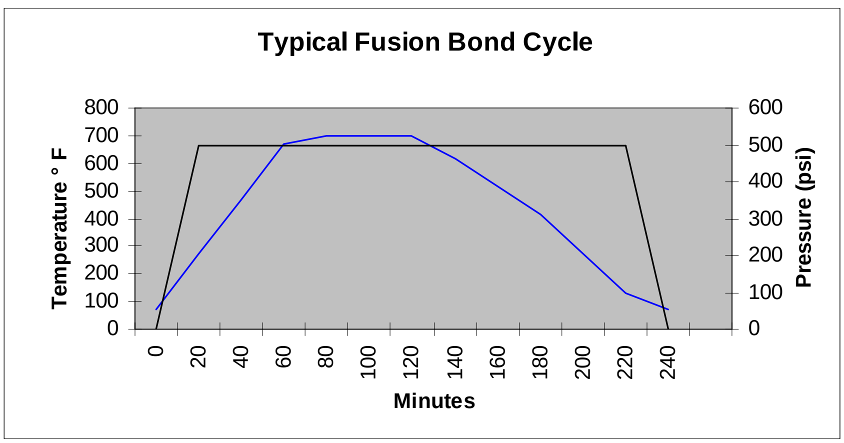
Fusion Bonding PTFE Laminates

Fusion bonding is a method of laminating PTFE laminates together without necessarily having to use a prepreg or bond film. The PTFE resin is heated to 700° F (371° C) under pressures exceeding 300 psi (20 bar), and the resin fuses together. This differs from laminating with bonding film in that bonding films flow into the structure of the PTFE surface left after the copper foil is etched off, thus creating more of a mechanical than chemical bond. The primary advantages to fusion bonding are the ability to sequentially laminate and the ability of the bonded package to withstand subsequent processes in excess of 550° F (260° C) without delaminating. The major drawback to the fusion bond method is the need for a laminating press capable of temperatures in excess of 700° F (371° C) and 300 psi (34 bar) pressure. As of this writing, only a few printed circuit board shops have presses with this capability however their numbers are growing.

It is recommended that inner layers use a light copper weight such as ½ ounce when fusion bonding to assure complete fill around the copper traces. Many sequential lamination designs require buried vias which increases the thickness of the copper due to the plating of the hole wall. In such cases, it is recommended that a thin film of skived PTFE be used to aid in filling around the traces. Skived PTFE is simply sintered PTFE resin in film form that is made by skiving (slicing a thin layer) a large billet of PTFE. Skived PTFE is available in a wide range of thicknesses and sizes.

Lamination

Etch the inner layers taking care not to disturb the surface of the PTFE after etching. Although the surface texture is not critical as with other methods of bonding, mechanical scrubbing may stretch the inner layer causing misregistration. If subsequent cleaning of the copper surface is necessary, use a chemical cleaning process. Bake the inner layers for 30 minutes at 220° F [105°C] to remove any moisture from the surface. The PTFE surface does not need special preparation. Lay up the bond package and place a thermocouple at the bond line of the middle laminate in the middle opening of the press. Place the bond package in a hot or cold press and apply full pressure of 300psi - 500psi [20bar -34bar] and maintain throughout the complete press cycle. Monitor the package temperature. When the package reaches 700° F [371°C], maintain the temperature between 700° F [371°C] and 715° F [380°C] for 60 minutes. Turn off the heat and allow the package to air cool to approximately 450° F [230°C] before quick cooling.



TacBond HT 1.5 Bond Film

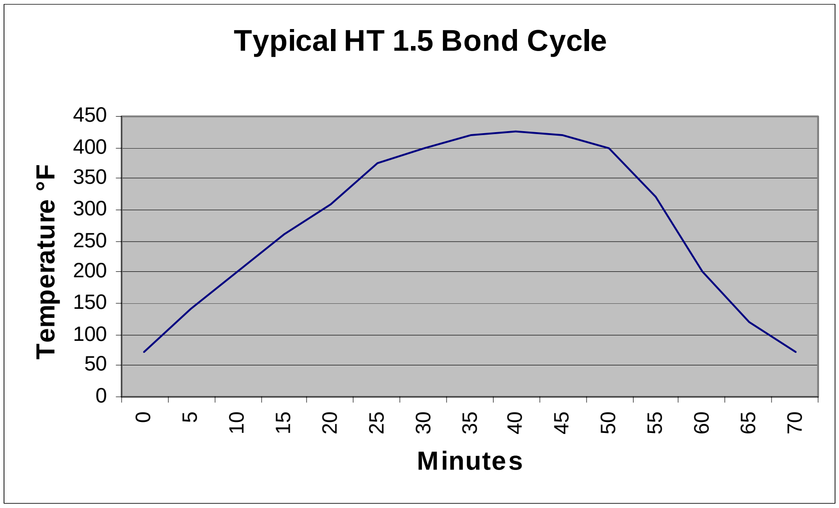
TacBond HT 1.5 is a CTFE (ChloroTriFluoroEthylene) thermoplastic film used for bonding PTFE laminates together. CTFE has been used for this purpose since the mid 1970's due to its excellent bonding and electrical characteristics. The crystalline melt point of CTFE is 397°F [202°C] which is within the press capabilities of most printed circuit board shops. TacBond HT 1.5 can be used on a wide range of PTFE based materials and closely matches the dielectric constant of Taconic TLY and TLX laminates. TacBond HT 1.5 is not recommended when post lamination process temperatures exceed 350° F [176°C] such as hot air solder leveling or for multiple sequential lamination designs.

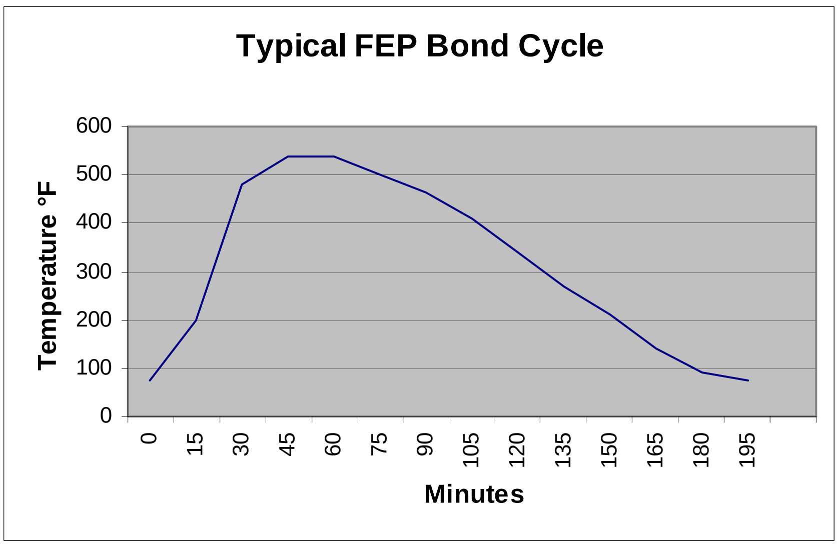
Lamination

Etch the inner layers taking care not to disturb the surface of the PTFE after etching. If subsequent cleaning of the copper surface is necessary, use a chemical cleaning process. Bake the inner layers for 30 minutes at 220° F [105°C] to remove any moisture from the surface. The HT 1.5 bond filmdoes not need special preparation other than tooling holes and relief cutouts, if required. Lay up the bond package and place a thermocouple at the bond line of the middle laminate in the middle opening of the press. Place the bond package in a hot or cold press and apply full pressure of 100 – 200 psi [7bar – 14bar] and maintain throughout the complete press cycle. Monitor the package temperature. When the package reaches 400° F [205°C] maintain the temperature between 400° F and 425° F [205°C to 218°C] for 20 minutes. Turn off the heat and allow the package to air cool to approximately 300° F [150°C] before quick cooling.

Property	Benefit
Closely controlled melt point	Predictable lamination cycle
Dielectric constant of 2.35	Very little effect on DK of total package
Dissipation factor of 0.0025	Excellent low loss performance
Chemically stable	Not affected by standard processing chemicals

TacBond HT 1.5 Typical Properties			
Property	**Value**	**Unit**	**Test Method**
Dielectric Constant	2.35		ASTM 3380D
Dissipation Factor	0.0028		ASTM 3380D
Thickness	0.0015"/0.038mm	Inches/mm	Starrett Micrometer
Water Absorption	0.0005	%	ASTM D570
Volume Resistivity	10^{12}	Mohm/cm	ASTM D257
Surface Resistivity	10^{10}	Mohm/cm	ASTM D257





TacPreg® TP-32 Prepreg

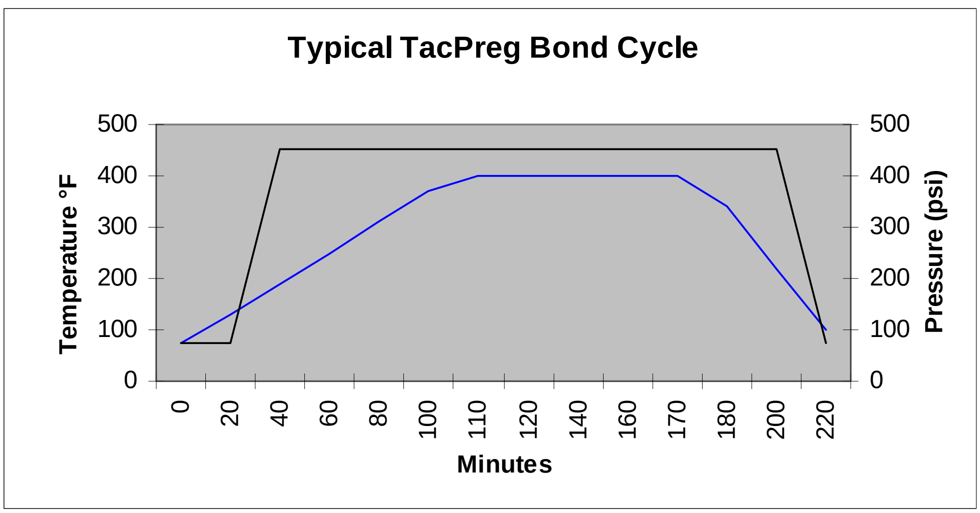
TacPreg TP-32 is a hybrid prepreg specifically designed to facilitate bonding of RF-35, RF-35P, RF-35A, and TacLam laminates for multilayer applications. The low loss PTFE/ceramic base coated with BT epoxy offers the excellent electrical performance of thermoplastics with the bonding advantages of a thermoset resin system. A further advantage is the ability to closely match the dielectric constant of the prepreg with the laminate.

Property	Benefit
BT epoxy coating	Excellent for sequential lamination Enables cap layer lamination designs
Dielectric constant	Matches DK of laminate
Dissipation factor	Good low loss performance
400°F [205C] Cure temperature	Wide industry capability

TacPreg TP-32 Typical Properties			
Property	**Value**	**Unit**	**Test Method**
Cure Temperature	392	°F	
Dielectric constant	3.20		IPC TM 650 2.5.5.3
Dissipation Factor	0.0050, 0.0030		IPC TM 650 2.5.5.3
Moisture Absorption	0.1	%	IPC TM 650 2.6.2.1
Flammability Rating	V-0		UL 94

Lamination

Etch the inner layers taking care not to disturb the surface of the PTFE after etching. If subsequent cleaning of the copper surface is necessary, use a chemical cleaning process. Bake the inner layers for 30 minutes at 220°F [105°C] to remove any moisture from the surface. TacPreg prepreg does not need special preparation other than tooling holes and relief cutouts, if required. Lay up the bond package and place a thermocouple at the bond line of the middle laminate in the middle opening of the press. A vacuum assisted press is recommended. Place the bond package in a cold press and apply 73 psi [5bar] of pressure until the package reaches 150°F [65°C] at which time apply full pressure of 450 psi [31bar] and maintain throughout the remainder of the press cycle. Monitor the package temperature. When the package reaches 392°F [200°C], maintain the temperature between 392°F and 425°F [200°C to 218°C] for 60 minutes. Turn off the heat and allow the package to air cool to approximately 300°F [150°C] before quick cooling.



About the Author

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