Voiding Performance with Solder Pastes Containing Modified SAC Alloys for Automotive Applications in Bottom Terminated Component Assemblies

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Abstract

Voiding is a key concern for components with thermal planes because interruptions in Z-axis continuity of the solder joint will hinder thermal transfer. When assembling components with solder paste, there is a high propensity for voiding due to the confined nature of the solder paste deposits under the component. Once reflowed, many factors contribute to the amount of voiding in a solder joint such as the reflow profile, designs of the component, board and stencil, and material factors. This study will focus on the solder paste alloy and flux combination as well as profile and board surface finishes.

Several alloys have been developed in the last decade to boost performance in high-temperature environments and reliability in thermal cycling tests. These alloys typically consist of SnAgCu with additional elements such as Sb and Bi to modify performance. One of the key barriers to adoption of these alloys has been higher levels of voiding. Previous papers have explored the effect of process and stencil modifications with one or more of these alloys[1].

The solder pastes include several alloys within the range of compositions suggested for automotive applications in combination with different paste fluxes. The results will compare voiding with various alloys and common board surface finishes.

Keywords: QFN voiding, surface finish, OSP, ENIG

Introduction

The Challenge of Assembling BTCs

Voiding under bottom terminated components (BTCs) is a challenge for the electronics industry. Currently, common assemblies require a large number of QFNs, and these assemblies will often include several different types of BTCs. These components have flat terminations with a surface finish on the underside of the component, often with no exposed leads or solder joints. Typically, the center of the component has a large thermal ground pad with additional signal leads around the perimeter. Initial assembly testing will assure continuity on the signal leads, but in some cases this does not prevent field failures. These can be attributed to poor thermal conductivity in the center solder joint leading to overheating and die cracking. Poor thermal conductivity results from discontinuity in the z-axis of the solder joint due to voids in the solder joint.

Inspecting BTCs can be challenging because there are concealed solder joints, requiring X-ray scans of the assemblies. X-ray imaging gives a 2-dimensional view of the component and designates lower density areas with lighter contrast (Figure 1). Software is then used to quantify the % of the area that shows voids, the size of the largest void, and total number of voids. It is also important to look at the images of perimeter solder joints as bridges can be detected and varying shapes can sometimes indicate variations in component coplanarity.

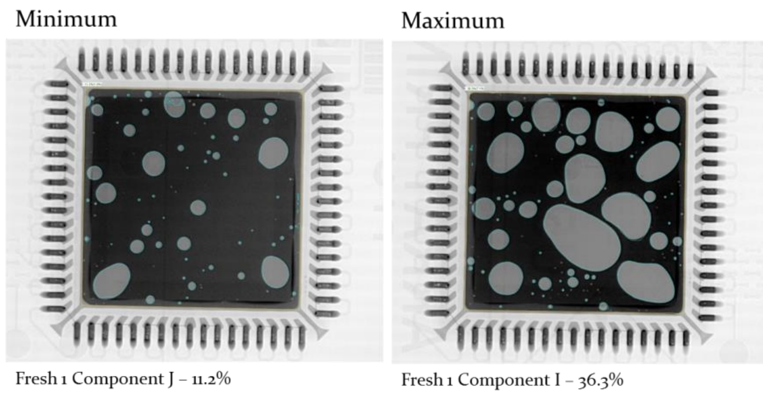


Figure 1: QFN voiding X-rays showing examples of minimum and maximum values with analysis.

Optimizing an assembly process to minimize voiding will mean looking more closely at many aspects of the assembly. Minimum voiding is not easily achieved by changing one part of the process or simply switching solder materials. Many different assembly scenarios have been investigated when voiding has played a part in failures. The contributing factors are varied and are grouped into three types of factors: design, process, and material. Figure 2 shows some examples of variables critical to consider in efforts to optimize performance.

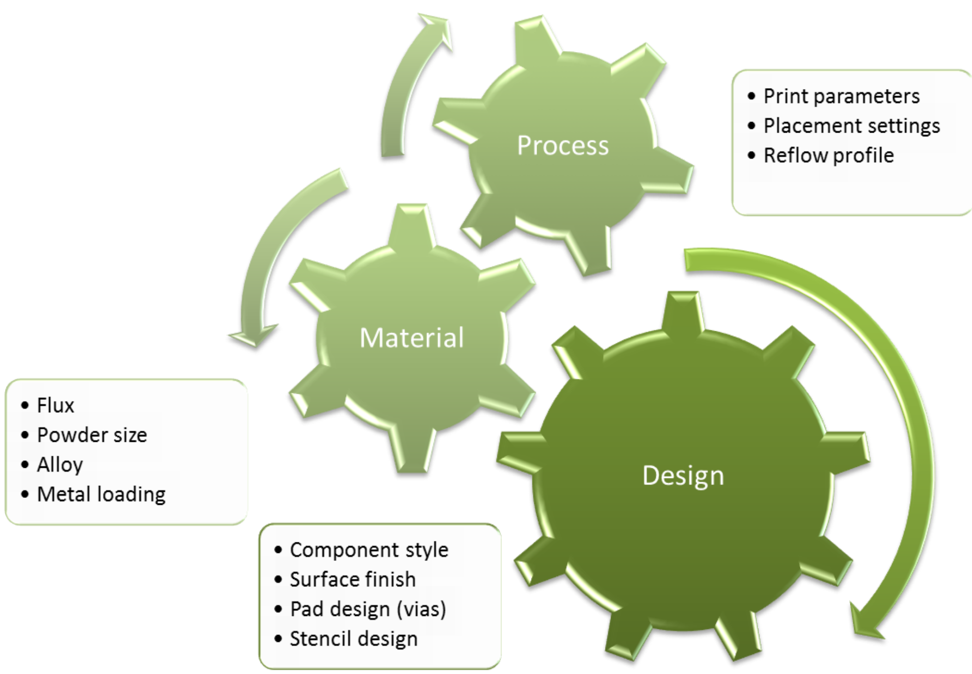


Figure 2: Diagram of assembly process variables

There are two main mechanisms that contribute to void formation: poor wetting and volatile entrapment. First, areas that do not allow the solder to wet well will cause inconsistency in solder joint formation and increase the probability for voiding. Poor wetting is often caused by deterioration of the surfaces of components and pads. Surface finishes protect copper pads from oxidation in contact with air. They also serve as a barrier to solder joint formation because the flux or metallurgy must make a bond despite the presence of the surface finish. In this way, surface finishes can vary greatly in their impact on voiding. Solder paste flux works to remove oxides and enhance wetting.

Volatile entrapment, the second mechanism, is uniquely challenging with BTCs because of the large covered area and low standoff between the components and the board. During reflow, board and solder materials that contain volatile compounds will outgas. These gases freely escape around other components because they are not constrained by the tight spacings found in BTCs. Once liquidus is reached in reflow and the solder alloy melts to form the solder joint, any remaining entrapped gas can form bubbles. Many of these bubbles are pushed to escape by the surface tension of the liquid solder, but those that do not escape before the alloy solidifies will be present in the solder joint as voids.

While focused on voiding, it is easy to lose sight of the most critical factor in assembling BTCs: standoff height. Component manufacturers recommend a certain amount of standoff provided by the solder joint. Component manufacturers recommend that the minimum acceptable standoff is around 50 microns. This is typically measured through destructive analysis such as cross-sectioning and using SEM imaging for measurement. Some X-ray machines are now also capable of topographical analysis that can detect height and coplanarity. If the solder joint is less than this minimum thickness, there will not be enough solder to bridge the gap for CTE mismatches between the board and component. This can lead to additional functional failures, with only a tenuous link to voiding.

Solder joints with sufficient standoff have shown acceptable performance in accelerated life testing with voiding up to 50%[2]. This does not take into account the thermal load required for the component to function optimally, but does demonstrate the robust nature of the solder joints associated with BTCs.

This study will look at the impact of some of the factors in Figure 2: surface finish, solder paste material selection, and component/stencil design.

Experimental Design

A new test board was designed to include only QFN components. The two component designs have the same dimensions, but the main difference is the size of the central thermal pad. Figure 3 shows the two designs. Only five of the possible nine component locations were populated, therefore the stencil design is exposed. Design J has a smaller central thermal pad, but more window panes in the stencil design. Design B has a four-quadrant design, thus depositing a larger amount of solder paste proportionally.

A.

B.

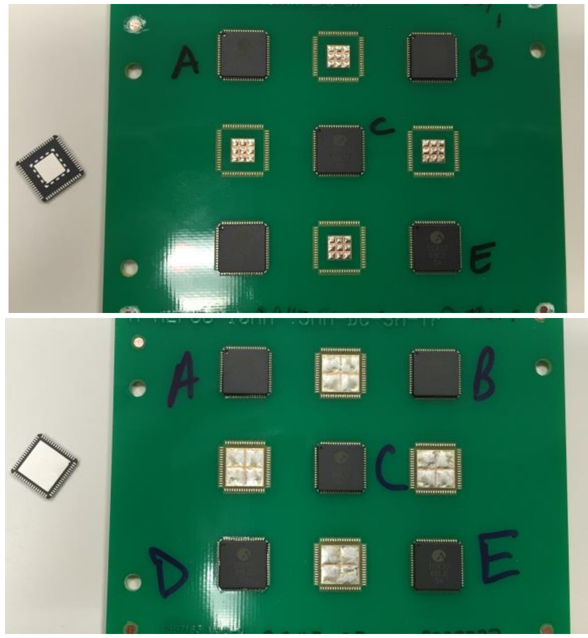


Figure 3: Test boards J (top) and B (bottom), respectively, with slightly different QFN and stencil designs.

These board designs were then ordered from the same board manufacturer in four different surface finishes: immersion silver (Ag), immersion tin (Sn), conventional organic solderability preservative (OSP), and electro-less nickel immersion gold (ENIG). To test the impact of oxidation after multiple reflows, some boards were oxidized by completing two reflows before printing and component placement, always with the profile in Figure 4.

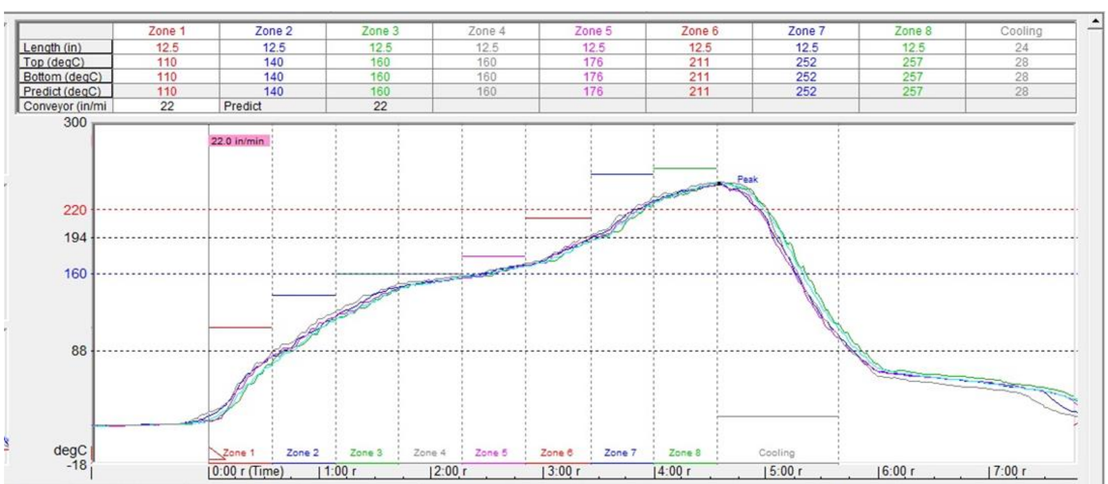


Figure 4: Reflow profile

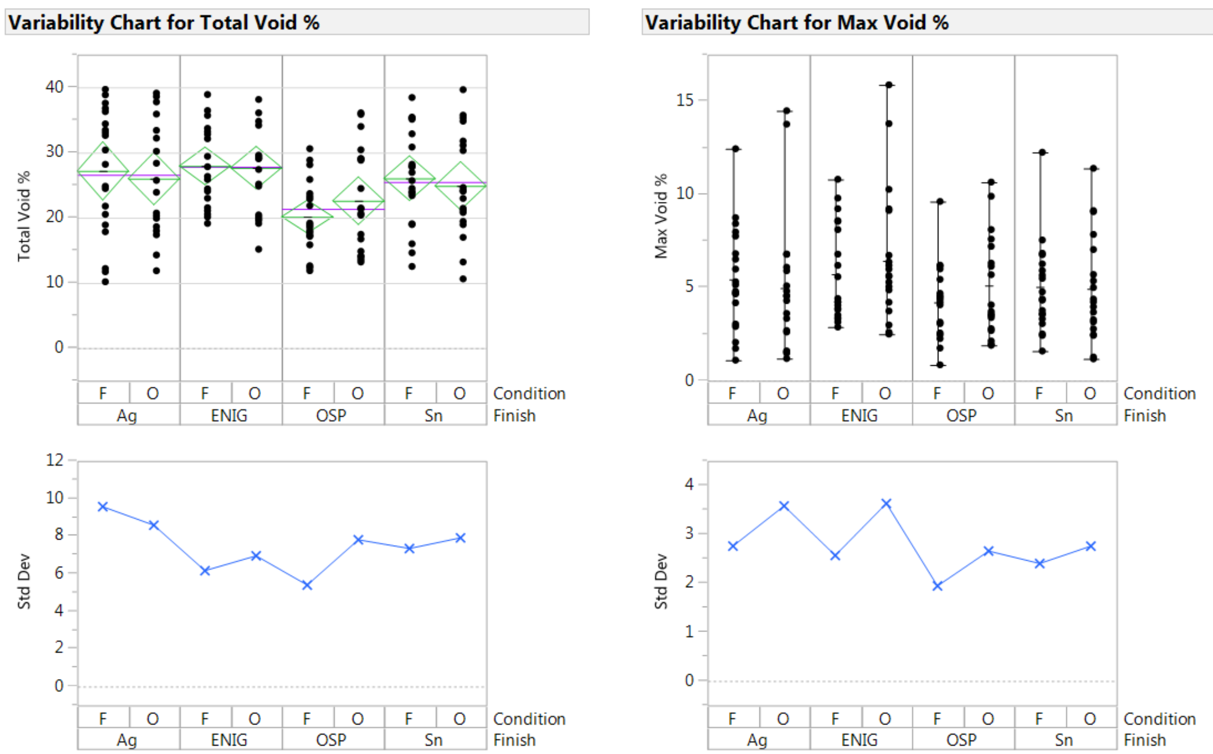
Three alloys were tested in this study: SAC305 and two modified SnAgCu alloys promoted for automotive applications, referred to as Auto Alloy1 which exhibits the composition as 90.95Sn3.8Ag0.7Cu3Bi1.4Sb0.15Ni and Auto Alloy 2 which is similar but without nickel. All three alloys were tested in solder paste form using the same ROL0 no-clean halogen-free flux vehicle (paste A).

Paste A with Auto Alloy 1 was also tested at the beginning and end of its one year refrigerated shelf life to assess the effect of paste aging. To investigate the potential effect of the flux vehicle on voiding performance, two other pastes were tested with Auto Alloy 1: a ROL1 no-clean solder paste and a ROL0 developmental solder paste designed to reduce voiding. The same reflow profile, with a peak of 243°C and around 60 seconds above liquidus was used for all of the boards and is shown in Figure 4.

Results and Discussion

All of the components were measured for overall voiding percent and the percent of the largest void by X-ray analysis. The results are typically displayed in a variability chart which shows the scatter of all points by categories. Often, a representation of the average and distribution is added, such as a diamond plot. Quantile bars and group means also help compare to the mean.

a.



b.

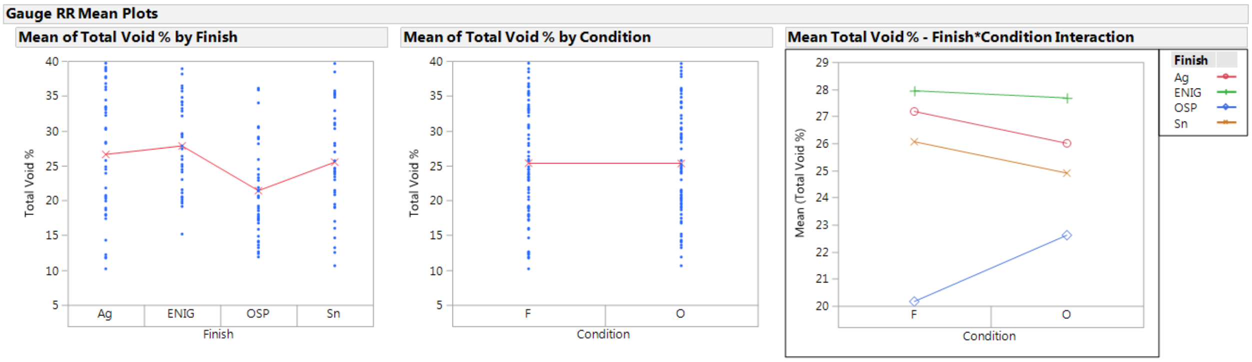


Figure 5: Paste A(Auto Alloy 1) effect of surface finish

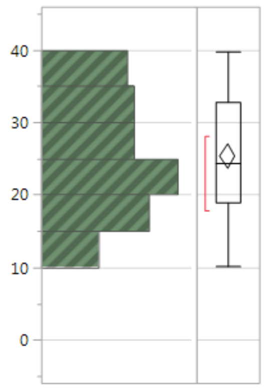
First, let us consider the effect of just the board surface finish. Paste A with Auto Alloy 1 results for all surface finishes, including fresh and oxidized conditions, are displayed in Figure 5. All of the total voiding percentages have less than 10% standard deviation and there is little difference between fresh (F) and oxidized (O) conditions. The difference between surface finishes is small, less than 5% difference from the mean of the entire data set. Results for the maximum void % show that there are some outliers with one large void. The highest data points do not seem preferential to one surface finish. This may indicate that variations in another characteristic such as component finish or cleanliness may also play a factor.

Figure 5b summarizes the same data as in Figure 5a and more clearly indicates that the OSP finish showed the lowest average voiding. It also verifies there is little difference between fresh boards and boards that have already oxidized through two reflow cycles.

Data Table=Paste Name=Paste A End of SL,Linked Subset=This subset is linked to QFN 9-up Boards Combined for Paper,Paste Name=Paste A End of SL

Distributions Paste Name=Paste A Fresh

Total Void %



Quantiles

100.0%	maximum	39.68
99.5%		39.68
97.5%		38.88875
90.0%		36.21
75.0%	quartile	32.7425
50.0%	median	24.475
25.0%	quartile	18.9775
10.0%		14.733
2.5%		11.714
0.5%		10.17
0.0%	minimum	10.17

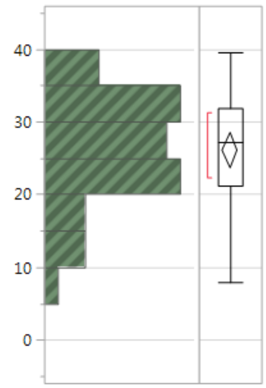
Summary Statistics

Mean	25.333125
Std Dev	7.779783
Std Err Mean	0.8698062
Upper 95% Mean	27.064431
Lower 95% Mean	23.601819
N	80

Data Table=Paste Name=Paste A End of SL,Linked Subset=This subset is linked to QFN 9-up Boards Combined for Paper,Paste Name=Paste A End of SL

Distributions Paste Name=Paste A End of SL

Total Void %



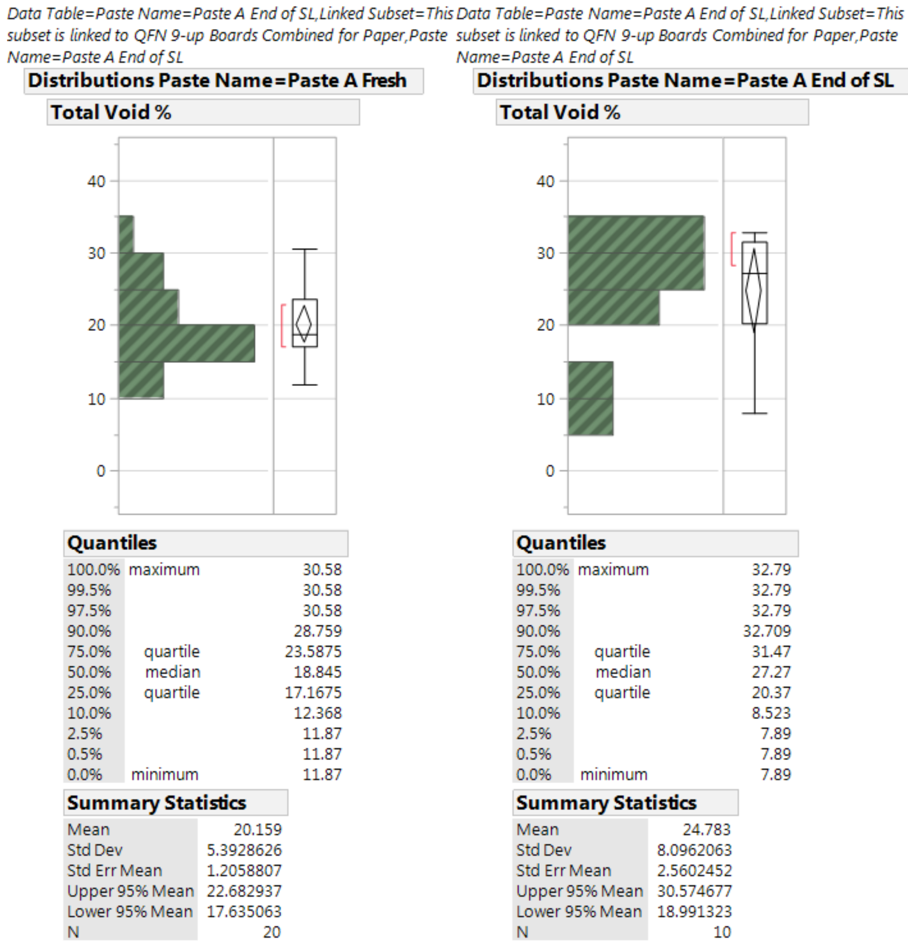
Quantiles

100.0%	maximum	39.62
99.5%		39.62
97.5%		39.55825
90.0%		36.708
75.0%	quartile	31.81
50.0%	median	27.27
25.0%	quartile	21.2275
10.0%		14.354
2.5%		7.9685
0.5%		7.89
0.0%	minimum	7.89

Summary Statistics

Mean	26.16675
Std Dev	7.598254
Std Err Mean	1.2013894
Upper 95% Mean	28.59679
Lower 95% Mean	23.73671
N	40

A.



B.

Figure 6: Paste A distributions showing effect of paste age on results with all surface finishes (A) and OSP (B)

Test boards were assembled with the same solder paste that was at the end of its refrigerated shelf life of one year. The distributions shown in Figure 6 are slightly different. The paste at the end of its shelf life has a slightly higher mean and variation, but also has some of the lowest voided components in this data set. The variation here is similar to the variation seen between any two QFN voiding data sets.

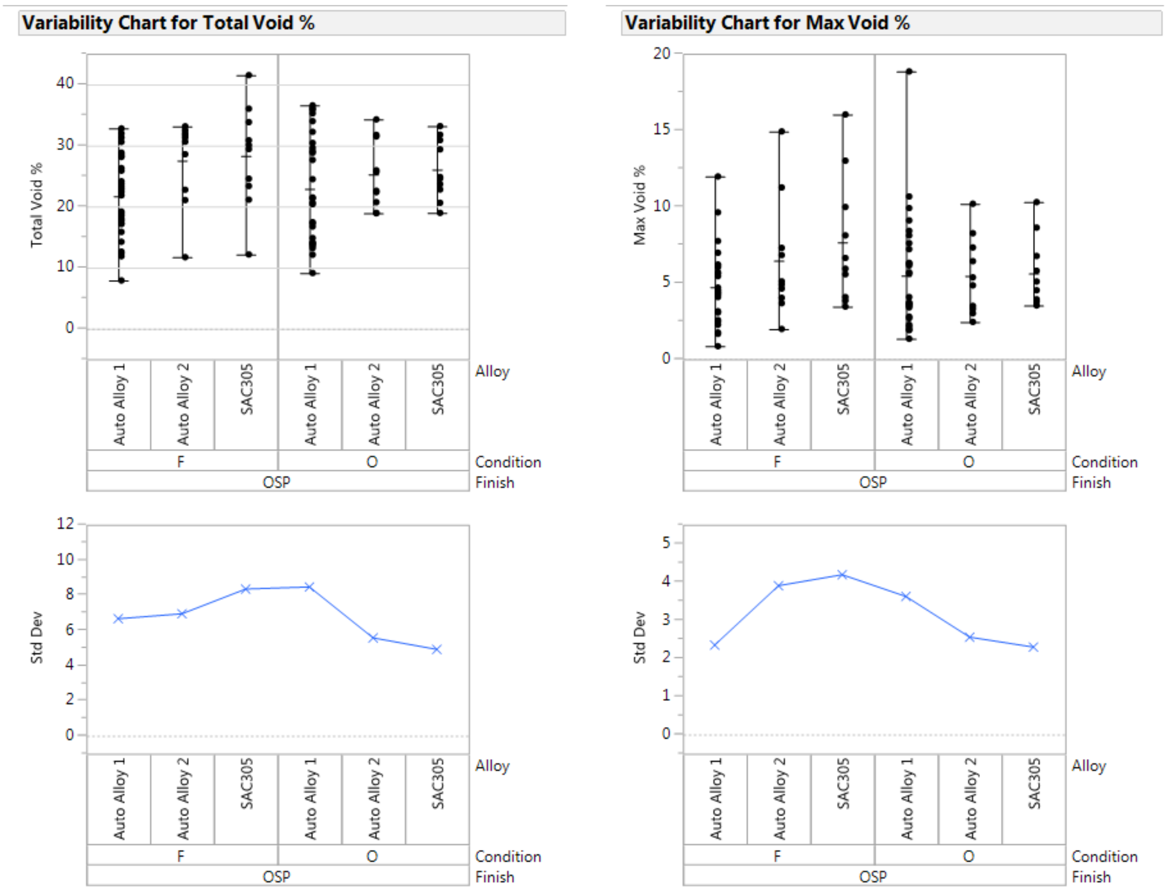


Figure 7: Paste A showing the effect of solder alloy with OSP

Next, let us consider the effect of the solder alloy. All three pastes contain the Paste A flux vehicle and type 4 powder at the same metal loading. Figure 7 also shows little difference between fresh boards and oxidized boards, with little difference in the averages. Note that the data set for Auto Alloy 1 has more data points because additional boards were assembled.

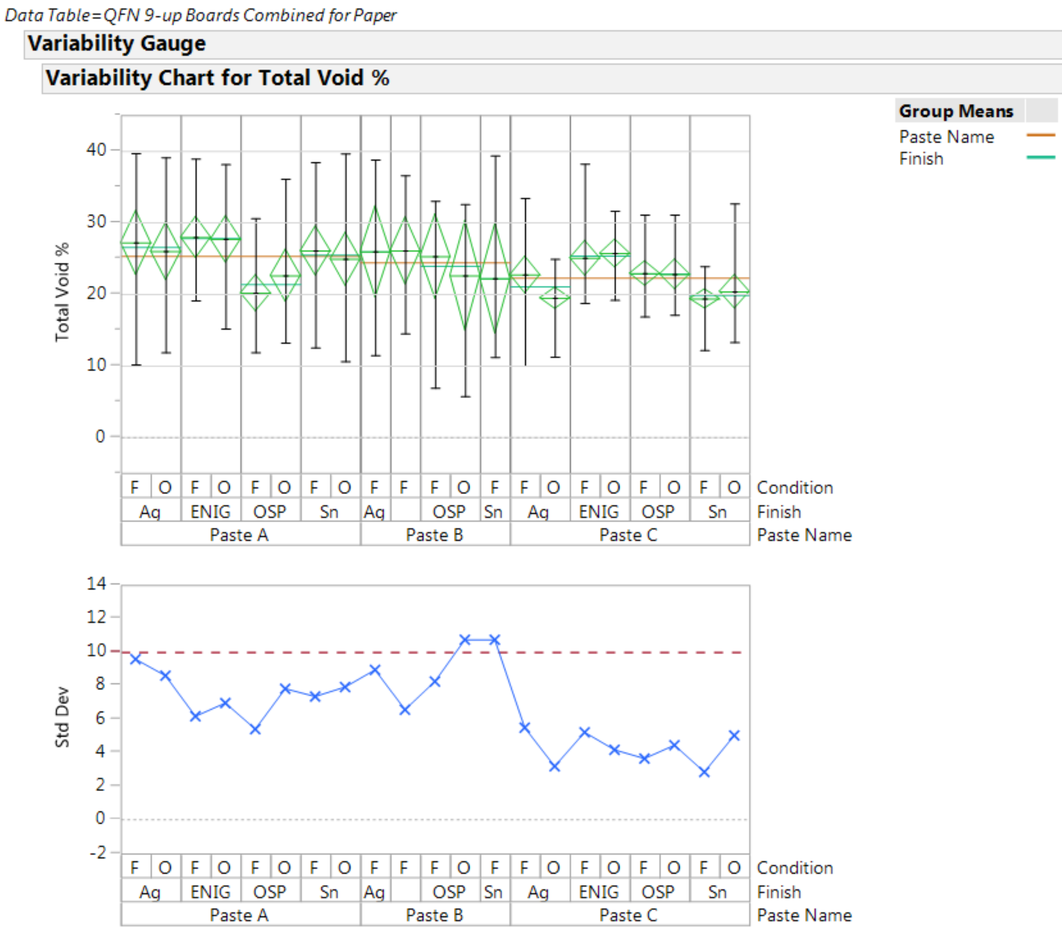


Figure 8: Auto Alloy 1 results comparing flux vehicles

To investigate the effect of different fluxes on voiding, three different flux vehicles were mixed with Auto Alloy 1 and type 4 powder at different metal loads to adjust to the same viscosity. The average results in Figure 8 show a slightly lower voiding trend for experimental ROL0 Paste C (shown in top graph in orange) and slightly more variation in results with ROL1 Paste B. The trends related to board surface finish seem to translate with the different paste fluxes.

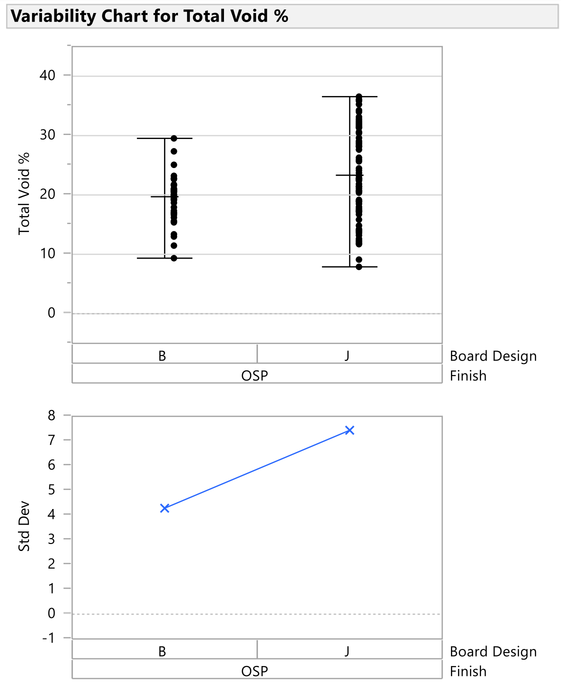


Figure 9: Effect of component design and stencil apertures on voiding

Lastly, consider the effect of component design as shown in Figure 9. Note that the stencil design for component J contributes less solder volume to the solder joint. This lack of solder volume has been shown to increase voiding percent and contribute to insufficient standoff height because there is not enough solder volume to fill the geometric gap under the component.

Summary/ Conclusions

This study set out to investigate the impact of several different factors on voiding, namely: test board surface finishes, board oxidation, solder alloy selection, paste flux, paste aging, and component design/stencil pattern. Each of these factors showed some difference in overall mean voiding, but all of the differences were very small compared to the variation in the data sets. The voiding values were also high compared to typical values less than 20% for these solder materials on other test boards. This indicates that the test board design can be improved to give lower overall voiding percentages. For comparison, these test boards can be used to demonstrate how material and process variations affect a worst-case design.

Any hypotheses about which surface finish or which alloy would perform best were not supported. The OSP finish consistently showed lower voiding results whether fresh or oxidized, while ENIG, which is typically regarded as the best oxidation inhibitor, showed higher voiding results. The trend in board surface finishes may also be attributed to the way they have been applied, more so than the nature of the surface finish alone.

The material comparisons showed that the developmental flux did show a slight improvement in overall voiding, but the alloy had a lesser effect. The solder paste aged past its shelf life showed slightly higher average voiding but within a range that could be attributed to normal variation. This raises confidence that paste aging has little effect on voiding, although this might change based on the flux vehicle.

Acknowledgements:

Thanks to John Russo at the company for assistance in preparing all the test boards and to STI Electronics for X-ray analysis.

References:

1. B. Sandy-Smith, How Stencil Design and Reflow Profiles Affect Variation in QFN Voiding Data: A Case Study, SMTA ICSR 2016.
2. D. Hillman, BTC Voiding: Component and Solder Joint Reliability, SMTAi 2016.

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Agenda

- The challenges of assembly BTCs
- Experimental design
- Results
- Discussion

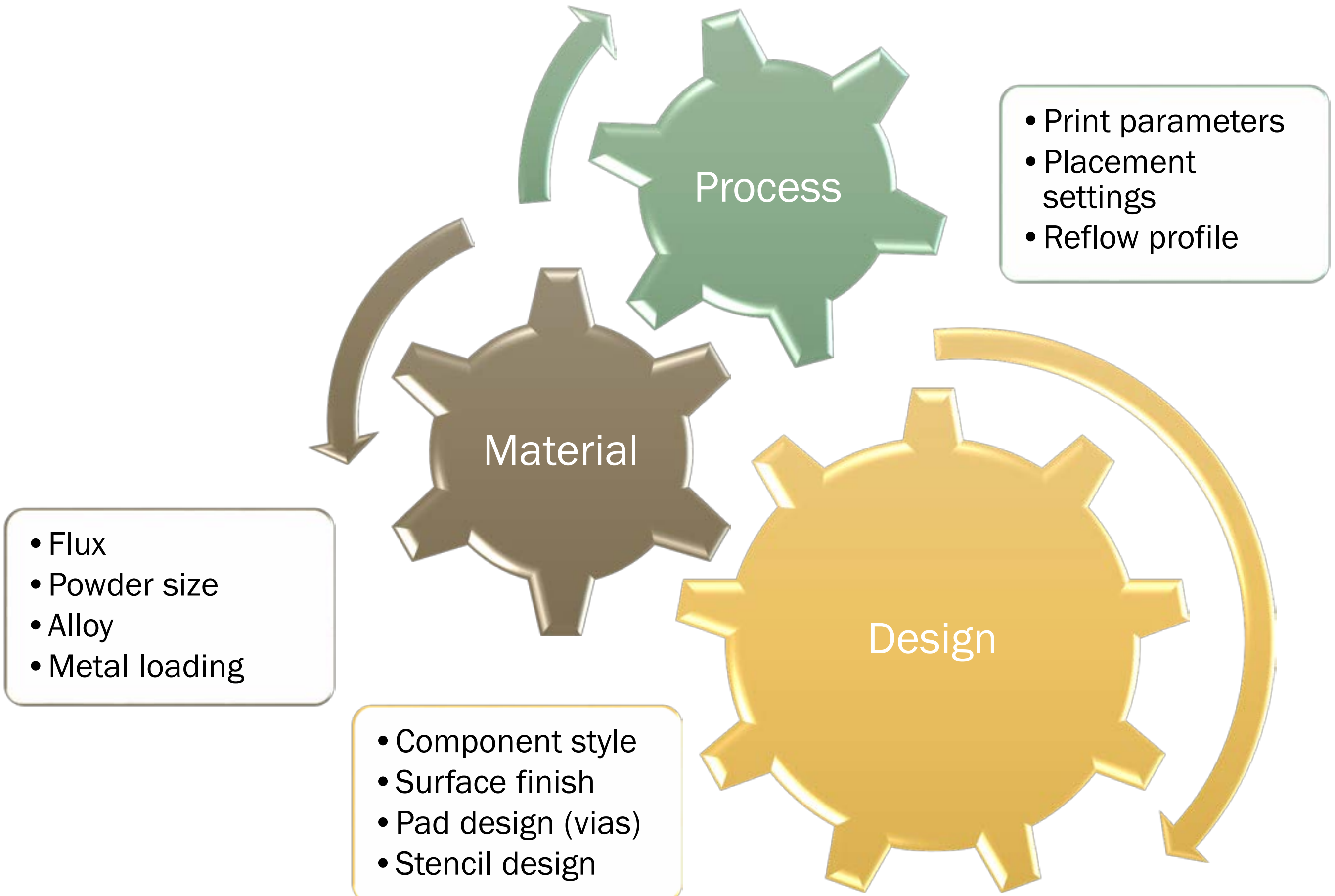
Voiding Comparison by Materials

Goals:

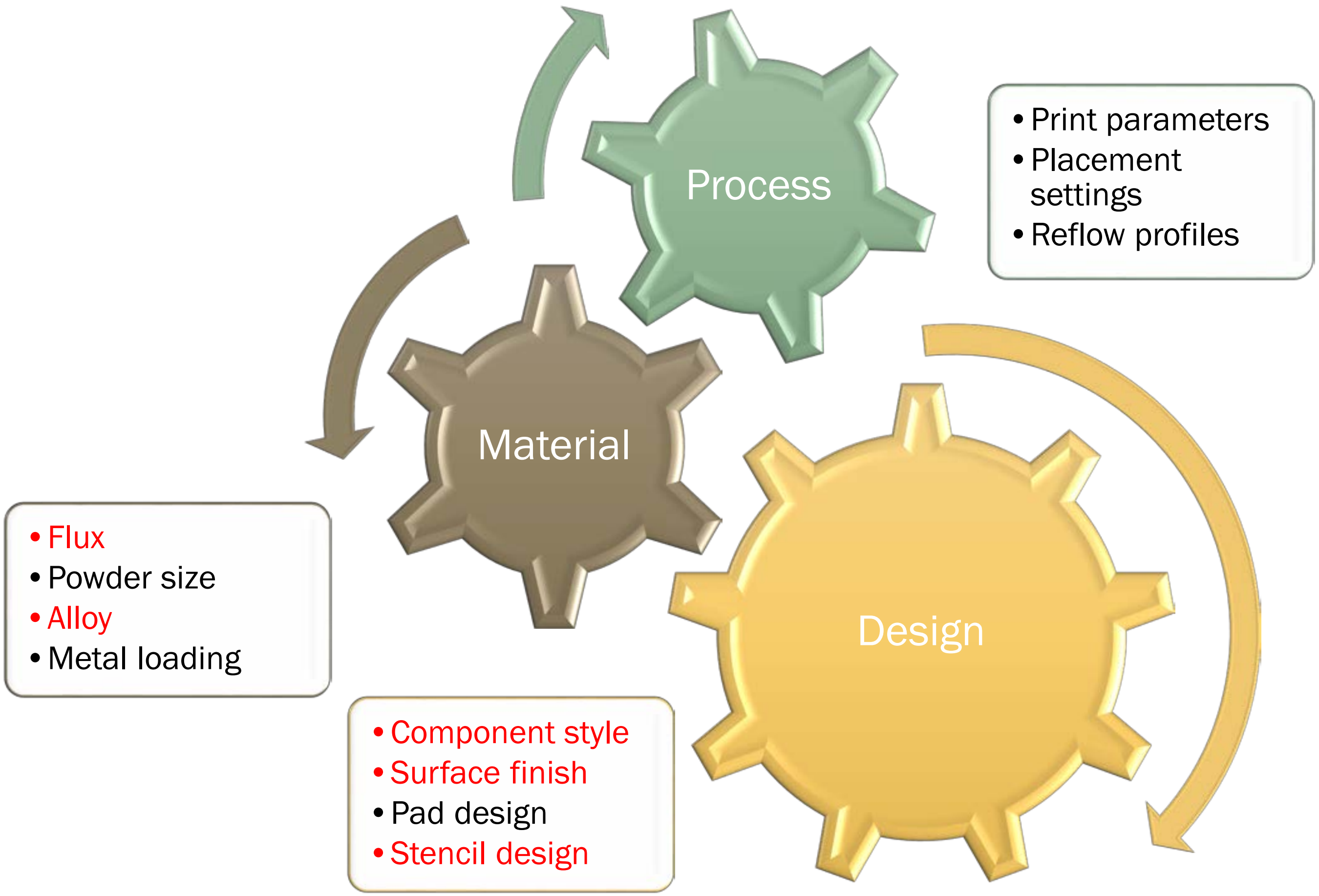
- Develop better test vehicle and method to characterize voiding of a material to form comparisons
- Learn about how other assembly factors influence the results
- Identify worst case factors for tests to push the limits of material properties

Previous work: How Stencil Design and Reflow Profiles Affect Variation in QFN Voiding Data from SMTA ICSR 2016

Many Factors Influence Voiding

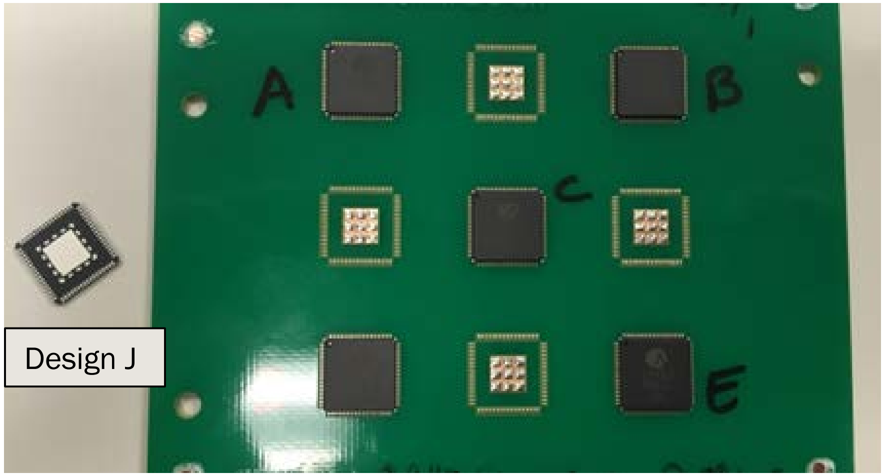


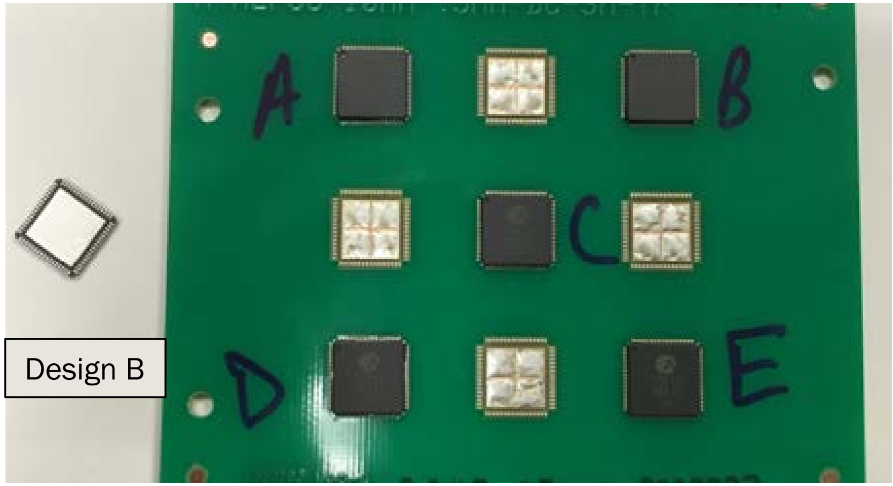
Factors to Investigate



Boards and Components

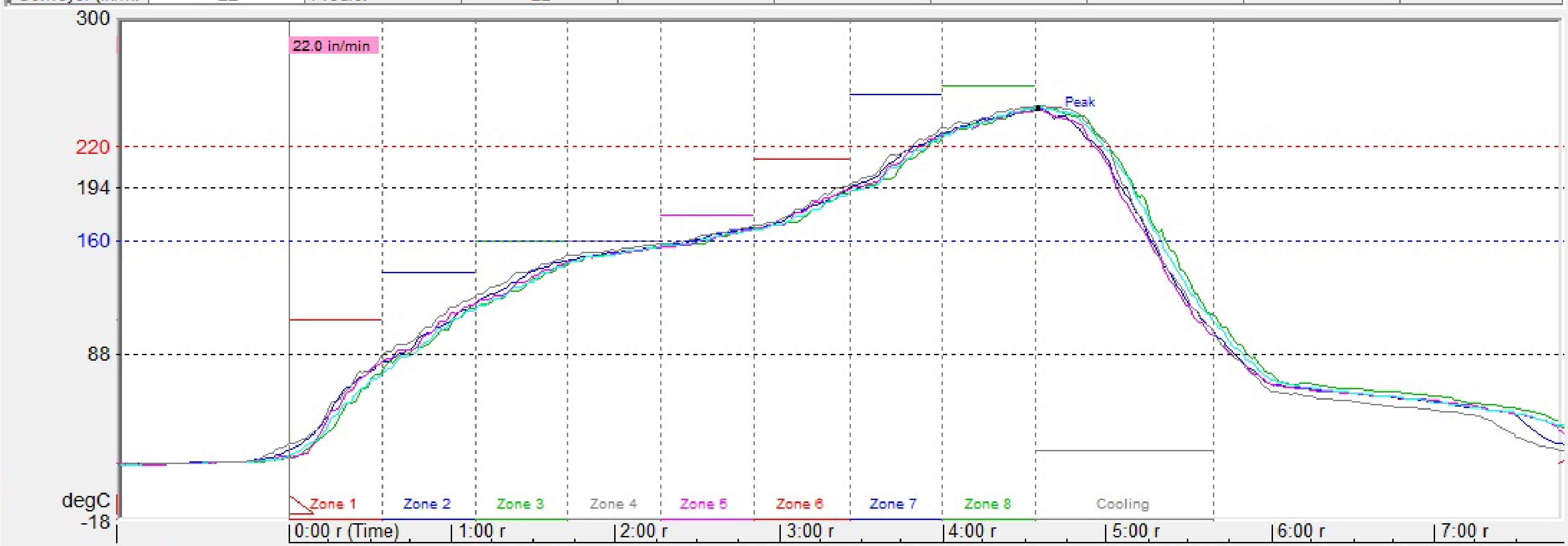
- Two components, same dimensions different thermal pad design
- Two different stencil design: 9 squared window pane (small thermal pad) and 4 squares (large thermal pad)
- All boards from same supplier with surface finishes: immersion silver (Ag), immersion tin (Sn), electro-less nickel immersion gold (ENIG), and organic solderability preservative (OSP)
- Only 5 of 9 possible locations populated





Reflow Profile

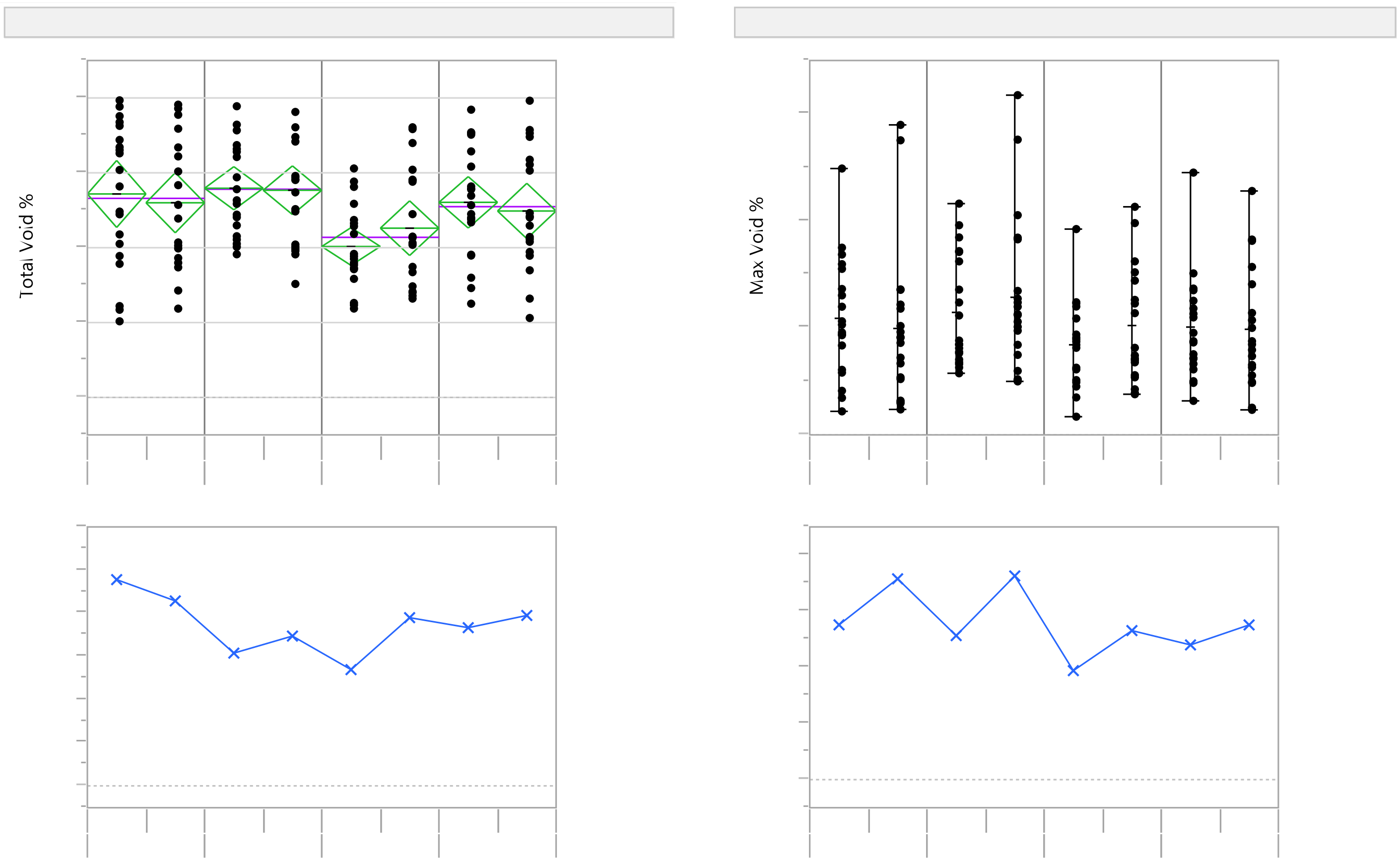
	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Cooling
Length (in)	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	24
Top (degC)	110	140	160	160	176	211	252	257	28
Bottom (degC)	110	140	160	160	176	211	252	257	28
Predict (degC)	110	140	160	160	176	211	252	257	28
Conveyor (in/mi	22	Predict	22						



Material Selections

- Paste A – ROL0 commonly available material
  - *SAC305*
  - *Auto Alloy 1*
  - *Auto Alloy 2*
- Paste B – ROL1 commonly available material
  - *Auto Alloy 1*
- Paste C – ROL0 developmental material
  - *Auto Alloy 1*

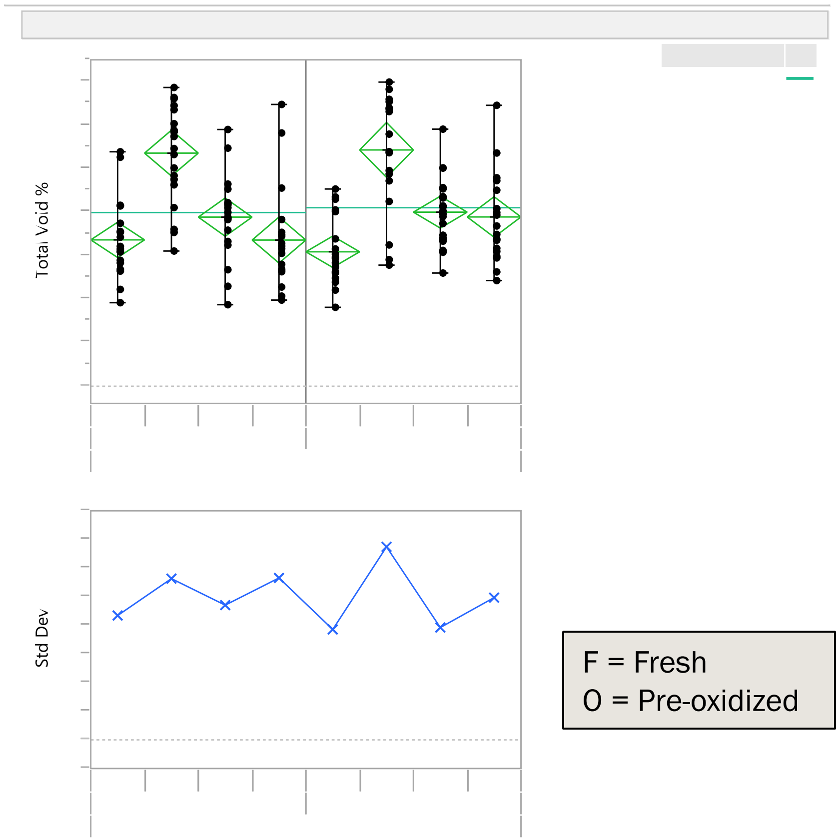
Paste A: Effect of Surface Finish



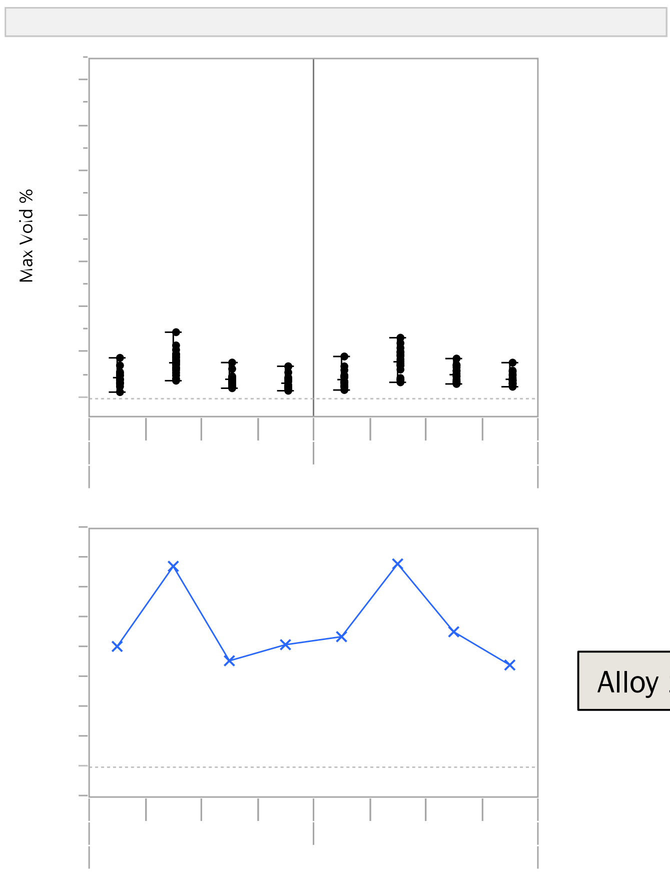
F = Fresh
O = Pre-oxidized

Alloy 1 T4 88.5%

Paste A: Effect of Surface Finish (B Design)

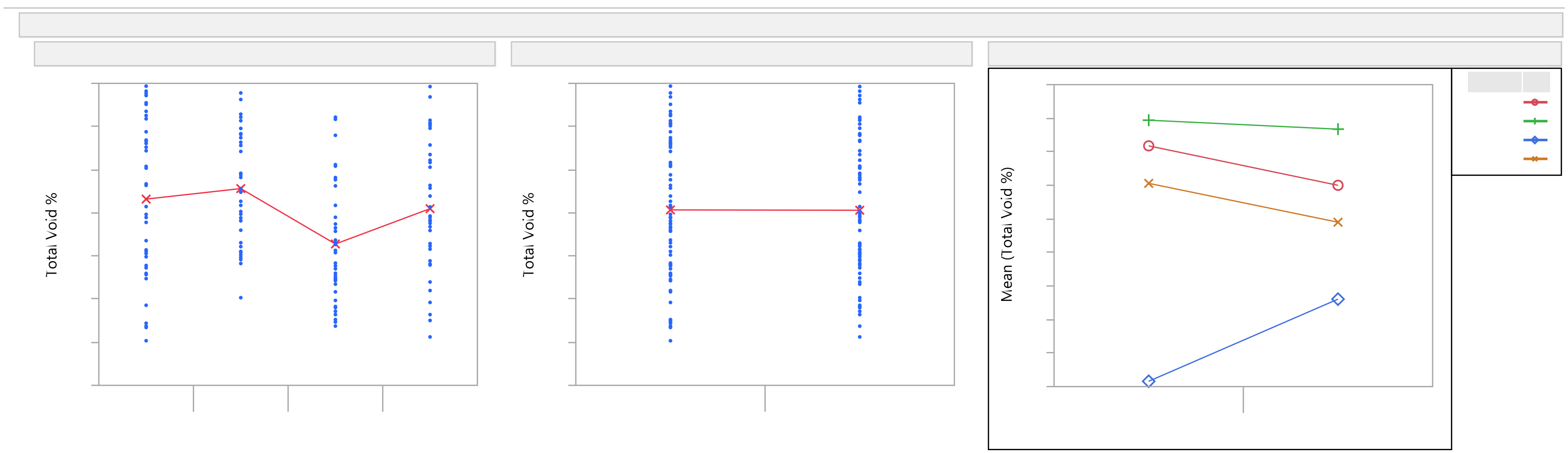


F = Fresh
O = Pre-oxidized



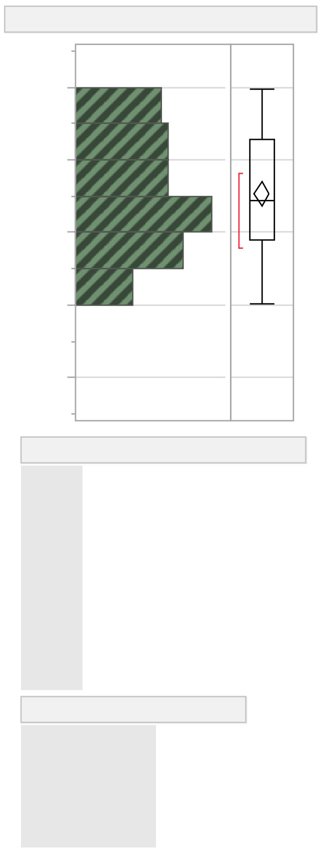
Alloy 1 T4 88.5%

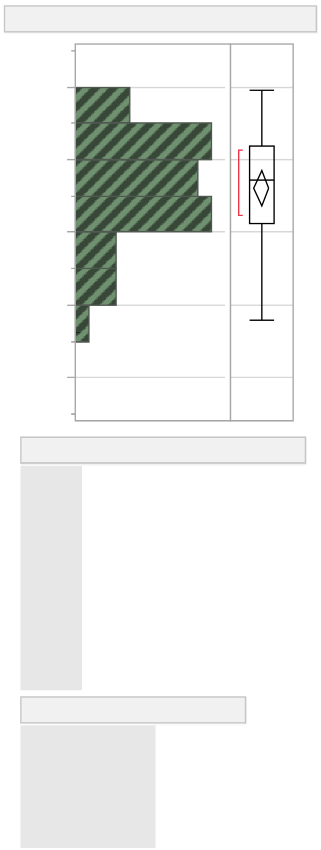
Paste A: Effect of Surface Finish



Alloy 1 T4 88.5%

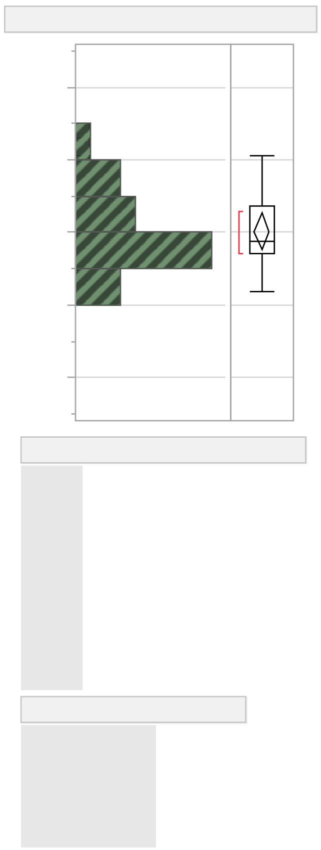
Paste A: Effect of Age All Finishes

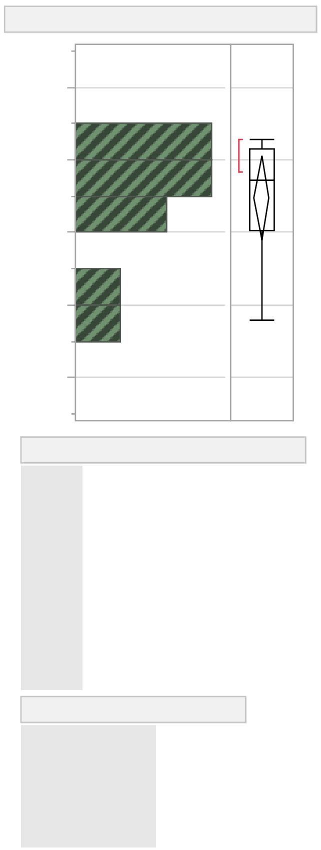




Alloy 1 T4 88.5%
Board J

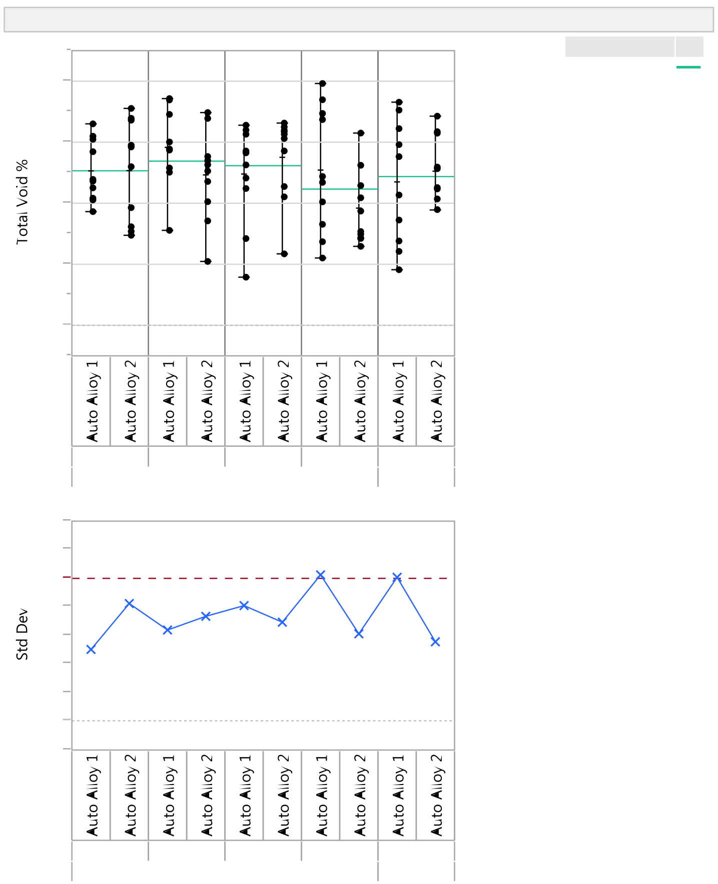
Paste A: Effect of Age - OSP

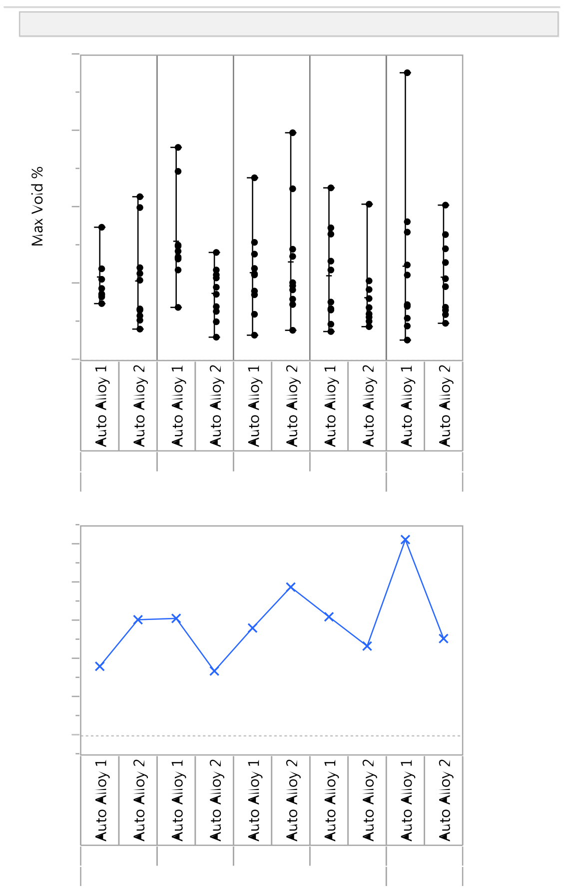




Alloy 1 T4 88.5%
Board J

Paste A: Effect of Alloy

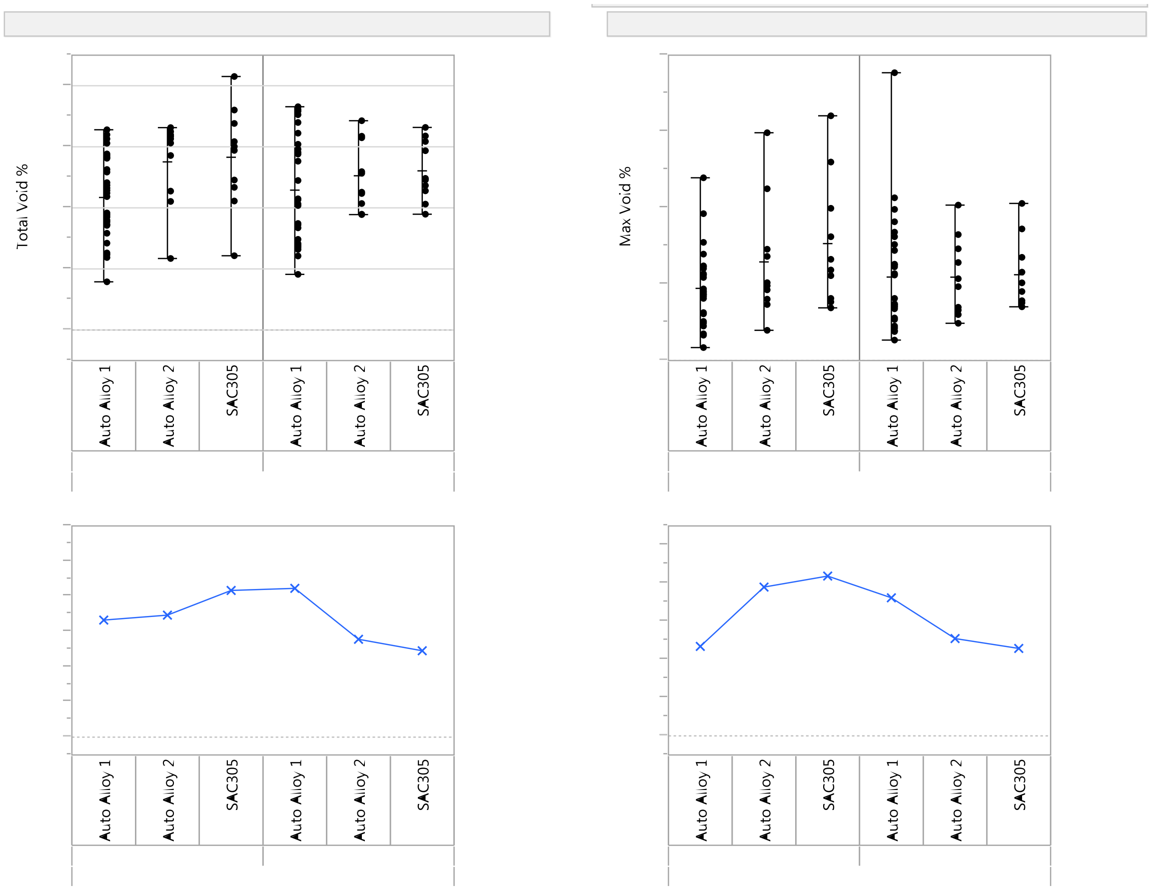




F = Fresh
O = Pre-oxidized

T4 88.5%
Board J

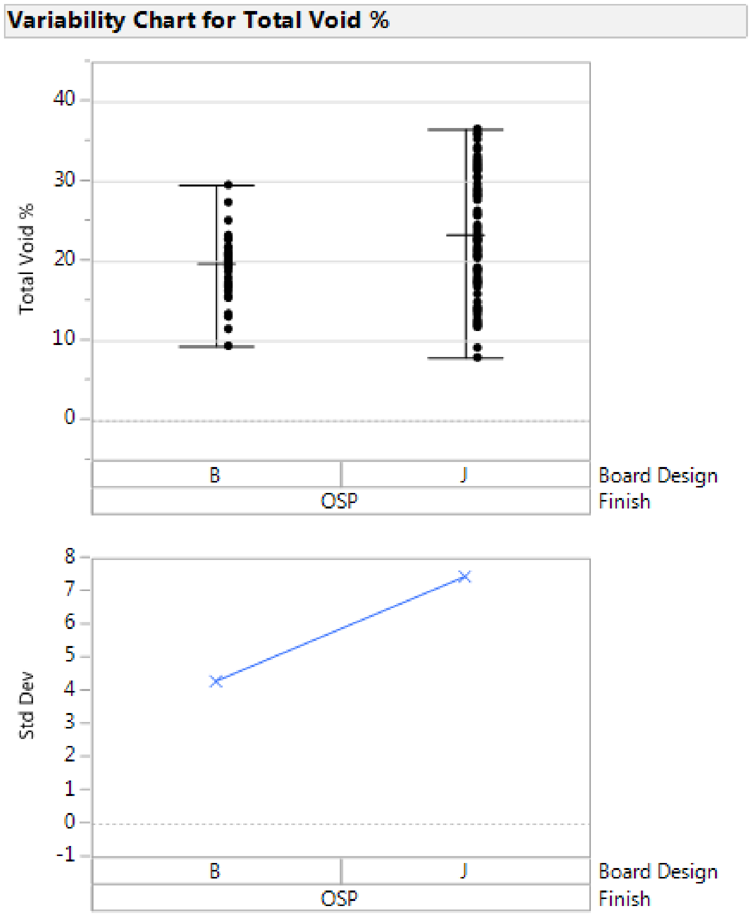
Paste A: Effect of Alloy



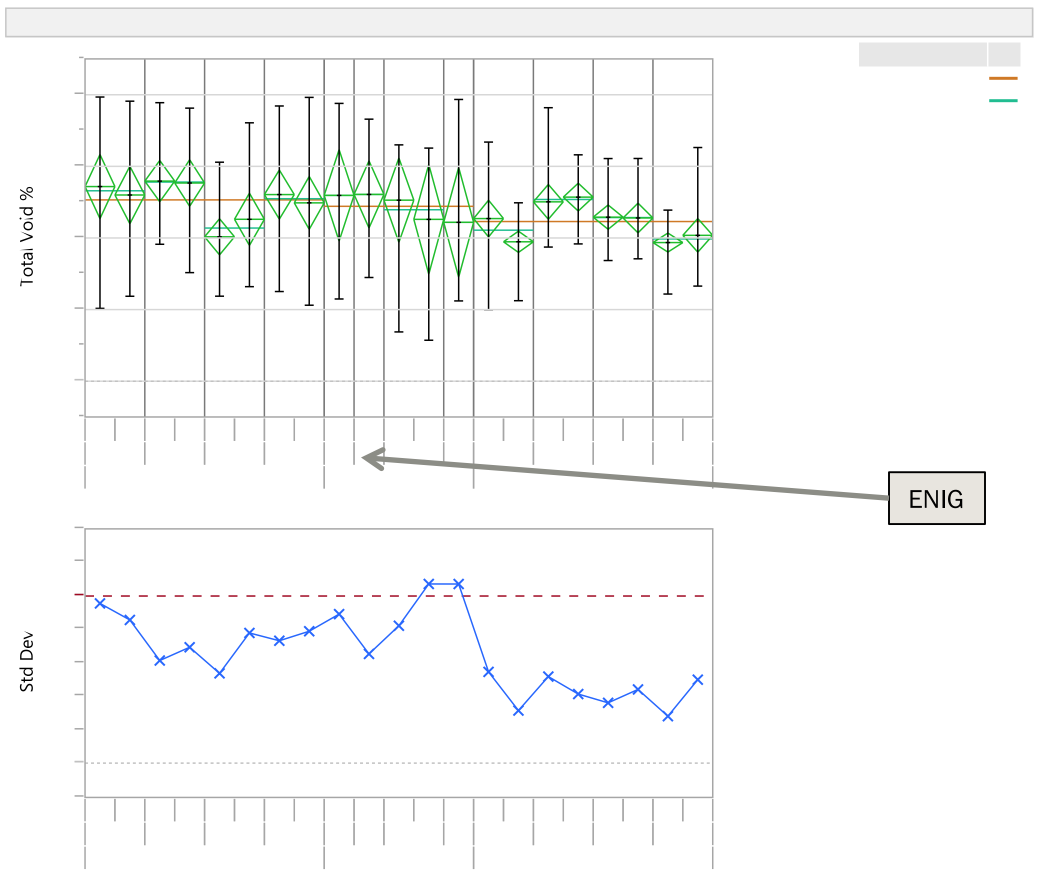
F = Fresh
O = Pre-oxidized

T4 88.5%
Board J

Paste A: Effect of QFN Design



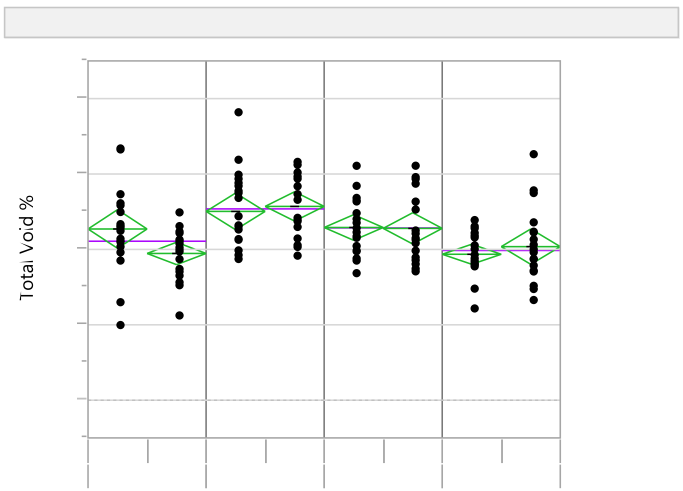
Alloy 1: Effect of Paste Flux

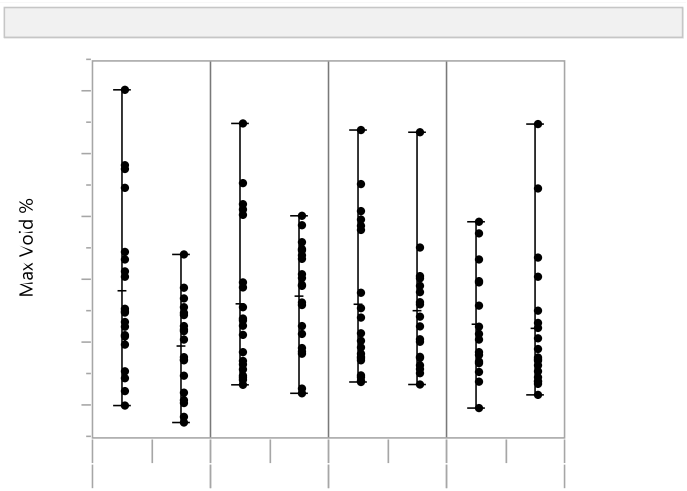


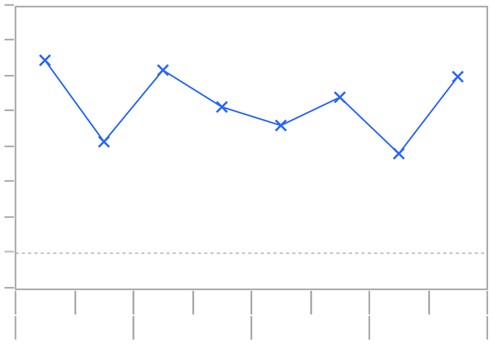
F = Fresh
O = Pre-oxidized

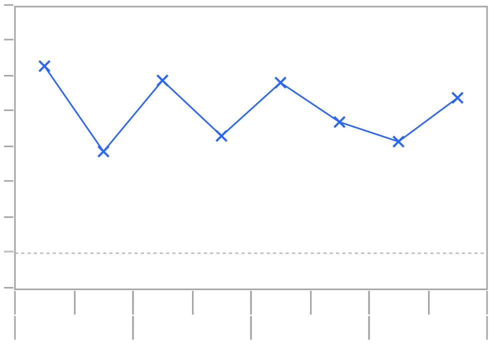
Board J

Paste C: Effect of Surface Finish









Factors Tested -> Observed Effects

Factors Tested	Observed Effects
Flux/paste formula	Potentially significant
Alloy choice	Not significant
Paste storage	Not significant
Surface finish	Variation trends
Pre-oxidation	Not significant
Component choice	Stencil design also
(Air vs. Nitrogen)	Nitrogen better
(SnPb Paste)	SnPb better

() Factors Tested Previously in “Evaluating the Effects of SMT Material and Process Variables on Voiding Under QFNs” IMAPS 2016

Untested Factors -> Potential Impact

- Vias
- Solder mask patterning
- Standoff height

- Higher variation
- May help with standoff and paste flow
- Most critical to performance, not a controlled variable