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MOISTURE ABSORPTION AND BAKEOUT CHARACTERISTICS
OF RIGID-FLEXIBLE MULTILAYER PRINTED WIRING BOARDS

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Topical Report
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Prepared by J. W. Lula

Moisture absorption and bakeout characteristics of Allied-Signal Inc., Kansas City Division (KCD) rigid-flexible printed wiring boards were determined. It was found that test specimens had absorbed 0.95 weight percent moisture when equilibrated to a 50 percent RH, 25°C environment. Heating those equilibrated specimens in a 120°C static air oven removed 92 percent of this absorbed moisture in 24 h. Heating the samples in a 80°C static air oven removed only 64 percent of the absorbed moisture at the end of 24 h. A 120°C vacuum bake removed moisture at essentially the same rate as the 120°C static air oven bake. Conformal coating the samples with parylene slowed the absorption rate by approximately 50 percent but did not appreciably affect the equilibrium moisture content or the drying rate.

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SUMMARY

Absorbed moisture affects rigid-flexible multilayer printed wiring boards (rigid-flex pwb) in several ways. Moisture can cause delamination, blisters, measles, raised lands, misregistration, blowholes in solder joints, and lowered insulation resistance. Oven bake cycles are essential in the rigid-flex pwb manufacturing process to minimize these problems. This project determined moisture absorption and bakeout characteristics for Allied-Signal Inc., Kansas City Division (KCD) rigid-flex pwbs so that oven bake cycles could be accurately specified.

Test specimens were cut from panels having standard KCD rigid-flex pwb construction. The structure includes a Kapton flexible circuit in the center and polyimide/glass rigid layers on the outside of the pwb. The polyimide/glass outer layers are bonded to the flex-circuit with epoxy/glass no-flow prepreg. Overall laminate thickness is 1.14 mm.

The test specimens initially were dried by baking in a static air oven for several weeks at 135°C. These samples were then placed in a 50 percent RH, 25°C chamber and weighed periodically over 3 months. After the weights had stabilized, one group was baked at 80°C in a static air oven. A second group was baked at 120°C. A third group of samples was baked in a vacuum oven at 120°C. After 24 h, approximately 92 percent and 64 percent of the moisture was lost in the 120°C and 80°C static air ovens, respectively. The addition of a vacuum at 120°C did not have a significant effect on either the rate or the total amount of weight loss.

After drying, reabsorption of moisture can be prevented by storing the pwb in a dry environment. This is difficult because most storage and manufacturing areas at KCD are maintained near 50 percent RH. A test was run which simulated a process in which the pwb is exposed to a 50 percent RH environment for 8 h, such as would occur when an operator is soldering components, followed by a 16-h storage in a dry nitrogen chamber, such as would occur if a partially finished assembly were stored overnight in a desiccator. After 1 week, the pwb laminate stored overnight in a desiccator had absorbed only one-third of the moisture that similar samples continually exposed to 50 percent RH during the same time interval had absorbed.

Another means of slowing down the moisture absorption is by coating the pwbs with parylene. Coating the rigid-flex laminates with parylene reduced the rate of absorption by roughly one-half although the total moisture content at equilibrium was unchanged. The parylene coating had little effect on the rate of weight loss during bakeout.

DISCUSSION

SCOPE AND PURPOSE

Many quality defects that occur during manufacture and assembly of pwbs are aggravated by moisture. Delamination, blisters, measles, raised lands, misregistration, blowholes in solder joints, and lowered insulation resistance¹ are all caused or aggravated by the presence of moisture within a pwb. Minimizing the occurrence of these problems requires the moisture content within a pwb be reduced as much as practical and maintained at a reduced level throughout the manufacturing and assembly process.

Rigid-flex multilayer pwbs are more susceptible to problems from moisture when compared to other types of pwbs made at KCD. This work was directed towards determining the moisture absorption and bakeout characteristics of rigid-flex multilayer pwbs made at KCD. Such information can be used as guidance to set bake cycles and humidity exposure times during manufacture and assembly.

ACTIVITY

Background Information

It has long been recognized that moisture affects the processing of pwbs at KCD.^{2,3,4} Experience at KCD has shown that some epoxy/glass, double-sided pwbs are susceptible to raised lands and measles during soldering if the pwb has high moisture levels. The delamination resistance of other epoxy/glass multilayer pwbs is reduced if the innerlayers and prepreg contain as little as 0.1 to 0.3 percent moisture during the lamination process. The occurrence of blowholes in solder joints of polyimide/glass multilayer pwbs has been reduced by drying out the pwbs before soldering.

The common denominator is that each of these problems occur during thermal stress situations such as lamination, soldering, or hot air leveling. The mechanism is relatively simple. Under these high temperature situations, moisture within the pwb is suddenly vaporized, creating high internal pressures. If the pwbs integrity is not sufficient to withstand the sudden internal pressure rise, then a defect will occur such as a delamination, blister, or measles. The internal stress within a pwb, generated during a high temperature process, is directly proportional to the pwb moisture content.

Rigid-flex pwbs are among the latest in pwb technology and are currently under development at KCD (Figure 1). As with more conventional pwb designs, moisture within rigid-flex pwbs has

Figure 1. Rigid-Flex Multilayer PWB

been found to cause problems. Bake cycles have been included in the pwb manufacturing process to prevent these problems. Efficient bake cycles depend on accurate moisture absorption and bakeout information.

Obtaining moisture absorption and bakeout data can easily become complicated. In the simplest situation, moisture diffusion in pwbs can be treated as a simple, unidirectional mass transfer problem, assuming the pwb laminate is homogeneous and edge effects are negligible. Discounting the edge effects is probably an acceptable assumption, but unfortunately the pwb laminate is far from homogeneous. The laminate contains discrete volumes of resin, fiber reinforcement, and copper circuitry. Rigid-flex construction complicates matters further because of the several resin and adhesive types used.

If the pwb contained only resin, then moisture diffusion would be relatively simple to predict. In reality, moisture diffusion is impeded by the presence of fiber reinforcement, copper circuitry, and copper ground planes. It is unrealistic to try to accurately predict moisture diffusion in every pwb design. The approach taken in this work is to determine the moisture absorption and bakeout characteristics in a test panel having standard rigid-flex layup, without any copper circuitry.

With this approach, obtaining moisture absorption and bakeout information becomes relatively uncomplicated. Equipment that is needed includes an accurate balance to monitor weight changes, constant humidity chambers to store the test specimens, an oven to bake the test samples, and representative test specimens.

For this study, an electronic balance was used. This enabled samples to be quickly and accurately weighed thereby minimizing the time the specimens were out of the storage environment.

Controlled humidity chambers at 50 percent RH were prepared by placing a pan containing a saturated solution of magnesium nitrate in the bottom of a desiccating cabinet. A stainless steel desiccating chamber constantly purged with dry nitrogen served as a low humidity chamber.

The rigid-flex sample panels were made according to the cross-section in Figure 2, which was the standard KCD construction at the start of this project. The actual test specimens were 5 by 5 cm, sheared from a 30.5 by 30.5 cm panel. Before any weighing, these specimens were dried by baking in a 135°C oven for several weeks. Those specimens not immediately used were stored in the 135°C oven.

Some of the test specimens were parylene coated. Parylene has been used successfully to slow down the moisture absorption in

NOMINAL THICKNESS 0.0494 INCH

Figure 2. Rigid-Flex Material Composite

certain molded desiccant parts made at KCD. Similar effects were expected on pwbs.

Moisture Absorption

After the test specimens had been dried at 135°C, a group of both coated and uncoated specimens was placed in a dry nitrogen

cabinet and allowed to cool overnight. The specimens were then weighed and placed in a 50 percent RH, 25°C constant humidity cabinet. The weights of these samples were monitored over the following months. The initial weight was assigned a moisture content of zero and the weight gains were calculated in percent based on this assigned zero moisture content.

The moisture content of these test specimens is shown in Figure 3. The total moisture content of the uncoated specimens at equilibrium reached approximately 0.95 weight percent. Those specimens coated with parylene closely approached this weight gain, although it took nearly twice as long to reach equilibrium.

While Figure 3 shows the total amount of moisture which could be expected to be present in a rigid-flex pwb after reaching equilibrium at 50 percent RH, Figure 4 shows the rate of initial moisture uptake. In this figure it can be noted that a rigid/flex pwb will absorb close to one-half of its total moisture content within 24 h. In the first 8 h it will have absorbed one-third of its eventual total moisture content. As expected, parylene lowers the initial moisture absorption rate.

The high rate of initial moisture absorption is significant. This implies that moisture related problems may be difficult to avoid even with baked pwbs, if no precautions are taken to prevent or minimize the reabsorption of moisture, or if the pwbs are not processed immediately after the bake.

Moisture Bakeout

After the specimens had reached equilibrium at 50 percent RH, they were baked in an oven and the weight loss was monitored. One group of both coated and uncoated specimens was placed in a static air oven at 80°C. After the weight of the first group had stabilized, a second group of coated and uncoated specimens was placed in the oven and the temperature increased to 120°C. Finally, a third group of samples was placed in the oven and a vacuum was pulled at 120°C.

The results of treating the uncoated samples are shown in Figure 5. It is seen that the bakeout temperature has a pronounced effect on the rate of weight loss. In 24 h at 120°C, the weight had practically stabilized, while at 80°C, the weight took almost a week to stabilize. Vacuum baking had little effect on the rate of weight loss as can be seen from the curve showing weight loss in a 120°C vacuum.

Although the parylene coating on the test specimens reduced the moisture absorption rate, it had little effect on the bake cycle, especially at 120°C. Figure 6 shows the weight loss of the

Figure 3. Rigid-Flex, Long-Term Moisture Absorption at 50 Percent Relative Humidity

parylene-coated specimens. For comparison, the weight loss of the uncoated specimens is included also.

Overnight Storage of PWB Assemblies

From the information gathered up to this point, possibly the ideal situation, in terms of moisture control, would be to have the rigid-flex pwb baked immediately after manufacture and then have the components quickly assembled and soldered in a dry (less than 10 percent RH) environment. This is not always practical or even possible at KCD.

In the pwb manufacturing facility, moisture can be controlled by frequent oven bakes. The bakeouts are strategically placed just prior to the high temperature processes such as lamination and

Figure 4. Rigid-Flex Moisture Absorption at 50 Percent Relative Humidity

hot air solder leveling. Other bakeouts can be added where required or advantageous.

However, electronic assembly areas are a different case. In this situation, electronic components may be soldered to a pwb over several days. It is not feasible to bake out an assembly each time a component or group of components is soldered. If the area cannot be controlled to a low humidity, then another approach is to have an initial bakeout followed by dry nitrogen storage at all times except whenever the pwb is actually being worked on.

This approach can be simulated by taking dried test specimens and exposing them to a 50 percent RH environment for 8 h, such as would occur while an operator was assembling and soldering components on the pwb. This is followed by storing the specimens

Figure 5. Rigid-Flex Moisture Loss During Bakeout at 80°, 120°, and 120°C With Vacuum

in a dry nitrogen cabinet for 16 h, as might occur when the operator stored the partially finished assembly overnight in a desiccator.

A test was set up to monitor the weight changes over 5 days which included cycles of 8 h at 50 percent RH plus 16 h at 0 percent RH. This was followed by 2 days of storing at 0 percent RH to simulate weekend storage. This was done with both coated and uncoated specimens and the results are shown in Figure 7. The chart shows that storing an electronic assembly overnight in a desiccator will slow the moisture absorption process by roughly 40 to 50 percent. Parylene-coated specimens treated in this manner absorbed moisture at a much reduced rate, as expected.

Figure 6. Rigid-Flex PWB Moisture Loss During Bakeout of Parylene-Coated Specimens

ACCOMPLISHMENTS

The moisture absorption characteristics of a standard KCD rigid-flex pwb at 50 percent RH, 25°C were determined. The bakeout characteristics in 80°C, 120°C, and 120°C/vacuum were also determined. Parylene conformal coating was found to slow the rate of moisture absorption but not significantly affect the rate of weight loss during baking. Storing the pwbs overnight in a desiccator proved to be one means of reducing the rate of moisture absorption in partially completed pwb assemblies.

FUTURE WORK

Moisture absorption information is being gathered on five pwb laminate types used or proposed to be used at KCD, having

Figure 7. Rigid-Flex Laminate Workstation Moisture Absorption, Alternating 8 h in 50 Percent RH and 16 h in Dry Nitrogen

thicknesses ranging from 0.25 to 1.60 mm and in relative humidities of 15, 25, and 50 percent. Bakeout information for these laminates is being gathered at 80°C and 120°C.

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