Thermal Mechanical Analysis T-260 Printed Wiring Board Testing

William Varnell and Helen Enzien
Cookson Electronics PWB Materials and Chemistry
Franklin, NH

Introduction

Evaluation of printed wiring boards (PWBs) for thermal reliability during assembly and rework operations by Thermal Mechanical Analyzer (TMA) “T-260” testing has been an accepted practice for many years. Test procedures are specified in IPC-TM-650-2.4.24. It is common to see finished PWB T-260 requirements of 2 minutes or greater. In general PWBs produced using FR4 substrates pass this requirement. Recently, however, T-260 results from PWBs of thickness greater than 8mm, produced with high Tg FR4 substrates, using industry standard TMAs supplied by two manufacturers have delaminated in less than 2 minutes. Samples 4mm thickness or less produced with the same substrate materials consistently survive. Significant variation of the measured glass transition temperature (Tg) has also been observed. Tgs measured by TMA for the very thick PWBs are significantly lower than those measured for thinner PWBs.

When T-260 samples are examined following the testing, the delamination is always observed to be on the top few layers of the PWB. This is true even for thin samples. The sample is significantly degraded at the top surface with the resin bubbled and charred while the bottom of the PWB resting on the sample stage is not significantly different from the pre-tested sample (Figure 1). These results suggest that the thickness of the sample and instrument used are influencing the T-260 time to delamination. To better understand the influence of the sample thickness and instrument set-up on T-260 and Tg results several studies were performed.

Study 1 - Influence of Sample Height on Measured Indium Melting Temperature

Background

High purity indium metal is commonly used as a calibration standard for thermal analysis equipment. Indium metal has a very sharp melting transition at 156.6C. Typically the TMA is calibrated (per Thermal Analysis Procedures) by placing Indium metal in a small aluminum pan on the sample stage and placing the quartz expansion probe on top of the Indium. For standard measurements the instrument thermocouple is located on the sample stage surface close to the base of the sample. The TMA is heated at a controlled heating rate (10C/min) until the indium melts. For calibration of the TMA the measured melting point is entered into the instrument software and correlated to the true melting point of indium. The TMA from manufacturer A is designed to measure very small changes in the thickness of thin samples as they are heated and cooled in order to determine coefficients of linear expansion. According to Manufacturer A the furnace was not designed to uniformly heat samples thicker than 1 or 2 mm. As the sample thickness is increased differences between the average sample temperature and the measured temperature increase due to the time lag to heat through to the center of the sample. Thermal gradients within the furnace will also increase the difference between measured and actual sample temperature.

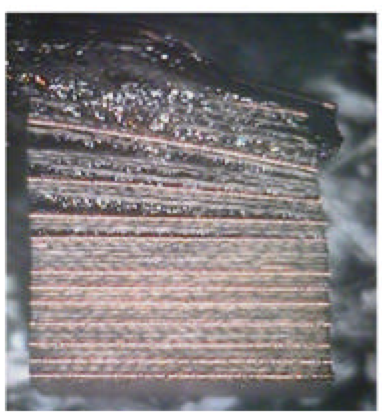

Figure 1 – 40 Layer FR4 PWB TMA T-260 Sample

Set-up

Indium samples were tested at various heights above the sample stage within the TMA furnace by setting the indium sample on top of PWB blocks from 0 to 10mm in height. The thermocouple used to measure the sample temperature remained in the “calibrated” position on the sample stage. Thermal gradients present in the furnace can cause the measured melting point of Indium to differ from the calibrated value. Moving the thermocouple to the same height as the indium and rerunning the sample can achieve confirmation of the existence of thermal gradients. If the indium and thermocouple are at the same position in the furnace, the measured melting point should again be close to the true melting point. Results of this study are shown in Figures 2 and 3.

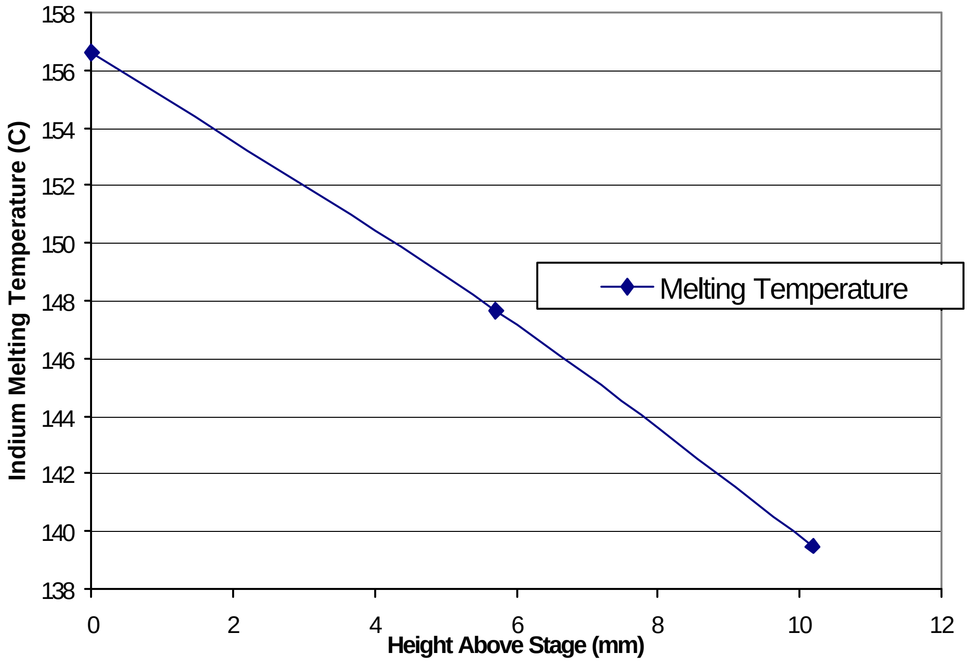

Figure 2 – Indium Melting Point vs. Height above TMA Stage

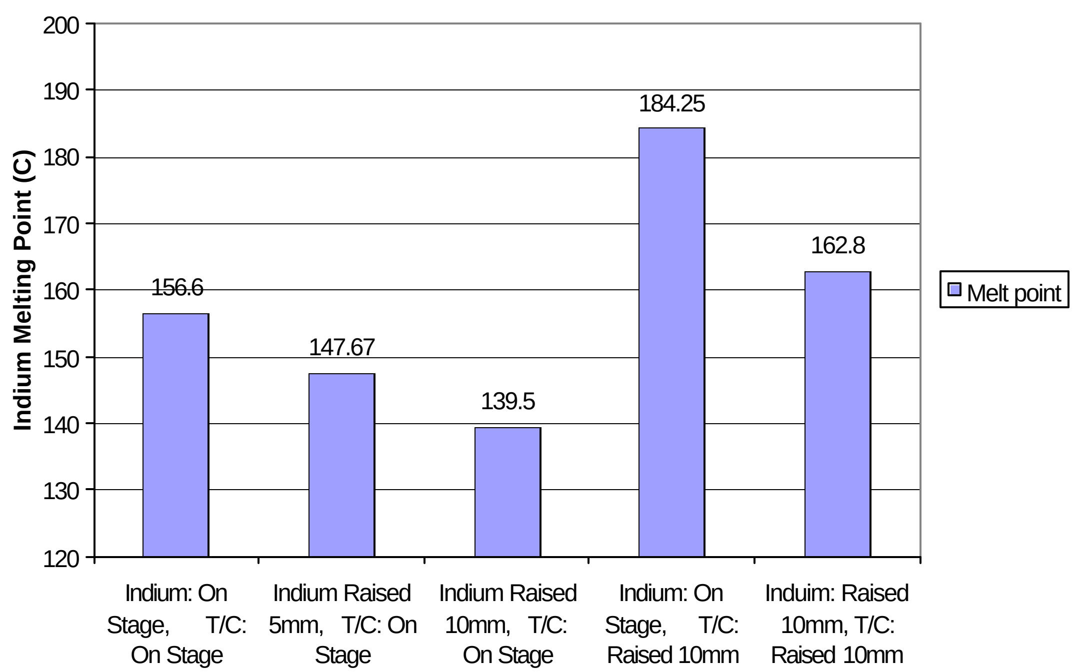

Figure 3 – Manufacturer A TMA Heating Rate 10C/Min Indium Melt Point for Various Indium and Thermocouple Locations

Results

The measured melting temperature of indium decreased linearly as the distance above the stage platform and thermocouple was increased. At 10mm above the stage a 17C melting temperature reduction was observed. This indicates that at 10mm above the stage the temperature is 17C higher than measure at the surface of the sample stage. This was verified by reversing the configuration by raising the thermocouple to a position above the stage and placing the indium on the sample stage. The measured melting point of indium as tested in this configuration was 27.6C higher than the true melting point of indium.

Conclusion

There is a significant temperature gradient in the TMA furnace. The temperature gradient 10 mm above the stage to the stage surface is between 16 and 27C. The presence of a thick PWB sample reduced the difference between the true and actual indium melting point as compared to measurements without the PWB sample. This difference is possibly due to conduction of heat through the sample to the stage.

Study 2 - Effect of Sample Thickness (height) on TMA Tg and T-260 Results

Set-up

Samples from a 40 layer PWB with 17 micron innerlayer copper planes spaced every 0.2 to 0.25mm, 8.4mm total thickness were cut into blocks about 6 mm on edge, and 8.4, 4.2, 2.1mm in height. The thermocouple was set at a height above the stage equal to the sample height. Also for an 8.4 mm sample the thermocouple was set on the stage surface. The samples were tested in the TMA for T-260 failure time and Tg. The results of the testing are shown in Table 1.

Table 1 - TMA Analysis of a 40 Layer PWB with 17 micron Cu Planes Test Vehicle

	Thermocouple	**Tg by TMA**	**Delamination**	**T-260 Time**
Sample Height	Location	(C)	Temperature	To Delaminate
8.4mm (entire PWB)	On stage	151.2	247.48	Delam prior to 260C
8.4mm (entire PWB)	8.4mm high	171.2	None	2.6 minutes
4.2mm (1/2 PWB)	4.2mm high	166.4	None	3.4 minutes
2.1mm (1/4 PWB)	2.1mm high	178.7	None	4.2 minutes
2.1mm (1/4 PWB)	On stage	161.1	None	2.2 minutes

Results

The difference between the Tg measured for the 8.4mm thick sample at the high and low thermocouple location was 20C. The Tg measured with the thermocouple on the sample stage was only 151C. The Tg as measured for each sample thickness with the thermocouple set parallel to the top surface of the sample varied from 166 to 179C.

The T-260 results show that for the sample tested with the thermocouple on the sample stage delamination occurred prior to reaching 260C. The delamination occurred on the top two plies of the PWB. With the Thermocouple set equal to the height of the sample T-260 times between 2.6 and 4.2 minutes were measured. Delamination still occurred near the top surfaces of the samples.

Discussion

It was difficult to set the thermocouple to a height above the stage equal to the sample height. Careful calibration procedures would need to be established if this were to become a standard procedure. While for T-260 testing there seems to be a relationship between sample thickness and time to fail, even after adjusting the thermocouple height, much more data must be obtained to determine if the difference in T-260 results are significant. If the thermocouple is not adjusted to be parallel to the top surface premature failure would be expected to occur since the temperature at the top of the sample is much higher than measured by the thermocouple in the standard position at the base of the sample. As the sample thickness is increased, the time until delamination measured will decrease. For samples tested with the thermocouple set parallel to the top surface it is expected that T-260 failure temperatures would be relatively independent of sample thickness.

The relationship for measurement of Tg is more complicated. The Tg measured is the average transition for the entire sample. The lag for the entire sample to pass through Tg from top to bottom and outside edge to center will cause the transition to broaden. For thick samples tested with the thermocouple in the standard position the Tg measured will always be artificially low. For thick samples tested with the thermocouple parallel to the top surface the Tg will be artificially high. Testing of thin samples minimizes this issue.

Study 3A - Effect of Sample thickness on T-260 and Tg Results

Set-up

Unclad laminates were prepared from PCL-370 FR4 7628 prepreg. Increasing the number of plies used produced samples of various thicknesses. The cure time was 90 minutes at 370F. Samples were cut and submitted for T-260 testing.

Samples were tested in the TMA using standard conditions of 10C per minute heat rise and thermocouple parallel to the sample stage surface. Results are shown in Figure 4.

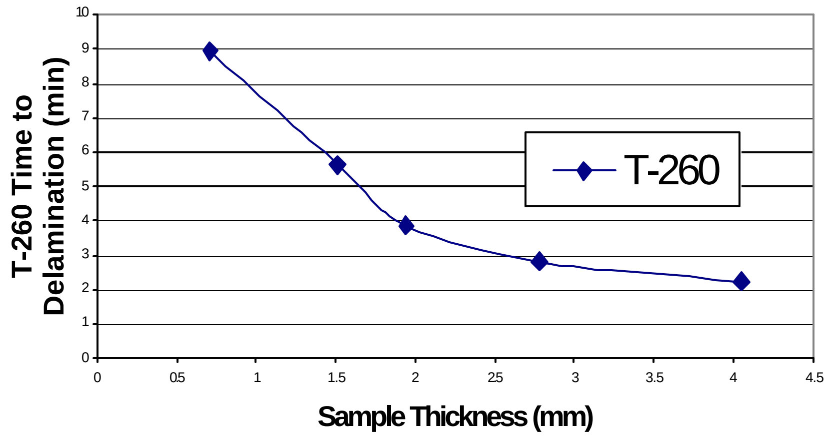

Figure 4 – TMA T-260 Testing: Effect of Sample Thickness on T-260 Time to Fail Unclad 370D Laminate Presses Twice at 370F 90 Min

Results

The time to delaminate decreased significantly as the sample thickness increased. The .7mm thick sample delaminated after 8.9 minutes at 260C while the 4mm thick sample delaminated after only 2.2 minutes. All samples delaminated near the top surface.

Conclusion

T-260 results are significantly influenced by sample thickness. Thicker samples delaminate at measured times much shorter than thin samples. Since samples were prepared under identical conditions from the same starting materials, variation within the TMA must be affecting test results.

Study 3B - Effect of Sample Thickness Using A Manufacturer B TMA

Set-up

Samples of various thicknesses were prepared from the 40 layer, 8mm thick PWB used in study two above. These samples were sent to an independent test lab testing on the manufacturer B TMA. Prior to testing, samples 8.4, 4.4, and 2.4mm thickness were conditioned at 105C for 2 hrs and then cooled to room temperature in a desiccator. Two samples of each thickness were tested. (See Table 2)

Table 2 - TMA Test Results: Sections from a 40 layer 8.4mm PWB

Sample Thickness	TG	T-260 Delamination Time
8.41 mm	150.5C	0.0 Min
8.44 mm	149.2	0.0
3.78 mm	168.7	1.02
4.56 mm	150.2	0.70
2.33 mm	165.6	1.50
2.47 mm	151.5	1.40

Results

The Tgs and T-260 delamination times were determined for each sample. Results are reported in Table 2 and Figures 5 to 6. There was significant variation in the Tgs reported for the samples tested. A clear relationship between the sample thickness and T-260 results was observed.

Conclusions

Increased sample thickness decreased the T-260 time to fail for both the TMA's Tested. Tg values vary significantly from test to test when measured on the manufacturer B TMA.

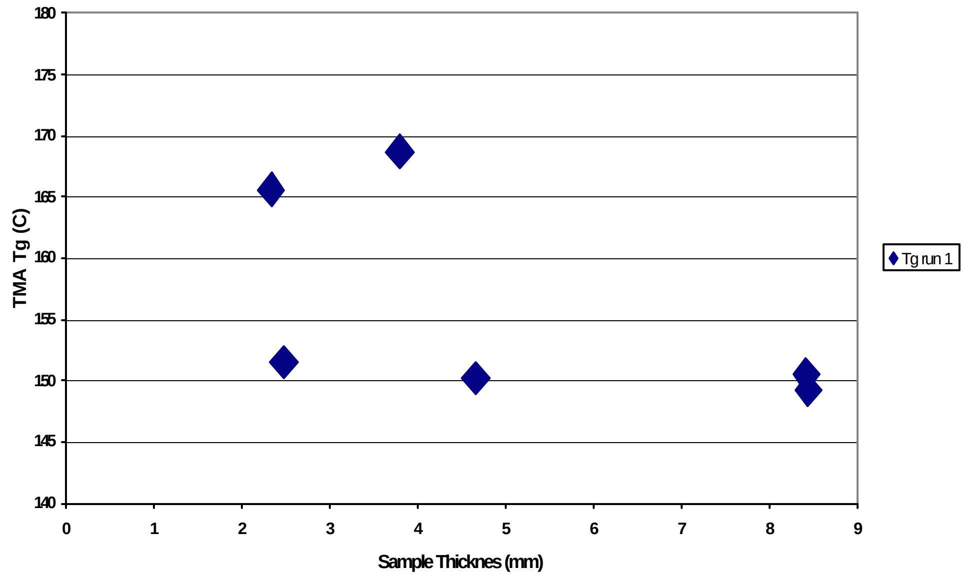

Figure 5 – Tg by TMA: Influence of Sample Thickness Data Measured by Independent Lab on Manufacturer B TMA

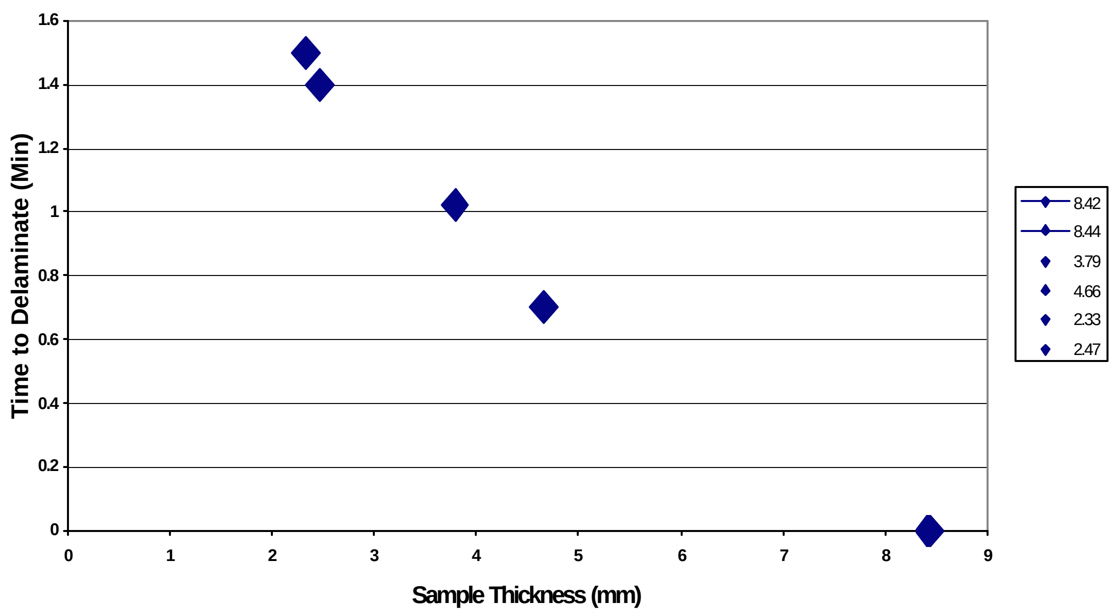

Figure 6 – TMA Testing: T-260 Delamination Time vs. Sample Thickness Test Performed by Independent Lab Using Manufacturer B TMA

Study 3C - TMA Testing Of Samples Sectioned to 1.5mm Thickness

Setup

A set of samples of multilayer PWBs was tested at the "as received" thickness and after slicing sections 1.5mm to 1.6mm thick. All of the PWBs were produced from PCL-FR-370 substrate. Two sections from each sample were tested using a manufacturer A TMA for T-260 delamination time and Tg. Tg by DSC was also determined for comparison. (See Table 3)

Results

Table 3 and Figures 7 to 8 show the results of study 3C. Samples sliced to the same thickness had similar Tg and T-260 failure times. Tgs measured for samples 1.5mm thick are significantly higher than Tgs measured for thicker samples of the same PWBs. 1.5mm TMA Tg results are also very similar to the results determined by DSC. Significant difficulty was experienced however determining the by TMA for some samples. These samples have non-uniform thickness changes as the PWBs were heated through the Tg region. TMA failure times increased significantly for the thin sections as compared to the thick as received samples. For samples of similar thickness the Repeatability of the TMA test for Tg was 3sigma = 13.3C and for T-260 failure times 3 sigma = 1.08 minutes.

Table 3 - TMA Test Results - Effect of Sample Thickness on Results

Sample	Tg "As Received"	Tg Test1 1.5mm	Tg Test2 1.5mm	T-260 "As Received"	T-260 1.5mm	T-260 1.5mm	Tg by DSC
0558661-01 8.4mm	156.04C	183.6C	179.3C	0 minutes	2.78 min	2.96 min	167.1
058661-02 4mm	161.45	178.9	175.3	2.19	3.24	3.03	169.1
058662-01 4mm	149.45	179.2	172.8	1.73	2.53	2.3	171.2
058662-02 8.4mm	151.67	172.2	168.0	0	4.69	4.21	169.1
058662-SIP 8.4mm	153.13	161.4	167.2	0	2.77	3.11	172.8
58534-SIP D 8.4mm	148.32	174.0	166.2	0	3.47	2.69	169.9
58531-01 SIP4 4mm	146.98	171.6	162.5	1.8	2.53	3.25	166.8

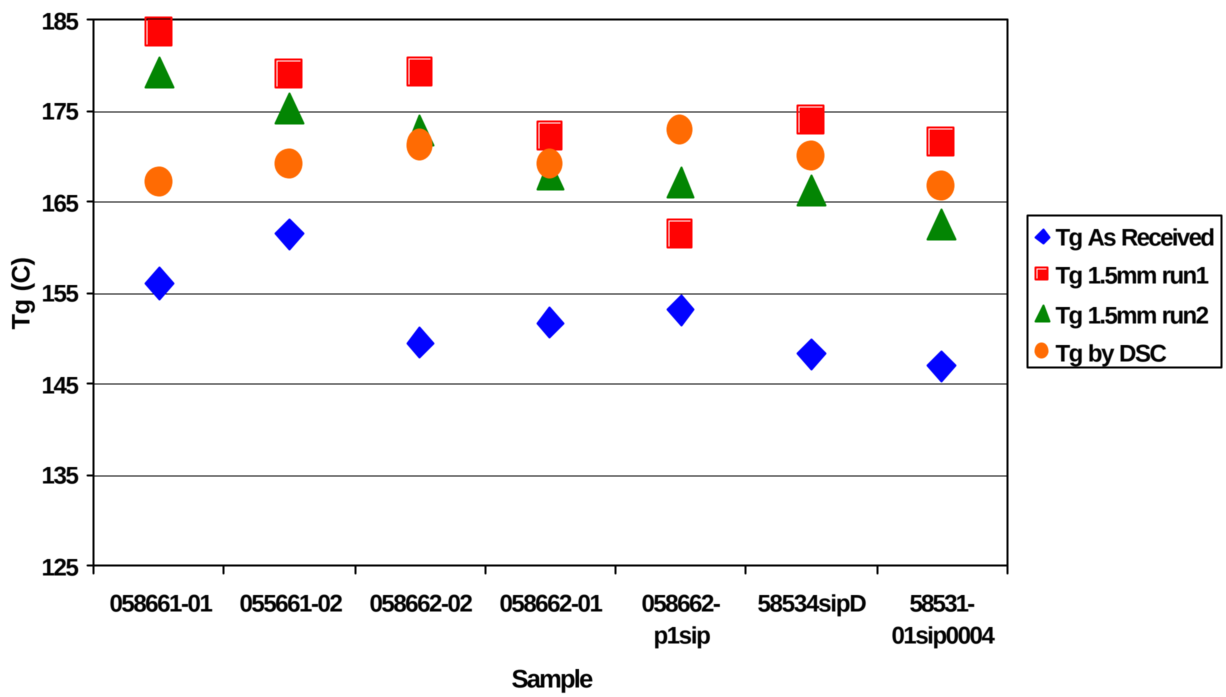

Figure 7 – TMA Study: Tg vs. Sample Thickness 370D PWBs

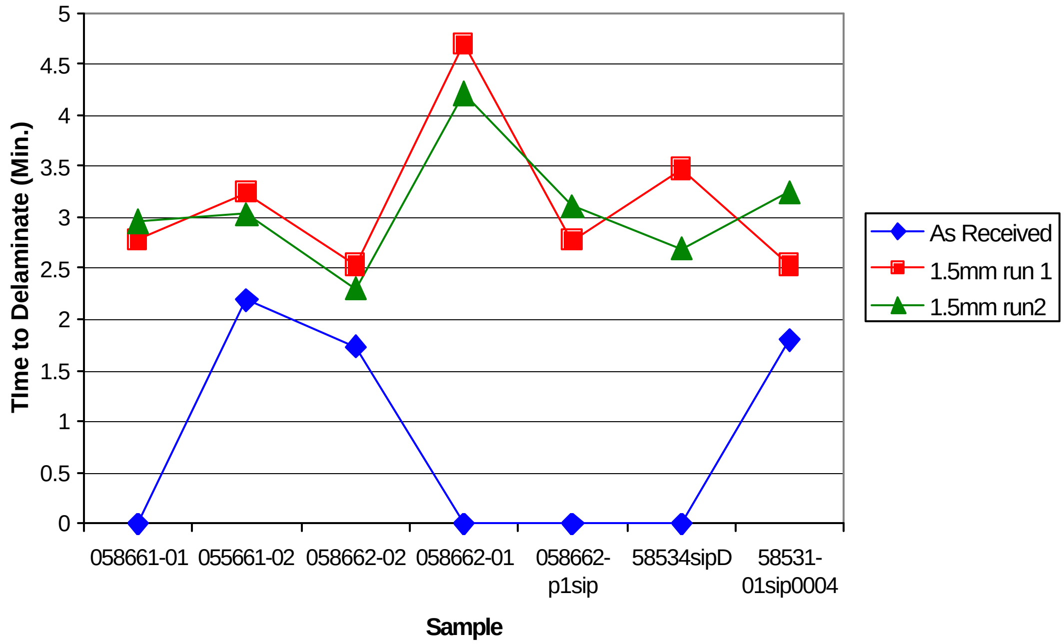

Figure 8 – TMA T-260 Testing: Time to Fail vs. Sample Thickness

Study 4 - Effect of TMA Isotherm Temperature on Delamination Time

Set-up

Samples of 1.5mm thick PCL-FR-370 clad with one oz copper were tested on Manufacturer A's TMA for the time to delaminate at increasing isotherm temperatures. T-260 test procedures were followed with only the isotherm temperature increased incrementally from 260C to 270C. (See Table 4)

Results

Results of the testing are shown in Table 4 and Figure 9. In general the time to delaminate decreased as the isotherm temperature increased. Longer times to delaminate were observed for samples tested at 264 and 265C. This variation is attributed to the variation within samples and from test process variation.

Table 4 - TMA Test PCL-FR-370 1.5mm 1/1

Isotherm Temperature	Time to Delamination
260C	3.87 Min
261C	2.95
262C	2.88
263C	2.74
264C	4.13
265C	4.33
266C	1.94
267C	1.87
268C	1.16
269C	0.60
270C	0.96

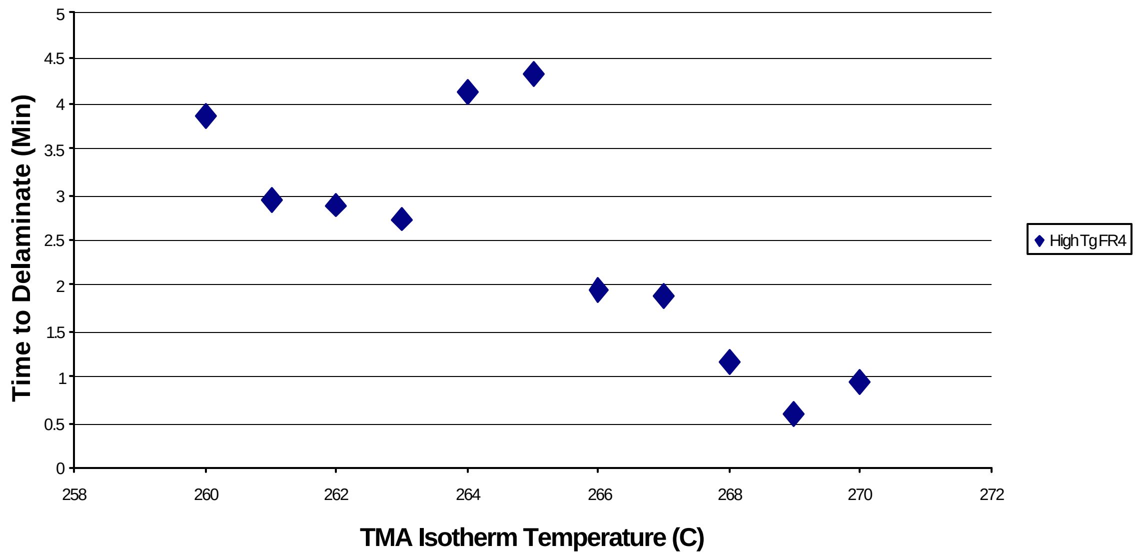

Figure 9 – Effect of TMA Isotherm Temperature on Time to Delaminate PCL-FR-370 Copper Clad Laminate 1.5 mm Thick

Overall Conclusions

Thermal gradients within both manufacturers TMA furnaces significantly affect measured times for delamination at 260C and the measured Tg. The effect of the thermal gradient is largest with very thick samples. The temperature variation from the top to bottom of a 8mm sample can be more than 17C In the Manufacturer A TMA. Similar issues were observed for the Manufacturer B TMA. Without modification of the T-260 test method from standard procedures the T-260 test is actually a T-277C test. Tgs measured on 8 mm samples can be more than 10C too low.

Options to minimize the variation of T-260 related to sample thickness include:

1. Moving the thermocouple parallel to the top surface of the sample
2. Creating a temperature vs. sample height calibration and reducing the isotherm temperature appropriately
3. Obtaining a modified furnace designed to minimize the variation in temperature.
4. Testing thin sections of thick PWBs or using an established "standard" test sample thickness of 1.5mm or less.

Options to minimize the variation of Tg related to sample thickness include:

1. Moving the thermocouple parallel to the center of the sample
2. Obtaining a modified furnace for the TA Instruments TMA (now available)
3. Testing thin sections of the thick PWBs
4. Heating the sample at a slow heating rate to minimize the temperature lag from edge to center of the sample

Unless the IPC test method is modified for evaluation of thick samples false premature failures will routinely occur. These failures will ultimately lead to specification of material with performance beyond that needed to meet functional requirements of assembly and rework. Experience performing this investigation into TMA T-260 and Tg testing using Manufacturer A's TMA suggest that a reasonable solution would be to require samples tested to have a maximum thickness of 1.5mm. PWBs thicker than 1.5mm would have to be reduced in thickness prior to testing. This solution would provide reasonable consistency and eliminate the need to routinely move and recalibrate the thermocouple. Evaluation of the improved TMA furnace now supplied by manufacturer A is planned for the near future. Use of this new improved furnace may significantly reduce the impact of sample thickness on TMA test results.

References

1. IPC-TM-650 Specification 2.4.24 Rev C.
2. IPC-TM-650 Specification 2.4.24.1.
3. Polyclad Laminates Inc Analytical Test Method ASP-4 Rev. D.
4. Operation of the TMA.
5. Perkin Elmer Applications Note PETECH-122.
6. Effects of Temperature Calibration and Purge Gas on Thermomechanical CTE Analysis.