D-PAK Voiding: A Study to Determine the Origins of D-PAK Voiding

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Abstract

Voiding in bottom termination components (BTCs) like QFNs and LGAs have become quote the hot topic in the SMT industry. Surprisingly, one type of BTC component that is observed to have excessive amounts of voiding is the D-PAK. One would think that a component with leads located on only one side would mitigate flux entrapment and allow outgassing to escape more easily from beneath the component, as compared to other BTCs where the component is affixed to the PCB on two or more sides. However, the exact opposite has been observed in most cases.

This study looks at an analysis of why a D-PAK exhibits more voiding than other types of BTCs. Voiding results based on an analysis of several process variables, such as adding weights to the tops of D-PAKs and cutting off the leads of the D-PAKs, will give insight into the physics behind D-PAK voiding, and provide an answer to the root cause to provide more insight on how to remedy the phenomenon.

Introduction

The growth in the electronics industry has driven a significant demand for higher power components. For high-power components like transistors, heat dissipation is crucial for maintaining reliability and maximizing power output. Solder is an excellent thermal interface material for these components with large thermal pads, providing a thermally conductive medium for heat to travel through and out of the component die. Typical, lead-free solder, such as SAC305, has a thermal conductivity of about 60 $\frac{W}{m*K}$; however, that number should be understood with care as this number represents the thermal conductivity of bulk solder, not solder with voids.

Voids in solder disrupt the flow of heat transfer, reducing efficiency. Bottom termination components (BTCs) are known for being more prone to voiding because flux in the solder paste contains volatiles that outgas during reflow and get trapped beneath the large thermal pad, preventing the gaseous volatiles from escaping. This leaves pockets of gas within the bulk solder joint that can be a problem for high-power devices. There are several techniques for mitigating voids, such aslow-voiding solder paste, adjusting the reflow profile, and altering the design of stencil apertures. Unfortunately, some BTCs consistently show higher voiding results than others. D-PAKs (or Decawat Packages) are one of them. This study will determine the root cause for why D-PAKs experience more voiding than other BTCs.

Theory

There are several theories about why D-PAK components have been observed to void more than other types of BTCs. One theory states that because the D-PAK has leads only on one side of the component, the leads sit lower than the body of the component, tilting the body of the component upwards at an angle away from the board.

Variables

Several variables were included in this study: surface finish, stencil thickness, solder paste flux vehicle, component type, leads cut off from the D-PAKs, weights added to the tops of the components, and the reflow profile.

Surface finish - Three different surface finishes were tested: OSP copper, electroless nickel immersion gold (ENIG), and immersion tin.

Stencil thickness - The two stencil thicknesses used for this experiment were 100µm and 127µm. The theory was that printing less solder paste would mean that there is less flux involved, which should reduce the voiding. However, it has also been proven in previous studies that for low stand-off components, having a thicker solder paste deposit can help reduce voiding by raising the stand-off height of the component, promoting more space for outgassing volatiles to escape from under the component rather than being entrapped by a low stand-off.

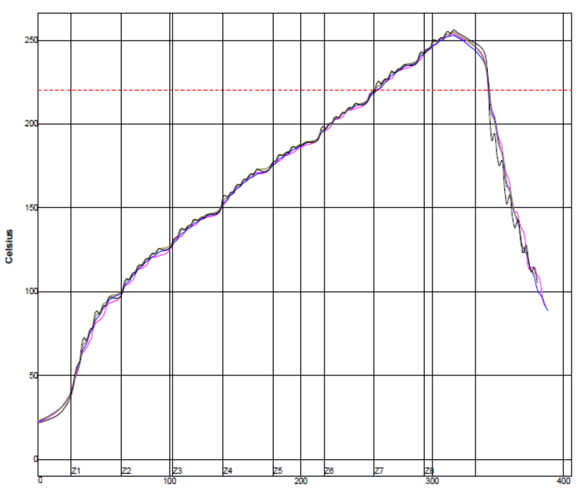
Solder paste flux vehicle - Two different solder pastes were used - both were Type 4, SAC305, no-clean, solder pastes with ROL0 classification per IPC.

Component types - Five different types of D-PAKs were assembled and one type of QFN.

D-PAK leads - Cutting the leads off of the components will provide a better understanding as to whether or not excessive voiding of D-PAKs actually results from the fact that leads exist on only one side of the component. Without the leads being pulled downward by the reflowing solder, the component body should sit flat as it was placed.

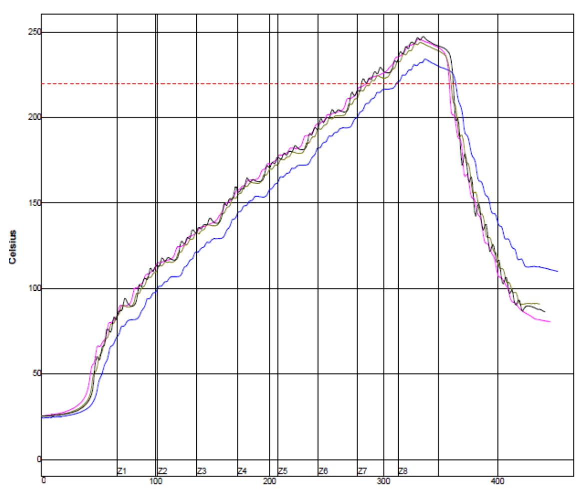
Weights added - Copper weights were added to some of the boards to see how forcing the components to lay flat during reflow effects the amount of voids; however, two considerations must be taken into account. The first is that the weights would press down on the component and the solder paste, which would then decrease the overall stand-off height making it more difficult for outgassing volatiles to escape from under the component. The second consideration is that the copper weights would add more to the amount of thermal mass to the assembly. This affects the reflow profile, which generally plays a major role in the amount of voiding in a solder joint. Adding more thermal mass to the assembly decreases the amount of heat input to the solder joint.

Reflow profiles - Two different reflow profiles were used to analyze how the copper weights affected the thermal profile, and thereby, the amount of voiding: a standard Sn3.0Ag0.5Cu (SAC305) profile with a straight ramp-to-peak and a slightly hotter SAC305 profile that was also straight ramp-to-peak. The parameters for each profile are listed in the Figures below. Reflow profiles were also run with and without the copper weights. The thermocouples measured readings beneath the underside of each component analyzed. Holes were drilled in the bottom side of the board under each component analyzed in order for the thermocouple tips to make contact with the solder under the components. The thermocouple locations are specified in each test vehicle Figure (Figures 6 and 11). Below is a summary of the reflow profiles and also Table 1 summarizing the peak temperatures each thermocouple read.



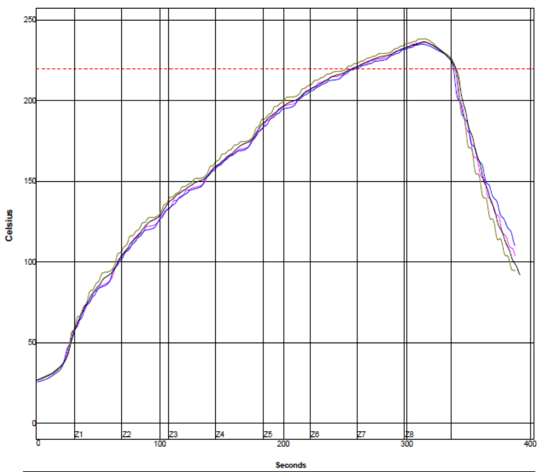
PWI= 112%	Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	84.56	38%	254.05	91%	0.74	-51%
<TC3>	86.14	45%	252.97	80%	0.74	-53%
<TC4>	86.65	47%	255.01	100%	0.74	-52%
<TC5>	86.52	46%	256.21	112%	0.76	-48%
Delta	2.09		3.24		0.02	

Figure 1 Hot Profile for Test Vehicle I



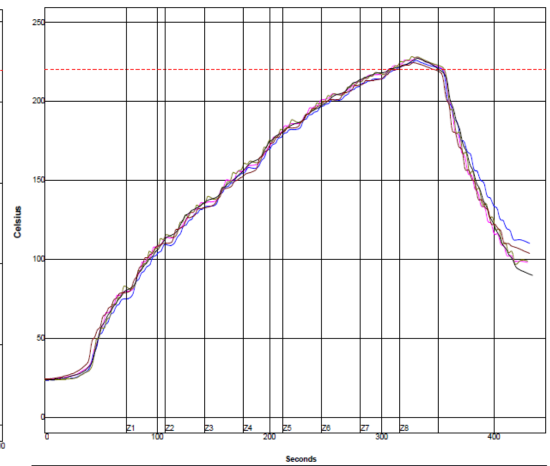
PWI= 107%	Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	72.67	-9%	246.12	11%	0.67	-66%
<TC3>	52.12	-92%	234.32	-107%	0.65	-70%
<TC4>	70.85	-17%	243.99	-10%	0.66	-68%
<TC5>	80.62	22%	247.51	25%	0.67	-67%
Delta	28.50		13.19		0.02	

Figure 2 Hot Profile for Test Vehicle I with Cu weights



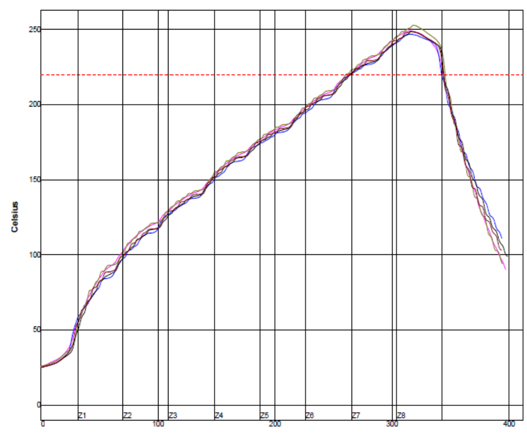
PWI= 99%	Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	83.64	35%	236.45	-85%	0.68	-65%
<TC3>	78.77	15%	235.11	-99%	0.67	-65%
<TC4>	88.52	54%	238.45	-65%	0.69	-63%
<TC5>	83.94	36%	236.56	-84%	0.68	-65%
Delta	9.75		3.34		0.02	

<u>Figure 3</u>StandardProfile for Test Vehicle II



PWI= 205%	Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	49.20	-103%	228.06	-169%	0.64	-71%
<TC3>	41.78	-133%	225.84	-192%	0.66	-68%
<TC4>	49.19	-103%	228.43	-166%	0.68	-64%
<TC5>	45.19	-119%	227.34	-177%	0.65	-71%
<TC6>	36.95	-152%	224.51	-205%	0.63	-74%
Delta	12.25		3.92		0.05	

<u>Figure 4</u>Standard Profile for Test Vehicle II with Cu weights



PWI= 79%	Reflow Time /220C		Peak Temp		Ramp- 25C to peak	
<TC2>	80.86	23%	249.17	42%	0.71	-58%
<TC3>	77.70	11%	247.06	21%	0.71	-59%
<TC4>	85.10	40%	252.90	79%	0.72	-56%
<TC5>	80.08	20%	248.73	37%	0.71	-59%
<TC6>	80.59	22%	248.73	37%	0.71	-58%
Delta	7.40		5.84		0.01	

<u>Figure 5</u>Hot Profile for Test Vehicle II

Test Vehicle	Profile	Weights?	Thermocouple	Peak Temperature (°C)
I	Hot	No	2	254.05
I	Hot	No	3	252.97
I	Hot	No	4	255.01
I	Hot	No	5	265.21
I	Hot	Yes	2	246.12
I	Hot	Yes	3	234.32
I	Hot	Yes	4	243.99
I	Hot	Yes	5	247.51
II	Standard	No	2	236.45
II	Standard	No	3	235.11
II	Standard	No	4	238.45
II	Standard	No	5	236.56
II	Standard	Yes	2	228.06
II	Standard	Yes	3	225.84
II	Standard	Yes	4	228.43
II	Standard	Yes	5	227.34
II	Standard	Yes	6	224.51
II	Hot	No	2	249.17
II	Hot	No	3	247.06
II	Hot	No	4	252.9
II	Hot	No	5	248.73
II	Hot	No	6	248.73

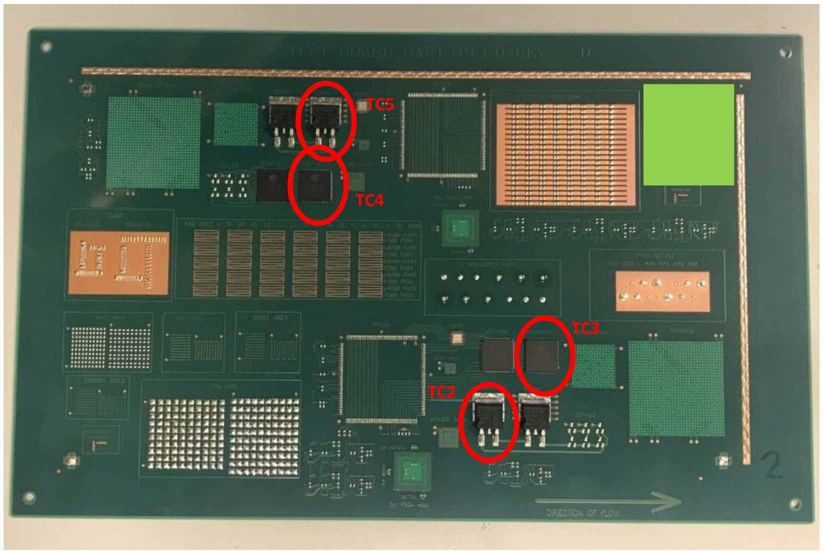
Table 1 Summary of Peak Temperatures for all Thermocouples

Design of Experiment (DOE)

Two different test vehicles were used, each with its own specified DOE. The first test vehicle is outlined in Part 1, the second in Part II.

Part I

The first DOE was a general solder paste printing test vehicle that contained a total of four D-PAKs and four QFNs. The D-PAKs used in Part I will be referred to as component B. A total of 18 test vehicles were assembled and reflowed. The test vehicle is shown below. It should also be noted that the QFN pads did include vias while the D-PAK pads did not. All stencil apertures for component placements were window-pane.



<u>Figure 6</u>Test Vehicle I

Boards 1-9 were printed with Solder Paste A and boards 10-18 were printed with Solder Paste B. All boards for this part of the experiment had OSP board surface finish, used a 127µm thick stencil, and used the hotter SAC305 profile. Three variables were tested for the boards. The first 3 boards for each solder paste included both D-PAKs and QFNs with no copper weight added or cut leads. The next 3 boards were reflowed with 50-gram copper weights sitting on top of the components - one weight for every two components. The last 3 boards were reflowed with only the D-PAKs, but with all the leads cut off.

Part I Analysis

There were several observations from the data gathered in Part I:

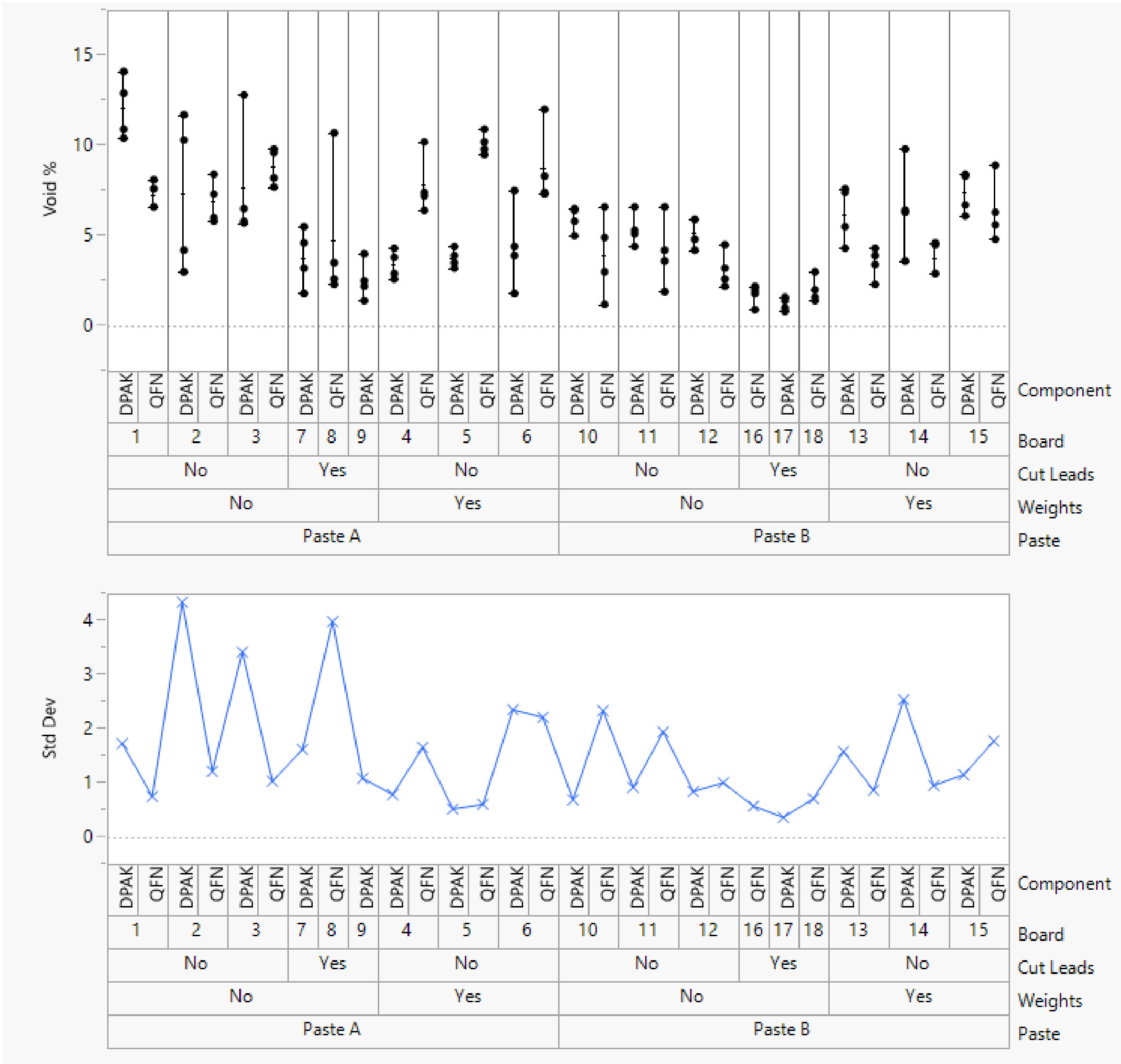


Figure 7 **All Components**

- Solder Paste B seemed to exhibit less overall voiding than Solder Paste A.
- For Solder Paste A, the QFNs voided significantly more than D-PAKs when the weights were added.
- For Solder Paste B, D-PAKs voided more than QFNs when the weights were added.

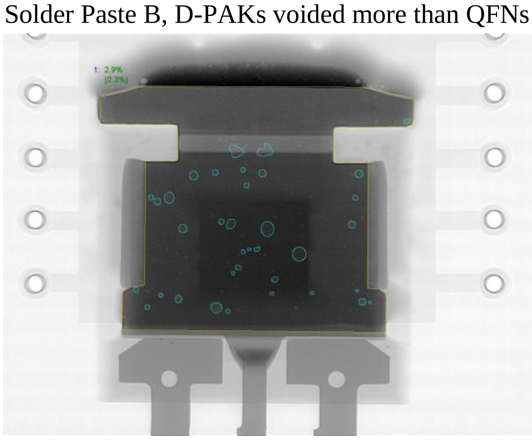


Figure 8 **D-PAK with weight**

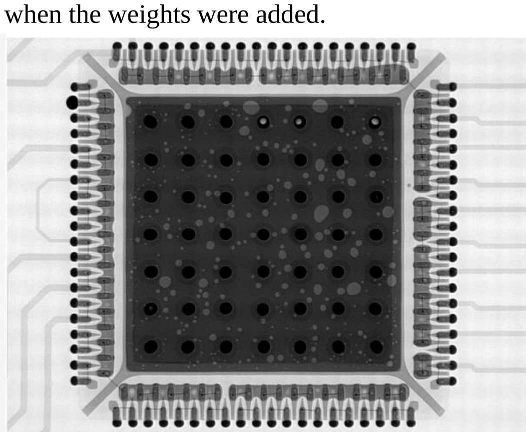
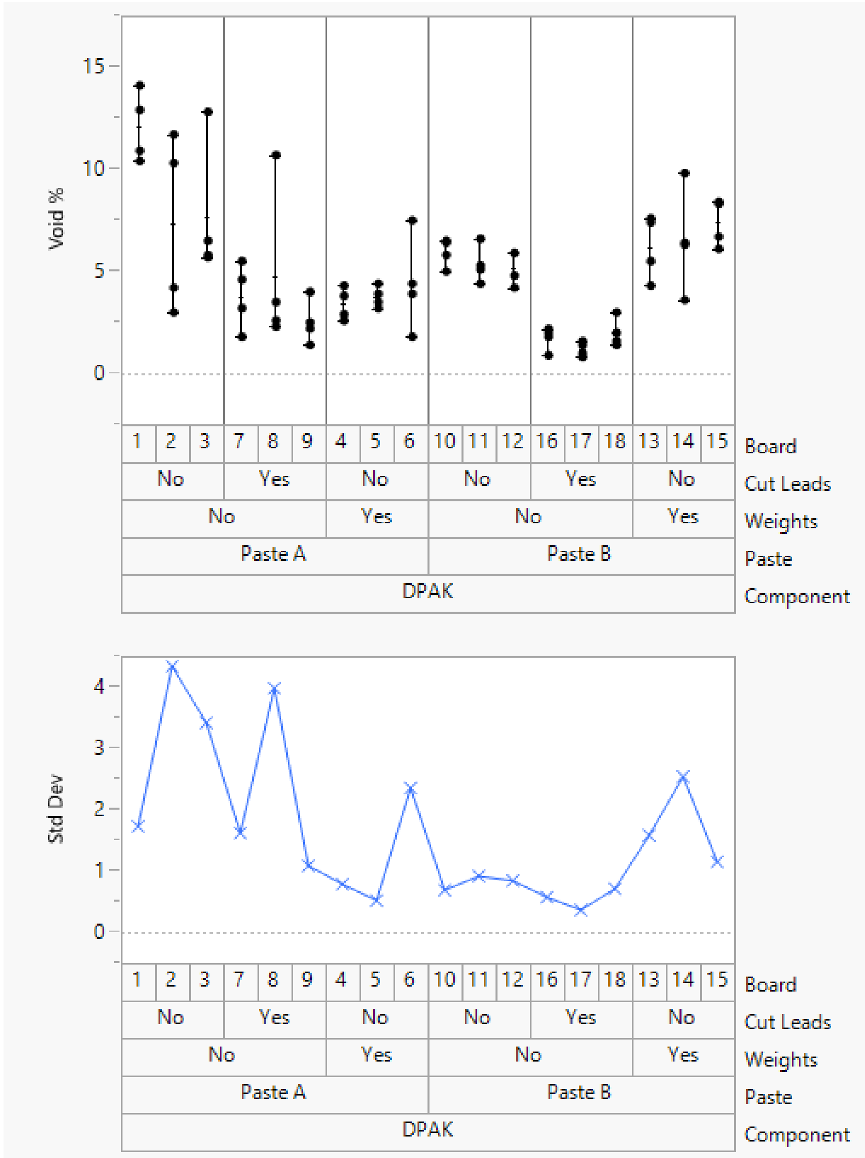


Figure 9 **QFN with weight**

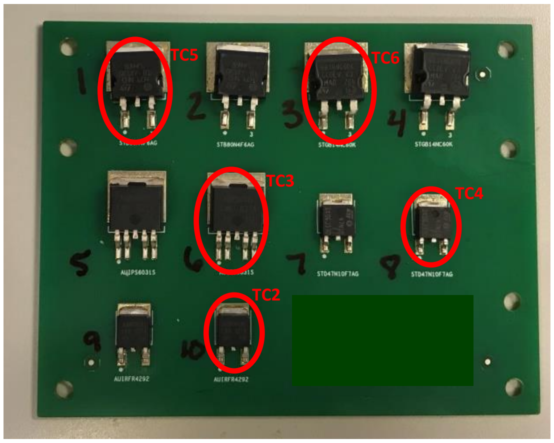


<u>Figure 10</u>D-PAKs Only, No QFNs

- For Solder Paste A,D-PAK voiding was greatest for the test vehicles that did not include any variables
- For Solder Paste B, D-PAK voiding was greatest when the copper weights were added
- For both solder pastes, cutting the leads seemed to reduce overall voiding for D-PAKs

Part II

The test vehicle used for Part II of the experiment was a custom design. It included all five D-PAKs and no QFNs. There were two replicates of each type of D-PAK for a total of ten components per board. The components were labelled 1- 10 as seen in the picture below. Components 1 and 2will be referred to as component A, components 3 and 4 will be referred to as component B, components 5 and 6will be referred to as component C, components 7 and 8 will be referred to as component D, and components 9 and 10will be referred to as component E.Components A, B, and C were D2PAKs and components D and E were D-PAKs. Component C had five leads (the middle one trimmed), while the other four components had three leads (with the middle one trimmed). All boards were RoHS compliant with tinned leads.



<u>Figure 11</u> Test Vehicle II

A total of 45 boards were assembled, reflowed, and analyzed for voiding in Part II of the experiment. Solder Paste A was the only solder paste used on all 45 boards.

One more thing to note is that the aperture design for Test Vehicle II included no window-panes, unlike the test vehicle used in Part I of the experiment. The apertures for each thermal pad were one large, open rectangle.

Both reflow profiles (standard and hot) were used for the first 18 boards (boards 1-9 for the standard profile and Boards 10-18 for the hot profile), and were all printed with the 127µm thick stencil. Boards 19-45 used only the standard profile and were printed with the 100µm stencil.

Boards 1-18 had three replicates of each surface finish for each reflow profile used. Boards 19-45 had nine replicates of each surface finish. Three of those replicates were either reflowed normally, reflowed with the copper weights added, or reflowed with the leads cut off. Component E was not included in the part of the study with the weights.

Part I Analysis-

There were several general observations:

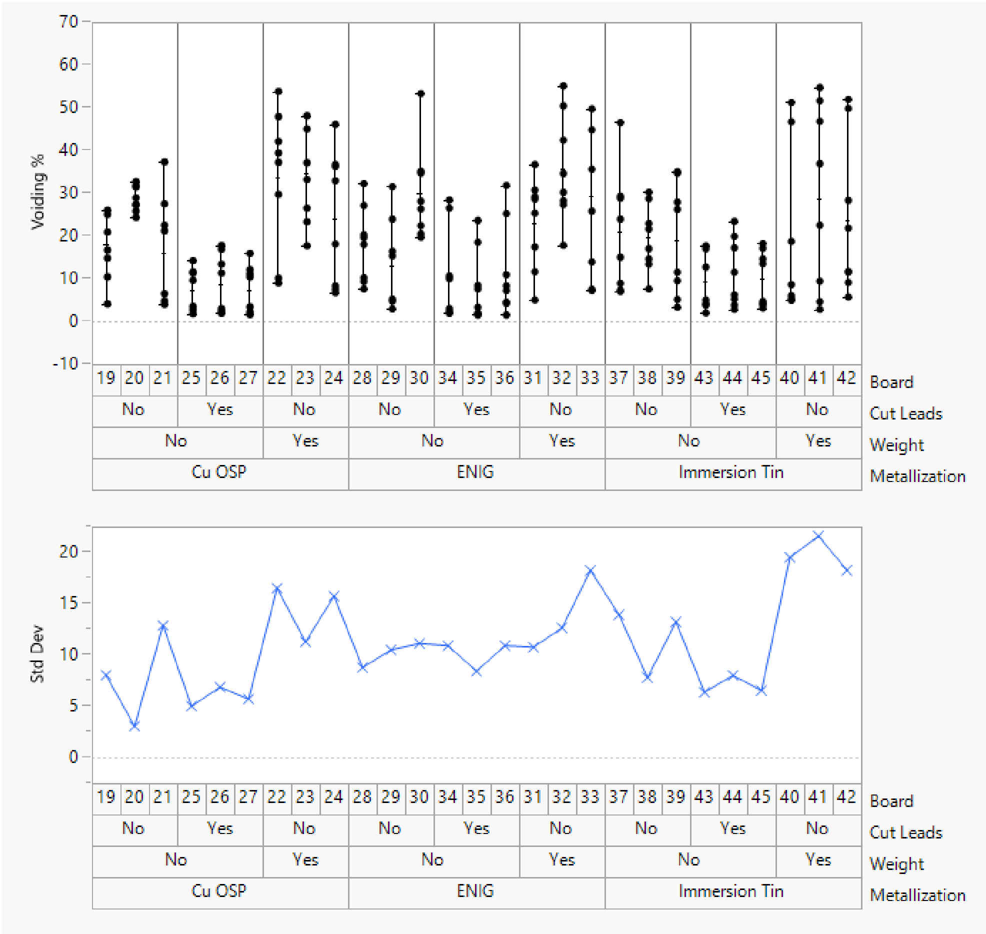


Figure 12Overall Voiding for Boards 19-25

- Adding the copper weights increased the overall voiding and standard deviation for all three surface finishes
- Cutting the leads decreased the overall voiding and standard deviation for all three surface finishes

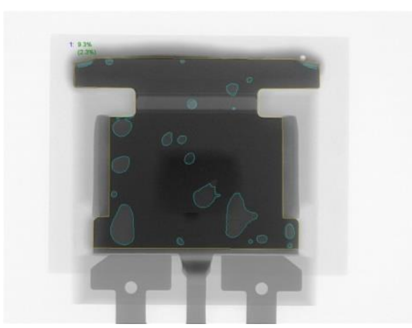


Figure 13Component A, ENIG, no variable

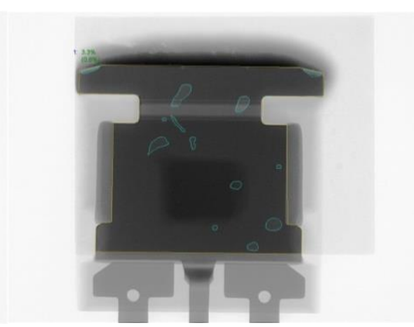


Figure 14Component A, ENIG, cut leads

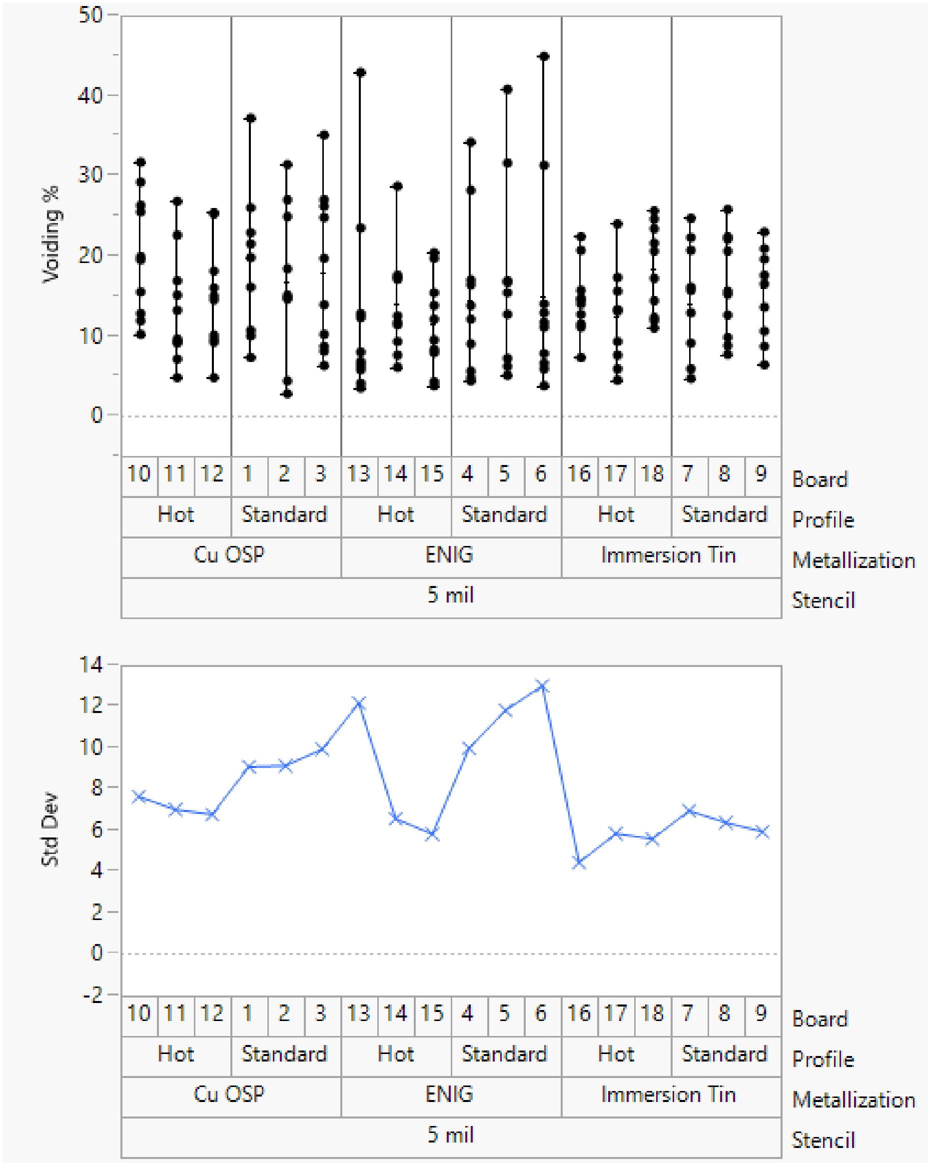


Figure 15Boards 1-18 comparing reflow profile

- For boards 1-18, there was no significant voiding difference between the standard profile and the hot profile.
- It seems as though the voiding was greatest with OSP board surface finish for both profiles.
- For ENIG surface finish, there were consistently two data points for each board that had significantly higher voiding percentage than the rest of the data points; otherwise the rest of the ENIG data points showed relatively low voiding percentage.

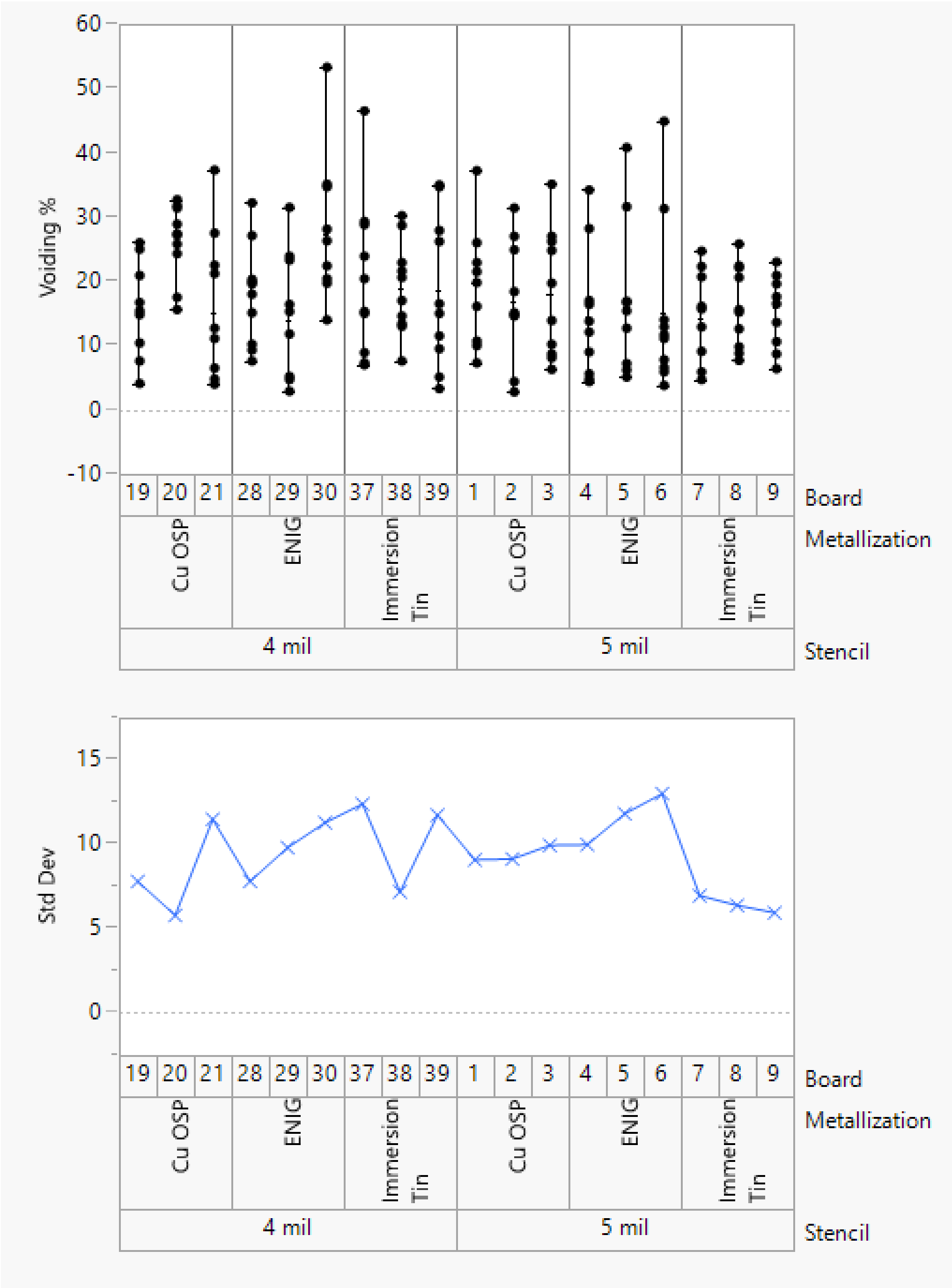


Figure 16 Stencil thickness comparisons for boards with no weights added and no leads cut

- Using the 5 mil (127µm) stencil showed an overall decrease in voiding percentage compared to using the 4 mil (100µm) stencil.

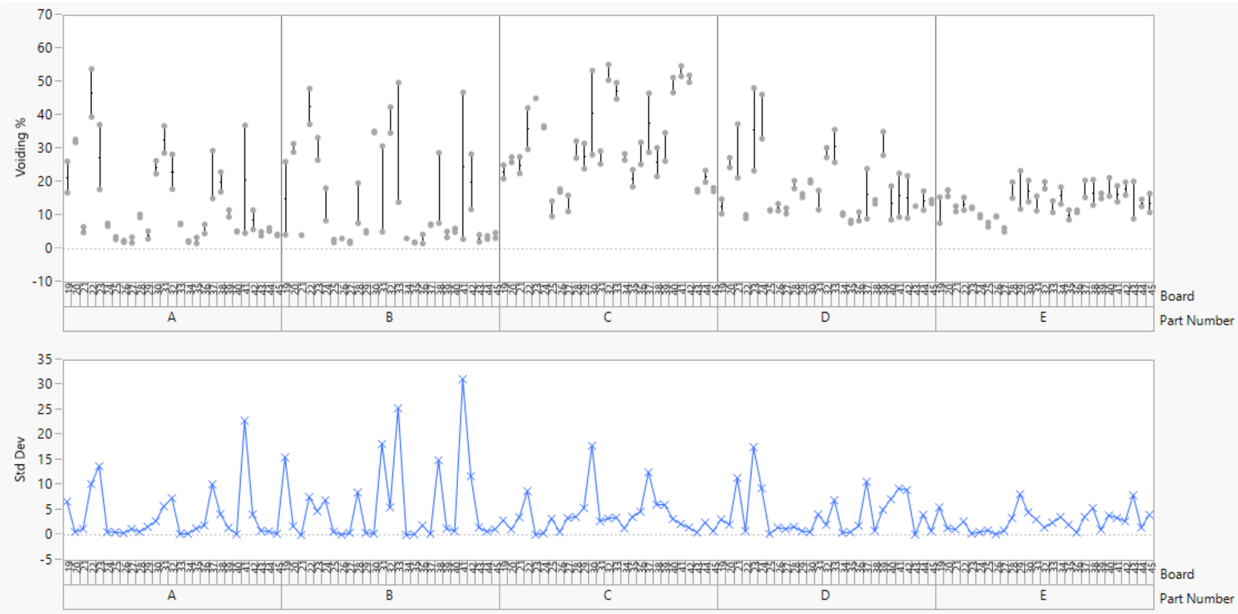


Figure 17Boards 19-45 comparing components

- Components C consistently voided the most
- Components E had the lowest range of standard deviation of voiding
- Components A and B had reflowed components with the lowest value of voiding percentage

Conclusions

Cutting the leads off the component improved voiding for D-PAKs for both Part I and Part II of the experiment. This would support the initial theory that leads on only one side of the component contribute to higher voiding.

Another key point that should be noted is that voiding varies between the different types of D-PAKs. D-PAKs are designed in all different profiles. For example, reviewing the drawing specifications of the components, it was noticed that the two components that voided the least have a "step" on the underside of the component from the seating plane, while the component that voided the most does not have a "step". It is important to note that even though voiding is primarily the result of outgassing volatiles in fluxes during reflow becoming trapped in the solder joint, non-wetting and solder starvation are crucial factors that promote voiding, as well.

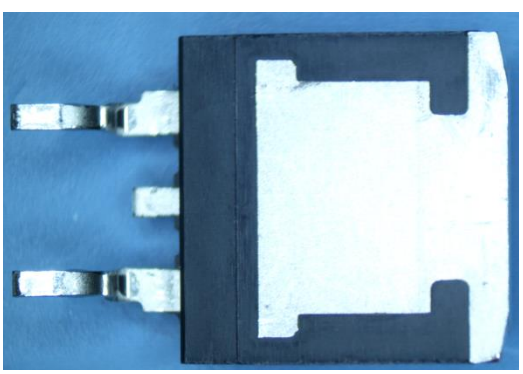


Figure 18Component A underside with step

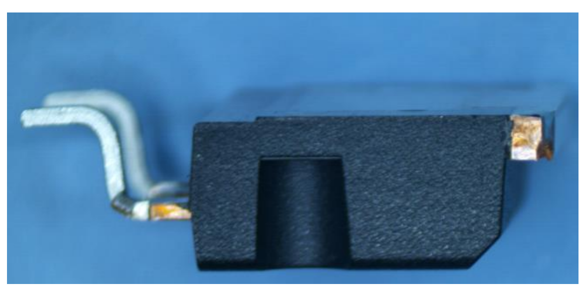


Figure 19Component A side view with step