Can peel strength predict the structural integrity of the adhesive bond between the copper and laminate in a PCB?

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Abstract

Original Equipment Manufactures (OEMs) want more flexibility in the selection of processes in the manufacture of printed circuits boards. Most notable is the industry trend away from Reduced Black Oxide to Alternative oxide processes. However, for some market segments the change has been slow limiting manufacturing options was well as increasing costs. The primary obstacle to change is that OEMs have specified minimum peel strengths for most resin systems that are based on Reduced Black Oxide and thus limit the use of Oxide Alternatives. This quantification of bonding performance however does not directly correlate to the structural integrity of the final printed circuit board.

Introduction

Reduced Black Oxide is the industry standard and is well established as the "bar" that all other inner-layer bonding systems must meet. Peel strength has been an "un-quantified" industry standard for decades; high peel strengths equal high thermo-mechanical performance has always been the rational. Typically oxide alternatives have significantly lower peel strengths than reduced black oxide (Figure 1).

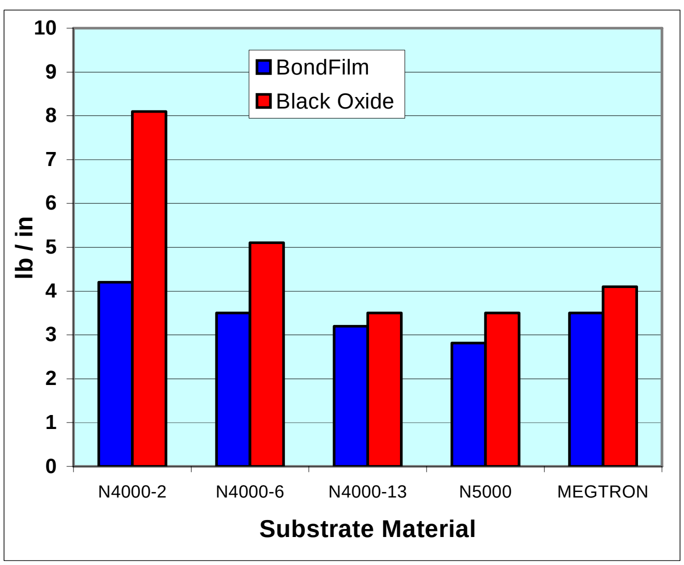


Figure 1. Bonding Adhesion Comparison Reduced Black Oxide versus Oxide Alternative.

Most OEMs subscribed to the traditional concept that lower peel strength would result in decreased thermo-mechanical performance. As this document will present, although oxide alternatives may yield peel strengths somewhat lower than reduced black oxide, their thermo-mechanical performance is comparable to that of black oxide. At question is what test method(s) most accurately predicting the performance of the inner-layer bonding system in the final product other than peel strength.

Test Matrix

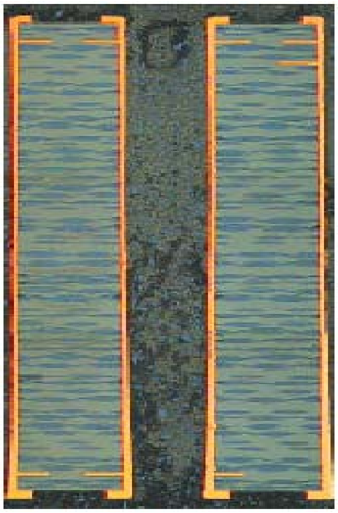
To reduce the variance from the manufacturing process several factors that may have a significant effect on the performance will be varied. Etch depth was chosen as it is the primary output of the Oxide Alternative process. Copper foil thickness and prepreg types to simulate varying manufacturing processes.

Test Lot	Etch Depth	Cu Foil Thickness	Prepreg
1	1.0 µm	17 µm	Megtron
2	1.0 µm	70 µm	N4000-13
3	1.6 µm	17 µm	N4000-13
4	1.6 µm	70 µm	Megtron
5	RBO	35 µm	N4000-13
6	1.2 µm	35 µm	Megtron
7	1.2 µm	35 µm	N4000-13

Table 1. Test Matrix

Test Vehicle

The primary test vehicle is a 26-layer, 5.3-mm thick printed circuit board with an Oxide Alternative bonding process. The panel contains 17-µm, 35 µm and 70-µm copper layers, constructed with Nelco's High Tg N4000-13 material, and Matsushita's Megtron. This panel was used for multiple reliability tests, including interconnect stress test, thermal cycling test, thermal shock, and PTH evaluation (Pink-Ring).



Picture 1. Cross Section of Primary Test vehicle

Test Methods and Responses

In this case several more intensive and quantifiable tests were done with peel strength being measured with each test lot for reference. The other test performed were thermal mechanical analysis (T-260), multiple-solder-float testing, interconnects stress testing (IST), and thermal cycling testing (TCT).

In the case of T-260, the samples were heated to a predetermined temperature, in this case 260°C. Then held at temperature until time-to-failure in which an irreversible change in thickness of the sample occurs. This irreversible change is normally defined as Delamination. The temperature ramp was 10 °C/minute.

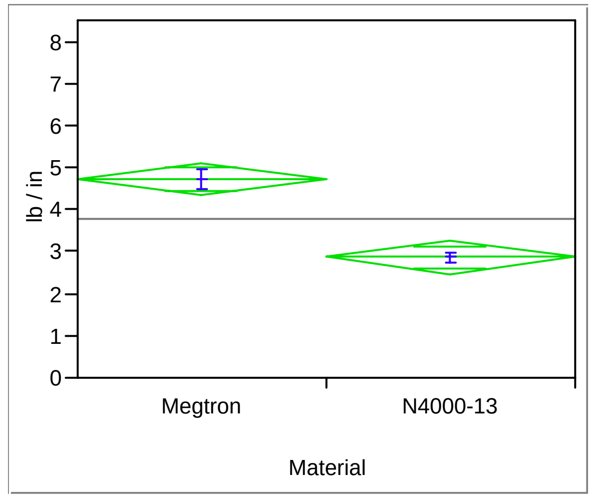
The interconnect stress testing was performed by using DC current to heat coupons from room temperature normally 25 °C up to 150 °C within 3 minutes. The samples are then air-cooled back to room temperature. The samples were then cycled until failure. Failure in this case was a resistance change of more than 10%. It is important to note that the samples were not preconditioned at 230 °C for 6 cycles but rather passed through a re-flow oven 5 times.

Thermal cycle testing was performed by heating samples to 125 °C within 5 minutes. The samples were then held at 125 °C for 30 minutes then cooled to –40 °C also within 5 minutes, this is considered 1 cycle. Samples were cycled until failure. Failure condition was set to a 3% increase of the resistance at high temperature with respect to the resistance at high temperature of the 3rd cycle. TCT coupons were also conditioned as IST coupons.

The thermal shock samples or multiple-solder-float were first conditioned in an over at 125 °C for 4 hours. Then floated on solder at 288 °C 6 times with 2 minutes between floats. Failure was recorded as a visible Delamination, although samples were analyzed by cross section to ensure thermal stability.

Results

The results were just as expected with the type of resin being the most significant factor in our evaluation in terms of peel strength. Copper Foil weight (thickness), and Etch Depth had little to no effect on peel strength (Figures 2-4).

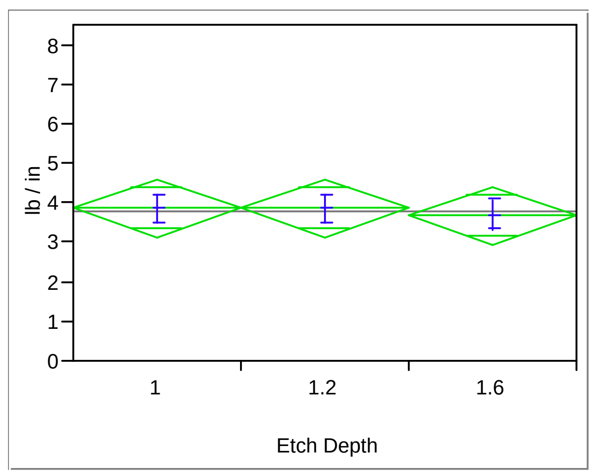


Means and Std Deviations

Level	Number	Mean	Std Dev
Megtron	18	4.75351	1.03589
N4000-13	18	2.88278	0.43431

Figure 2. Peel Strength (lb/in) By Prepreg

Etch depth was not significant to the peel strength of the two materials tested. Although for some materials etch depth has been found to have a significant influence on peel strength.

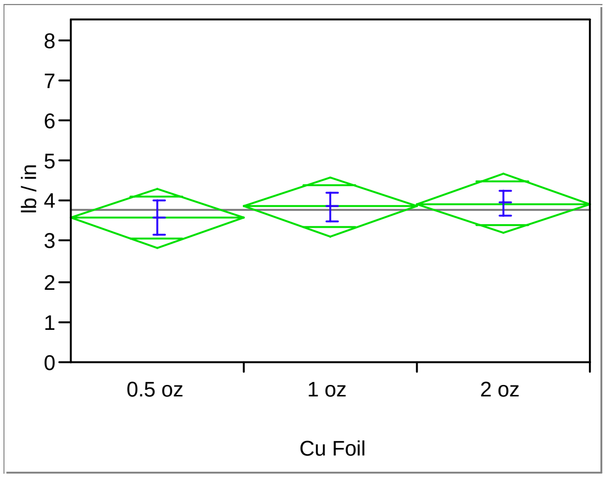


Means and Std Deviations

Level	Number	Mean	Std Dev
1.0 µm	12	3.88065	1.27040
1.2 µm	12	3.88205	1.23124
1.6 µm	12	3.69173	1.28733

Figure 3. Peel Strength (lb/in) By Etch Depth (m)

There was also not significant effect from copper foil thickness as well.



Means and Std Deviations

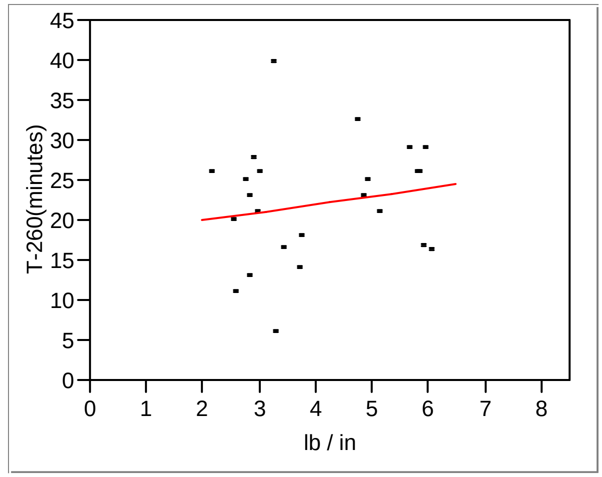
Level	Number	Mean	Std Dev
0.5 oz	12	3.60648	1.48988
1 oz	12	3.88205	1.23124
2 oz	12	3.96590	1.00019

Figure 4. Peel Strength (lb/in) By Copper Thickness (oz)

The peel strength measurements were most effected by the resin system. Megtron exhibit significantly higher peel strengths than the N4000-13. However, this difference did not directly translate to enhanced thermal performance.

Comparing T-260 to Peel Strength

The T-260 results when correlated against peel strengths show that having higher peel strength does not predict longer T-260 times (figure 5). This is most significant because the failure of interest, to most OEMs and PCB suppliers, is a dynamic change in the thickness of the sample i.e. a Delamination failure during assemble, or over the lifetime of the product.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	40.2017	40.2017	0.7202
Error	22	1228.0479	55.8204	***Prob > F***
C. Total	23	1268.2496		***0.4052***

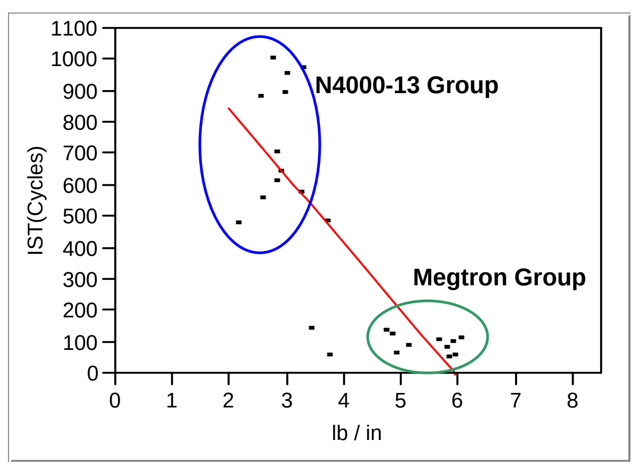
Figure 5. Fit of T-260 (minutes) By Peel Strength (lb/ in)

Comparing IST to Peel Strength

The IST results display an inverse relationship with peel strength with the N4000-13 samples withstanding a greater number of IST cycles than the Megtron group (figure 6).

There was a very large range between test groups however; within each test group there are not significant amounts of variance. The IST results were also confirmed by the TCT result, which also shows correlation to peel strength in an inverse relationship (figure 7).

The thermal float results had no resolution with all samples passing 6x thermal shock without Delamination or barrel cracks.

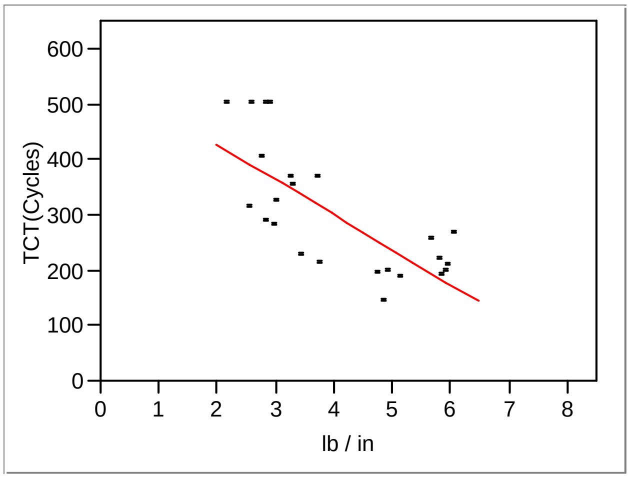


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1853682.4	1853682	39.5846
Error	22	1030223.6	46828	**Prob > F**
C. Total	23	2883906.0		***<.0001***

Figure 6. Fit of IST (Cycles) By Peel Strength (lb / in)

Comparing TCT to Peel Strength

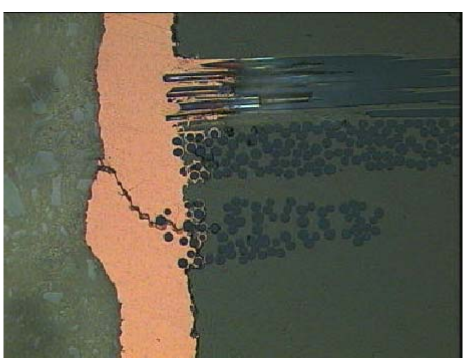


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	163078.72	163079	26.6942
Error	22	134401.28	6109	***Prob > F***
C. Total	23	297480.00		***<.0001***

Figure 7. Fit of TCT (Cycles) by Peel Strength (lb / in)

It was also observed that the same amount of wedging was present no matter what the material. To be sure the major cause of failure of IST coupons was due to barrel and inner-layer cracking (picture 2), no IST or TCT failures could be tracked to copper-epoxy separation or Delamination.



Picture 2. PTH Barrel Crack

The Megtron's meager number of IST cycles was contradictory to its otherwise superior performance in terms of peel strength, T-260, thermal stress and wedging. This variance was explained by an error in sample processing.

TMA and DSC analysis of the of both sample groups show a significant difference in Tg of the material as compare to vendor, data sheets.

Material	Tg (DSC)	Vendor Spec.	Judge
Megtron	147.4 °C	180 °C (DMA)	FAIL
N4000-13	213.6 °C	210 °C (DSC)	PASS

Table. 4 Material Analyses

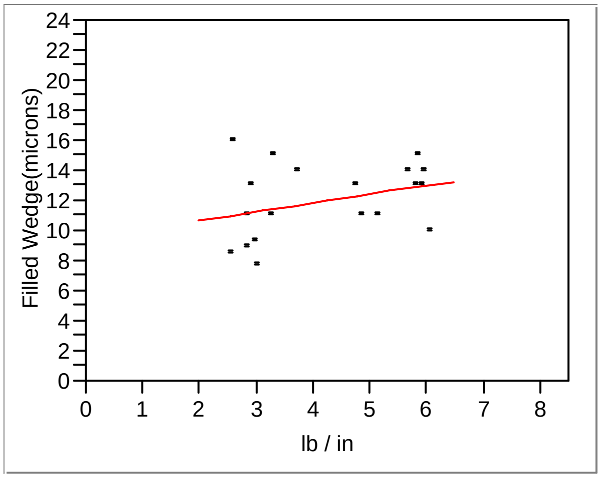
This would explain the extremely poor performance of the Megtron samples during IST cycling. It would appear that the Megtron material was not laminated at the appropriate temperature in order for it to achieve its proper Tg. However, even with this know we can still draw conclusion on the performance of the Oxide Alternative process.

Returning to the initial hypothesis of this evaluation, the value of peel strength as an indicator of performance we find that it does not. All samples were able to meet thermal requirements, regardless of peel strength.

This trend would hold true for all the other responses in the evaluation. Where peel strength relates only to the material and has little to bearing on actual performance of the final products.

IST cycles did not correlate with peel strength or T-260 results. The IST results in effect stand-alone. The most critical factor for IST results appears to be the Tg of the material and plating quality. More so the Tg of the material as all sample with Tg > 200 were able to achieve average 600 cycles. This is due to the fact that due IST cycling the sample reaches temperature in excess of 150 °C. This temperature is slightly above the Megtron Tg thus these samples experienced severe thermal expansion during the testing resulting in the rapid failure as opposed to the N4000-13 samples which have Tg > 200 °C. This may be an excellent tool for through-hole plating, however an indication of inner-layer bonding performance it lacks the resolution.

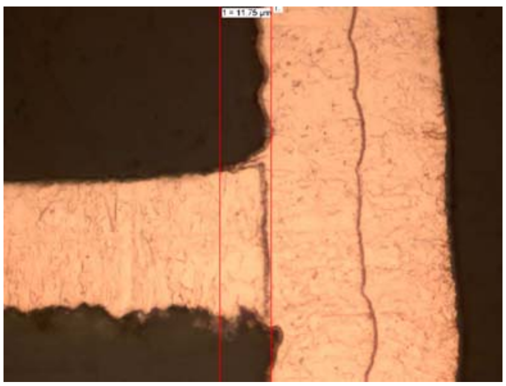
The tendency for wedging and thus wedge-voids has always been strongly related to peel strength. Stronger adhesion between the I/L-coated surface and the resin helps to create a more robust product prior to drilling. The increased adhesion helps to reduce "micro-wedging" which could at worst become a wedge-void (pink-ring) and at best a filled wedge less than 1 mil (m). However, there is no relationship found between the peel strength and the propensity for wedging.



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11.12702	11.1270	1.9751
Error	17	95.77087	5.6336	Prob > F
C. Total	18	106.89789		0.1779

Figure 9. Filled-Wedge length (µm) by Peel Strength (lb/in)



Picture 3. "Typical" Filled-Wedge

DISCUSSION/CONCLUSION:

The underlying premise of this evaluation was to evaluate peel strength as an indicator of performance In sum Oxide Alternative has proven to be very robust. The DOE samples were processed while the Oxide Alternative bath was at "steady-state" operation for standard production simulation. Varying of the copper weight of the foils, etch depth, and materials had little effect overall results of the test.

Peel strength as a process indicator has shown not to correlate to any other performance criteria. It appears that for higher performance materials peel strength does not predict to a large degree how many IST cycles, T-260 minutes, or thermal stress cycles the final product can achieve.

The Oxide Alternative with Megtron had peel strengths in excess of 8.7 N/cm (5 lb/in) and 20 minutes at T-260. However the same samples were not able to achieve greater than 200 IST cycles. While Oxide Alternative with N4000-13 had peel strengths just above 5.22 N/cm (3 lb/in) and had 11 minutes at T-260 but had over 600 IST cycles. Both had nearly identical performance for thermal stress and TCT.

It would actually appear that not only is peel strength not a major factor for inner layer bonding final performance but also IST cycling. IST as expected relates more to plating integrity and the final Tg of the base materials than to inner layer bonding performance.

Expectedly it becomes clear that no single tool can be to heavily weighted in predicting final PCB performance (table 3).

Test	Pass/Fail Criteria	Oxide Alternative Megtron	Oxide Alternative N4000-13	Reduced Black Oxide N4000-13	Result
Pink Ring	Not to exceed 25 µm	See Wedging	See Wedging	See Wedging	PASS
Delamination	None Allowed	NONE	NONE	NONE	PASS
Wedging	Not to exceed 25 µm	12.6 µm*	11.7 µm*	12.7 µm*	PASS
Wedging Voiding	None Allowed	NONE	NONE	NONE	PASS
T-260	>2.0 minutes	25 min.*	11 min.*	12 min.*	PASS
Prepreg bond strength	6 lb/in min for FR4 laminates. 3 lb/in for other laminates	11.72 N/cm* (6.73 lb/in)	5.56 N/cm* (3.19 lb/in)	3.26 N/cm* (1.84 lb/in)	PASS
Ionic Contamination	<6 µg/in^2	< 0.2 µg/in^2	< 0.2 µg/in^2	< 0.2 µg/in^2	PASS
Surface Insulation Resistance (SIR)	No shorting or dendrite growth allowed	1000 hrs	1000 hrs	1000 hrs	PASS
Interconnect Stress Test (IST)	>250 cycles	89 cycles*	646 cycles*	746 cycles*	PASS
Thermal Stress	Must Pass 6 floats with no Delamination	> 6 cycles	> 6 cycles	> 6 cycles	PASS

Table 3. Summary of Test Results

* Average of test results