

## Chapter 6 Conclusions

The goal of this research was to demonstrate that waterborne latex epoxy impregnating resins meet or exceed the adhesive and dielectric performance of solventborne resins in PCB applications. The key differences between these types of resin have been identified as:

- a) the dissimilar physics of film formation leading to different distributions of DICY curing agent during processing and in the final cured system
- b) the presence of residual surfactant in the latex resin and its role in adhesive performance

Distinct DICY crystal-related void morphologies in the bulk of the neat latex resin system led to greater moisture sorption, thereby degrading the dielectric performance of the material. No such DICY morphologies were observed within the bulk of the glass/epoxy laminates, but surface segregation of the curing agent was found to locally degrade the copper foil/laminate peel strength. The process of surface DICY crystal formation during the drying of glass prepreg sheet was related to a threshold concentration of the curing agent in the impregnating latex resin formulation and the conditions of the drying environment. A two-stage drying model was successfully employed both as an engineering aid in identifying suitable drying conditions for the impregnated glass and as an analytical tool to gain a better understanding the drying and coalescence processes. The application of the two-stage drying model, in conjunction with gravimetric drying data, led to the following conclusions about the drying of latex epoxy resins:

- 1) Conditions favoring faster drying (higher temperature and lower relative humidity) lead to the rapid formation of a coalesced skin layer of latex resin, thereby trapping the curing agent in the bulk and reducing the surface deposition of DICY by percolating water.
- 2) Although the drying rates of latex resins were retarded by the presence of surfactant, no surface segregation of surfactant was observed. Instead, the surfactant is believed to remain concentrated in a receding wet zone until it is driven to the surfaces of the glass fibers upon the completion of drying.

The impact of different DICY distribution between the solventborne and latex resin systems, and the presence of residual surfactant were found to play a role in the adhesive PCB laminates. Adhesive strength of the copper foil/laminate interface was evaluated by a 90° peel test as part of two different studies. The first study was an analysis of the viscoelastic response of the interface during peel in which tests were conducted at varied temperatures and peel rates. A second study evaluated the durability of the copper/laminate interfacial peel strength as a function of aging time at elevated temperatures. The observations from these two adhesion studies and the analysis of the resulting failure surfaces by several techniques, in conjunction with a DMA analysis of the postcuring behavior of the laminate substrate, led to the following conclusions:

- 3) The surfactant acted as a plasticizer to toughen both the bulk resin and the fiber/matrix interphase, resulting in larger observed peel strengths in the latex resin impregnated materials relative to the solventborne-impregnated system. This toughening effect was evident in both the viscoelastic and the thermal aging studies; the increase in relative peel strength was maintained throughout the aging study in systems clad with brass-stabilized copper foils. Large-scale surfactant migration to the copper/epoxy interface was doubtful, since no surfactant-related weak boundary layer was observed
- 4) It is hypothesized that DICY segregated to the glass fiber surfaces during drying of the solventborne resin impregnated cloth. During cure this DICY layer formed a highly cross-linked fiber/matrix interphase which was brittle relative to the surrounding bulk matrix resulting in greater interfacial fracture during peel.
- 5) Surfactant segregated to the fiber surface during coalescence to form a highly plasticized fiber/matrix interphase during the initial cure of the latex impregnated laminates. This surfactant segregation, in concert with a homogeneous distribution of DICY in the cured latex resin bulk, led to the formation of a relatively high  $T_g$  matrix phase. As the laminate was postcured, the surfactant migrated into the bulk to yield a more homogeneously plasticized epoxy matrix.

Dielectric measurements of neat resin and laminate materials, performed using DEA, resulted in the following observations:

- 6) The 100 kHz dielectric constants and loss factors of the model resin-impregnated laminates met the performance criteria set forth in the standards literature for PCB substrates of their class, regardless of surfactant content.
- 7) The results of cooperativity and Fox equation analyses, based on the electrical loss modulus representation of the dielectric data, support the findings and hypotheses of conclusions 4) and 5) above.

Overall, the adhesive performance, adhesive durability, and dielectric properties of PCB systems fabricated with model latex epoxy resin, containing native surfactant (5 wt %), met or exceeded the performance of an equivalent solventborne resin impregnated system.