Rheology Materials in Motion, Part II

Applying the science of *rheology* to the PCB lamination press.

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Part I of this article, which appeared in the May 1993 issue, defined rheology as the science of material deformation and flow and viscosity as the ratio of shear stress to shear rate. The parallel plate rheometer was recommended as an instrument for measuring resin viscosities and as a model for the production lamination process.

The lamination press may be considered as a rheometer of sorts. While it deos not provide units of viscosity, observations of the type and the amount of flash around the edges of laminate books provide the lamination engineer with quick theological information about the press cycle. The amount of flash shows whether resin flow is excessive, inadequate, or sufficient as a qualitative instrument, the edge flash can be used to determine whether the press cycle is providing consistent resin flow.

Too much flow can stem from excessive pressure or rapid heating, causing resin to exude onto the press plates and encapsulate the parts and the caul plates. In addition to unproductive press maintenance time, high resin flow results in thin or severely tapered product. A slower heating rate with decreased pressure can decrease the flow and result in flatter laminate. When the resin Flow is too low, evidence of dry corners, partial lack of bonding, or voiding in low-pressure areas can usually be seen, and boards can exhibit poor- interlaminar shear strength. Faster heating rates and higher pressure are the usual fix.

Fluidity Studies

Table 1 lists the effects of opposing press heating profiles. Fast heating rates provide more flow, but extremes can induce so much flow or such uneven flow in a multilayer package that dryness (resin-starved glass 1. voids (gel occuring too rapidly). or thickness tolerance) problems are produced. The fast temperature rise in creases the cross-linking reaction rate, brings the material to the gel point faster, and decreases working time. At a a slower heating rate. prepregs become less fluid, reducing the amount of' flow and flash during lamination. If the heating rate is too slow, however, there may be voiding, incomplete encapsulation of traces, or poor innerlayer adhesion.

In the region where the resin starts to soften and flow as an elastic material. viscosity drops from about 10 poise to 10^2 to 10^3 poise, where gelling reactions begin and viscosity starts to increase. The gel point defined as

Cycle Type:	Advantages	Disadvantages
Fast heating rate	• Better filling • Better wetout • Less voiding	• More movement • More taper • Faster gelation • More stress • Glass crushing copper • Warpage
Slower heating	• Longer work time • Less movement • Less stress • Thickness control • Flatness	• Lower fluidity destroys oxide • Poorer wetout • Dryness • Voiding • Poor adhesion to oxide • Poor thermal resistance

the point where storage and loss moduli have the same value and tan Delta = 1. The gel point and the unset of flow for a polyimide resin system are about 50° F higher than for an cpoxu system. For the former, maximum fluidity (inverse viscosity) happens to occur where the difference between product and platen temperature is very small, resulting in a heating profile slower than that of a lower temperature epoxy system. This explains why a slightly faster heating rate is specified for some polyimides-the heating rate must be faster to get a similar viscosity profile. Removing press padding to increase the heating rate can also change pressure distribution and is some what limited in the amount of heat increase it can provide at higher temperatures. The most effective process change is usually to increase the starting platen temperature, where fluidity occurs in a higher temperature region.

The Kiss Cycle

Fluidity profiles support the traditional kiss Cycle, where high-pressure application) is delayed until a product temperature of 190° to 210° is reached for epoxy and 265° F for standard polyimide. Full pressure is applied just as the resin becomes fluid but before the resin reachre its minimum melt viscosity and starts to gel. If full pressure is applied at higher temperature. working time is lost and voids might result.

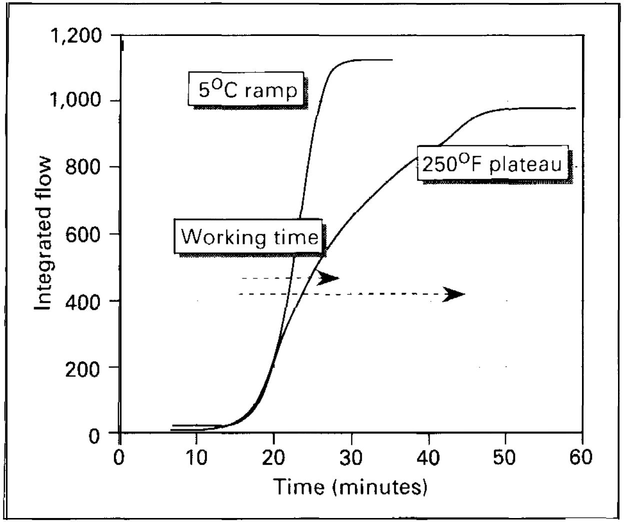

Figure 1. Straight ramp vs. 250°F hold epoxy prepreg

By waiting until the resin softens to apply full pressure, the kiss cycle does several things. The greater fluidity of the melt creates less shear stress in the elastic melt region and less glass reinforcement stretching. When the parts are cooled and pressure is removed, less "snap back" occurs and registration is improved. Use of a kiss cycle also allows the resin to work and wet in a more laminar flow, providing better filling of details and often improving bond strength by reducing shear on black or brown oxided innerlayers.

The Plateau Cycle

The fluidity curve can also be integrated to derive a fluidity time interval or integrated flow index:

$$IF = \int \frac{1}{n} \, dt$$

This integral is a valuable tool for comparing relative changes in resin flow between press cycles. Experimental work has shown that plateau cycles can be used when a particularly difficult fill configuration requires a lot of fill (e.g., heavy opposing copper planes) and when excessive resin flow results in poor dielectric thickness control and crushed or deformed innerlayers.

In Figure 1 the package is quickly heated to a temperature just before the point of minimum viscosity. This fast temperature rise provides the advantage of a lower minimum melt viscosity than is furnished with a slow heating rate where the resin is thermally aged in a slow heating ramp. (This explains the higher melt viscosities with slower heating rates.) Since the package is not being ramped with additional heat, there is a slower reaction rate and a longer gel time. After a plateau time of 15 to 25 minutes, the plateau cycle continues to final cure,

The plateau cycle has the advantages of both the fast heating-rate-cycle (for low viscosity] and the slow heating rate cycle (for longer working time) . As a result, wetting is improved, and more uniform printed circuit hoard resin retention provides for better thickness control.

Summary

Prepreg rheology provides the lamination engineer with several perspective views of the lamination process. The parallel plate rheometer offers the advantage of observing within the instrument the effects of a process change. Modeling can be done on a laboratory instrument without putting expensive product at risk.

More educated process changes can be made with rheoiogical information. An understanding of the critical rheological parameters of a given resin system allows for a robust lamination process. As circuit configurations change, an understanding of resin rheology can be used to counterbalance rheological effects. Pressure application temperatures (kiss cycles) and plateau cycles can be used to push prepreg to new performance levels. FAB

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