A New Lamination Method: Heating the Laminates through Metal Separators Equipped with Electrical Heating Medium

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Abstract

Prepregs used in the PCB industry possess various properties and need to be handled with care to maintain identical chemo-rheological properties to yield dimensionally stable laminates. A prepreg is a viscoelastic polymeric material which losses some portion of energy exerted on it. The characteristic viscoelasticity property depends on the chemical reaction and rheological flow path. To heat the prepreg more uniformly, a new method is invented, utilizing a metal separator as an electrical heating medium (Heated Electrical Separator -HES). The HES technology has been tested to demonstrate the improvement in temperature uniformity among the boards in daylight. A mathematical squeeze flow model is used to stress the consequences of different heating histories on the pressed laminate thickness.

Introduction

The modern electronic industry is driving to meet the never ceasing quest for a finer, faster and more functional circuitries. As a result, fine line fabrication to save every mils of inches of real estate are keys for survival. A host of new technologies are emerging into the industry, and printed circuit board fabrication technology is no longer such a technology as the name itself describes. More and more chip scale fabrication technology and environmental considerations are being made. However some of the areas are still at the primitive era of mid-1900s.

Lamination is the process that consolidates all the processed innerlayers into one, and it is one of the most important processes, as any single mistake cannot be corrected. In particular, dimensional stability and dielectric thickness are key parameters to lamination. In order to produce a reliable and high yield multilayer circuitry board, one must obtain precise dielectric thickness and dimensional stability.

Prepreg is most widely used in making the innerlayer of a multilayer board. The prepreg consists of reinforcing material and resin matrix. The reinforcing material such as glass fabric is impregnated with resin varnish of c-stage, and followed by drying and cure to some extent. It is very well known to the industry that the prepreg thus made is not fully cured. In case of epoxy prepreg of normal use, the extent of cure is in the range of 20 to 30%. In other word, the unreacted portion of the impregnated resin undergoes chemorheological changes. The chemorheological path is one of the important factors in obtaining uniform thickness and dimensionally stable laminate.

Also the cooling cycle is very important to dimensional stability. The difference in cooling path results in different levels of stress embedment in the laminate, unless it is properly relieved.

In this article, the author will explore the resin flow characteristics due to the temperature difference during the heating cycle and compare the temperature difference during the cooling cycle between conventional stainless steel separator and HES.

During Heating Cycle

Quite a few authors[1-5] studied the Hot press lamination process to control the resin squeeze out flow. However, in case of glass fabric containing prepreg, the complexity in the flow path due to the presence of the glass fabric, authors simplified the situation and solve the transport phenomena mathematically.

All the works may be different in accuracy in the prediction of the resin squeeze out and the resulting laminate thickness. However, they all emphasize the importance of temperature difference among the stacks in a daylight.

M. Chu and H. Tong[3] assumed the prepreg as a porous slab which is characterized by a constant permeability coefficient k for the flow in the lateral direction, r, and a large permeability for the flow in the thickness direction, z. From the Brinkman equation[6] and the Navier-Stokes equation,[7]

$$-r\left[\frac{\partial v_r}{\partial t}+V_r\frac{\partial v_r}{\partial r}+V_z\frac{\partial v_r}{\partial z}\right] = -\frac{\partial p}{\partial r}+?\left[\frac{\partial}{\partial r}\frac{1}{r}\frac{\partial (r v_r)}{\partial r}\right]+\frac{\partial^2 v_r}{\partial z^2}-\frac{\mathbf{V}_r}{k} \qquad (1)$$

$$-r\left[\frac{\partial v_r}{\partial t}+V_r\frac{\partial v_r}{\partial r}+V_z\frac{\partial v_r}{\partial z}\right] = -\frac{\partial p}{\partial r}+?\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{\partial^2 v_z}{\partial z^2}\right] \qquad (3)$$

where ρ is the resin density, t is the time, P is the dynamic pressure defined as the pressure above ambient and η is the resin viscosity which can be a function of time and the local temperature T_j, where j is an integer for the resin layers and a non-integer for the slabs. The radial and thickness direction velocities V_r, V_z are related from the continuity equation:

$$\frac{1}{r}\frac{\partial}{\partial r}(r v_r) + \frac{\partial v_z}{\partial z} = 0 \qquad (2)$$

From the appropriate boundary and initial conditions, they derived a theoretical equation for the thickness of a prepreg pressed. Conventional hot pressing involves N_I (≥ 1) prepregs and N_{IL} innerlayers per stack and N_D stacks per daylight. As the purpose of this article is to show the significance of the temperature different among the stacks to the chemorheology, the solution can be restricted to the case where there is only one prepreg per stack for the sake of simplicity. Then the solution of Equations (1), (2), and (3) can be obtained. For simplicity, M. Chu and H. Tong introduced Darcy's law to Equations in case $V_r >> V_z$, and obtained the solution as follow.

$$\dot{h} = f''\left[\frac{\Delta^3}{3} + 2k(a\Delta + H)\right] \qquad (4)$$

The glass fabric in a prepreg is assumed semi permeable. Δ is the thickness of resin layers above and under the glass fabric, H is the height of the compressed glass fabric, α is the slip coefficient between the resin and the glass fabric surface, k is permeability of the glass fabric, and *h* and *f''* is,

$$f'' = -\frac{4P}{R^2 h(t,T)} \quad , \quad \Delta = \frac{h-H}{2}$$

f'' is a function of z only at a set resin viscosity. And the rate of prepreg thickness change is,

$$\dot{\Delta} = f''\left(\frac{\Delta^3}{6} + ka\Delta\right) + kHf'' \qquad (5)$$

As an example, 1080 is used which is one of the most widely used glass fabric nowadays. The resin used is dysfunctional epoxy. Then Equation (4) can be solved with the *h*(t,T), which is calculated from the experimentally obtained temperature profile. For the calculation, the viscosity and temperature relationship Bartlett has proposed.[4]

$$h = h_\infty \exp\left[\frac{\Delta E_h}{RT} + tk_\infty \exp\left(\frac{-\Delta E_k}{RT}\right)\right] \qquad (6)$$

h_∞ and k_∞ are the constants related with zero time viscosity and viscosity rate, and ΔE_h *and* ΔE_k are the viscous flow and cure activation energies, respectively. These constants are experimentally found. Table 1 lists the values used for the calculation.

Table 1 - Physical Parameters and Data Used for the Simulation

h_∞	11.5 cp	k_∞	$10^{-14.5}$/sec
ΔE_h	26 kcal/mol	ΔE_k	–20 kcal/mol.
k	$1.3\text{x}10^{-7}$	H	1.15mils

α is assumed 1. Round shape prepreg is used for ease of mathematical approach. For the calculation 10 inches radius is used.

Equation (4) is numerically solved and the result is plotted in Figure 1. The thickness of the laminates pressed at the top and in the middle of a book is shown. The case illustrated is when one ply of 1080 is used for each laminate. In this case, both surfaces are contacted with solid copper and the resin flow is restricted. In a real situation, each stack contains multiple number of processed innerlayers and more than one ply is inserted per stack. Therefore the thickness difference from location to location will be amplified as the thickness of neat resin where two prepregs are in contact.

Figure 1 is the plot with all the prepregs in the middle and at the top in a book. The pressed thickness difference is about 2.5%.

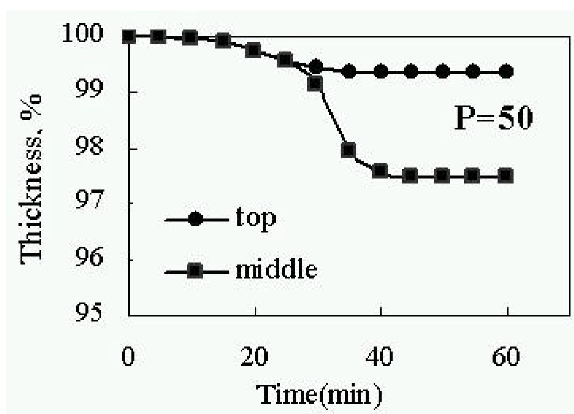

Figure 1 - The Difference in the Thickness between the Prepregs at Top and in the Middle in a Book

Figure 2 shows the importance of pressure on pressed thickness. If the press are increased to 200 psi from 50 psi, the thickness difference in the prepregs placed in the middle is as much as 5.5%. One of the reasons why high pressure is required in conventional pressing system comes from the fact that the minimum viscosity of a prepreg is strongly dependent on the heating rate. In direct heating cases such as conti-press, Adara and HES, there is only one minimum viscosity, assuming the temperature in a stack is uniform, which can be much lower than that of conventional system.

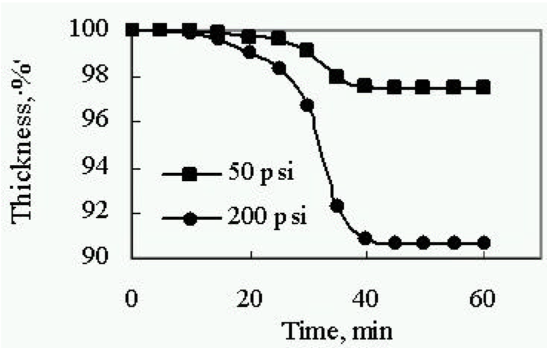

Figure 2 - Pressure Effect on the Pressed Thickness

Laminate dimensional stability is strongly dependent on the ratio of resin to glass fiber. The first step toward fabrication of a dimensionally stable laminate can be said thickness controlling. Following can be highlighted as key factors during heating cycle.

- Pressure is to be lowered as much as possible
- Temperature difference among the stacks of prepregs is to be lowered as much as possible.
- The neat resin layer on top of glass fabric is to be lowered as much as possible.

It is very well known that the temperature difference during heating cycle in conventional presses are in the range of 15 to 30°C around a nominal of 100°C. Figure 3 is a plot of the experimental data with HES system. In the experiment, HES separators, in Figure4B, are used in replacement of conventional stainless steel separators, and electrically connected with (C) in Figure 4. Figure 3 shows the maximum temperature difference among the boards during heating cycle is less than 5°C. With the temperature difference of this order, the pressed thickness variation was calculated to be less than 0.5%.

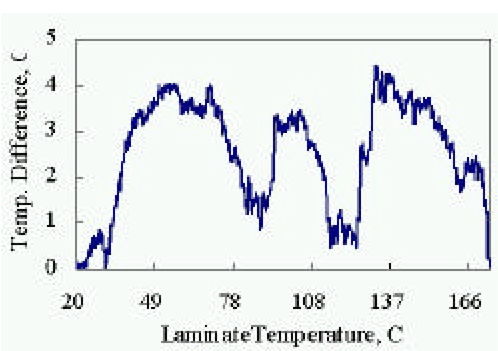

Figure 3 - Maximum Temperature Difference Among the Stacks During Heating

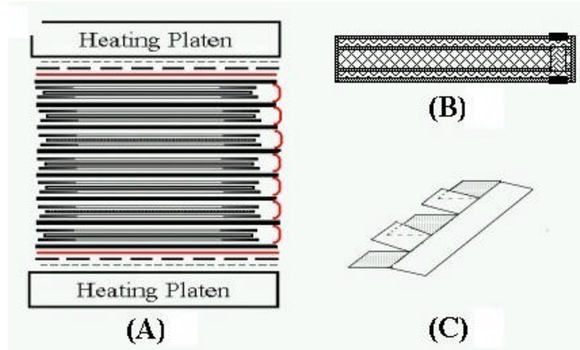

Figure 4 - Schematic Drawings of HES: (A) A Daylight Stacked with HES Parts, (B) HES Separator, and (C) Electric Connector Placed Between HES Separators

The temperature difference is even larger in a PCB shop as the stack includes already fully cured innerlayers of which thermal conductivity is much lower than the prepreg, which becomes soft and stays in a melt and rubbery flow stage until it is cured to some degree of cure. Therefore it can be conclusively marked that no dielectric thickness controlled multilayer board can be fabricated without control of the temperature difference among the stacks in a daylight.

During Cooling Cycle

Most of the dielectric material in use in the electronic industry is a polymeric material such as phenol formaldehyde modified resin, epoxy, polyimide, Teflon, and etc. One of the characteristic properties of a polymeric material is the viscoelasticity. It means it has both elasticity and viscosity. Figure 5 shows the typical strain-time relationship of viscoelastic materials. In other word, a strained polymeric material can never come back to its original position. If a copper clad laminate is heated and expanded, it does not resume its original shape.

However, in most of innerlayer lamination to a multilayer board, the coordinate of the innerlayer board shrinks in some location and expands in the other. It is because of the stress the innerlayer board has been embedded during the previous processes. The major source of the stresses is known to be the hot pressing lamination. And, in particular, cooling cycle is most susceptible. The sources of the stress during cooling cycle are;

- Mismatch in the CTE between the metal separator and the laminate.
- Temperature difference within a board.

The stress sources above cannot be avoided. If a polymer film is inserted inbetween the metal separator and the pressed laminate, the stress build-up can be minimized. Once stress is embedded in a laminate, some portion of the stress is not recovered rendering dimensional change in a laminate. Therefore the temperature difference among the boards during cooling cycle results in different level of stress build up in the laminate, and thus the strain (the coordinate shift in other words) of a laminate is different from one to another. Figure 5 shows the strain-time relationship for a generalized mechanical model.[7]

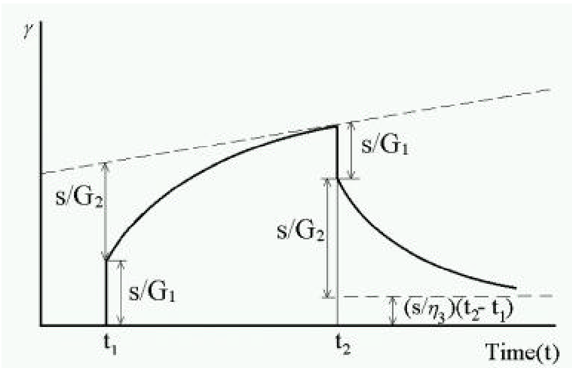

Figure 5 - Strain Time Relationship for a Generalized Mechanical Model

Therefore, during in order to obtain a dimensionally stable laminate, cycle should be such that the cooling paths of the laminates in a book are to be as much the same as possible.

Figure 6. is the experimental data of the temperature difference among the laminates in a book during cooling cycle. Conventional cooling cycle and that with HES separator are compared. A daylight inserted with a book stacked with HES seapartors (B) in Figure 4, and electric connectors, (C) in Figure 4, is shown in (A) in Figure4. The laminates were held at 170°C for an hour for curing before cooling water was introduced to the platens at top and bottom of the book. It took about 40-50 minutes to cool the laminates in the top of the book to 100°C. Conventional pressing system uses in most cases stainless steel plates as a separator. And the cooling is done through conduction from the cold platens. Heat flows from stack to stack including stainless steel plate and to the platens. What make things worse is the cushion pad inserted at the bottom and top of the book. In the experiment, HES also used cushion pad only to compare the fin effect through the electric contact shown in Figure 4.

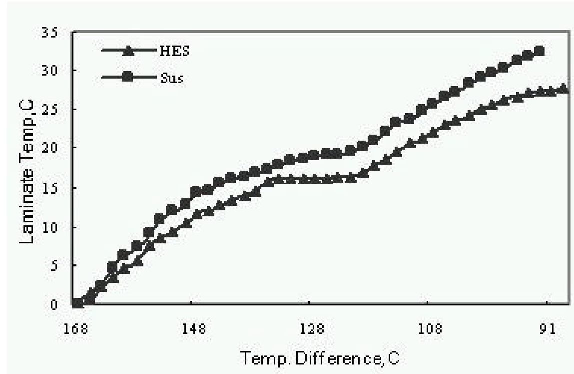

Figure 6 - DT's During Cooling Cycles Between Stainless Steel Separator and HES - Data is Obtained from the Boards at the Center of a Book

Both conventional and HES systems show quite a large difference in temperature among the laminates. The most important temperature range is in between 150°C and 120°C. In this range, HES showed about 3 to 5°C lower temperature differences.

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