H.A.L.T. TEST VEHICLE FOR LEAD FREE SURFACE FINISH AND SOLDER PASTE SELECTION

Tim Murphy
Thomson Inc.
Indianapolis, IN, USA
Tim.murphy@thomson.net

ABSTRACT

Thomson has developed a test vehicle and protocol to enable our engineers and management decision makers to easily measure and compare the often elusive, interactions between surface finish, paste flux and solder alloy. This thermo-mechanical test method measures the average energy required to fracture SMT solder joints using nine, (9) different strain conditions. The ease of replication and simple test geometry allows practical multifactor experiments to be conducted on paste alloys and their flux vehicle. The method permits measurement of thermal stability, packaging and shelf life studies on PCB finishes and allows measurement of their complex interaction with paste alloys, i.e. wetting, fillet formation, intermetallic phases distribution and, alloy dilution. Data presented in this paper has expanded upon our earlier work now including evaluation of multiple suppliers of Immersion silver & tin coatings, OSP, ENIG and Lead free HASL. Additional reliability data on 3% & 4% SAC alloy is presented along with comparisons to non silver bearing paste alloys; SnCuNi and SnZn.

INTRODUCTION

Lead Free Assembly requires that we use new alloy pastes with more active fluxes. Conventional Tin Lead HAL and OSP's are being replaced by lead free HAL and high temperature resistant OSP's, ENIG, Immersion Silver or Tin. Considering the many solder paste suppliers who offer different activity flux pastes and Lead-Free alloys, the multitude of possible combinations of paste/Flux – surface finish is very large indeed.

Most reliability data for Lead free finishes and solders is based on evaluation of functional components and electrical designs. Not often is the mechanism of failure clear and doubt exists as to the location of failure. Did the component itself fail electrically? Did the joint crack at the interface between the component and solder joint? Did the failure occur at the interface between the solder joint and the PCB surface finish? Did the bulk solder fail within the joint?

The first paper in this series [1] discussed the test development and showed interesting performance differences between Lead and new SAC alloys. It showed general performance ranking of multiple surface finishes and demonstrated sensitivity to defective, oxidized and tarnished coatings.

It is well known that Lead free alloys do not wet as well as conventional tin lead materials[2]. This often results in different fillet geometry. These new alloys have different metal ratios, metallurgical properties, grain size and intermetallic distribution and exhibit different mechanical properties.

Conventional methods of reliability testing typically subject a test vehicle, usually a BGA, to temperature cycling and measure the number of cycles it takes to fail the typical joint[3]. Another method involves Impact or (drop) testing and enables measurement of strain rate sensitivity on fracture behavior of the joint.[4]

During reflow, solder paste flux activity, and melting behavior of the fluid alloy combine to wet-out the PCB and component finish dissolving them into the melt. Ultimately the slightly altered alloy solidifies to form the solder joint. These key variables directly impact the fillet geometry and interfacial metallurgy of surface mount solder connection.

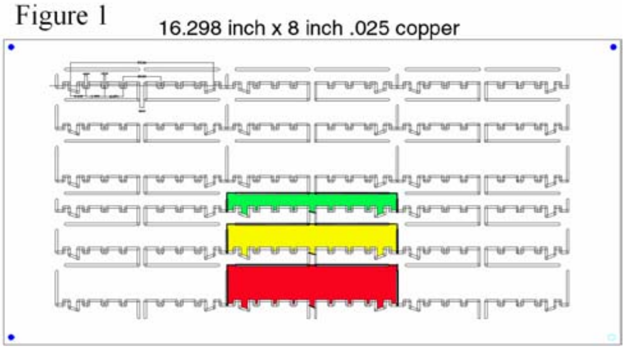
During test, failures can occur at one of three locations,
1) At the component to solder paste interface, 2) at the PCB to solder joint interface, 3) within the bulk solder.

The HALT test board and protocol was developed to enable rapid screening best combination of assembly materials and reflow processes. It has helped our company make decisions on the best paste/finish material for our various applications. We were tasked by our management to develop a test to meet the following requirements.
1) Non Labor-intensive technique, i.e. use electrical measurement of first failure. 2) Capable to measure solder paste and surface finish interactions. 3) Simplify coating and use identical surface finish on both PCB and component. 4) Apply both thermal and vibratory stresses to components to achieve failure within 1 work day, or 8 hour test time. 5) Test a wide range of stress levels and introduce a wide range of thermal stress and creep mechanisms to simulate a wider variety of field conditions. 6) Get results in days, not months.

ADAPTATION OF HALT METHODOLOGY

HALT, (Highly Accelerated Life Testing) is a technique used by electronic equipment designers to evaluate field durability and life of their products. It allows us to uncover design weaknesses and iteratively eliminate failures and strengthen our designs. Thomson uses this method to evaluate our system boards and improve durability. It has been our experience that often times during standard HALT procedures, devices stop functioning because of a non-solder related problem i.e. failures occur within discrete components, ASICs, crystal glass to metal seals, wire bonds, etc. or are due to thermal bit error rate problems. In order to eliminate component vulnerability, we have selected a very robust test vehicle in which we can force failure to either be reflowed bulk alloy or the surface finish/paste interface. Our design, uses a simple fin shaped copper component and a PCB uses copper as base metallization. Fin components are delivered to coating supplier's process in strip form, just like the PCB, and for this reason solderable surface finish coatings can be applied using identical conditions.

Figure 1



Reflow Solder joints formed between PCB and component fail either within the solder or at the solder/finish interface. This novel design eliminates all failure mechanisms unrelated to surface finish or solder paste alloy. Wetting conditions and fillet geometry are dependant on paste volume, flux alloy and surface finish.

Ultimately Failure of each component will occur when cumulative damage exceeds a fixed value for that alloy and is contributed to by local micro-structural effects which are related to thermo-mechanical stress/strain and loss of fatigue ductility of the solder. During our HALT test there will be 2 contributors to the Solder joint fatigue. And because of the protocol, Fatigue strains will have both thermal and mechanical components.

TEST VEHICLE

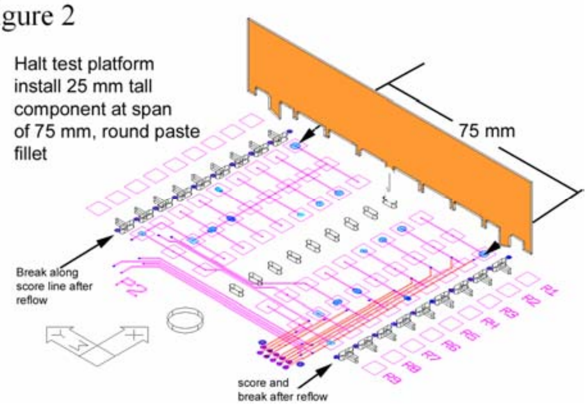
The test vehicle consists of a 1.6 mm thick Double sided FR4, PCB and, 0.64mm thick Cu patterned sheet, **Figure 1.** Since both the PCB and Copper sheet are flat they can be run through any Solderable surface finishing line. For example, OSP, ENIG, HAL, Ag, Sn. Each PCB has (3x3x3) =27 Pairs of solder pads which enable 3 different component spans and 3 different fin heights, replicated 3 times to be assembled simultaneously.

EXPERIMENTAL PROCEDURE

Test procedure combines both thermal cycle and HALT vibration at 9 different strain levels produced by varying the component height and span between solder joints. The wetting of solderable coating by a specific flux/paste alloy produces a peculiar fillet shape. Different fillet shapes fail at different strain energies which can be measured by electrical open in this test.

Figure 2 shows a 3D view of the HALT test platform. In this view a 25 mm tall component is shown just above the board surface. After solder paste application, this component will be placed onto the test board surface using alignment slots. Solder paste printed at 75mm span will make this the worse case failure condition. After reflow the slotted areas will be broken free leaving the component attached just at 2 fixed points.

Figure 2



The following is the procedure followed for a typical test.

- Coat PCB and Copper components with Identical Experimental test coating.
- Separate the copper fin components using guillotine shear. Each sheet coated produces eighteen (18) 6 each 10, 18, 25 mm test components. **Figure 1**
- Print PCB with 8 mil stencil using Experimental Paste producing fixed pattern of paste pads at spacing 25, 50 and 75mm
- Place 27 fins onto each test platform contacting 2 solder paste pads per fin. This is mechanically assisted by guide tabs on each fin and 2 alignment slots, **Figure 2.**
- Reflow solder using Thermal Profile. **Figure 3**

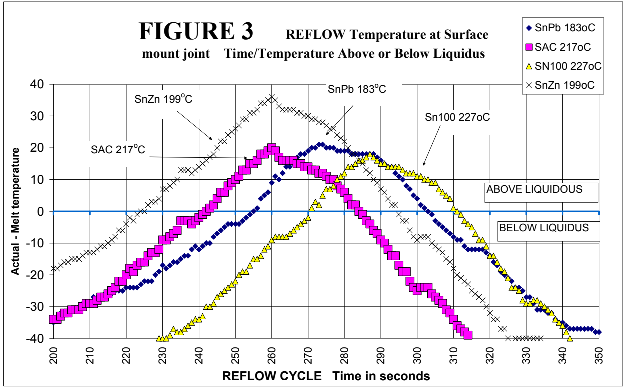
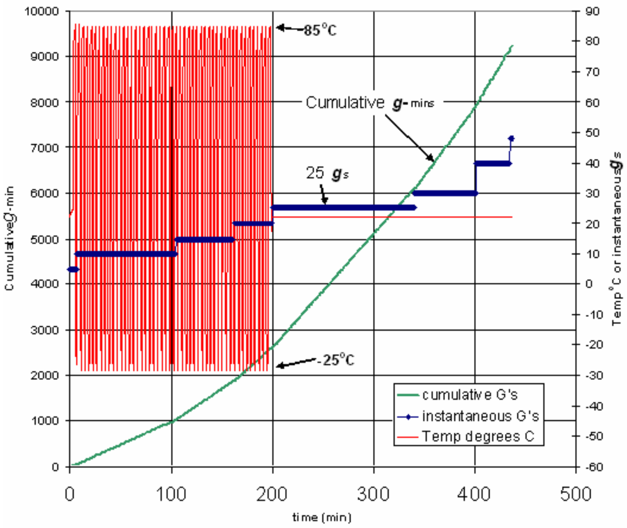


FIGURE 3 REFLOW Temperature at Surface mount joint Time/Temperature Above or Below Liquidus

- Hand solder test connector (s)
- Break off support area of PCB leaving Component attached by only 2 joints.
- Load inverted test platform into HALT test chamber[5] attach monitoring cable to connector.

- Begin Rapid Thermal Cycle -25 +85C and low *g* vibration.
- Run automating test protocol thermal cycle step stress shown in **Figure 4.**

Figure 4 Typical HALT EXPERIMENT Conditions Rapid Temp for 48 cycles during first 200 min, STEP STRESS *g*'s



- Monitor and record electrical resistance of each joint pair the accelerometer g level and temperature.
- Continue until all fins have failed.
- Integrate and Compute the cumulative g-level for each failure using the relationship shown below

$$\sum g_{\min} = \sum_{start}^{fail} g \times 60\,\text{sec}$$

- Analyze and report results.

TABLE 1 HALT TEST PROTOCOL				
Step Stress	***g*** level	Cumulative Shock cycles	Range of Cumulative ***g***'s . min	
Step 1	**5 *g***	**1**	0	25
Step 2	**10 *g***	**25**	26	981
Step 3	**15 *g***	**40**	982	1829
Step 4	**20 *g***	**48**	1830	2561
Step 5	**25 *g***	**NO Cycle**	2562	6046
Step 6	**30 *g***		6047	7869
Step 7	**40 *g***		7870	9089
Step 8	**50 *g***		9090	11141
Acceleration due to gravity - a = 9.8067 meters/sec^2				
Thermal cycle -25 to +85 C			Cycle time 4 minute	

Based on experience and earlier data we have frozen Copper pad size on these and future experiments to be 5mm square having round 2.0 mm resist defined pads fixed, 0.20 mm, (8mil) thick paste stencil with pad diameter of 2.75 mm.

DEFINITION OF 9 STRESS LEVELS

The use of 3 different components (Heights 10, 18 and 25 mm) with solder joint spans of (25, 50 and 75mm), result in Nine (9) levels of joint strain. Table 2 shows the 9-value strain matrix. Cumulative g-min data is multiplied by the strain factor (N-m/g-min) to calculate the total strain energy (N-m) at failure for each joint pair. These failure energies are used to rank or classify the relative contribution of each test variable in the assembly process.

TABLE 2 HALT TEST VARIABLES						
RANK high to low strain	**Fin Height (mm)**	**joint span (mm)**	**CTE mis-match**	**TorqueTheta Θ**	**Height Torque γ**	**K const. N-m / *g*.min**
1	**25**	**25**	**low**	**HIGH**	**HIGH**	***0.173***
2	**18**	**25**	**low**	**HIGH**	**med**	***0.117***
3	**10**	**25**	**low**	**HIGH**	**low**	***0.065***
4	**25**	**50**	**med**	**med**	**HIGH**	***0.114***
5	**18**	**50**	**med**	**med**	**med**	***0.067***
6	**10**	**50**	**med**	**med**	**low**	***0.036***
7	**25**	**75**	**HIGH**	**low**	**HIGH**	***0.092***
8	**18**	**75**	**HIGH**	**low**	**med**	***0.045***
9	**10**	**75**	**HIGH**	**low**	**low**	***0.017***

Within our experiment, three (3) variants of thermal strain are used. Pairs of reflowed solder joints are formed on each component 25, 50 or 75 mm spans. The magnitude of thermal induced strain at each transient can be measured and controlled by selecting the materials used for the experiment and temperature range. Therefore the first contributor to failure is the differential strain between copper part and PCB caused thermal cycle and CTE mismatch between bulk Cu and PCBs' particular Glass/resin ratio. This is held constant for each experimental build by using identical components and PCBs. This thermally induced stress is caused by expansion mismatch between the copper and FR4.

Thermal induced strain is directly proportional to span and temperature change, the difference in coefficient of expansion between the two materials Cu, 18.3 and PCB 13, The number of cycle to failure can be predicted using equation 1

$$\text{Eq1.}\qquad \varepsilon_{strain} = \Delta CTE_{PCB,13}^{Cu,18.2} \times \Delta T_{-25}^{85} \times span \begin{matrix} 25 = 14.3\mu \\ 50 = 28.6\mu \\ 75 = 42.9\mu \end{matrix}$$

Thermal fatigue strain is expected to be greatest on 75 mm span, lowest at 25mm space. PCBs made from FR4 and Copper and tin lead solder we find that for static thermal cycle, the Cycles to failure can be predicted from the calculated micro-strain (ε)values listed above, using the following empirical defined exponential relationship.

Figure 5 shows expected cycles to failure for pure thermal cycling environment -25 to 85C for copper and FR4 measured by our laboratory on tin-lead solder.

$$cycles = \varepsilon^{-2.1} \times e^{13.3}$$

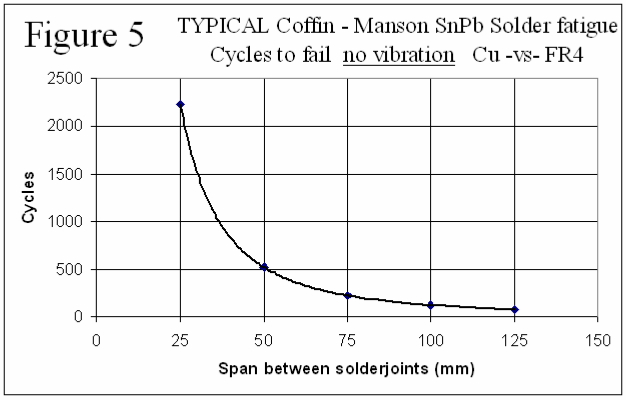
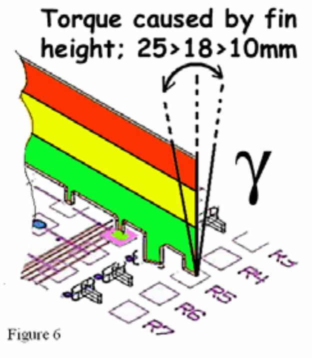


Figure 5 TYPICAL Coffin - Manson SnPb Solder fatigue Cycles to fail no vibration Cu -vs- FR4

The second Contributor to fatigue will be vibration. This has been adjusted in order to accelerate fatigue and get joint failure at all (3) spans within an 8 hour test period.

Vibration of the test platform during thermal cycling will propagate thermal cycle cracks and significantly reduce test time. Components of variable heights and spans will have bending and twisting torque applied to each solder joint the Resultant strains is proportional to their height above the solder joint. **Figure 6** shows the three components used in our test. They have heights of 10, 18 and 25 mm- Torque caused by tilting γ of the component height is represented by Equation 2.



Eq.2 $$\gamma_{span}^{hgt} = hgt \times mass \times 9.806 \times 60$$

SOLDER JOINT STRAIN

The results of our testing, show first failures on the tallest component and longest life for short components. We had expected that the span between joints to be the next contributing factor cause failure i.e. for large distance between joints, would place greater thermal expansion mismatch and induce thermal fatigue cracks. This was not as strong a factor as initially anticipated as the free swinging end of the close span components results in rotational joint torque caused by the distance between the outermost solder joint and the free end of the component. This free swinging mass was greatest for 25 mm span and smallest for 75 mm span.

Resolution of this torque is shown in **Figure 7**

Rotational torque Θ cause by component mass outboard of the solder joint is calculated using Equation 3

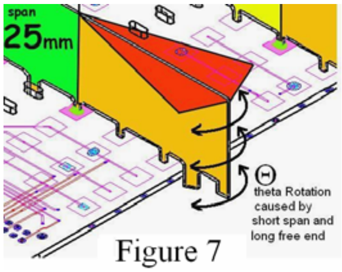


Figure 7

Eq 3. $$\Theta_{span}^{hgt} = L \times mass \times 9.806 \times 60$$

Finally both the height and span induced torque are resolved by equation 4 and multiplied by the cumulative g-minute value measured experimentally.

$$K_{span}^{hgt} = \frac{\sqrt{(\mu \times \gamma)^2 + \Theta^2}}{1000}$$

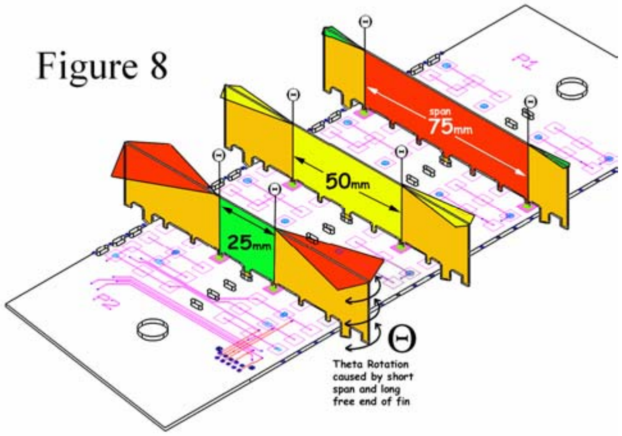
$hgt = meters$
$L = meters$
$mass = grams$
$K = multFactor$
$\mu = 0.66$

These results in calculation of total energy required to fail each joint as reported in (N**-m), equation** 5

$$Energy_{failure} \cong K_{span}^{hgt} \times \sum g_{\min} = Newton - meters$$

Figure 8 shows the variation in component span and how this span effects the rotational torque being greatest for 25mm span and least for 75mm span.

Figure 8



CONVERSION OF CUMULATIVE g-min → N-m

The cumulative damage (g-min) for each coating & solder paste was measured with 3 fold replication. Average values for each of the 9 strain conditions were calculated. **Figure 9** shows average of 3 measurements for each of 9 strain conditions for some representative materials in this test.

A table of values for component heights, mass and dimensions relating to calculation of the magnitude of torque and how are used to resolve joint strain energy are provided at the end of this report.[6]

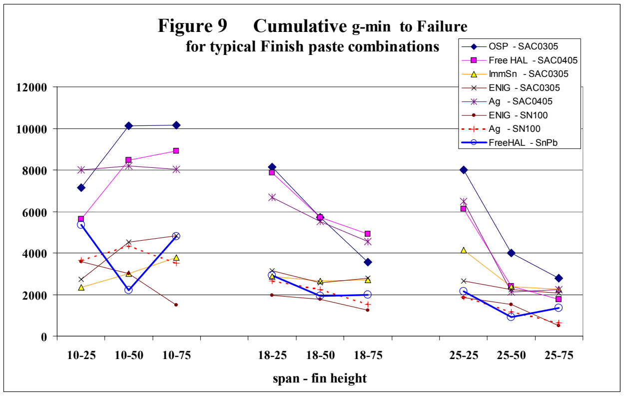


Figure 9 Cumulative g-min to Failure for typical Finish paste combinations

Figure 10 shows the same information as Figure 9 but, this data has been Normalized enabling direct comparison using standard energy units **(N-m)** per Equation 5.

Note: values of K_{span}^{hgt} for various heights and spans are listed in Table 2

$$Energy_{failure} \cong K_{span}^{hgt} \times \sum g_{\min} = Newton - meters$$

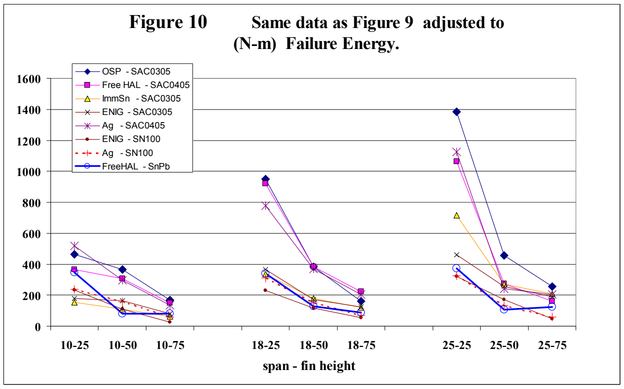


Figure 10 Same data as Figure 9 adjusted to (N-m) Failure Energy.

Failure energy data for all 56 experiments on 50 and 75mm span appears to be predictable from 25 mm span data, by the ratios ~2x (0.45:1), & ~4x, (0.25:1) respectively. As shown in **Figure 11**.

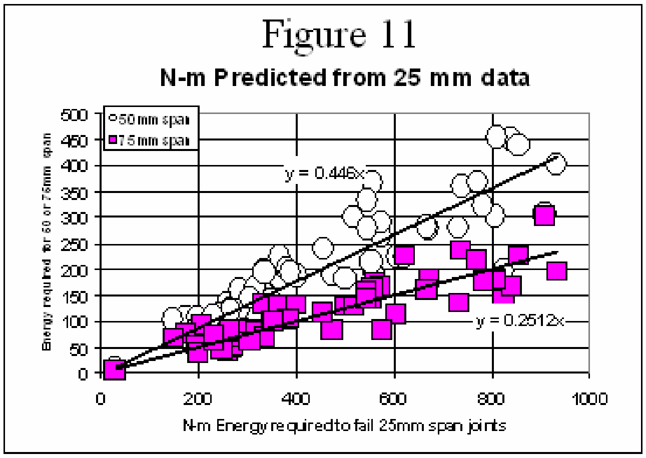


Figure 11

N-m Predicted from 25 mm data

POOLED COMPARISON / PASTES / FINISH

We measured the performance **56** different solderable coatings.

Measurements were distributed among five(5) different pastes and six(6) surface finishes Overall average pooled performance by paste and surface finish are listed in Tables 3 and 4 and shown graphically in Figures 12 & 13 respectively. This information is only of general interest since it is pooling multiple results and does not have identical sample size.

TABLE 3 Solder Paste	obs	Ave. Newton-meters
SnZn	2	107
Eutectic SnPb	11	150
99Sn.5Cu	12	186
SAC0305	21	340
SAC0405	10	351

TABLE 4 SURFACE FINISH	obs	Ave. Newton-meters
Free HAL	7	321
OSP	7	286
Lead HAL	7	247
Silver	20	251
Tin	12	263
ENIG	3	185

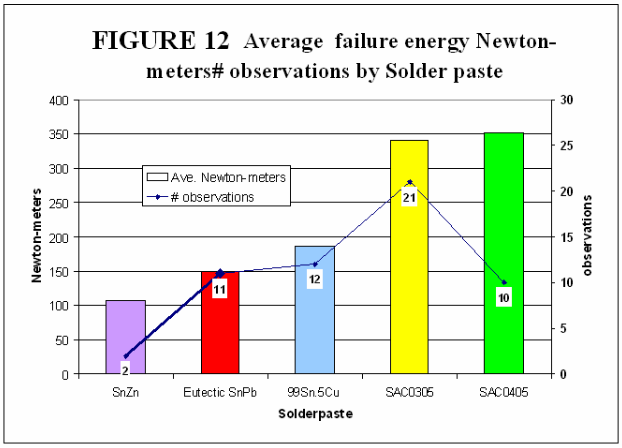


FIGURE 12 Average failure energy Newton-meters# observations by Solder paste

Figure 12 indicates SAC alloys have higher failure energy and there is little difference between 3% and 4% silver.

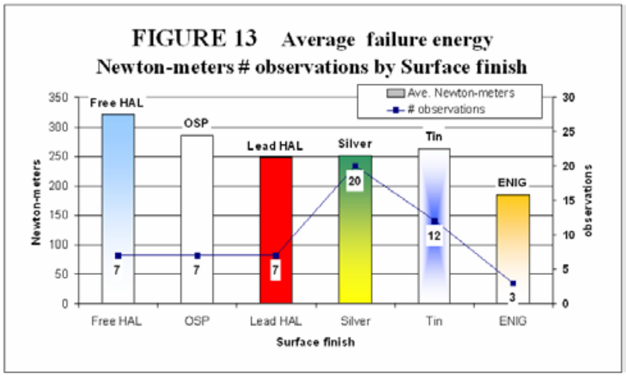


FIGURE 13 Average failure energy Newton-meters # observations by Surface finish

Figure 13 shows general similarity in all finishes Lead Free HAL being best and ENIG being worst.

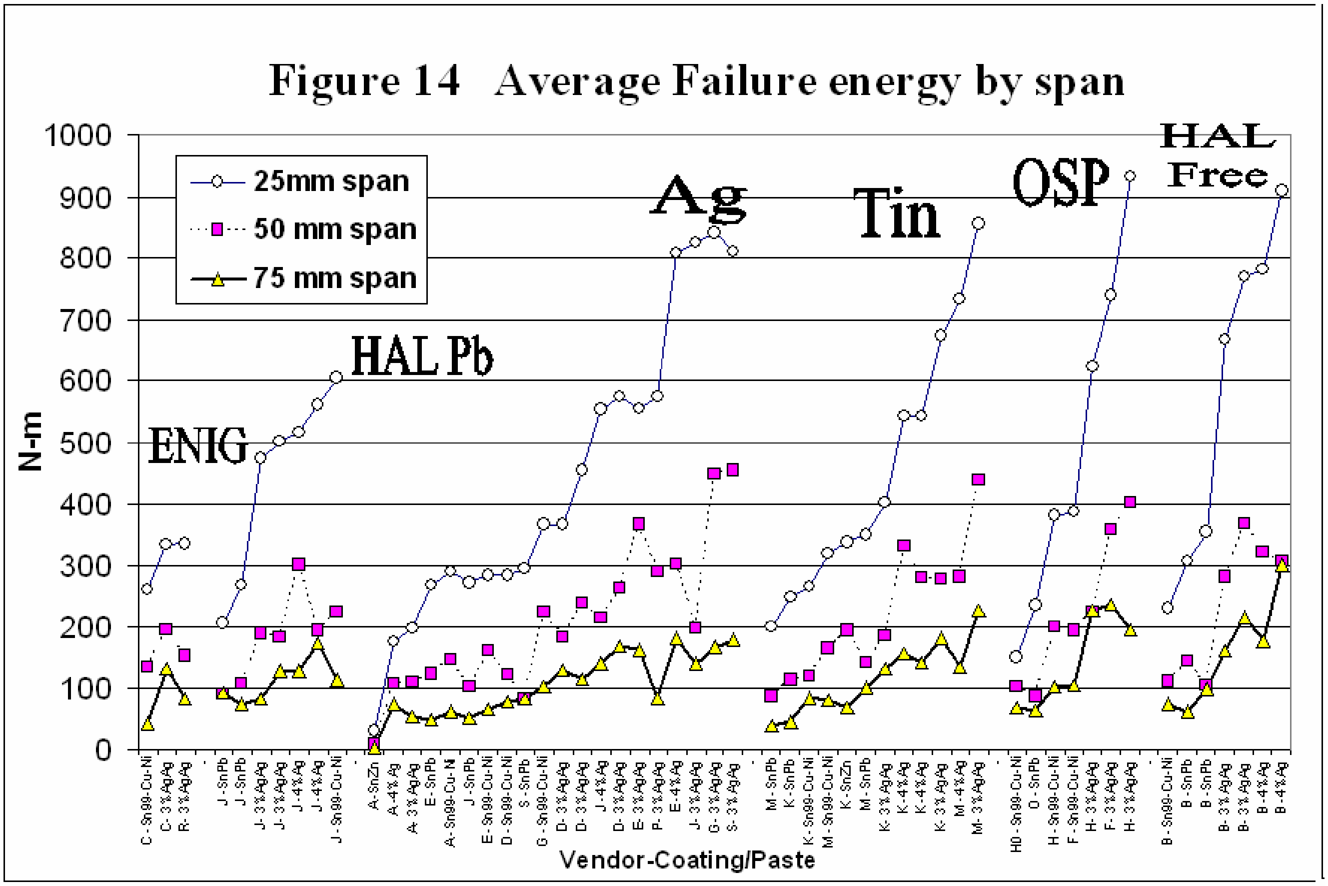


Figure 14 Average Failure energy by span

INTERACTIONS BETWEEN PASTE & FINISH

Average N-m results from all 56 trials are shown by **Figure 14;** this summary data is grouped by component span. The height contribution has been adjusted for using the constant, K^{hgt}_{span} mentioned earlier. Results for average failure energy are further subdivided along the X axis by surface finish then generally ranked from lowest to highest failure energy. Each group of finishes has two identifications, The Letter indicates the Chemical supplier, which is followed by the solder paste identification. **Figure 14** shows generally poor performance of ENIG and Tin Lead HAL and better overall performance by OSP and Lead Free HAL.

Failure energy data for (75 mm) span, represented by Yellow triangles in Fig 14, have been exposed to more thermal fatigue damage "CTE mismatch" The cracks which were formed during the first 48 thermal cylces now propagate during vibration. We believe this is why these joints longer span joints fail earlier than shorter span joints. The relative magnitude of this effect was indicated to be a factor of 2x or 4x for 50 and 75 mm respectively by Figure 11.

TARNISHED SILVER & OXIDIZED COPPER

Were the lowest performer of all finishes studied –Oxidized Cu and Low temperature OSP showed poor wetting, see **Figure 15**, which resulted in early failure and low failure energy. These were special cases but are included in this analysis to show its sensitivity to out of specification finish or non optimum reflow conditions.

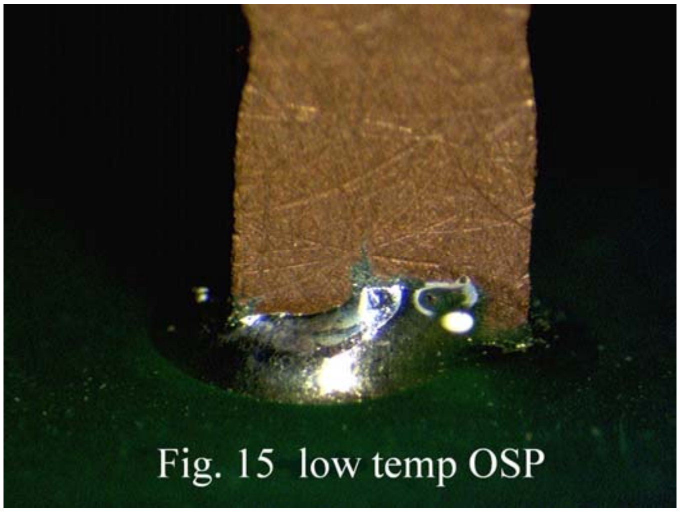


Fig. 15 low temp OSP

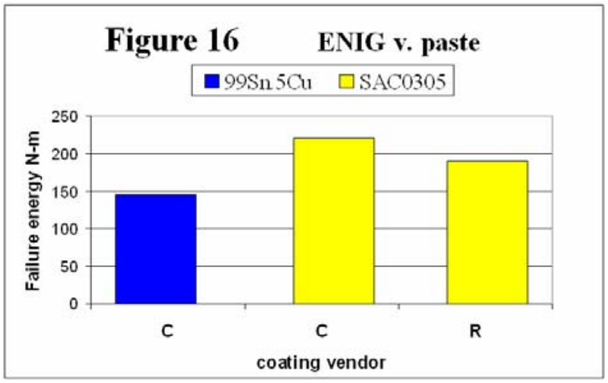


Figure 16 ENIG v. paste

ENIG

Electroless Nickel Immersion Gold. (ENIG) was third worst performer. According to **Figure 16**, Coating vendor C performed slightly better than vendor R. The energy required to fail ENIG joints was significantly below most for other immersion deposits clearly indicating moderate embrittlement by gold you will note that Fillet shape was well defined as Shown by **Figure 17.**

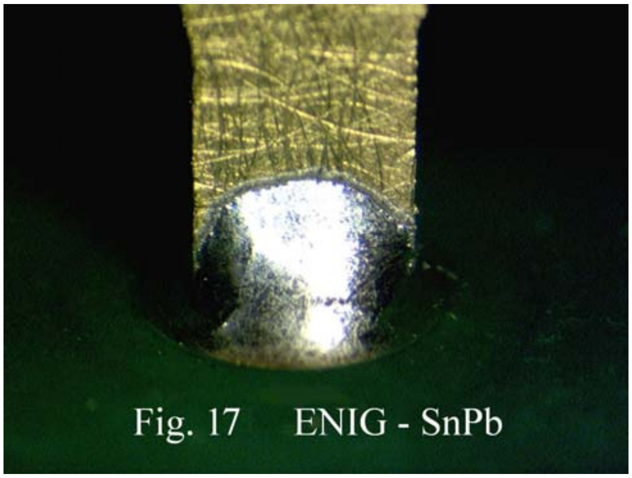


Fig. 17 ENIG - SnPb

CONVENTIONAL SnPb HASL

We only evaluated Tin Lead HAL from a single source,
We note that Lead free pastes **Figure 18**, had higher failure energy than conventional tin lead paste which is believed due to both the difference in melting points and joint metallurgy.

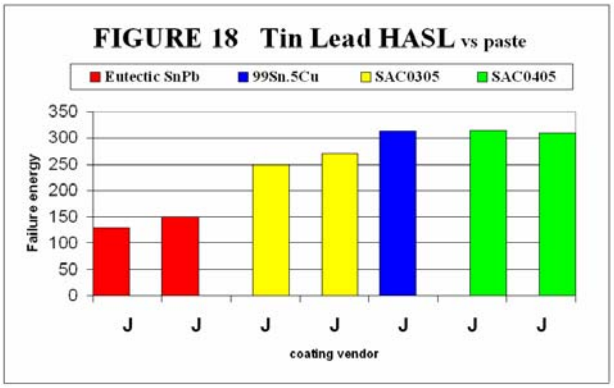


FIGURE 18 Tin Lead HASL vs paste

IMMERSION TIN

A single chemical supplier provided two different coating chemistries - Coating type M exceeds performance of Coating type K for all pastes tested as indicated in **Figure 19.** Note that Lead free pastes, had higher failure energy than conventional tin lead Paste

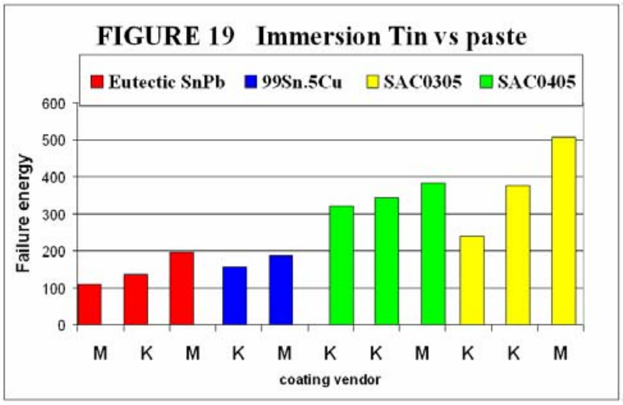


FIGURE 19 Immersion Tin vs paste

OSP

Figure 20 indicates that both Lead free OSP's tested generally show the same performance. SAC alloy shows higher failure energy than tin Copper paste. A comparison with tin lead was not made. Low temp OSP did not wet well at higher reflow temperatures needed for lead free assembly.

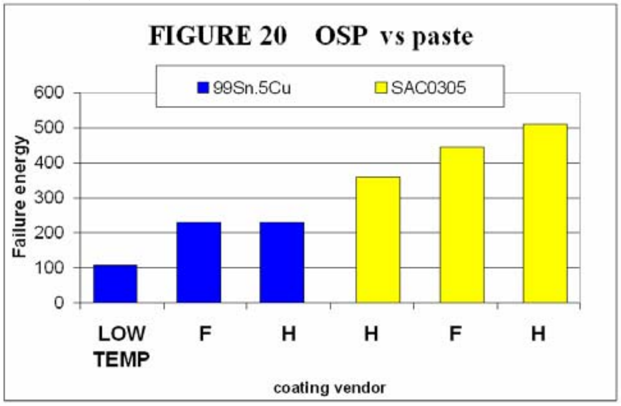


FIGURE 20 OSP vs paste

LEAD FREE HASL

Only one supplier for Lead free HASL coating was used. SAC paste alloys exceed performance of Tin lead and Tin Copper alloy.

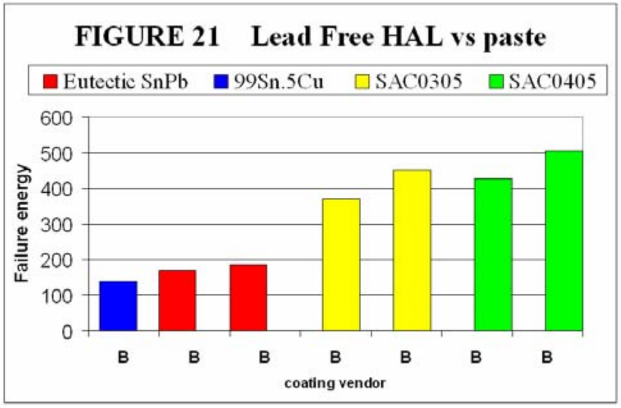
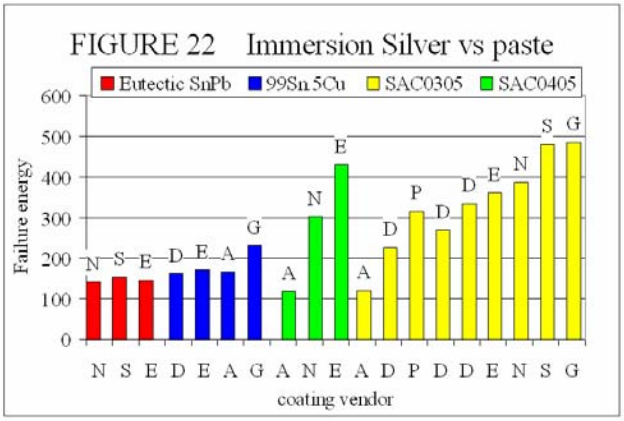


FIGURE 21 Lead Free HAL vs paste

IMMERSION SILVER

We evaluated seven different immersion silver formulations from 4 different chemical suppliers. Results are shown in **Figure 22.** We observed performance differences for each chemical supplier and site. "A consistently worse, This was tarnished before reflow.



CONCLUSIONS

The HALT based technique uses a novel test board, **Figure 23**, that is bolted upside-down onto the test fixture onto a test stand capable of applying *g*-forces from 0 to 50*g* RMS. **Figure 24.**

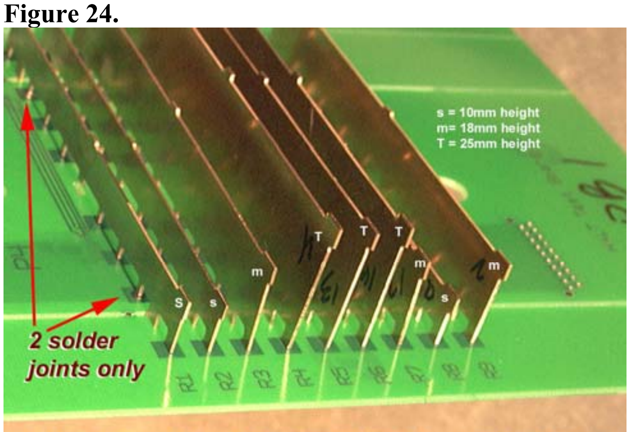


FIG. 23 HALT TEST PLATFORM

FIG. 24 Mounting of HALT TEST Assembly in Temp/Vibration Test Chamber

This configuration allows the fins to drop off as they fail. Cabling attaches each group of test boards to a data acquisition system which measures the temperature and accumulated *g*-s vibration level. The whole system is contained in an environmental chamber which is rapidly temperature cycled -25 to +85°C 1 cycle every 4 minutes, using Liquid nitrogen assistance **Figure 25**.

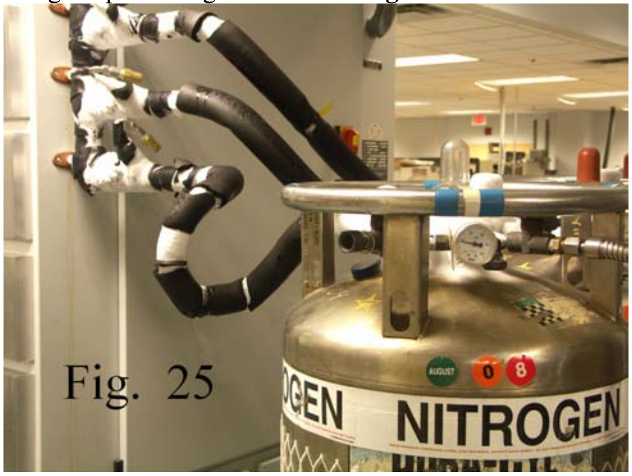


Fig. 25

Our PCB and component design has provided useful solder performance data and helped eliminate the haze surrounding these complex relationships and their trade-offs to our engineering management. It has allowed us to work with our suppliers and their suppliers to select the best products for manufacturing our PCB assemblies.

During this investigation we evaluated 56 paste and finish variables. The study used five (5) solder paste alloys; SnPb, 99Sn-0.5Cu+, SAC0305, SAC405 and SnZn and six (6) different surfaces coatings; Immersion Silver, Tin, OSP, & ENIG which were sampled from multiple chemical suppliers. –While, Eutectic SnPb and lead free HASL coatings were obtained from a single source.

TABLE 5

Vendor codes	Chemical supplier number			
Surface finish	1	2	3	4
Silver	**S,N,D**	P,G	E	A
TIN	M,K			
Free HAL	B			
ENIG	C	R		
OSP	F	H		
Pb HAL	J			

This investigation has attempted to compare the performance of surface finishes from different suppliers using multiple solder pastes. In general we conclude Lead Free HAL to be most robust. HAL showed better wetting and joints were larger than those formed on the flat chemically applied immersion deposits, ImmSn, ImmAg ENIG and OSP. Since Identical solder paste volumes were applied to all joints, the extra thick HASL solder becomes part of the reflowed joint adding to total joint volume. This increases the joint's ability to distribute and absorb strain, increasing its time to failure.

Total solder joint volume is a significant contributor to fatigue life as pointed out in the first paper in this series. For this reason, joint failure energies reported for HAL coatings are on average higher than thin immersion deposits of all materials tested.

Considering the handicap of paste printing on non-uniform HAL surfaces. We offer the following guidance, if you can print acceptably, on the rounded HAL surface, you should use this coating since its added thickness not only adds metal to the solder joint, but also provides thickness barrier to oxidation and intermetalic formation. Increasing shelf life of the unassembled PCB and enhancing solderablilty. Lead Free HAL coating equipment is now available in the industry, but since this coating equipment is not yet common at all suppliers you should contact your supplier before specifying this coating to make sure it is available.

This study reports that joints formed with SnPb solder paste usually failed earlier than lead free pastes the exception being SnZn which appeared to perform poorly However data on that paste is limited to only 2 observations so more work is planned to study this paste in the future.

Tin lead paste results were less than spectacular on all lead free surface coatings studied. This behavior is of course not un-expected, considering thermal fatigue strength and damage is inversely proportional to ½T_m (where T_m is the melting point of the joint alloy or materials under test). The damage produced in thermal cycling to 85°C appears to damage these joints more that the higher melting lead free alloys.

Considering only flat immersion deposits our results indicate OSP best, as it forms desirable and reliable uncomplicated joint. The high temperature version of OSP must be used with Lead free reflow cycles. Only problem we see with OSP is its ability to be electrically tested after reflow.

In cases where post reflow testing is a requirement, Immersion tin and silver each produce good joints and often the best joint metallurgy, And most importantly, these coatings usually remain testable after reflow soldering.

Mixing tin lead and lead free alloys can produce strong but <u>non -compliant joints</u>.

Gold embitterment caused by dissolution of gold into the joint should be avoided whenever possible.

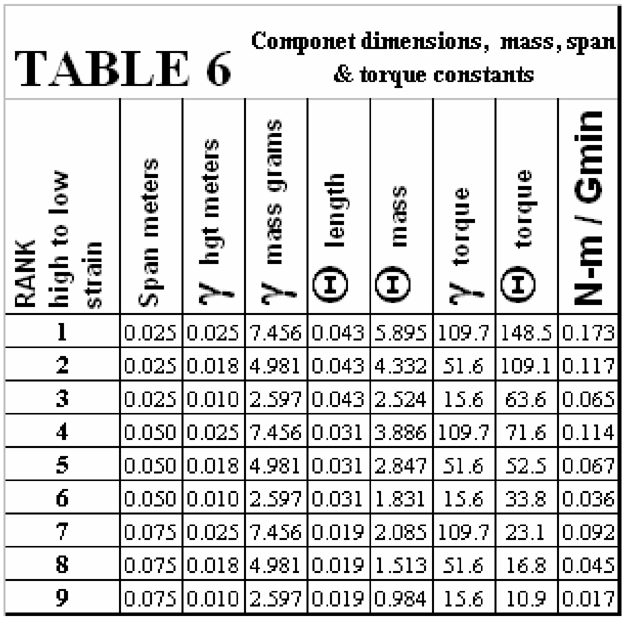


TABLE 6 **Componet dimensions, mass, span & torque constants**

RANK high to low strain	Span meters	γ hgt meters	γ mass grams	Ⓘ length	Ⓘ mass	γ torque	Ⓘ torque	N-m / Gmin
1	0.025	0.025	7.456	0.043	5.895	109.7	148.5	0.173
2	0.025	0.018	4.981	0.043	4.332	51.6	109.1	0.117
3	0.025	0.010	2.597	0.043	2.524	15.6	63.6	0.065
4	0.050	0.025	7.456	0.031	3.886	109.7	71.6	0.114
5	0.050	0.018	4.981	0.031	2.847	51.6	52.5	0.067
6	0.050	0.010	2.597	0.031	1.831	15.6	33.8	0.036
7	0.075	0.025	7.456	0.019	2.085	109.7	23.1	0.092
8	0.075	0.018	4.981	0.019	1.513	51.6	16.8	0.045
9	0.075	0.010	2.597	0.019	0.984	15.6	10.9	0.017

---

[1] Murphy, T. (2006) <u>SMTA Indiana Chapter Meeting</u>, Jeffersonville, Indiana February 23,2006 and <u>SMTA Ohio Valley Vendor Show</u>, Columbus, Ohio, July 27, 2006

[2] Walter, M (2006) "Processes and Their Parameters", <u>Circuits Assembly</u>, Volume 17, Number 1, January 2006

[3] Rhee, H. and Subamanian, K.N. (2006) "Roll of imposed cyclic strain amplitude and cyclic strain rate on the stress relaxation of pre-strained eutectic Sn-3.5Ag solder joints", <u>Soldering and Surface Mount Technology</u>, Volume 18. Number 1. 2006 ISSN 0954-0911, Emerald Group Publishing Ltd.

[4] Tsai, K.T., Liu, F-L., Wong, E.H, R., Rajoo, (2006) "High Strain rate testing of solder interconnections", <u>Soldering and Surface Mount Technology</u>, Volume 18 . Number 2. 2006 ISSN 0954-0911, Emerald Group Publishing Ltd.

[5] THERMOTRON model AST-35-LN2, Thermotron Industries, Kollen Park Drive, Holland, MI. 49423

[6] Consult **TABLE 6**

This paper was <u>Originally published in the Proceedings of the SMTA International Conference Chicago, Illinois Sept 2006</u>