Evaluating Laminates for High Temperature Assembly

by **SILVIO BERTLING**

The RoHS and WEEE Directive in Europe is the driving force for the implementation of high temperature lead-free assembly around the world. As designers struggle with these new goals, questions regarding the integrity and reliability of various high temperature, lead-free assembly capable laminates continue to rise. In short, the fabricators and end-users must select a laminate which can meet the rigorus demads of lead-free solder assembly. Unfortunately, at this time there is no standard test methodology that consistently and accurately assists in determining which laminates fall into this category.

This article introduces a test procedure that utilzes a daisy chain TV designed by IPC PCQR^2 suitable for both reflow testing and HATS (Highly Accelerated Thermal Shock) testing. We believe that this procedure can be used to determine how well a particular laminate performs when exposed to 6x reflow, thermal cycling and a combination of reflow and thermal cycling.

EVALUATING LAMINATES FOR HIGH TEMPERATURE ASSEMBLY

This test consisted of three phases. Phase 1 was a 6x reflow test; Phase 2 was a 500-cycle HATS test; and Phase 3 was a combination of reflow and HATS test. The materials chosen for the tests were a standard FR4 and two higher performance high-speed, low-loss FR4 laminates.

This evaluation test vehicle is an IPC PCQR^2 panel design. The coupon design is a 12-layer construction with no surface finish except soldermask. The coupon is 1 inch x 1 inch in size and 0.093 inch thick. The coupon has four through-hole via net structures with selectable hole sizes. The via to via distance is 0.040 inch.

The actual test was performed by taking resistance measurements of the via net structures.

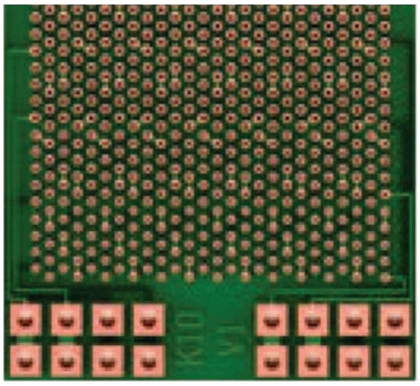


Figure 1. PCQR2 Coupon.

The test is designed to measure the resistance of each via net. The resistance is expected to be between 0.4 and 0.8Ω. A baseline is established by measuring the resistance at 23°C. A 10% resistance increase from baseline value counts as failure. Resistance above 20Ω is considered an open connection. Greater than 3% resistance increase from baseline counts as tendency to fail.

INTENT

A great deal of emphasis was placed on making sure that the laminates were being processed to the required "best practices" recommendations. This would provide consistent results and a better definition as to the suitability of the laminate to lead-free assembly.

Special attention is paid on material evaluation after fabricator has built the PCQR^2 panel. Properties, such as Tg by DSC, Tg by TMA, Tg by DMA, TGA and T260 are determined and compared to expected results. After each completed test, x-sections were made to determine the via hole plating thickness. The test results of each of these materials after PWB fabrication is provided in the table below. Since these results met our target expectations we can now say with confidence, that any failures during these tests shall reflect a material issue and not fabricator processing problems. [Note: Samples were not preconditioned prior to Phase 1 and 2.]

PHASE 1

The first part of the study was performend to determine if there is any significant performance difference between a standard FR4 and two higher performance high-speed, low-loss FR4 laminates at elevated reflow temperatures.

An 8 Zone Reflow oven was used to achieve the three profiles that were used. We ran single coupons as well as full 18"x24" panels at the specified temperatures. When the single coupons were run, resistance readings were taken to ensure that the coupons being tested were normalized to the rest of the population. No attempts were made to do this when the full 18" x 24" panels were run.

The first test run was performed on a standard high Tg FR4 laminate. The material was reflowed a total of six times using a Linear Reflow Profile at 230°C to establish a baseline. The peak reflow temperature choosen reflects real life soldering temperatures found in the industry today. A total of 12 coupons from two different panels (six coupons from each panel) were evaluated.

The second test run was performed on the same high Tg FR4 laminate mentioned above, plus two additional high performance lead-free capable epoxy laminates were added. A total of twelve coupons from two different panels (six coupons from each panel) were evaluated. All of the coupons were reflowed six times through a Linear Reflow Profile at both 245°C and 260°C.

After acclimatization, initial resistance measurements of each coupon were taken to establish a baseline. After each reflow run the

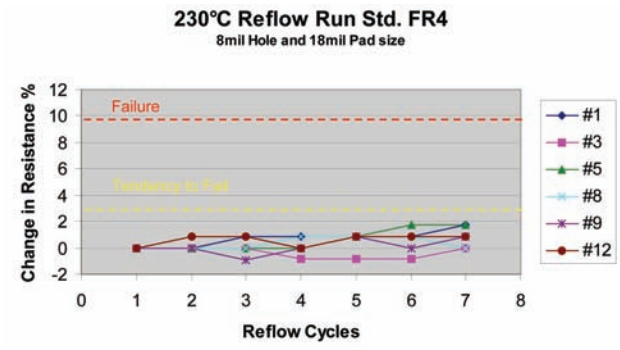


Figure 2. Standard FR4, 230C, 6x Reflow.

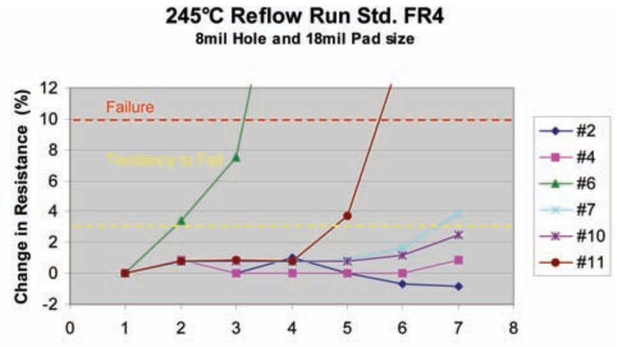


Figure 3. Standard FR4, 245C, 6x Reflow.

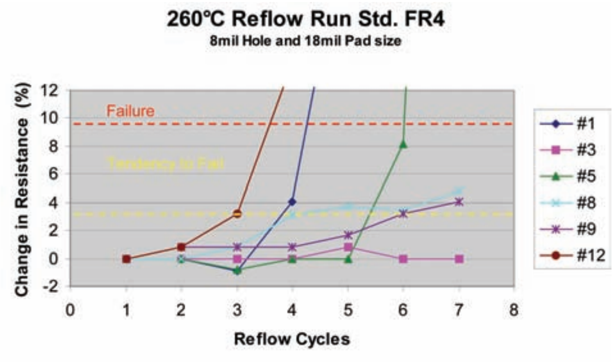


Figure 4. Standard FR4, 260C, 6x Reflow.

Figure 5. Advanced FR4A, 260C, 6x Reflow.

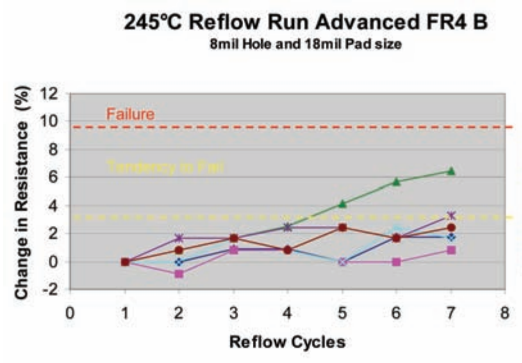


Figure 6. Advanced FR4B, 245C, 6x Reflow.

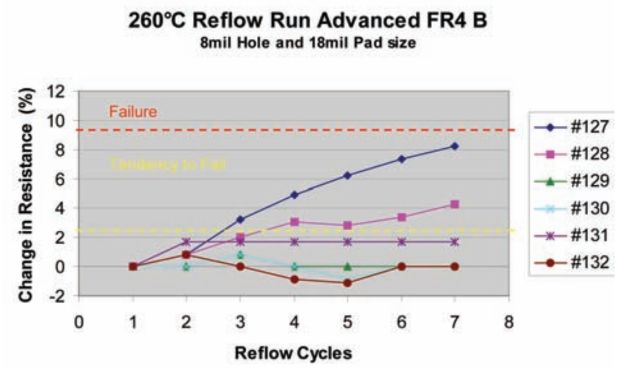


Figure 7. Advanced FR4B, 260C, 6x Reflow.

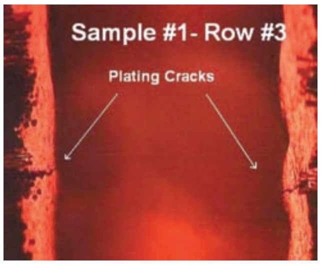


Figure 8. Sample of Barrel Crack Failure.

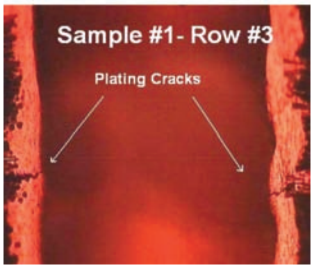


Figure 9. Sample of Barrel Crack Failure.

contacts were cleaned and actual measurements were taken twice to verify the results (Figures 2-9).

PHASE 2

The second part of the study targeted the thermal robustness of each tested laminate after 500 HATS (Highly Accelerated Thermal Shock) cycles.

The system from Integrated Reliability Test Systems, Inc. (www.hats-tester.com) provides an air-to-air reliability test method, and uses a single chamber in which high-volume hot and cold air alternately pass over stationary samples. It provides rapid thermal transfer and reduces the time for the samples to reach temperature equilibrium. The samples are fixed to a high-speed precision resistance sampling network, allowing continuous monitoring and recording of the net resistance.

HATS TEST CONDITIONS

None of the coupons had been preconditioned. The HATS Chamber can hold up to 36 Coupons. Before the evaluation begins, the HATS chamber is calibrated to determine its resistance tolerance limits ±2mΩ.

A chamber load consisted of 6 coupons of each laminate. The chamber program cycled between -40 to +145°C, with each thermal excursion lasting a total of 8 minutes. After the coupons reached the maximum temperature, a 15 second dwell time was applied to minimize variations in the response. Initial net resistance measurements were taken during the first few cycles allowing the system to self calibrate. This helps define how long a cycle will last during the evaluation. The test is stopped after 500 thermal cycles.

HATS DATA

Standard FR4: After about 270 cycles, a 10% resistance increase occurs and it takes about 320 cycles to get an open circuit. It takes several thermal cycles before an actual failure occurs.

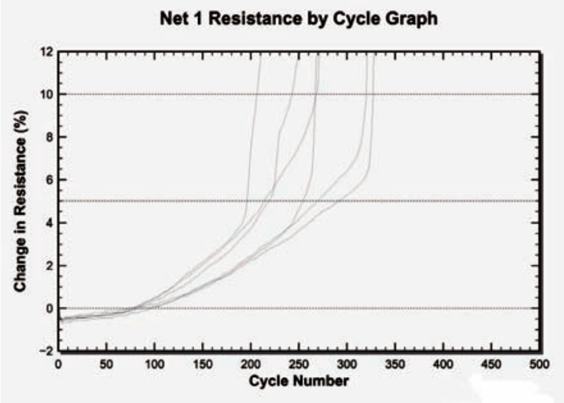


Figure 10. Standard FR4.

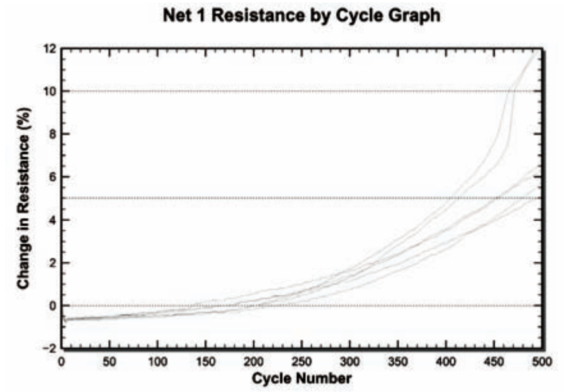


Figure 11. Advanced FR4 A.

Advanced FR4 A: After about 470 cycles a 10% resistance increase occurs and there are no open circuits. There is a tendency of a resistance increase but no failures.

Advanced FR4 B: After 500 cycles there are no significant resistance changes or any open circuits. There is a tendency of a resistance increase but no failures.

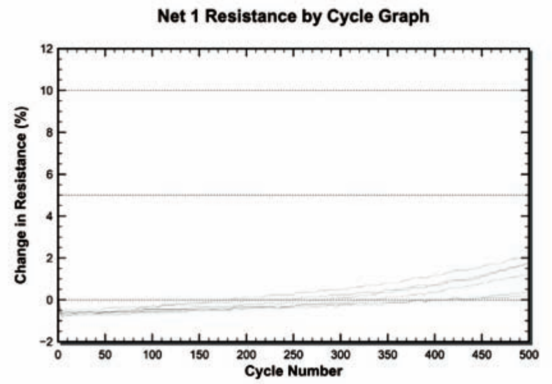


Figure 12. Advanced FR4 B.

PHASE 3

Phase 3 was a combination of reflow and HATS testing.

6x Reflow + 500 HATS Cycles Data

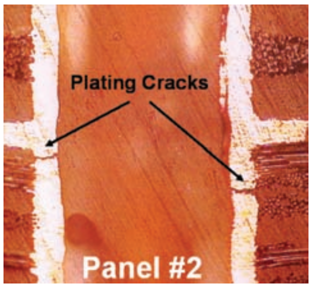


Figure 13. Sample of Barrel Crack Failure, Standard FR4.

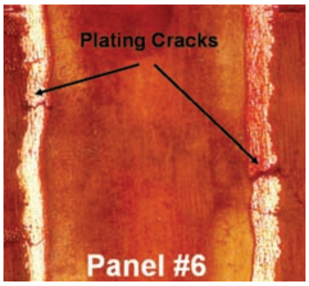


Figure 14. Sample of Barrel Crack Failure, Advanced FR4A.

FAILURE ANALYSIS

Figures 13-15 show only barrel crack failures, no delamination occurred.

Standard FR4: After preconditioning material performs about 50 cycles less to reach a 10% change in resistance and about 60 cycles less to get an open connection in comparison to unconditioned samples.

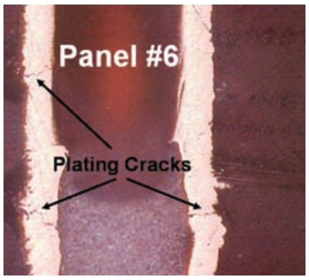
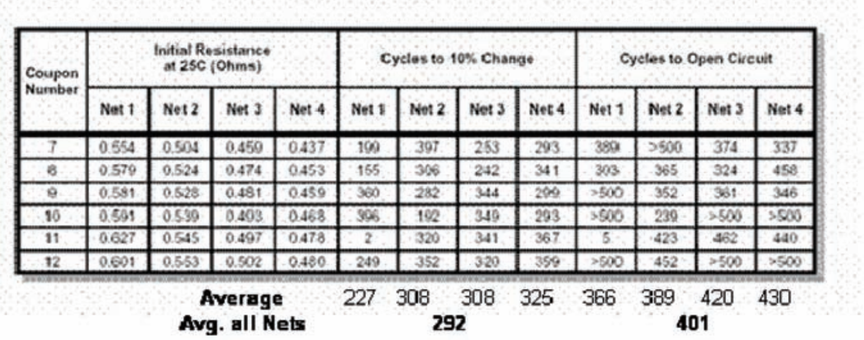
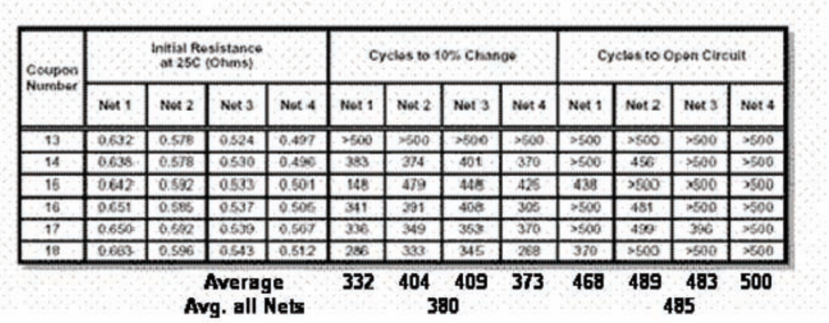


Figure 15. Sample of Barrel Crack Failure, Advanced FR4B.



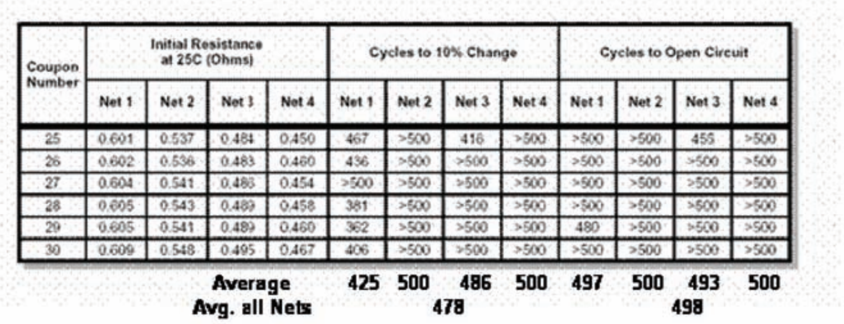
Coupon Number	Initial Resistance at 25C (Ohms)				Cycles to 10% Change				Cycles to Open Circuit			
	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4
7	0.554	0.504	0.459	0.437	199	397	253	293	389	>500	374	337
8	0.579	0.524	0.474	0.453	155	306	242	341	303	365	324	458
9	0.581	0.528	0.481	0.459	360	282	344	299	>500	352	361	346
10	0.591	0.539	0.403	0.468	396	192	349	293	>500	239	>500	>500
11	0.627	0.545	0.497	0.478	2	320	341	367	5	423	462	440
12	0.601	0.553	0.502	0.480	249	352	320	359	>500	452	>500	>500
Average					227	308	308	325	366	389	420	430
Avg. all Nets					**292**				**401**			

Figure 16. Standard FR4: 6x Reflow + 500 HATS Cycles Data.



Coupon Number	Initial Resistance at 25C (Ohms)				Cycles to 10% Change				Cycles to Open Circuit			
	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4
13	0.632	0.578	0.524	0.497	>500	>500	>500	>500	>500	>500	>500	>500
14	0.638	0.578	0.530	0.496	383	374	401	370	>500	456	>500	>500
15	0.642	0.592	0.533	0.501	148	479	448	425	438	>500	>500	>500
16	0.651	0.585	0.537	0.506	341	391	408	305	>500	481	>500	>500
17	0.650	0.592	0.539	0.507	336	349	353	370	>500	499	396	>500
18	0.663	0.596	0.543	0.512	286	333	345	268	370	>500	>500	>500
Average					**332**	**404**	**409**	**373**	**468**	**489**	**483**	**500**
Avg. all Nets					**380**				**485**			

Figure 17. Advanced FR4 A: 6x Reflow + 500 HATS Cycles Data.



Coupon Number	Initial Resistance at 25C (Ohms)				Cycles to 10% Change				Cycles to Open Circuit			
	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4	Net 1	Net 2	Net 3	Net 4
25	0.601	0.537	0.484	0.450	467	>500	416	>500	>500	>500	455	>500
26	0.602	0.536	0.483	0.460	436	>500	>500	>500	>500	>500	>500	>500
27	0.604	0.541	0.486	0.454	>500	>500	>500	>500	>500	>500	>500	>500
28	0.605	0.543	0.489	0.458	381	>500	>500	>500	>500	>500	>500	>500
29	0.605	0.541	0.489	0.460	362	>500	>500	>500	480	>500	>500	>500
30	0.609	0.548	0.495	0.467	406	>500	>500	>500	>500	>500	>500	>500
Average					**425**	**500**	**486**	**500**	**497**	**500**	**493**	**500**
Avg. all Nets					**478**				**498**			

Figure 18. Advanced FR4 B: 6x Reflow + 500 HATS Cycles Data.

Advanced FR4A: After preconditioning material performs about 120 cycles less to reach a 10% change in resistance and about 15 cycles less to get an open connection in comparison to unconditioned samples

Advanced FR4B: After preconditioning material performs about 20 cycles less to reach a 10% change in resistance and there is no change to get an open connection in comparison to unconditioned samples.

CONCLUSIONS

Based on the 12 Layer PCQR^2 design, a standard high-Tg FR4 laminate can withstand 6x 230°C reflow without any defects. At solder temperatures reaching 245°C or 260°C, the material starts to show failures after the second solder reflow in the 8mil vias.

The high performance FR4 materials do not show any failures at solder temperatures up to 260°C. After the third reflow, laminate 'A' shows a tendency to fail whereas laminate 'B' does not show any change.

The Highly Accelerate Thermal Shock (HATS) test shows standard high Tg FR4 can pass over 200 cycles before a 10% resistance increase occurs, and over 330 cycles before an open connection can be seen.

For both high performance FR4 materials 'A' and 'B', several coupons had passed 500 cycles without failures. Several coupons from material 'A' reached 390 thermal cycles, while coupons from material 'B' were thermally cycled 330 times before a 10% resistance increase was seen indicating a failure had occurred.

SUMMARY

Following laminator's best practices processing procedures is crucial. Deviation from the lamination processing window can have a negative impact during assembly. PCB fabricators capability and quality becomes more important prior to the determination of laminate lead-free capability. Drilling and copper plating thickness also have significant impact on via reliability.

As the data shows, vias below a 10-mil finished hole size are more sensitive to failure than larger hole sizes. When it's important a material withstand several reflow runs at 245°C and above, the High Density Interconnect board design can have significant impact on laminate performance.

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Silvio Bertling has over 20 years of experience in rigid PCB design, fabrication, assembly and R&D. He holds a B.S. of Electronics, Deutsche Post Berlin; and a M.S. He is the author and co-author of several technical papers and one patent in different areas of technology.