How can a user of Printed Circuit Boards know they received what they specified? Recently, a field failure called into question some of the traditional methods of ensuring product performance when the failure was traced back to a printed circuit board problem. During analysis of the product failure, an inconsistency was found between the quality report supplied by the fabricator and the root cause revealed by laboratory analysis.

Cross section analysis of a plated hole is the most accurate way to measure the copper thickness. However, the derived measurement is only valid if the cross section is precisely in the center of the plated hole. As the cross section location moves from the geometric center, the copper measurement will increase, leading to a false prediction of the actual copper thickness.

The PCB in question was produced to meet the IPC-6012C-2010 Class 2 performance specification. The fabricator had supplied a quality report and mounted cross sections (“pucks”) with the lot. The quality report indicated that the minimum copper thickness for Class 2 had been met (Table 3-3 Surface and Hole Copper Plating Minimum). The supplied puck, when measured with an inverted stage metallographic microscope, yielded a measurement that was 21 micro-inches above the required minimum thickness of 709 micro-inches.

Searching for Rules

Why is this measurement of copper plating significant, and does 21 micro-inches make a difference?

During the 1970s, the US auto industry devoted many research hours in the search for definitive rules that could be used to predict the performance of printed circuit boards in the unforgiving environment of an automobile engine compartment. Much of that work has evolved into industry guidelines even though the origins are becoming lost in history. The one element that was determined to be absolutely essential to product performance was the thickness of the through-hole copper plating. The reason is that in all epoxy-glass base printed circuit boards, there is a significant mismatch between the coefficient of thermal expansion (CTE) of the epoxy resin and the copper through-hole plating. For this reason, wide changes in the ambient temperature — without consideration of the I^2R heating within the PCB — create stress in the plated barrel as the epoxy-glass expands at a higher rate than the through-hole copper.

Extensive testing with 0.062-in. thick FR4 (flame retardant epoxy resin) has evolved an industry expectation that a plated hole, with an aspect ratio of less than 6:1, is able to withstand 1000 temperature cycles from -55 to +125°C. (See IPC-TM-650 section 2.6.7.2B and IPC 4101C/26.) The thickness of the copper plating is one of several variables in achieving 1000 thermal cycles. However experimentation has proven this one variable to be the most significant.

As the aspect ratio (board thickness: finished hole size) increases, plating throwing power — (hole copper plating/surface plating) x 100 — decreases. When the throwing power drops below 85 percent, it results in the through-hole plating...
resembling a “dog-bone” — copper plating in the hole is thick at the upper and lower surface and thin in the center. As the dog-bone plating becomes more pronounced, the opportunity for brittle fracture increases as does fatigue failure along the centerline area of thin copper plating.

Simple Rule of Thumb

Experts will have significant disagreement as to the impact on thermal cycles as the copper thickness is reduced from 1 mil (1000 micro-inches) to the IPC Class 2 copper average minimum of 709 micro-inches. They will correctly cite resin composition, support system, aspect ratio, surface plating, and etch back to name a few. However, excluding other factors, a reasonable rule of thumb is to assume a linear relationship for this non-linear effect and to reduce the expected number of thermal cycles by an equivalent percentage — approximately 30 percent — to 700 thermal cycles at the IPC Class 2 minimum. This rule of thumb is intended to give the designer some basic guidelines for product performance.

If the desired product performance is impacted by this rule of thumb, then far more exhaustive analysis is required.

Mismatch Between Cross Sections

In the case of the product failure analysis, two questions were raised:

- Was copper plating at the IPC Class 2 minimum a factor in the failure?
- Did the design require a higher number of thermal cycles than the rule of thumb was predicting?

The analysis determined that the root cause was the copper plating, but that the design expectations did not violate the rule of thumb for thermal cycles. How could this be?

The reason was that the copper plating in the thru-holes when measured on the failed PCB fell significantly below 709 micro-inches, not the 730 micro-inches predicted by the supplier “puck”. This revelation called into question the ability of the supplied quality data to predict the performance of the manufacturing lot. One obvious explanation is that the lot was mixed: two or more manufacturing lots interweaved and shipped as one. This explanation, while plausible, is far too “convenient”. Therefore, the mixed lot explanation was set aside as there was no way to prove or disprove the assertion with only one failed PCB.

Correlation Testing

A correlation experiment was devised to look at the product performance by a number of PCB vendors, including the vendor of the failed unit. By using multiple vendors, with no knowledge of the test, one could exclude a mixed lot theory if the data from multiple vendors exhibited a lack of correlation between quality data and actual boards within the lot.

The test concept was to use 10 vendors and evaluate the supplied quality data. The only item compared between the vendors was the through-hole copper plating. Of the ten vendors, two failed the 709 micro-inches minimum when pucks were actually measured, and the vendor in question was over by 11 micro-inches. The two failures were not “radical”. Both failed by 19 micro-inches.

A very interesting statistic evolved from the quality data. Of the 10 vendors, the largest margin of “excess copper” over the 709 micro-inches was only 121 micro-inches. None of the vendors approached the automotive standard of 1000 micro-inches.

DOE Test Method

Five PC boards from each vendor were examined, with three cross sections from each board. When the data was evaluated (test methodology described in the test report), three of the 10 vendors failed the minimum of 709 micro-inches, and the vendor in question was exactly 700 micro-inches, and only one vendor failed both the puck measurements and the sample product measurements. The test results infer that there is vendor-to-vendor variation in their correlation of quality data and actual product performance. Further, the results suggest it is not prudent to rely solely on supplier quality data to determine the performance of critical products.

Product Assurance Testing

An emerging model in the PCB industry is to provide Product Assurance Testing (Individual Lot Validation) to enhance the reliability of product quality while reducing the risk of a field failure and the resultant impact on the end user or customer. This model is a natural evolution of the venerable PPAP (Production Part Approval Process) for the auto industry or the FPAP (First Piece Approval Process) for general industry.

The model allows the higher mix/lower volume consumer of Printed Circuit Boards to use quality data to predict product performance. This predictive capability has long been the domain of only the high-end or high-volume users of Printed Circuit Boards.

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