Optimizing Pallet Materials for Long Life and Ease of Machining

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Abstract
This paper will present seven different materials used for the production of both wave solder and reflow solder pallets. The goal of this study will be for the purpose of depicting machining capabilities for depth, wall thickness, and accuracy of machining for each of the seven materials presented. Additionally, a lead free wave pallet (used for a high running Printed Circuit Board (PCB) product) will be built out of each of the materials being tested. Each pallet will be tested for the purpose of showing long-term wear effects over multiple heat cycle run times; monitoring pallet flatness for heat warping of the pallet; wall thickness changes; and, overall changes in surface condition. For the purposes of this study, each of the materials used is listed in terms of basic material properties.

1. Introduction

Solder pallets are primarily used for the assembly of PCBs in reflow and wave solder for through-hole components. With respect to reflow runs of Surface Mount Technology (SMT) components, palleting can serve to keep the PCB flat, eliminating warpage as the PCB passes through the screen printing operation, pick and place of all components, and the reflow oven. Maintaining flatness is critical for thin boards (<0.04 inches thick) especially where backside processing is needed. In addition, many components need a pallet to hold them in place until the solder is solidified. For this specific purpose, a pallet is constructed to conform to the board and its' components, holding everything in place during the reflow solder run time. One example is high-density PCMIA connectors where pins must be held to +/- 0.007 inches due to the pitch of the connector. The pallets hold the boards flat while keeping the connector in the proper position for defect free solder connections.

In the wave soldering of through-hole components, palleting is used to eliminate warping of the PCB and to allow selective soldering of specific areas while protecting others. Selective solder masking is needed when the exposure of existing bottom-side SMT component to a solder wave would likely remove the component or create a defect on the board. Another example of selective solder masking is gold plated connectors that need to be protected from solder exposure.

Palleting shields selected components from the solder wave and directs the solder to the specific areas needed for proper through-hole solder joints. In addition, PCB palleting can aid in reducing solder bridges from arrayed connectors and reduce voids of other components. The shielding of components is accomplished by the machining of pockets into the palleting material. This paper tests different materials for determining the minimum sustainable wall thickness between a bottomside SMT shielding pocket and a through-hole in the pallet. In circumstances where this specification must be broken, either stainless steel or titanium inserts are recommended. The tolerances with the metal are much tighter; however, the cost of a pallet is significantly increased due to machine time and material costs.

Table 1 - Material Specifications

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Color	Black	Grey	Black	Grey	Grey	Grey	Blue
Sheet Size Inches	48x96	48x96	25x25	18x25	18x25	25x25	48x96
Tensile Strength 25°C in Psi D-638	N/A	N/A	N/A	30,000	32000	N/A	16,000
Flexural Strength 25°C in PSI D-790	N/A	N/A	N/A	50,000	50,000	N/A	25,000
Specific Gravity ASTM D-192	1.85	1.9	N/A	1.75	1.72	N/A	1.98
Barcol Hardness	N/A	N/A	N/A	N/A	N/A	N/A	52
ESD Resistively	10E5-10E11	10E5-10E11	N/A	10E11	1E11	N/A	1E5-1E10
Thermal Expansion K-1	11E-6	11E-6	N/A	20E-6	0.000	N/A	N/A
Thermal Conductivity W/m*K	0.23	0.25	N/A	N/A	N/A	N/A	0.2
Maximum Short Term Operating Temperature °C	300	350	300	300	300	300	300

2. Minimum Wall Thickness

This test will examine minimum wall thicknesses of six different materials and their strength as a function of wall height. The machining observations in terms of speed, clean cuts and strength of the material are shown in Table 2. The materials used are labeled A thru G to maintain anonymity. Pictures of the key test structures are in Figure 1. This test also includes a pallet used in a lead free wave solder process. Photographs of pallets after heat cycle runs are shown in the Figure 2. In addition, critical measurements are shown in Table 2.

The pocket wall structures established minimum geometries possible with each material. The accuracy of the sidewalls is important for manufacturing pallets where tight dimensions exist between a through-hole and a shielded component. This test included four test dimensions created by changing the wall depth of one of the pockets. The purpose is to show resilience to vibration, and if any resonance exists within the material. The pocket depths included 0.150, 0.100, 0.075, 0.065, 0.050, 0.035, 0.025, and 0.015-inch depths. The measurements shown are the average taken between all pocket depths of each sample; this determines the capability to use the material for minimum geometry designs. If the geometries are too small, pallets are designed with metal inserts to achieve smaller geometries. The subjective rating is the ranking of the test samples pocket measurement averages and wall breakage relative to each other.

Table 2 - Pocket Wall Measurements

Sample	A	B	C	D	E	G	H
Subjective Rating of Measurements	2	5	3	4	3	2	1
0.010 Wall Thickness /Broken Pockets	0.013/1	0.015/3	0.011/4	0.015/3	0.013/2	0.011/3	0.011/2
0.015 Wall Thickness /Broken Pockets	0.018/0	0.017/0	0.016/1	0.017/0	0.016/0	0.016/0	0.015/0
0.020 Wall Thickness	0.022	0.023	0.021	0.021	0.021	0.017	0.020
0.025 Wall Thickness	0.027	0.028	0.025	0.026	0.024	0.023	0.024
0.035 Wall Thickness	0.037	0.039	0.037	0.038	0.036	0.036	0.035

3. Material Thickness Control and Flatness

Material flatness across the sheet is important to pallet manufacturers primarily for precision maintenance integral to and for palleting production. In this test, thickness measurements were taken across each manufacturer's sample for the purpose of variation determination across each piece (see Table 3). Here, it should be understood that if the material is not flat, a couple of occurrences are likely to happen. First, the potential of solder flooding can occur if there is a space between the PCB and the pallet. A variation to typical flatness can cause a dip between the PCB and the pallet where solder could enter. The other potential problem is due to stress placed on the material while it is clamped to the machining table, stress that could result in a warped pallet. If undetected, this particular defect is subsequently machined into the pallet design. Once the pallet is un-clamped and the stress removed, the machined surface may retain the stress-induced curvature.

Table 3 - Material Thickness Measurements

Sample	A	B	C	D	E	G	H
Minimum Thickness	0.230	0.229	0.228	0.234	0.230	0.228	0.235
Maximum Thickness	0.232	0.231	0.236	0.224	0.236	0.236	0.239
Thickness deviation	0.002	0.002	0.008	0.010	0.006	0.008	0.004

4. Machining Residue

Machining cleanup is a cost-saving benefit whereby pallet manufactures should not spend time removing fiber remaining after machining. The testing here is purely a subjective measurement ranging from 1 to 5, where a 1 signifies low cleanup required and a 5 signifies the maximum amount of cleanup required. The results are listed in Table 4.

Table 4 - Material Thickness Measurements

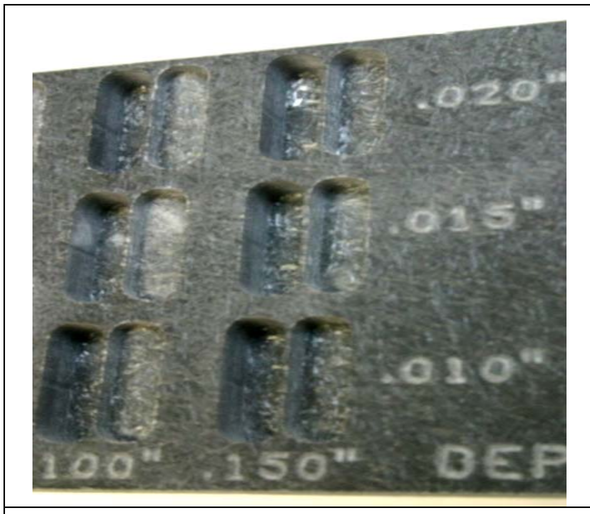
Sample	A	B	C	D	E	G	H
Clean-up required	3	3	1	3	2	3	1

5. Drilling Clean Holes of Varying Sizes Accurately

Cleanly and accurately drilling varying punch-through hole sizes is a fundamental for all pallets produced. Of the materials used in this study, there were a few samples that demonstrated inelastic/brittle properties, causing the drill to break the material at the hole exit. Such demonstrated brittleness causes potential pallet yield issues for machining. The same subjective measurement scale as used for machining residue (a scale of 1-5) was also used for determining material brittleness, 1 being the most elastic and 5 being the most inelastic/brittle. The results are listed in Table 5.

Table 5 - Drill Hole Measurements

Sample	A	B	C	D	E	G	H
Hole drilling	2	2	5	3	3	3	1



Sample A.   Pockets and Material Close-up

Sample B.   Broken Pocket at 0.010"

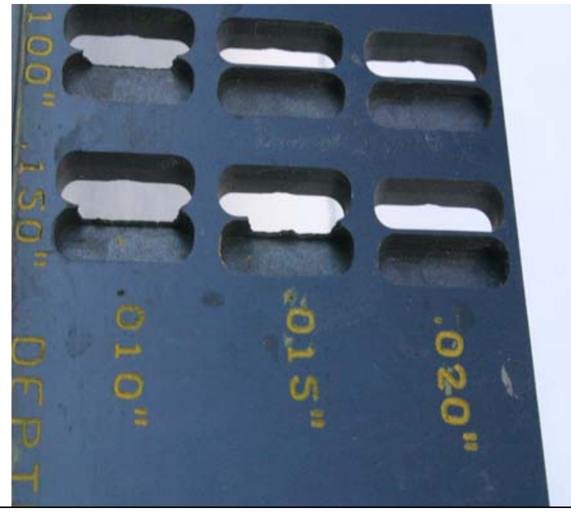
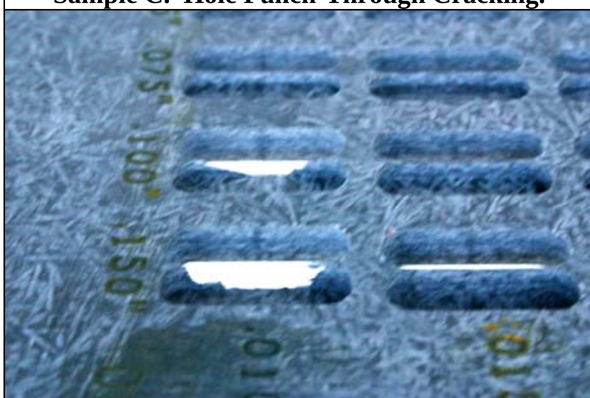
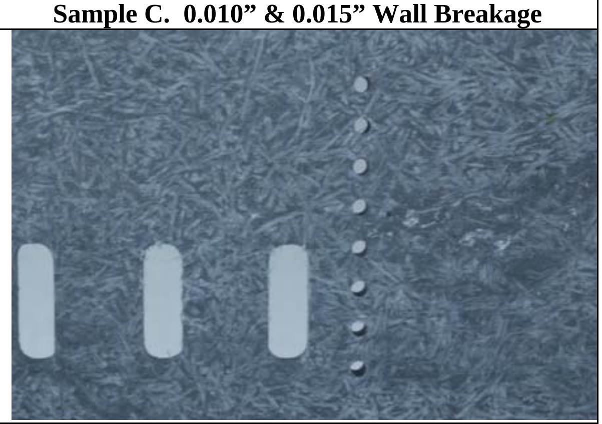
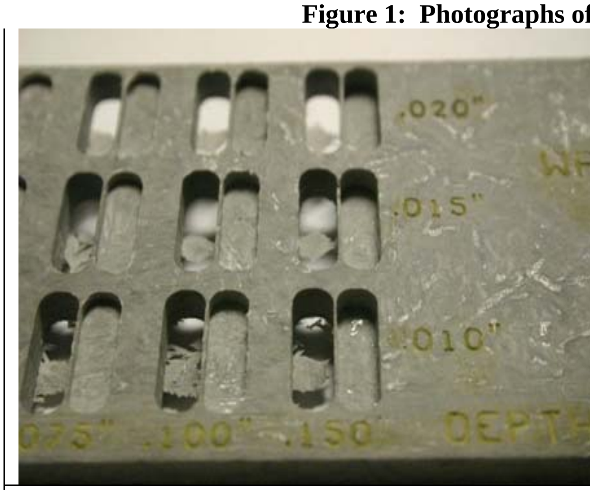
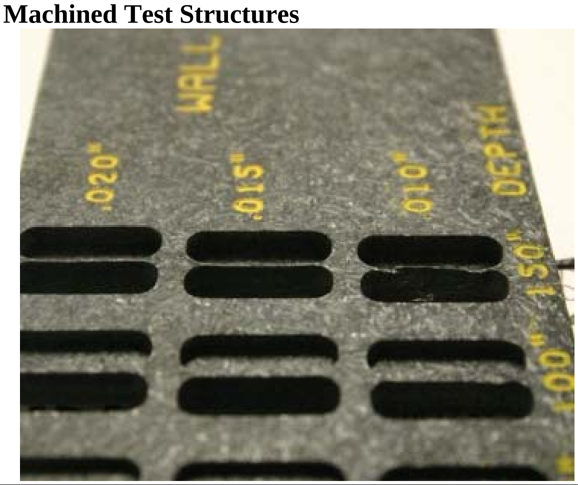
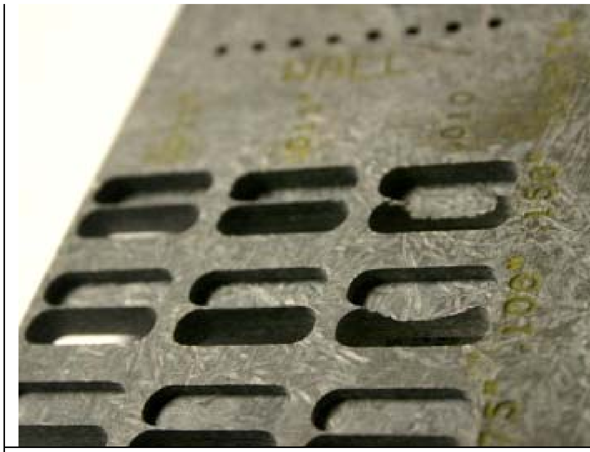
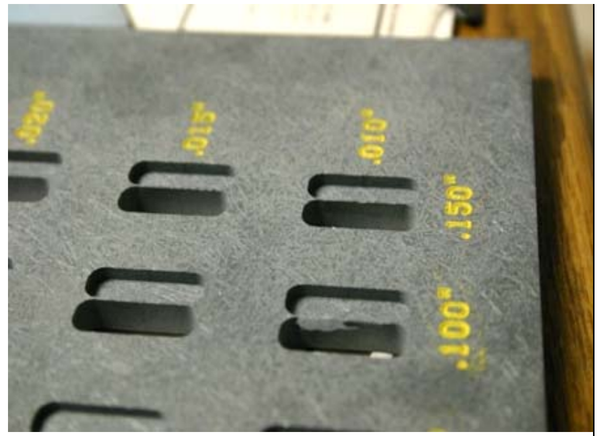
	
Sample C. Hole Punch-Through Cracking.	**Sample C. 0.010" & 0.015" Wall Breakage**
	
Sample D. 0.010" Wall Breakage	**Sample D. Backside of Holes**

Figure 1: Photographs of Machined Test Structures

	
Sample E. Walls Intact	**Sample F. Broken Wall at 0.010"**





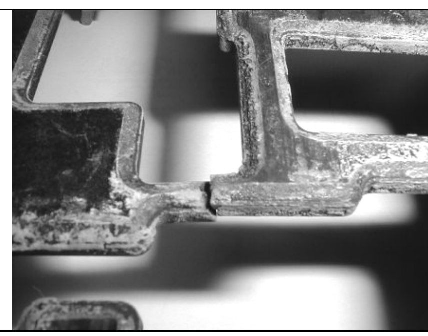
Sample G. Broken Walls	Sample H. Broken Wall at 0.010”

Figure 1 - Continued: Photographs of Machined Test Structures

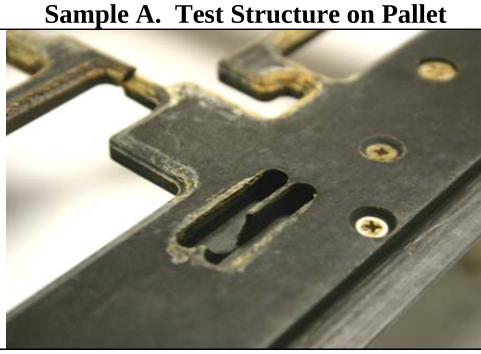
6. Test Pallets Made

From each material used in this test, a selective solder masking pallet was machined for a lead free process. Each pallet was produced with the same design and run on the same process line. The sample test pallet’s design was fabricated on material pieces 13 x 13 inches by 6mm thick. Heat cycle counts were recorded for each test sample pallet. On each pallet, two orthogonal pockets (a wall thickness of 0.025 inches) were designed to measure the change in the wall thickness over heat cycles. Unfortunately, only 130 heat cycles were made for each pallet at the time of this paper’s submission dead line; the heat cycle runs did not have any significant wear on the pallets. Each pallet was run with an ERSA wave solder system using preheat temperatures of 360, 410, and 460^{o} C; a pot temperature of 265^{o} C, and a belt run rate of 75 cm/min. The flux was Kester 959T with a spray volume of 75 l/min. The pallets were not cleaned during any of the testing.

Sample C exhibited a broken structure between two openings after 112 heat cycles and was removed from the heat cycle test. In addition, Sample C exhibited brittle behavior during the machining test phase (hole breakage), a characteristic that may have contributed to the breakage in the pallet structural design. Further, it can be seen that the wall pocket test structure on Sample C also broke during the heat cycling test phase (see Figure 2).

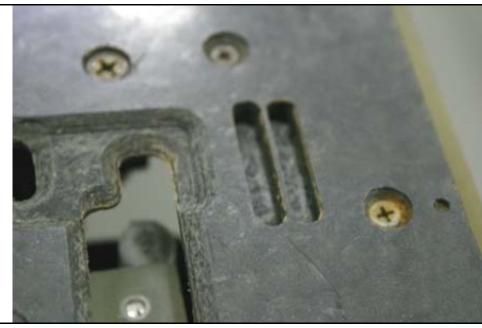


Sample A. Test Structure on Pallet	Sample C. Broken Pallet



Sample C. Broken Test Structure (0.025”)	Sample E. Close-up of Pocket Bridge

Sample E. Test Structure on Pallet



Sample F. Test Structure on Pallet

Figure 2 - Photographs of Pallet Test Structures

7. Data Conclusion

In testing for machining characteristics, each of the sample materials performed adequately for their intended purpose. The sample materials containing more glass fiber content required more cleanup time allocation. Material H exhibited the best critical dimension machining. However, the milling/machining process did result in there being two cracks on the 0.010 inch pockets. Material A had the best non-cracking record (a 1 on the scale rating of 1-5 for elasticity testing). Material C was found to be more brittle, causing drill hole punch-through cracking. This is of particularly concern since the majority of the work on a pallet is completed prior to the drill hole punch-through phase, a final machining operation whereby PCB hold-downs are added. This inelastic quality causes a substantial palleting loss when factoring in labor and machine time value. From the conducted tests, it appears that materials A, E, F, and G would tolerate minimum geometries of 0.020 inches to 0.015 inches without fear of machine inaccuracy or wall breakage. Longevity testing over heat and flux applications would confirm the long-term viability of this stated capability.

Samples A and B demonstrated the best flatness and overall machining capability. Samples E, F, and G were each close in rating for flatness characteristic. It has been determined that machining critical dimensions and maintaining wall thickness are functions of palleting material; the material cannot be too elastic, as it will flex with the mill bit, nor can the material be too inelastic, as cracking and breakage will occur.

Each material sample tested showed similar speed and feed rates for clean cuts. In addition, each test sample demonstrated glass content that quickly dulls the milling and drilling bits used in fabricating the test pallets. In all cases, the machining was done without any coolant.

The sheet sizes are a key factor for controlling costs in terms of scrap material. Assuming that each of the tested material samples cost the same per unit area, larger sheet sizes offer lower scrap and lower costs per pallet.

Unfortunately, the submission deadline of this paper resulted in the number of heat cycles allowably performed insignificant for meaningful test sample results. Nevertheless, testing of each material used in this study will continue. Parties interested in the resultant data can contact me at DMI International.

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Abstract

- Introduction
- Description of materials
- Wall thickness test
- Thickness control & flatness
- Machining residue
- Drilling clean holes
- Test pallets
- Conclusions

Introduction

- Seven composite materials tested for machining.
- Materials were rated relative to each other
- Test pallets were manufactured using the same design

Manufacture's Material Properties ratings

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Color	Black	Grey	Black	Grey	Grey	Grey	Blue
Sheet Size inches	48x96	48x96	25x25	18x25	18x25	25x25	48x96
Tensile Strength 25°C in Psi D-638	N/A	N/A	N/A	30,000	32000	N/A	16,000
Flexural Strength 25°C in Psi D-790	N/A	N/A	N/A	50,000	50,000	N/A	25,000
Specific Gravity ASTM D-192	1.85	1.9	N/A	1.75	1.72	N/A	1.98
Barcol Hardness	N/A	N/A	N/A	N/A	N/A	N/A	52

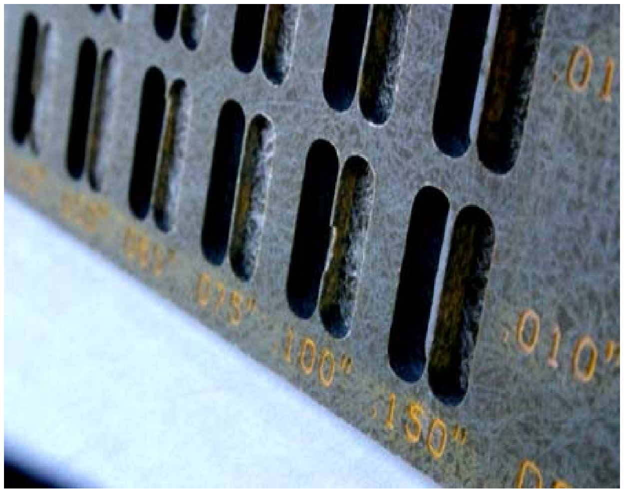
Manufacture's Material Properties ratings

	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
ESD Resistively	10e5 to 10e11	10e5 to 10e11	N/A	10e11	1e11	N/A	1e5 to 1e10
Thermal Expansion K-1	11e-6	11e-6	N/A	20e-6	1e-6	N/A	N/A
Thermal conductivity W/m*K	0.23	0.25	N/A	N/A	N/A	N/A	0.2
Maximum Short term operating temperature ^{o}C	300	350	300	300	300	300	300

Wall Thickness Testing

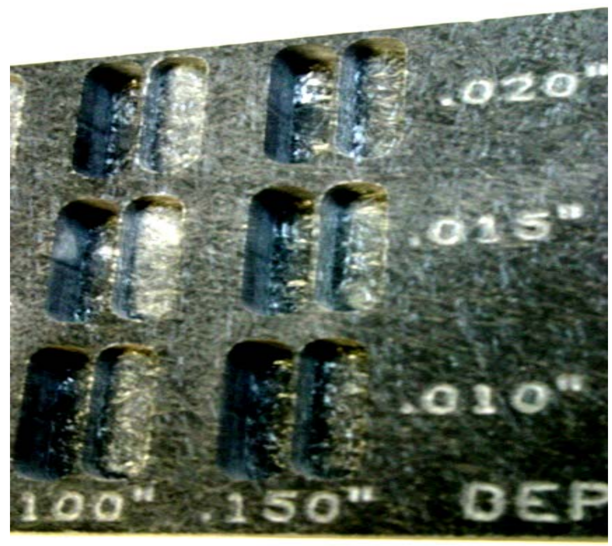
Sample	A	B	C	D	E	G	H
Subjective Rating of Measurements	2	5	3	4	3	2	1
0.010 Wall Thickness /Broken Pockets	0.013/1	0.015/3	0.011/4	0.015/3	0.013/2	0.011/3	0.011/2
0.015 Wall Thickness /Broken Pockets	0.018/0	0.017/0	0.016/1	0.017/0	0.016/0	0.016/0	0.015/0
0.020 Wall Thickness	0.022	0.023	0.021	0.021	0.021	0.017	0.020
0.025 Wall Thickness	0.027	0.028	0.025	0.026	0.024	0.023	0.024
0.035 Wall Thickness	0.037	0.039	0.037	0.038	0.036	0.036	0.035

Wall Thickness Example



Sample B with broken walls at 0.010 Inches

Sample A



Thickness Control & Flatness

- Flatness & Thickness Variation

Sample	A	B	C	D	E	G	H
Minimum Thickness	0.230	0.229	0.228	0.234	0.230	0.228	0.235
Maximum Thickness	0.232	0.231	0.236	0.224	0.236	0.236	0.239
Thickness Deviation	**0.002**	**0.002**	**0.008**	**0.010**	**0.006**	**0.008**	**0.004**

Machining Residue

Sample	A	B	C	D	E	G	H
Clean-up Required	3	3	1	3	2	3	1

Machining residue caused by fiber creates more clean-up prior to finished pallet. This is a subjective measurement on a scale of 1-5.

Drilling Clean Holes Accurately

- Three different hole sizes were drilled to measure issues caused by inelastic/brittle properties
- A subjective scale (1 to 5) was used with 1 as the most elastic

Sample	A	B	C	D	E	G	H
Hole Drilling	2	2	5	3	3	3	1

Test Pallets Made

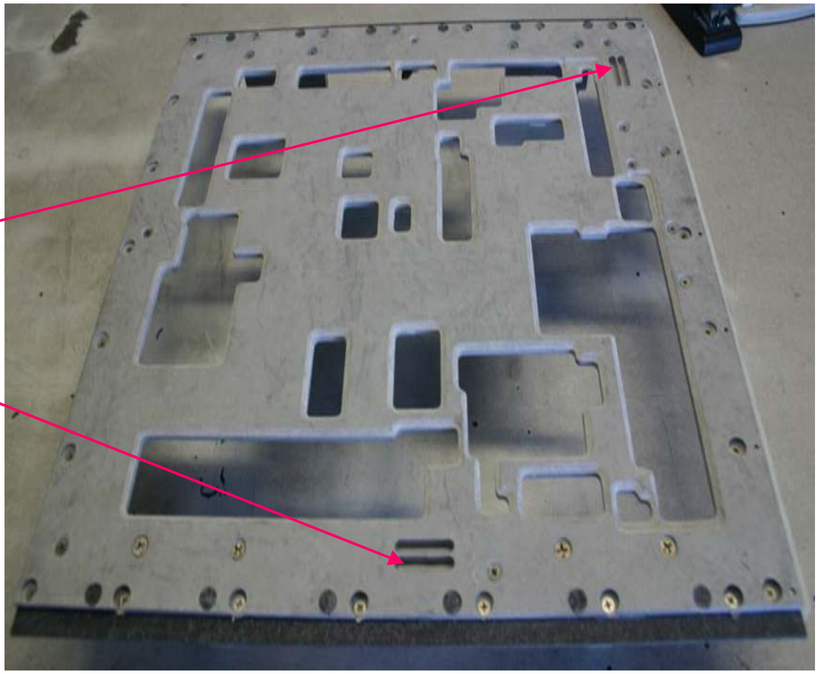
- 13x13 inch by 6mm pallet was made for the same PCB for selective solder masking.
- A no lead process was ran using an ERSA wave machine
- Process parameters used:
  - Preheat temperatures: 360^{o}C, 410^{o}C, 460^{o}C
  - Solder pot temperature: 265^{o}C
  - Belt speed: 75mm/min
  - Kester Flux 959T applied with a spray volume of: 75 l/min
  - Pallets were not cleaned after each use

Pallet Test Results

Sample E pallet bottom;

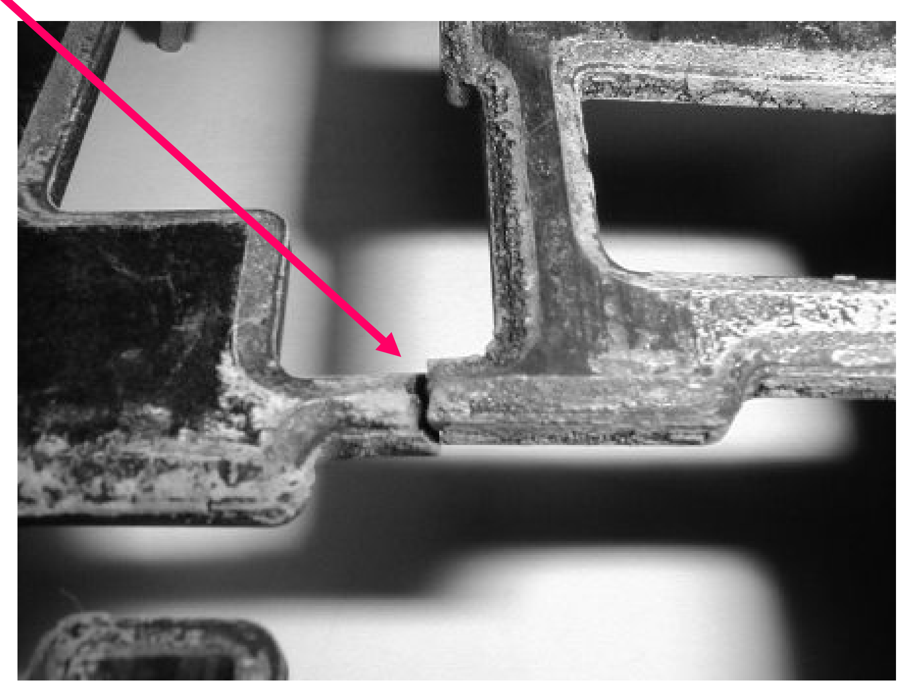
note wall thickness test structures on pallet

On all cases, there was no measurable difference in the wall thickness for all pallets tested.



Failed Pallet

- Sample C breakage after 100 cycles



Typical Pallet Wear

Pallet E wear after 290 heat cycles

Pallet G wear after 180 heat cycles

Conclusions

Machining & Pallet Testing Conclusions:

- A, E, F, and G offered the best for minimum wall thickness of 0.010 without cracking. From these measurements, minimum wall thicknesses of 0.015 to 0.020 would be tolerated
- A & B offered the best flatness and samples E, F & G were very close and found acceptable
- Samples A, B & G offered the large sheet sizes. Sheet sizes determine pallet manufactures yield for minimizing scrap costs
- More pallet heat cycles are needed for longevity testing conclusions. Please feel free to contact me at raj@dmipallet for updates on these pallets