Understanding the Effect of Process Changes and Flux Chemistry on Mid-Chip Solder Balling

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Abstract

This paper documents the experimental work performed to further understand the impact on mid-chip solder balling from both the manufacturing process and the flux chemistry.

Mid-chip solder balling is a defect typically associated with solder paste exhibiting poor hot slump and/or insufficient wetting during the reflow soldering process, resulting in paste flowing under the component or onto the solder resist. Once molten, this solder is compressed and forced to the side of the component, causing mid-chip solder balling.

To increase the understanding of what factors can impact mid-chip balling, a study was undertaken to examine the effects of process variants and flux chemistry. Stencil thickness, aperture size and aperture shape were all identified as potentially significant factors with regards to process influence. Testing also revealed that the volume of paste was not necessarily proportional to the number of mid-chip balls, but was more influenced by the position of the paste relative to the pad. Comparative testing of a range of flux chemistries indicated that this also had a substantial effect on mid-chip ball occurrence.

The data suggested that mid-chip balling could be controlled by both process and flux design. New methods of quantifying the severity of mid-chip solder balling are currently being investigated.

Introduction

Mid-chip solder balling is a defect typically associated with solder paste exhibiting poor hot slump and/or insufficient wetting during the reflow soldering process. If a solder paste exhibits excessive hot slump, there is an increased possibility that a proportion of the solder will become detached from the bulk deposit and flow under the component. In parallel, a paste exhibiting slow or insufficient wetting (low activity) will have a weak interaction with the solderable surface of both the PCB and component metallisation; this will increase the possibility of solder flowing onto the solder resist.

During the reflow process, as the alloy melts and the flux volatilises, the relative volume of a solder paste deposit decreases. This causes a reduction in the gap between the chip component and the PCB. Any molten solder that is present on the resist and under the component is therefore squeezed and forced to the side of the component, causing a mid-chip solder ball.

IPC states that a solder ball defect occurs when "solder balls are not entrapped, encapsulated or attached or can become dislodged in the normal service environment" and/or "solder balls violate minimum electrical clearance" [1]. In this study, all of the mid-chip solder balls counted were classed as defects.

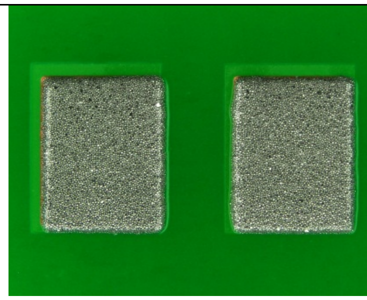
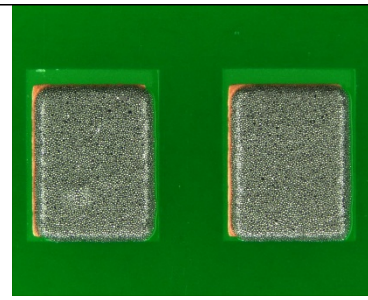
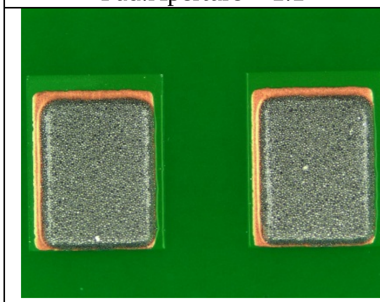
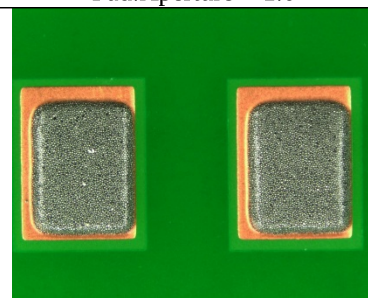
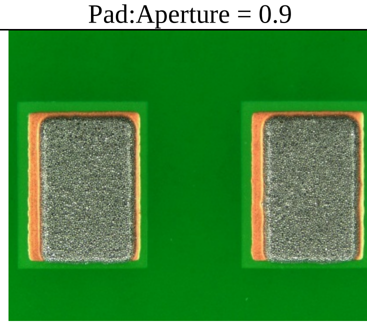
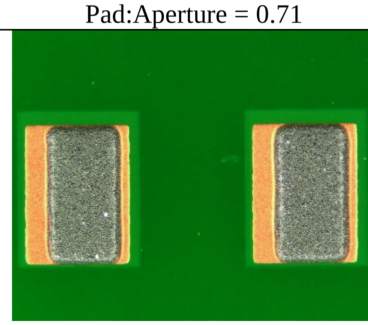
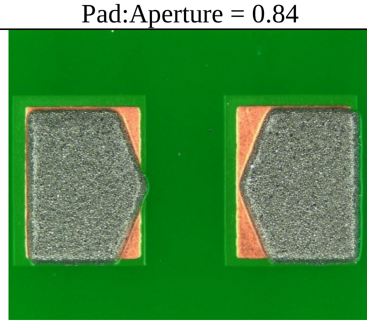
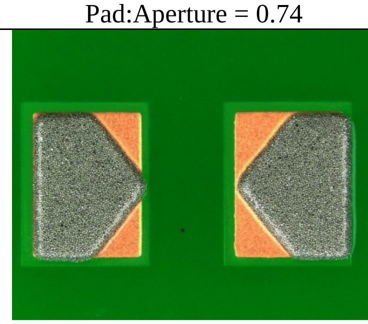
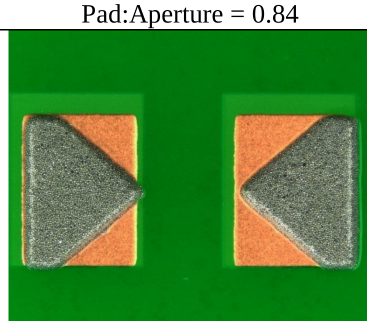
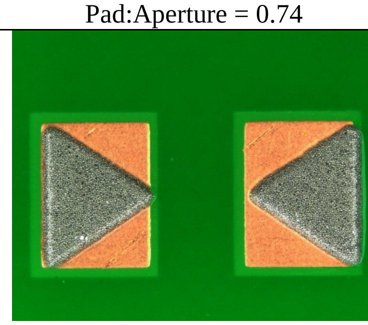
The study has been split into two parts: The first part investigates the effect of process on mid-chip balling and was carried out using a representative halogen-free no-clean solder paste formulation. The second part examines the effect of flux chemistry, using a range of both halogen-containing and halogen-free Pb-free no-clean solder pastes.

Method - Effect of Process on Mid-Chip Balling

PCBs with OSP coated copper pads were printed using an industry standard printer and two different stencil thicknesses – 100 µm and 125 µm. The paste deposit volumes were measured before resistor components were placed. A visual inspection was carried out to ensure central placement before the boards were reflowed through an industry standard oven in air using the profile in Figure 1.

The total number of mid-chip balls on 1206 component pads were counted independently by two individuals to ensure the reliability of the results. For each aperture geometry, the average number of mid-chip balls was calculated per component.

Table 1 – 1206 Pads Aperture Shape and Theoretical Ratios

Square Aperture	 Overprint 110% Coverage Pad:Aperture = 1.1	 100% Coverage Pad:Aperture = 1.0
	 90% Coverage Pad:Aperture = 0.9	 71% Coverage Pad:Aperture = 0.71
Rectangle Aperture	 84% Coverage Pad:Aperture = 0.84	 67% Coverage Pad:Aperture = 0.74
Homeplate Aperture	 84% Coverage Pad:Aperture = 0.84	 74% Coverage Pad:Aperture = 0.74
Triangle Aperture	 62% Coverage Pad:Aperture = 0.62	 51% Coverage Pad:Aperture = 0.51

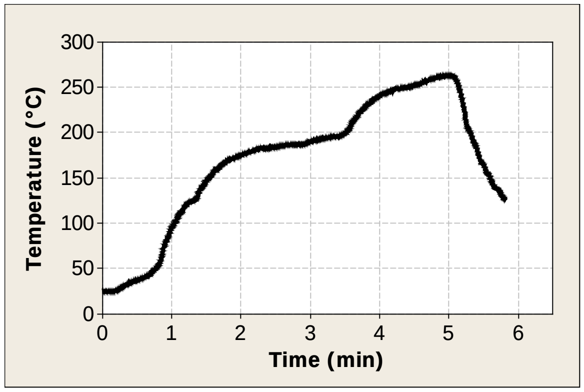


Figure 1 – Reflow Profile for Effect of Process Testing

Aperture Shape and Ratios

Table 1 details the different stencil aperture shapes used, the amount of the pad theoretically covered with paste, and the pad to aperture ratio used in the results for 1206 component pads. Square, rectangle, homeplate and triangle shaped apertures were all examined. The amount of paste coverage on the pad varied from an overprint of 110% down to 51%.

Results – Effect of Process

To fully understand the effect of process changes on mid-chip balling, the testing was carried out using a single solder paste throughout; any changes in mid-chip balling could then be directly related to the process involved.

Pad & Component Size

Mid-chip balling was counted on three different component sizes – 1206s, 0805s and 0603s. Figure 2 shows that the mid-chip balling on all three components followed the same trend, with the number of balls decreasing with decreasing component/pad size. Depositing less paste onto the pad reduced the potential for off-pad slump, therefore making it less likely that the solder would flow under the component and become detached from the main deposit.

For the rest of this study, only the results for the 1206 component pads have been reported; this was the most discriminating area and best illustrates the relationships between mid-chip balling and process/flux changes. The data for the 0805 and 0603 pads is available upon request from the authors.

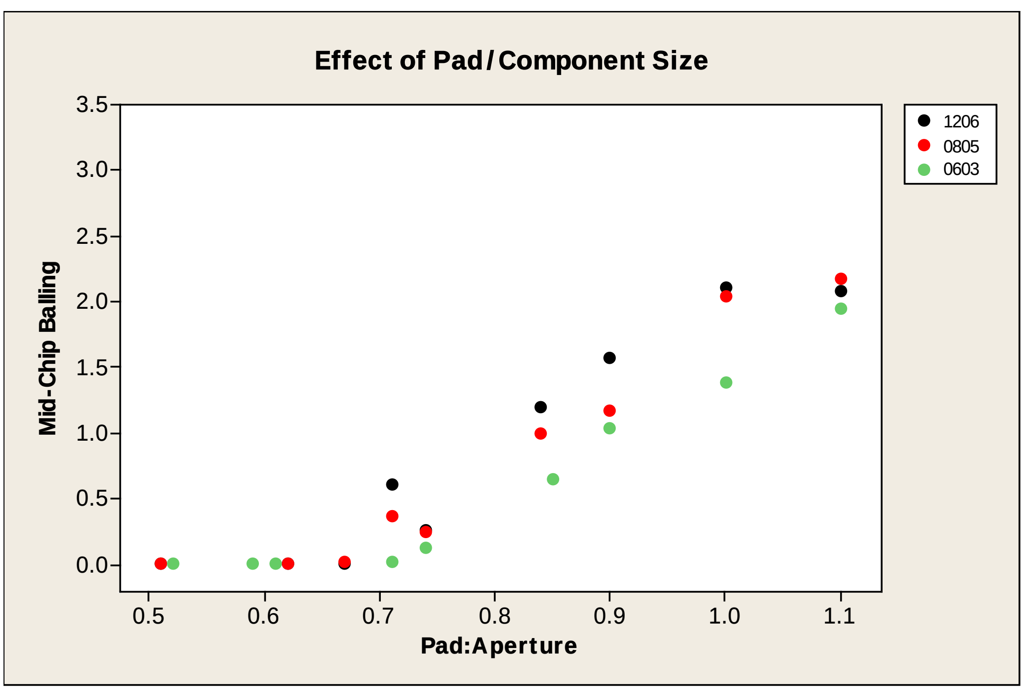


Figure 2 – Effect of Pad & Component Size

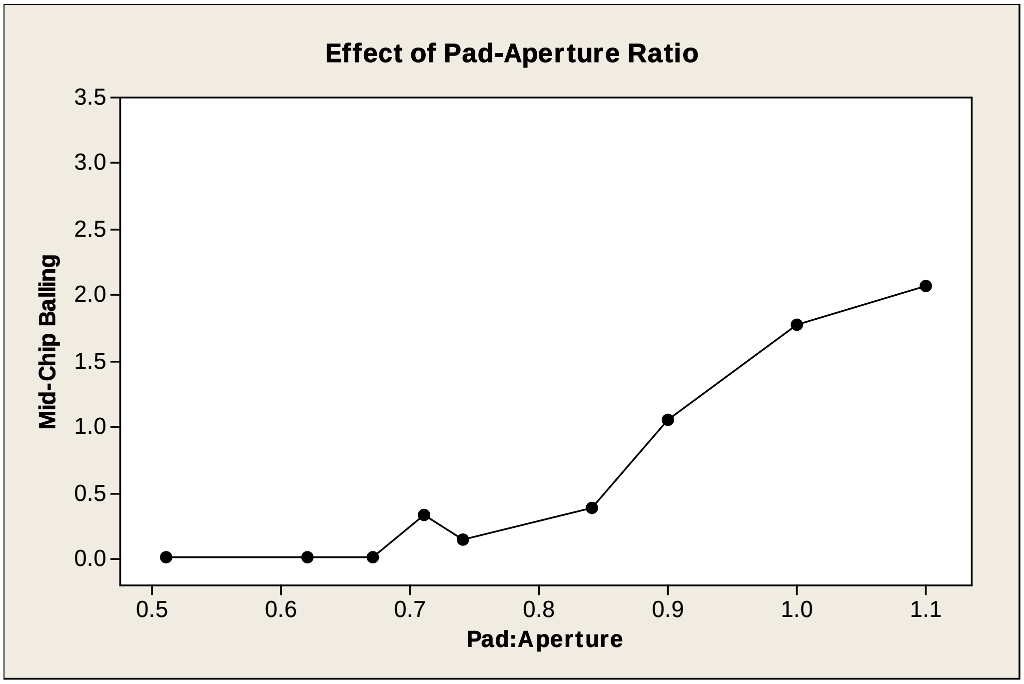


Figure 3 – Effect of Pad to Aperture Ratio on 1206 Pads

Pad to Aperture Ratio

Figure 3 clearly validated the relationship between the amount of paste deposited onto the pad and the number of mid-chip balls. Physically removing the paste from the pad reduced the amount of solder available to flow under the component during reflow. Minimal mid-chip balling was observed when less than 70% of the pad area was printed. It should be noted that the paste did fully wet to the components in all cases and there was no indication that the joint was insufficient.

Stencil Thickness

Stencil thickness had a considerable impact on mid-chip balling, as can be seen in Figure 4. A 100 µm stencil resulted in fewer mid-chip balls than a 125 µm stencil due to the reduction in paste volume, although with less than 70% paste volume, both stencils had little to no mid-chip balling.

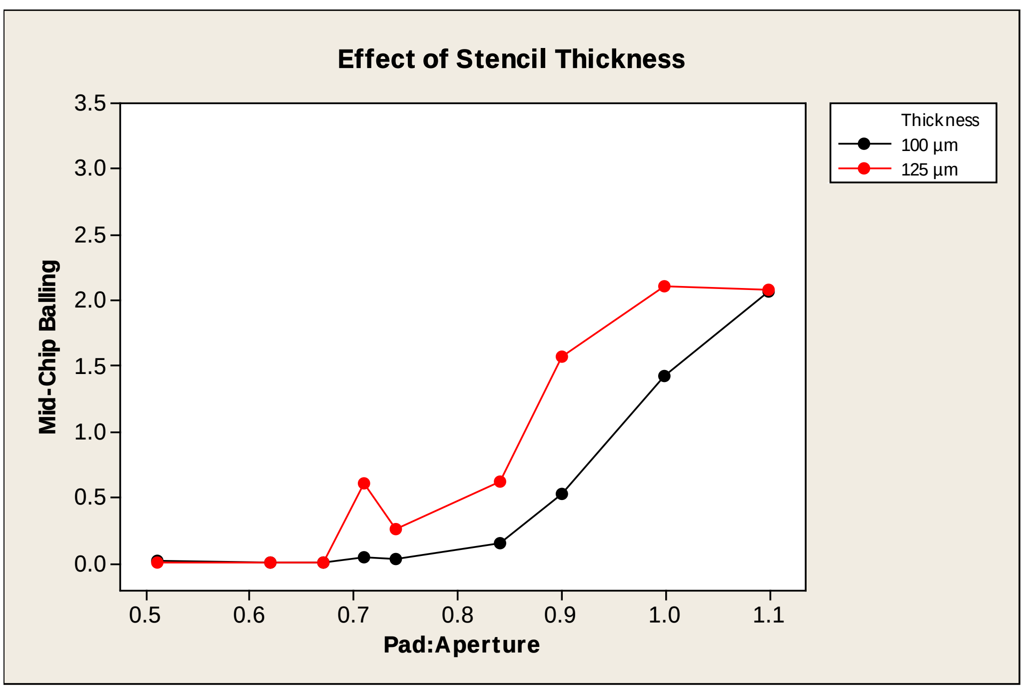


Figure 4 - Effect of Stencil Thickness on 1206 Pads

A printed deposit of 110% (equivalent to a 50 µm overprint on a 1206 pad) resulted in less differentiation between the two stencils; the results from the 100 µm stencil continued to follow the increasing trend, whereas the mid-chip balling counts for the 125 µm stencil were similar to those given by the 1.0 pad to aperture ratio. Irrespective of stencil thickness, if paste is printed onto the resist it is likely that paste will remain there after reflow. Therefore, controlling the printing process is essential to preventing mid-chip balling.

Aperture Shape and Pad Coverage

Mid-chip balling could be notably reduced by changing the shape of the aperture and the effect is summarised in Figure 5. Square apertures where the paste was deposited centrally on the pad resulted in higher numbers of mid-chip balls. The homeplate design, rectangles and triangles did have an improvement over the squares due to the paste being removed from under the component.

The position of the paste deposit compared to the component is vital – removing paste from underneath the component will be considerably more beneficial than removing it from the side of the pad away from the component. Removing paste from the wrong area will reduce the volume but not necessarily reduce the potential for mid-chip balling.

Ensuring that the paste is positioned on the pad in such a way as to allow minimal slump under the component means that a good volume of paste can be printed but with very few mid-chip balls as a consequence. This is clearly highlighted in Figure 6, where 84% theoretical paste volume resulted in a relatively high number of mid-chip balls when printed through a standard homeplate shaped aperture, but the same volume of paste printed using a rectangle off-set to the side of the pad had virtually no mid-chip balls. Figure 7 shows the absolute volume data calculated from all of the PCBs measured during testing.

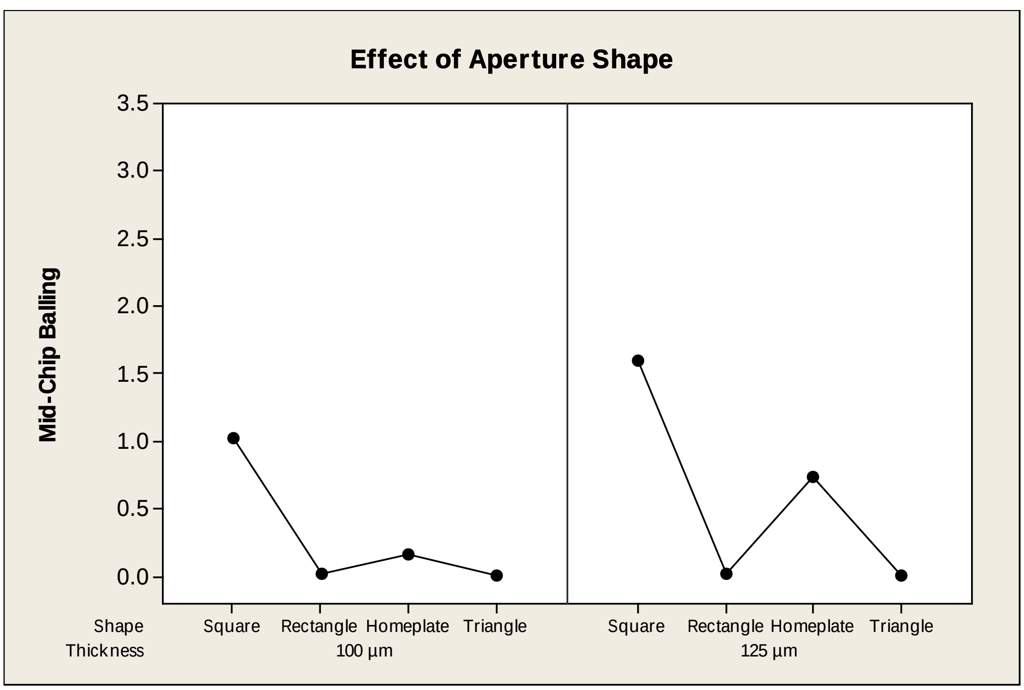


Figure 5 - Effect of Aperture Shape on 1206 Pads

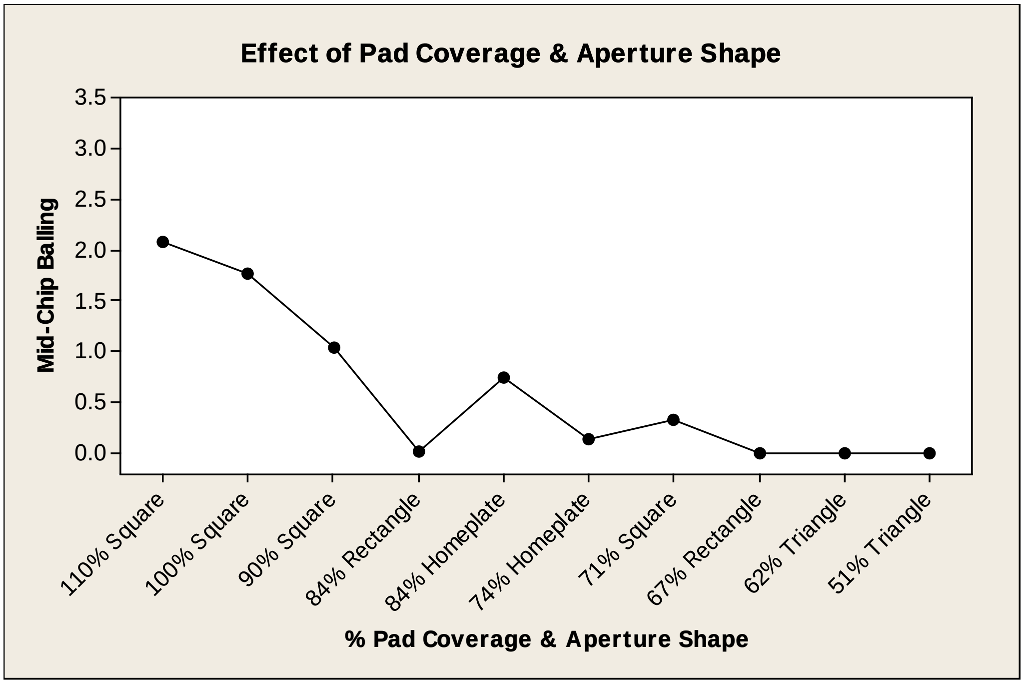


Figure 6 - Effect of Pad Coverage & Aperture Shape on 1206 Pads

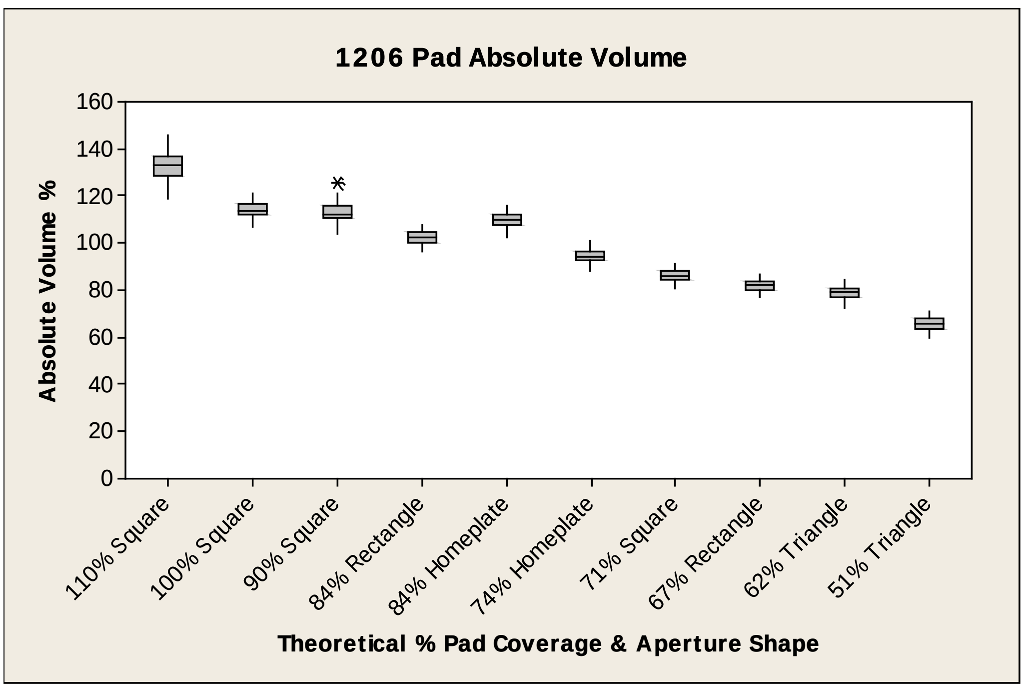


Figure 7 – Absolute Volumes on 1206 Pads

Method - Effect of Flux Chemistry on Mid-Chip Balling
PCBs were printed using an industry standard printer and a 125 µm stencil. The paste deposit volumes were measured before resistor components were placed. A visual inspection was carried out to ensure central placement before the boards were reflowed through an industry standard oven. A short cool linear profile and a long hot soak profile were used (Figure 8) under both air and nitrogen (1000 ppm O_2).

The total number of mid-chip balls on 1206 component pads were counted independently by two individuals to ensure the reliability of the results. The apertures in Table 1 were used and for each aperture geometry, the average number of mid-chip balls was calculated per component.

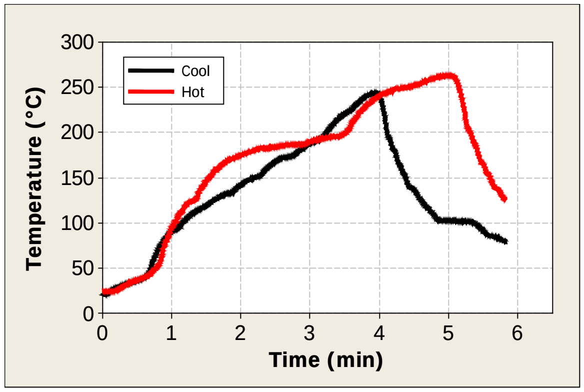


Figure 8 – Reflow Profiles for Effect of Flux Chemistry Testing

This method was designed to demonstrate the worst case scenario based on the results from the effect of process testing.

Results - Effect of Flux Chemistry

The pastes represented a range of halogen-containing (HC) fluxes and halogen-free (HF) fluxes. Each paste used the alloy and powder particle size distribution for which it was designed (Table 2).

Table 2 – Paste Details

Flux	Alloy	Particle Size Distribution
HC1	SAC305	IPC Type 3 equivalent
HC2		
HC3		
HF1	SAC305	IPC Type 4 equivalent
HF2		
HF3		
HF4		
HF5		
HF6		

Flux

Flux chemistry had a significant impact on mid-chip balling and considerable variation can be observed (Figure 9). The three HC fluxes had practically no mid-chip balling, a trend that was observed throughout the testing and is investigated further in the study. Some of the HF fluxes represented minor changes in formulation, whereas others had few materials in common. No correlation between HF flux technology and the level of mid-chip balling was observed. The results, therefore, indicate that using flux to minimise mid-chip balling is not necessarily a simple solution.

When compared against each other, the fluxes tended to follow a similar pattern under each condition; the data for Figure 9 was simplified by combining the results from all of the conditions tested for each aperture geometry.

Reflow Profile

The effect of using different reflow profiles on mid-chip balling can be seen in Figure 10. The short cool linear profile considerably reduced the number of mid-chip balls when compared to the long hot soak profile. It is a common industry practice to suggest a change of profile from a soak to a linear when trying to reduce mid-chip balling, as it is understood that the soak portion of a profile has a detrimental impact on the slump resistance of a paste, thus increasing the quantity of mid-chip balls. This data is the combined results from all the different fluxes and aperture geometries.

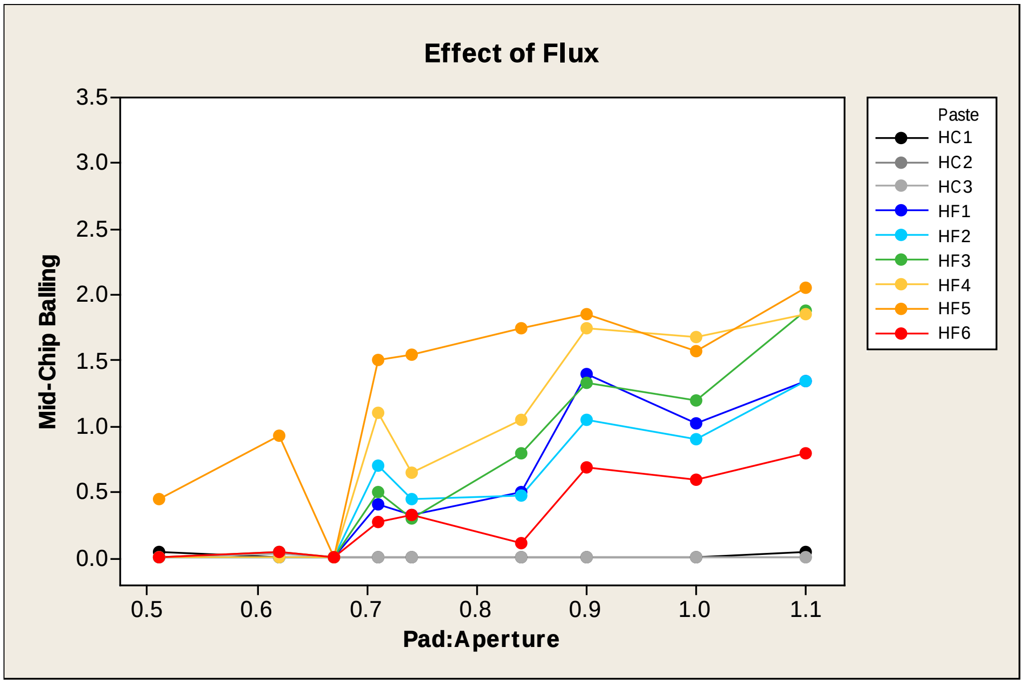


Figure 9 – Effect of Flux on 1206 Pads

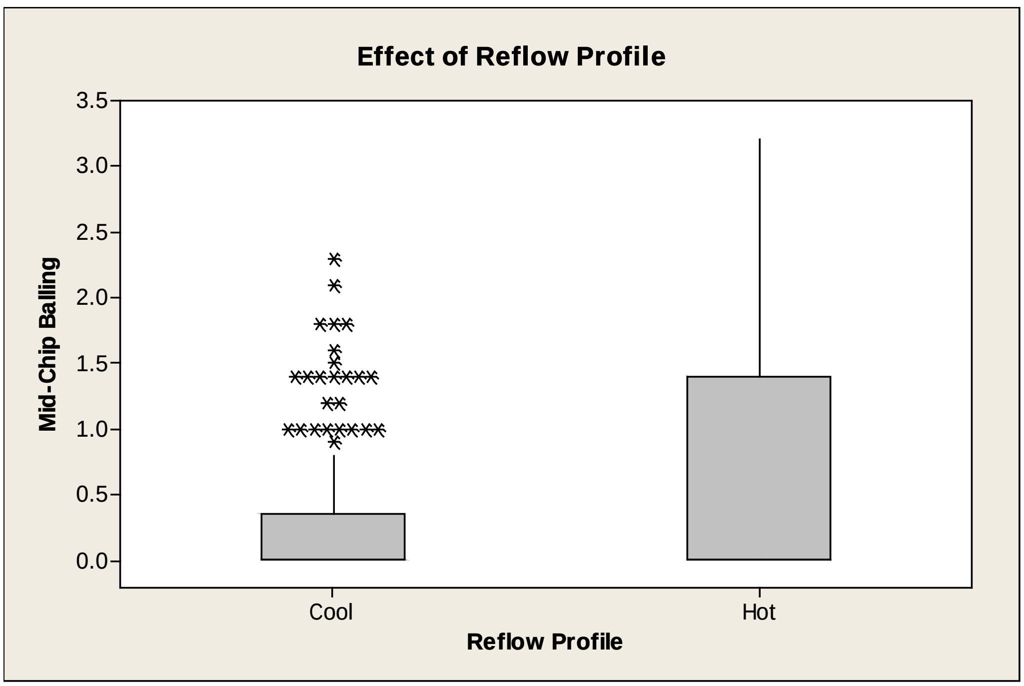


Figure 10 – Effect of Reflow Profile on 1206 Pads

In Figure 11, the results have been divided by the different fluxes and, in all cases, the hot profile had the higher number of mid-chip balls, with all of the HF fluxes showing at least a 50% increase in mid-chip balling when compared to the cool profile.

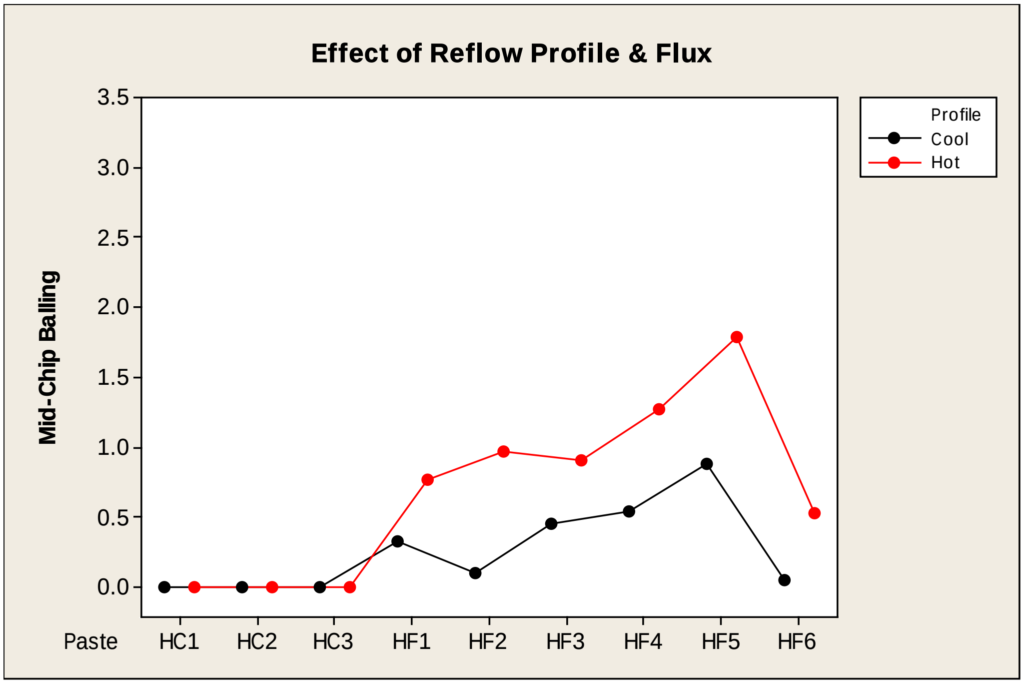


Figure 11 – Effect of Reflow Profile & Flux on 1206 Pads

Reflow Atmosphere

Changing the reflow atmosphere from air to nitrogen (Figure 12) did have a small effect on the number of mid-chip balls, potentially due to the improvement in wetting observed with nitrogen reflow. This is the combined data from all of the different aperture geometries.

The results have been divided by the different fluxes in Figure 13, where it is apparent that reflow atmosphere had no effect on the HC fluxes. The difference in mid-chip balling between air and nitrogen reflow with the HF fluxes was significantly smaller than that observed with different reflow profiles; an average reduction of 25% was achieved with nitrogen.

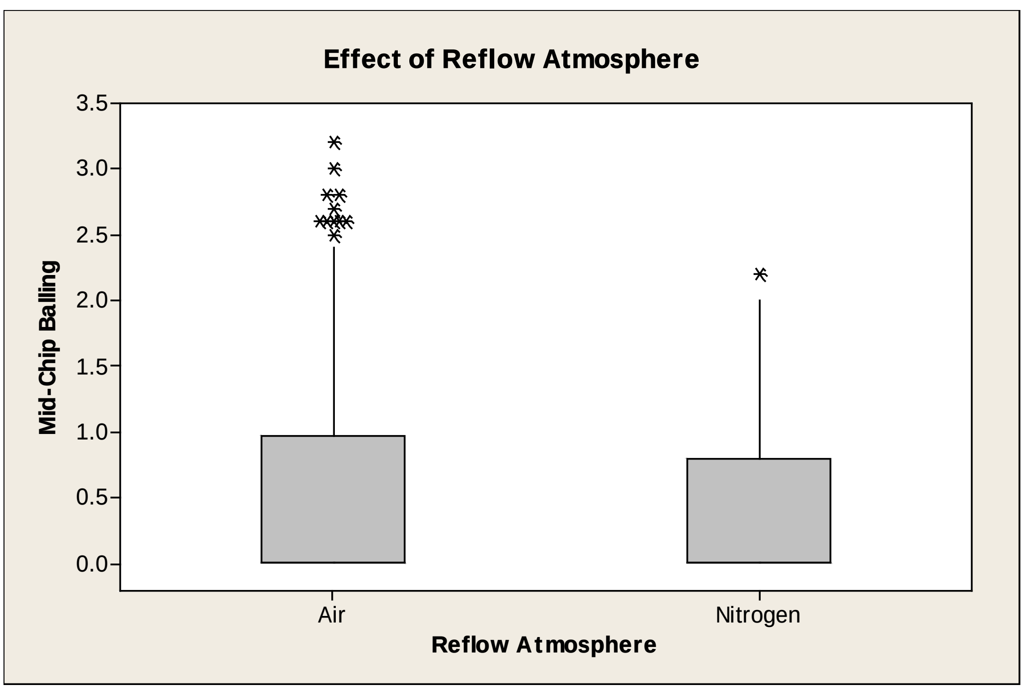


Figure 12 – Effect of Reflow Atmosphere on 1206 Pads

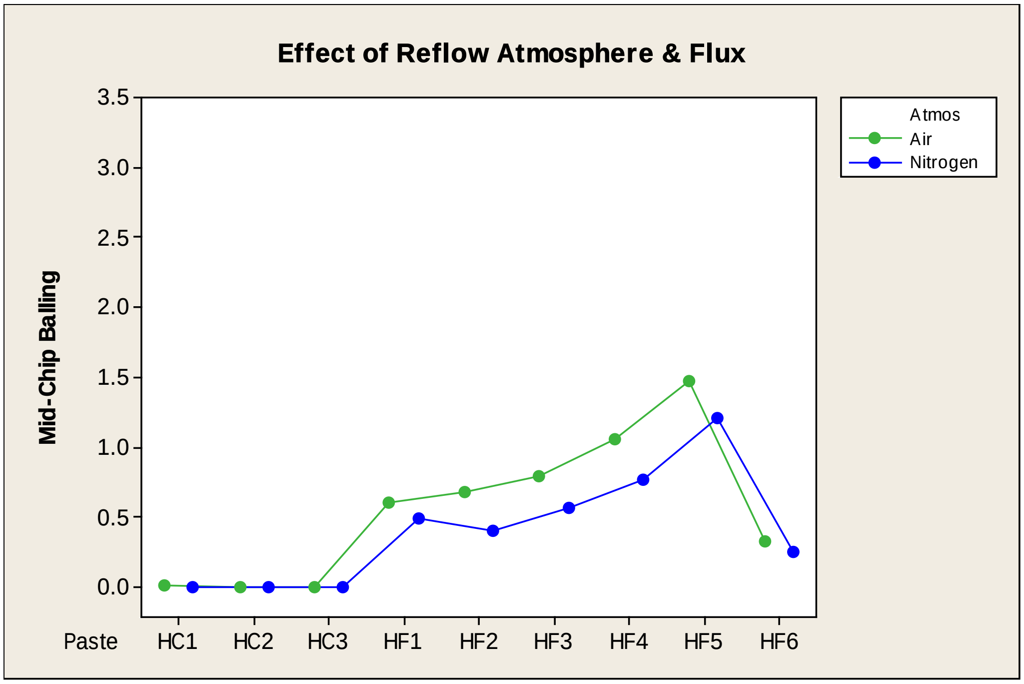


Figure 13 – Effect of Reflow Atmosphere & Flux on 1206 Pads

Reflow Profile and Atmosphere
Combining the results from the previous two sections in Figure 14 indicated that a hot soak profile in air produced the largest number of mid-chip balls, which could be reduced by reflowing in nitrogen. When using a cool linear profile, the mid-chip balling was substantially reduced and was less affected by the reflow atmosphere.

Figure 15 shows the impact each reflow profile and atmosphere had on the individual fluxes. No mid-chip balling was observed on the HC fluxes. With the HF fluxes, the mid-chip balling on the cool profile was unaffected by the reflow atmosphere, with both air and nitrogen giving very similar results. A clear improvement in mid-chip balling (over 25% reduction in all cases) was seen using a nitrogen atmosphere with the hot profile, most likely due to the increased wetting potential overcoming the effect of slump.

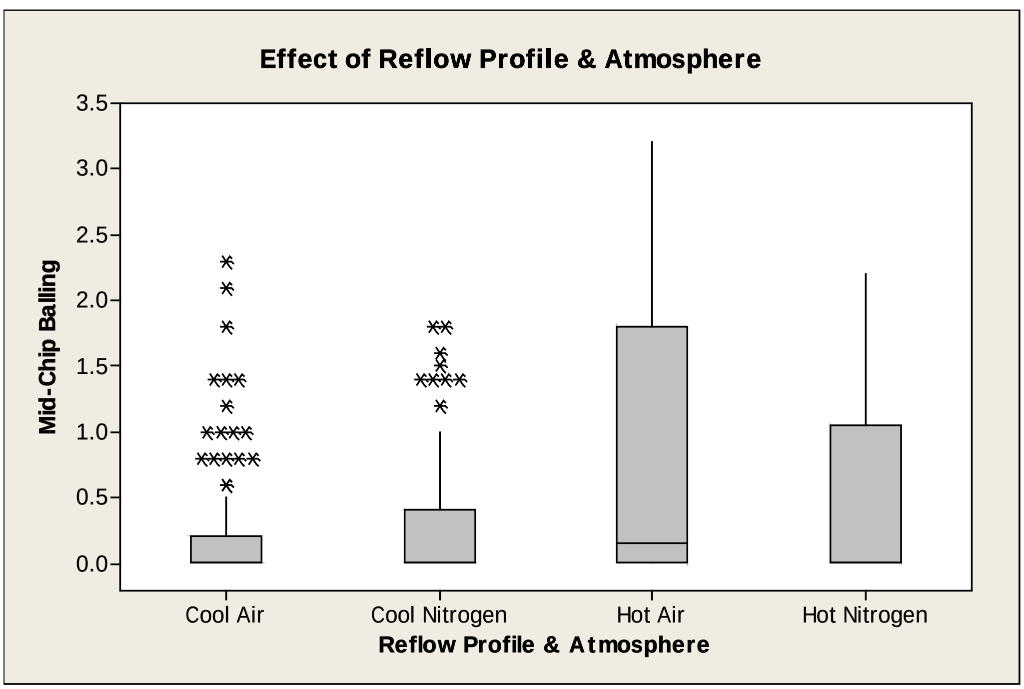


Figure 14 – Effect of Reflow Profile & Atmosphere on 1206 Pads

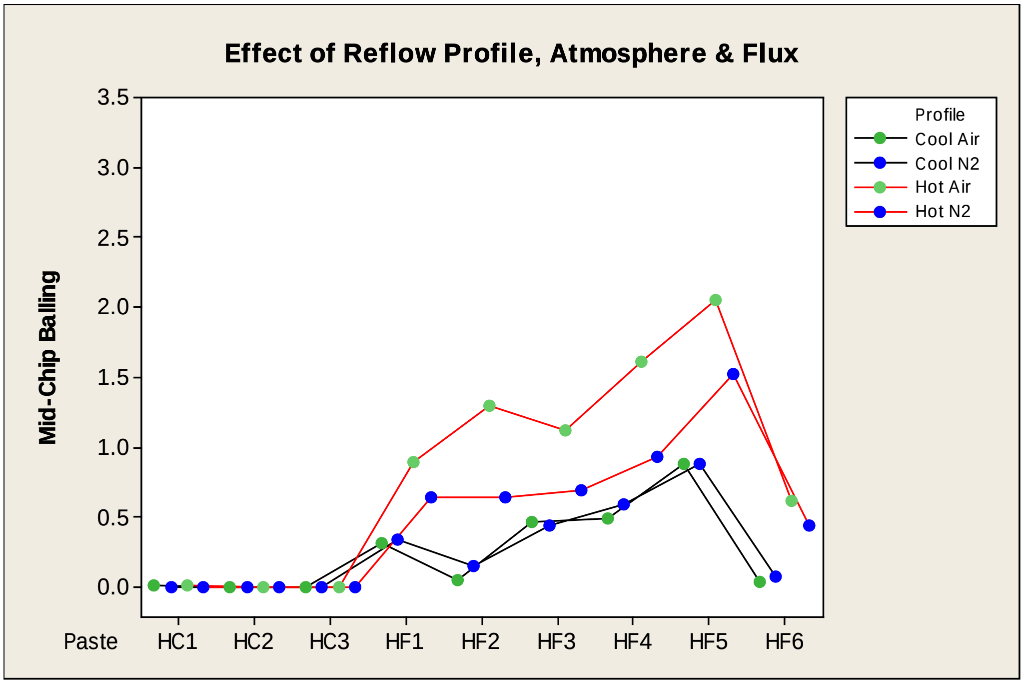


Figure 15 – Effect of Reflow Profile, Atmosphere & Flux on 1206 Pads

In the previous graphs, it is clear that the HC fluxes resulted in significantly reduced numbers of mid-chip balls when compared to the HF fluxes. These HC pastes were also made using Type 3 powder, compared to Type 4 for the HF pastes. In order to understand whether the presence of halogen and/or particle size distribution were real factors affecting mid-chip balling, extra pastes were produced to provide direct comparisons. All particle size distributions referenced are the equivalent of the IPC powder type.

Particle Size Distribution

To examine whether the particle size distribution (PSD) was the cause of the low mid-chip balling results in the HC fluxes, a selection of HC and HF fluxes were produced in both Type 3 and Type 4 powders.

The results in Figure 16 suggest that PSD was not a factor affecting mid-chip balling. The alternative powder type did not affect the printed deposit volume and the paste hot slump. It should be noted that these results are based on limited data and other fluxes may perform differently.

Halogen

The HC3 flux was modified to remove the halogen components (HC3HF). Figure 17 indicates that some mid-chip balling occurred with HC3HF as the pad to aperture ratio increased, but this was still low when compared to a standard HF flux. This suggested that the presence of the halogen did repress the mid-chip balling; however, these results are based on limited data. Further work would be required to understand whether this effect is true for all halogen containing pastes or if it is specific to the HC3 formulation.

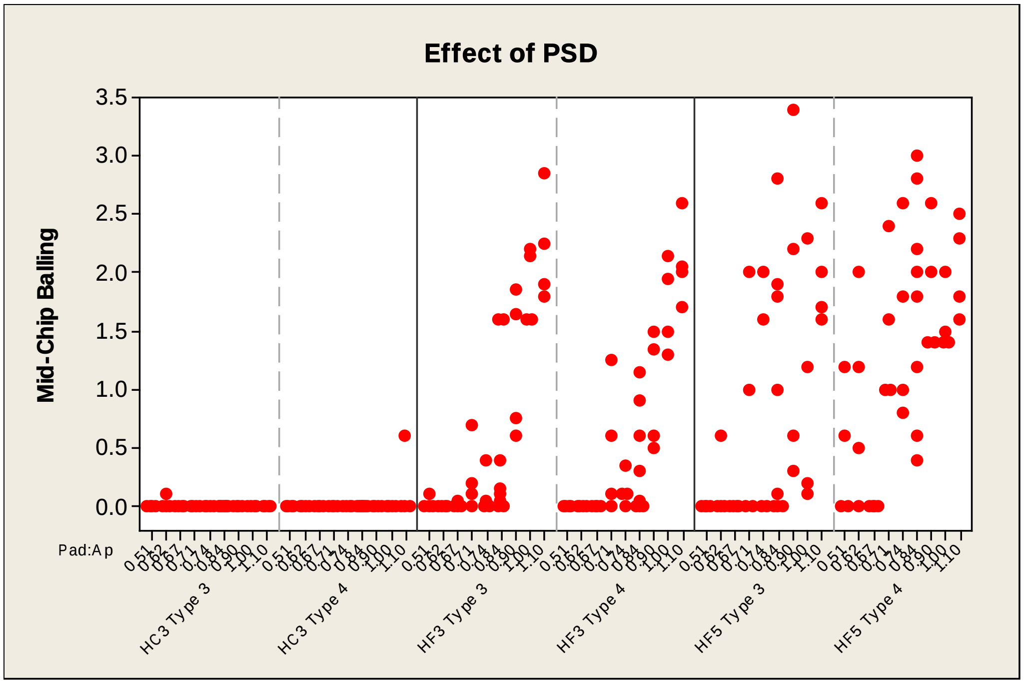


Figure 16 – Effect of PSD on 1206 Pads

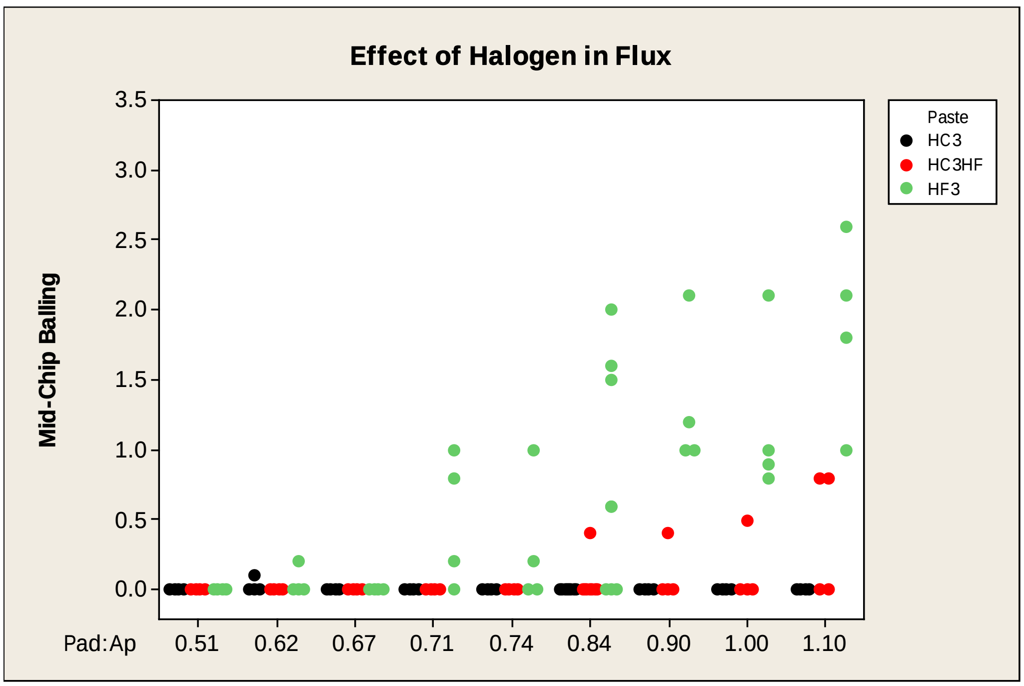


Figure 17 – Effect of Halogen in Flux on 1206 Pads

Slump

The data in Figure 18 confirmed that, in general, increased hot slump resistance did produce less mid-chip balling. The slump figures are the first spacing not bridged on 0.33 x 2.03 mm pads after 10 min at 150°C using an IPC-A-21 test stencil [2]. The mid-chip balling number represented the average quantity of balls for all pastes with the same slump result, regardless of reflow profile and/or atmosphere. Reflow conditions did not affect the relationship between slump and mid-chip balling.

The slump resistance of a flux did have an impact on the number of mid-chip balls. It is not necessarily the primary contributing factor as the flux type appeared to be more influential (Figure 19). Fluxes with low slump results still had high mid-chip ball counts on certain aperture designs, whereas high slumping fluxes could have no mid-chip balling providing the process was correct.

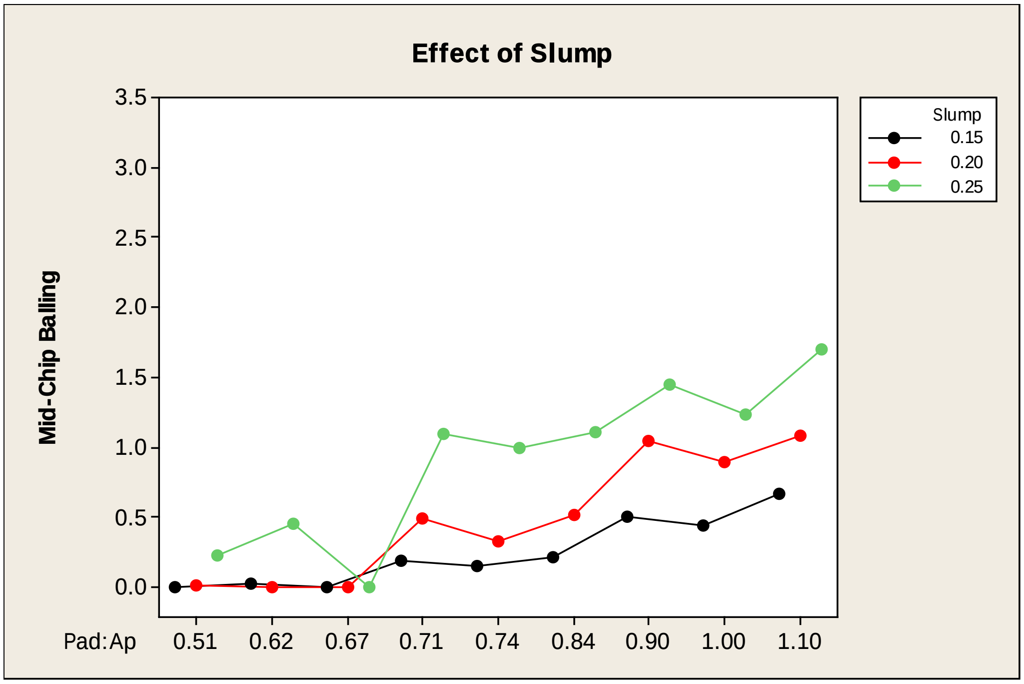


Figure 18 – Effect of Slump on 1206 Pads

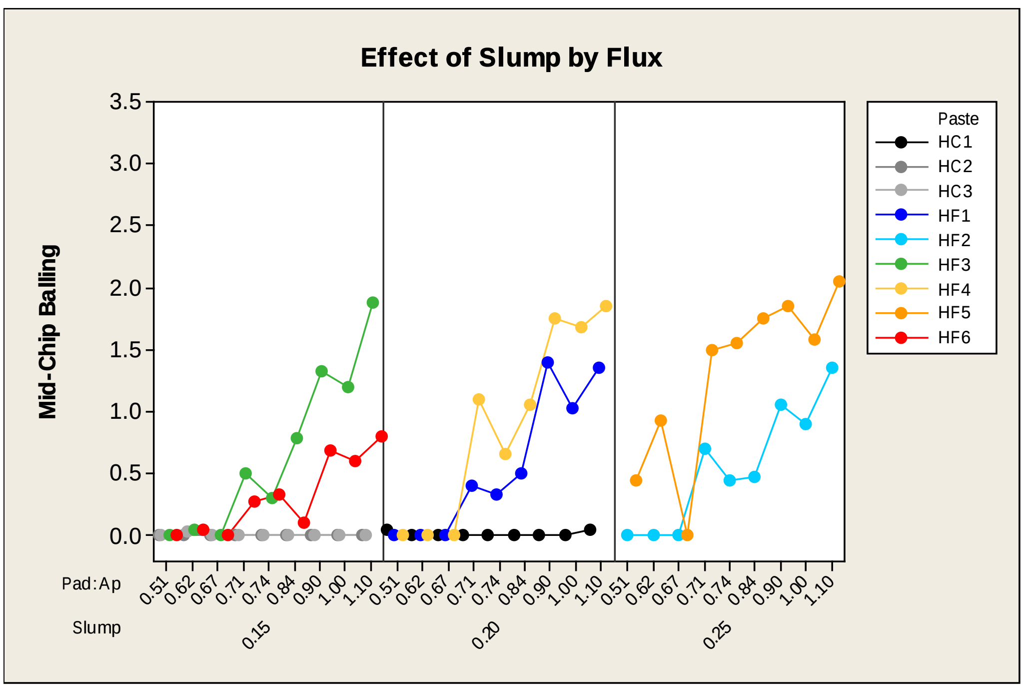


Figure 19 – Effect of Slump by Flux on 1206 Pads

Conclusions

Mid-chip balling can most effectively be reduced by implementing the following process changes:

- Changing aperture shape
- Reducing stencil thickness
- Changing to a cooler reflow profile
- Reflow in nitrogen if a hotter profile is required

The flux chemistry can also have an impact on the mid-chip balling, however:

- There is considerable variation between different fluxes
- Halogen appears to eliminate mid-chip balling
- It is possible to get zero mid-chip balls with halogen-free when the process is right
- Hot slump has only a minor impact on mid-chip balling when the process is right
- Further work is required to identify potential contributors to mid-chip balling

References

1. IPC-A-610E, Acceptability of Electronic Assemblies (2010)
2. IPC-TM-650, Solder Paste – Slump Test, 2.4.35

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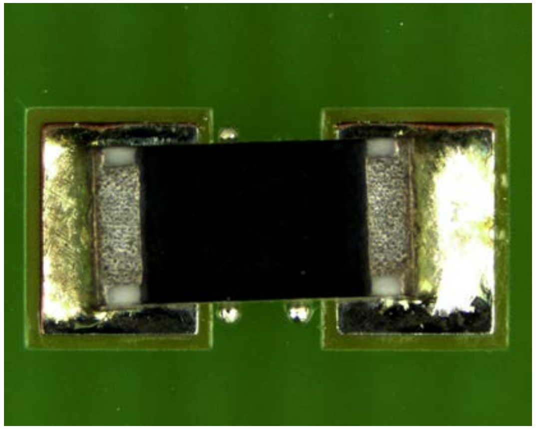
Background

Mid-Chip Balling

- Caused by solder flowing under the component
  - Poor hot slump resistance
  - Insufficient wetting

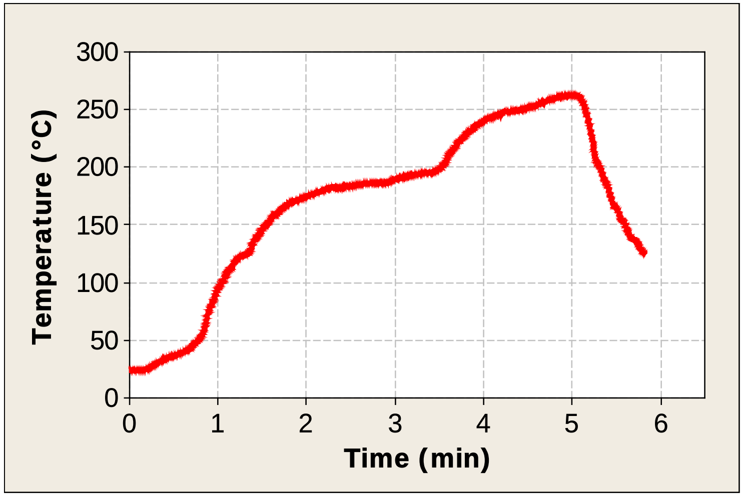


- Solder forced to the side when component drops during reflow

Effect of Process

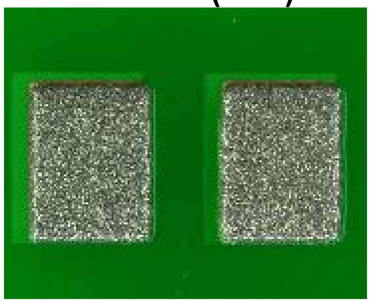
Effect of Process

- Same paste used throughout
  - Standard halogen-free; SAC305; Type 4
- Two stencils
  - Stainless steel, laser cut
  - 100 µm (4 thou)
  - 125 µm (5 thou)
- Multiple aperture designs
- Hot soak reflow in air
- Total number of mid-chip balls counted

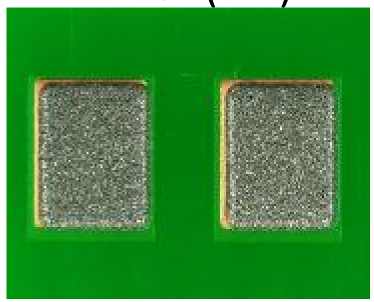


Aperture Shape & Coverage

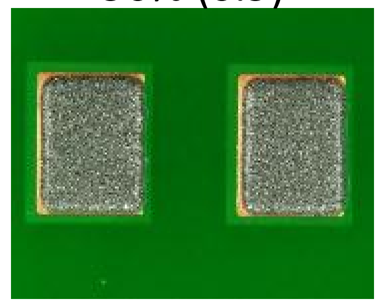
110% (1.1)



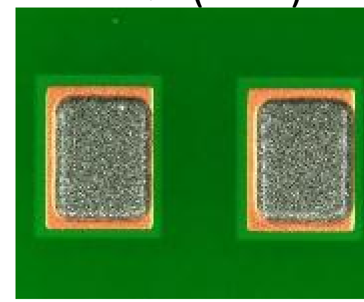
100% (1.0)



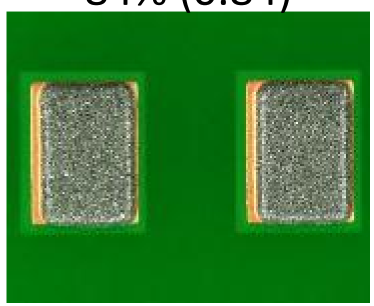
90% (0.9)



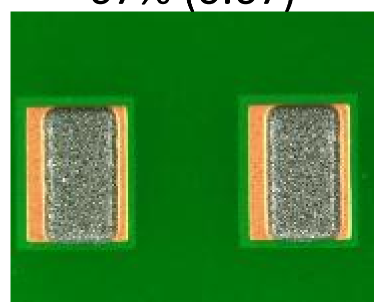
71% (0.71)



84% (0.84)



67% (0.67)



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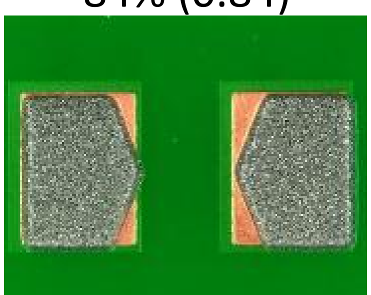
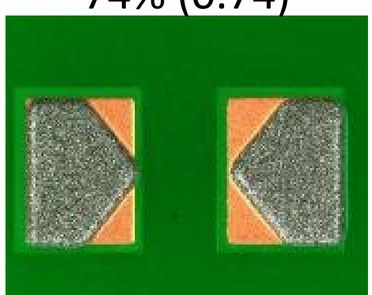
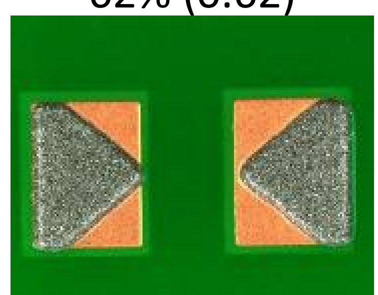


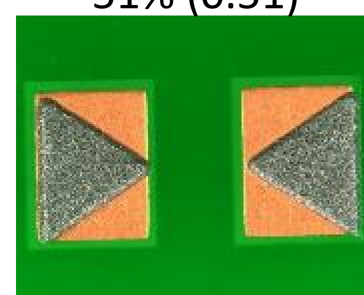
74% (0.74)



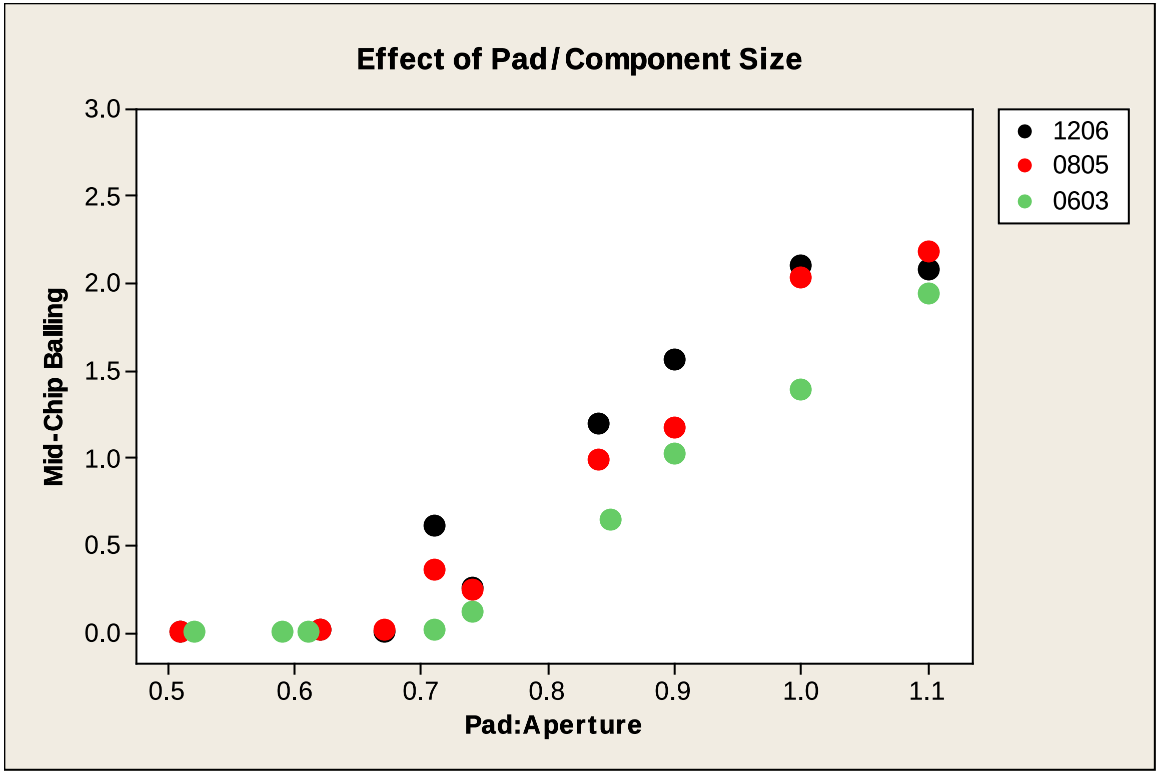
62% (0.62)



51% (0.51)

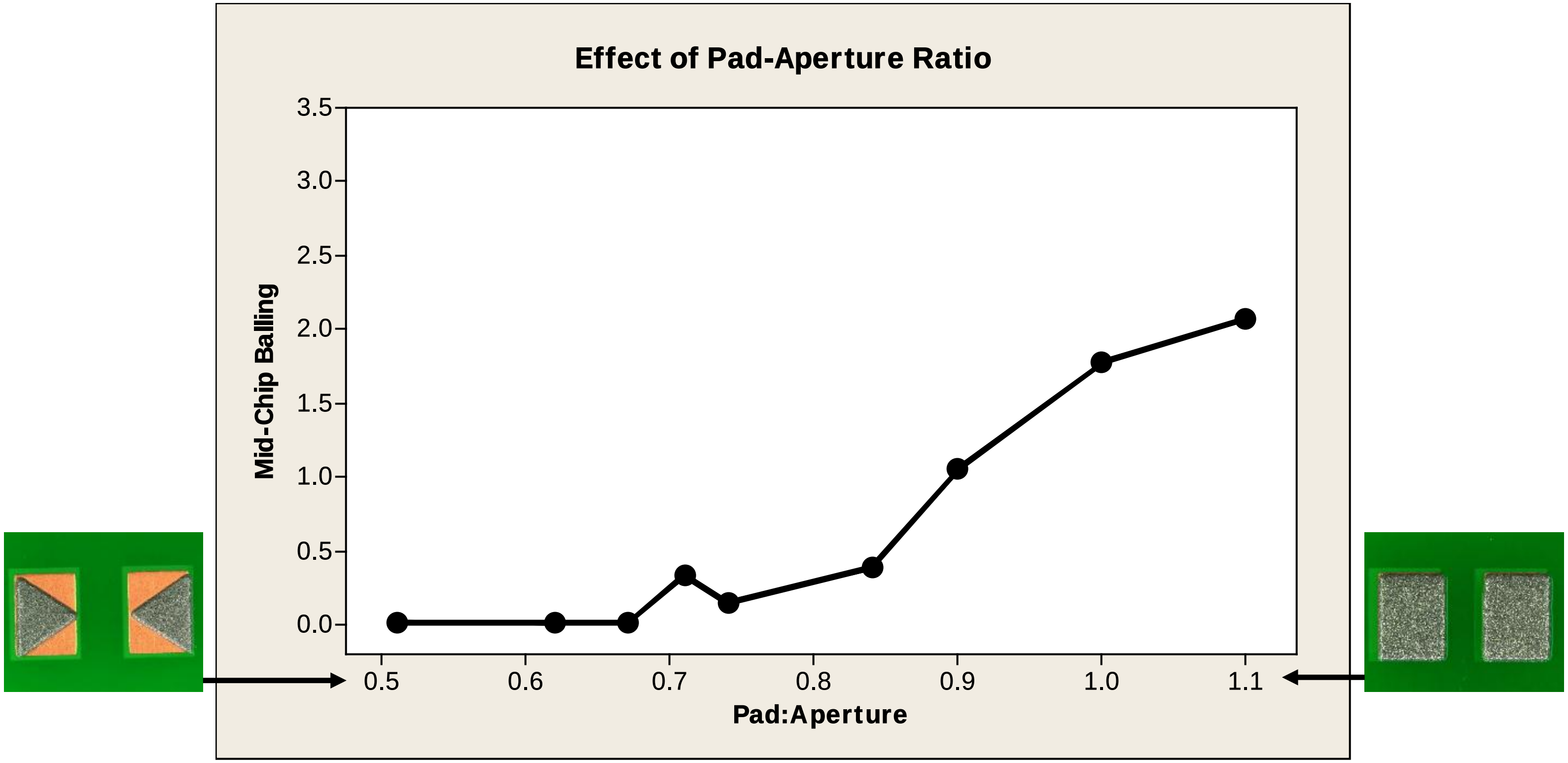


Pad & Component Size



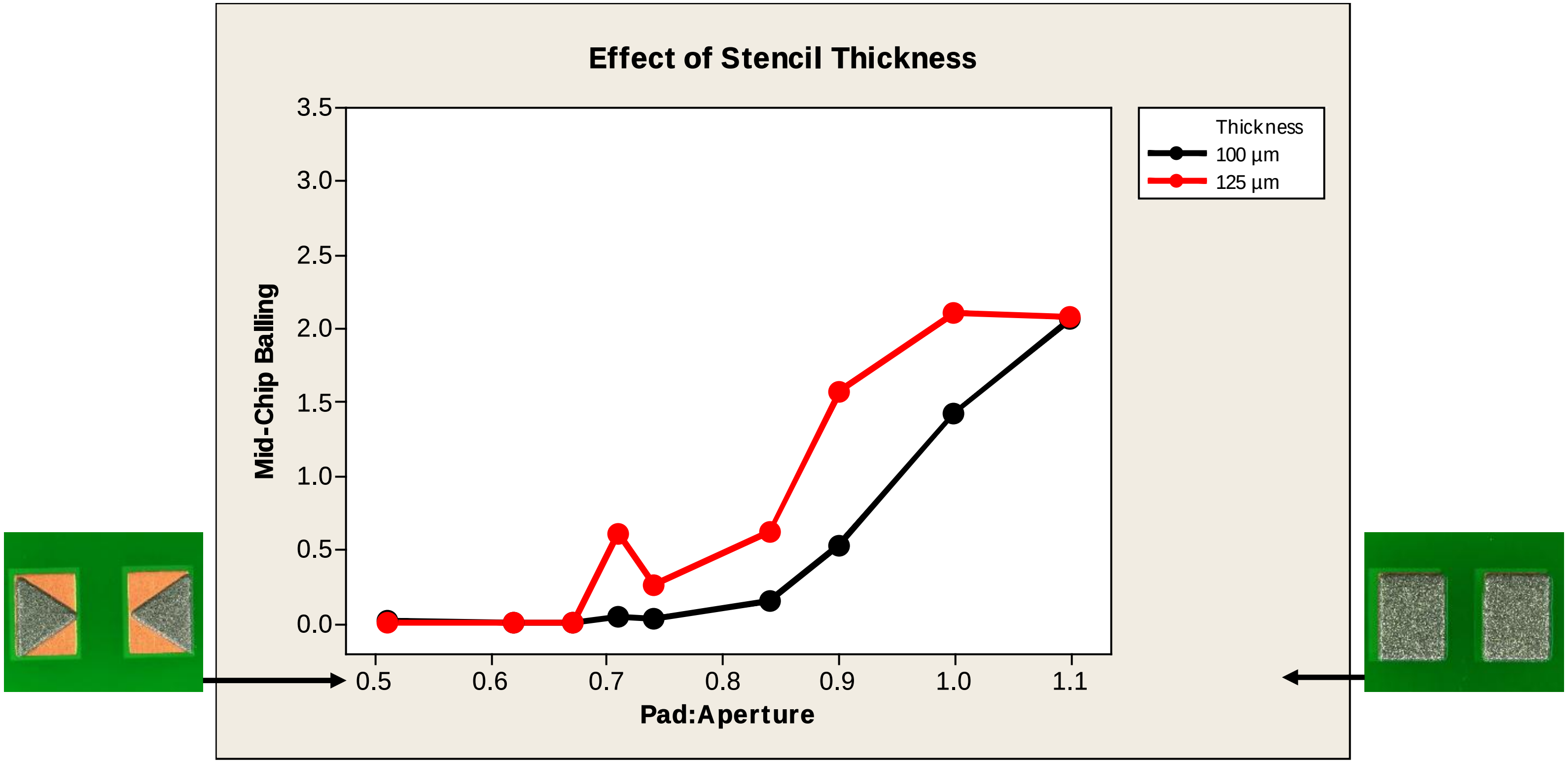
- Mid-chip balling decreases with smaller components
- Same trends observed throughout

Pad to Aperture Ratio



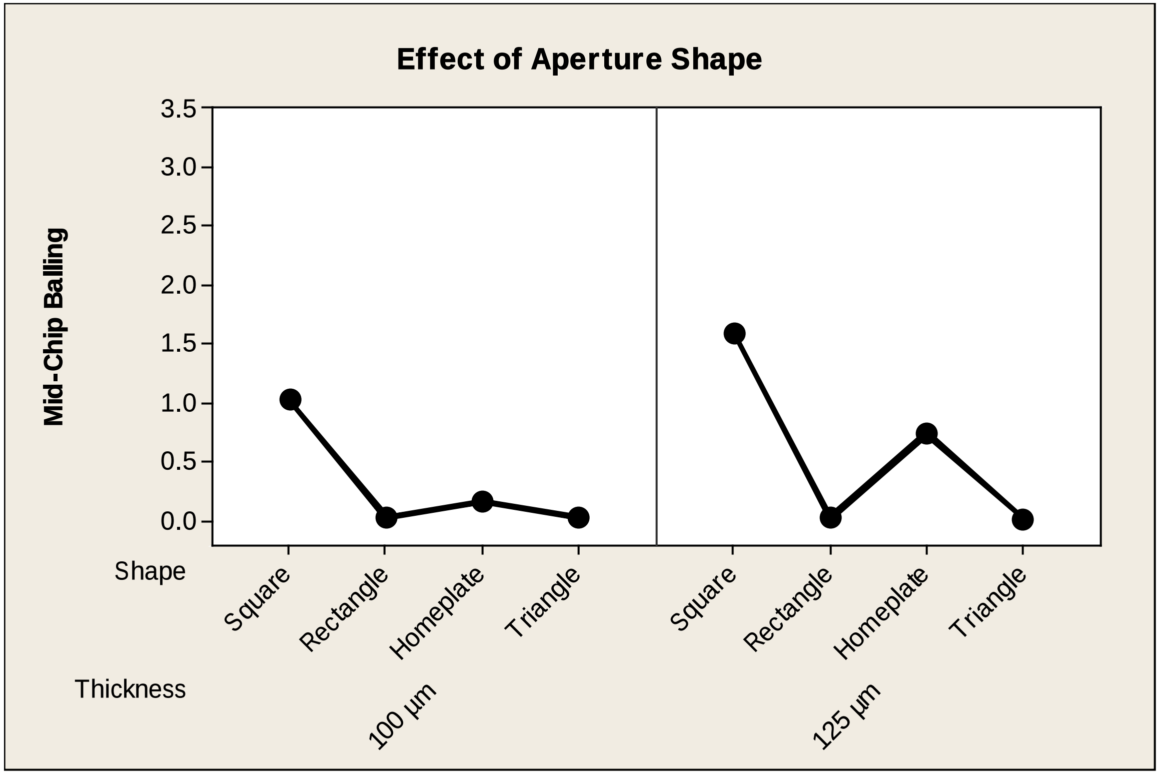
- Mid-chip balling increases when more paste is printed

Stencil Thickness



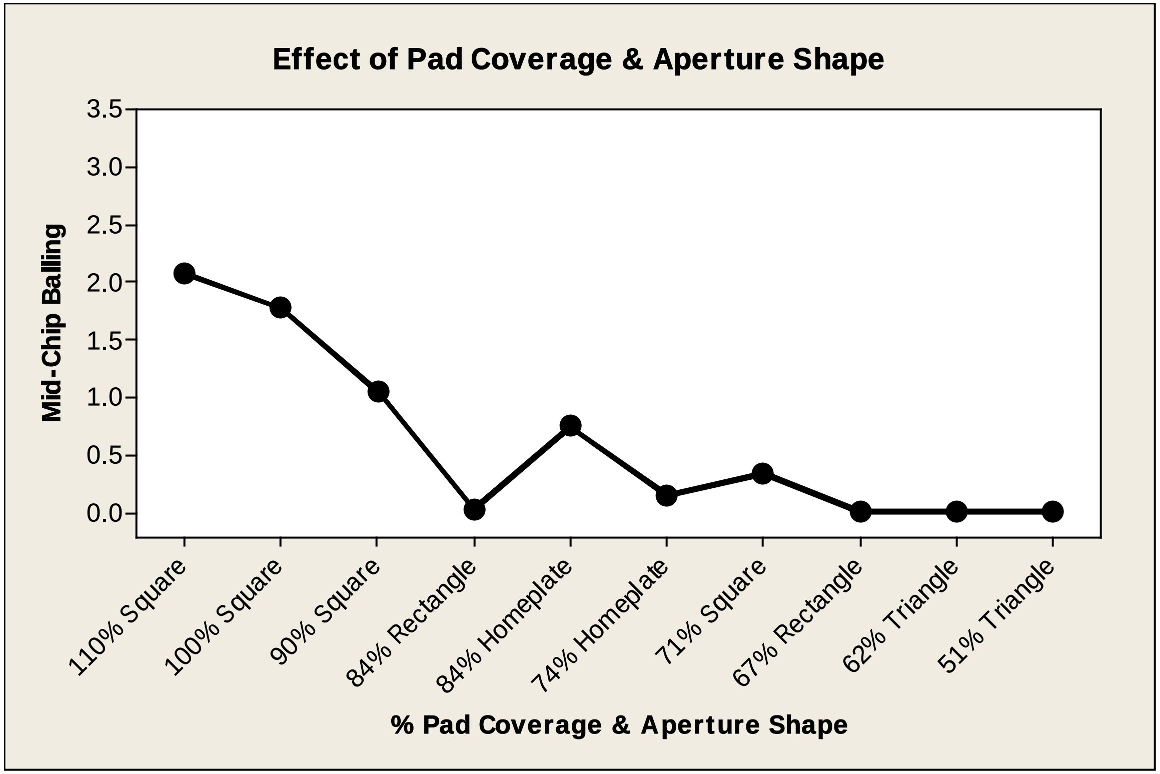
- Mid-chip balling increases when more paste is printed
- Mid-chip balling increases with increased stencil thickness

Aperture Shape



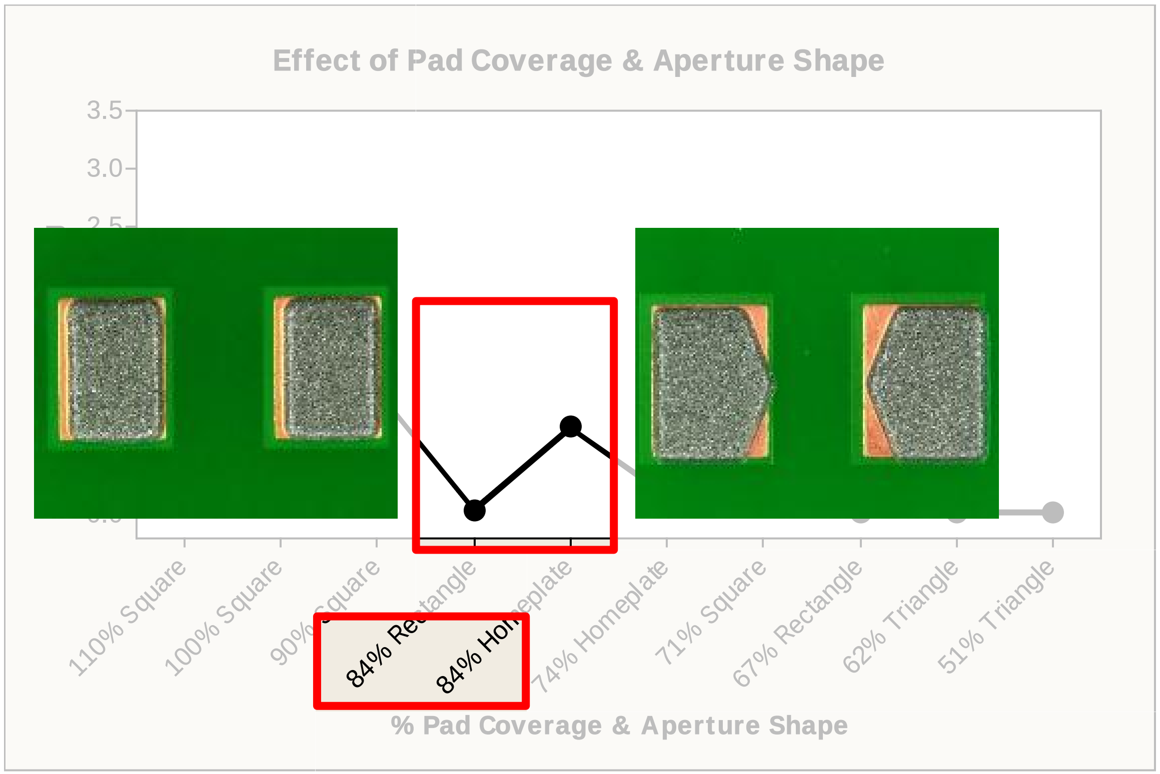
- Aperture shape has a significant impact on mid-chip balling

Pad Coverage & Aperture Shape



- Position of paste deposit on pad is more significant than amount of paste

Pad Coverage & Aperture Shape



- Position of paste deposit on pad is more significant than amount of paste

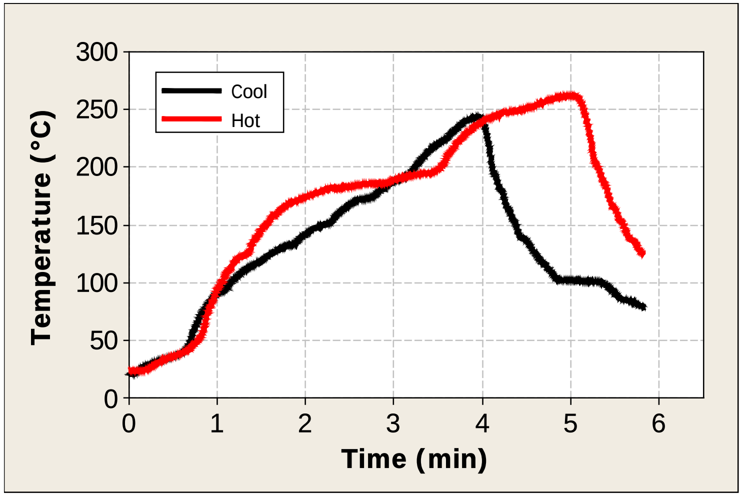
Effect of Flux Chemistry

Flux Details

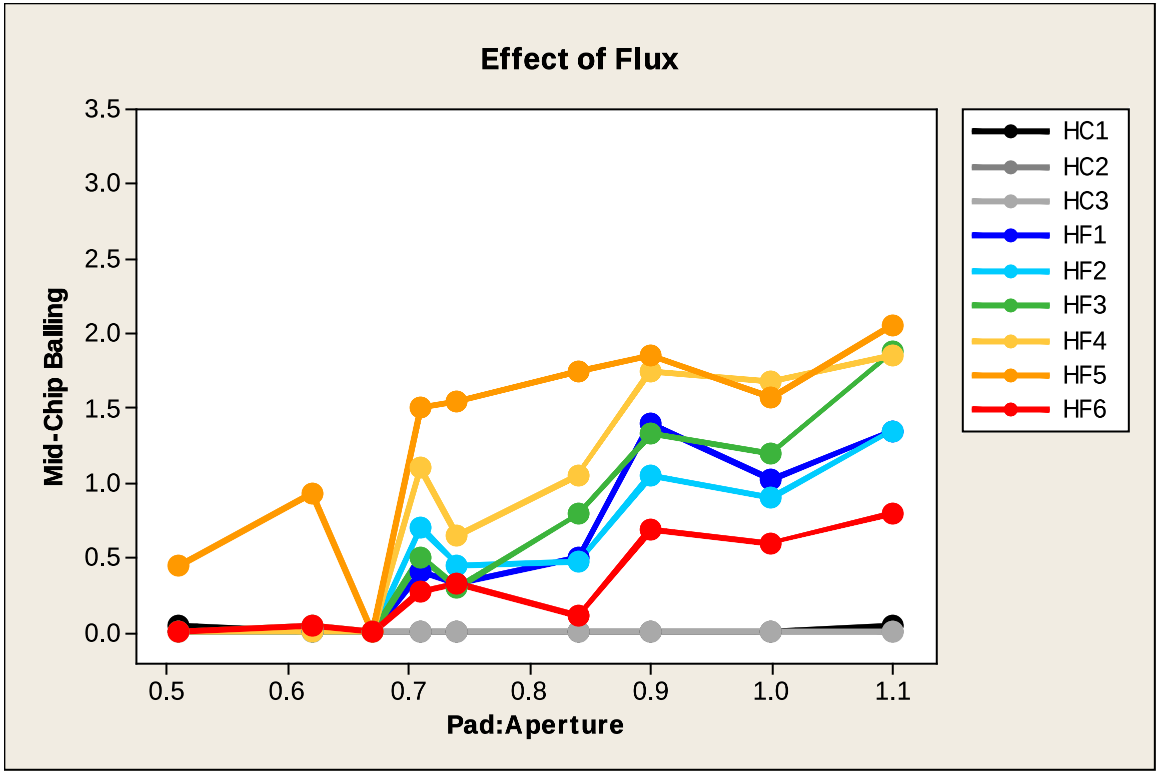
Paste	Flux	Alloy	Particle Size Distribution
HC1	Halogen-containing; Halide-free	SAC305	IPC Type 3 Equivalent
HC2			
HC3			
HF1	Halogen-free	SAC305	IPC Type 4 Equivalent
HF2			
HF3			
HF4			
HF5			
HF6			

Effect of Flux Chemistry

- 125 µm (5 thou) stencil
  - Stainless steel, laser cut
- Multiple aperture designs
- Reflow
  - Cool linear
  - Hot soak
  - Air & Nitrogen (1000 ppm O_2)
- Total number of mid-chip balls counted

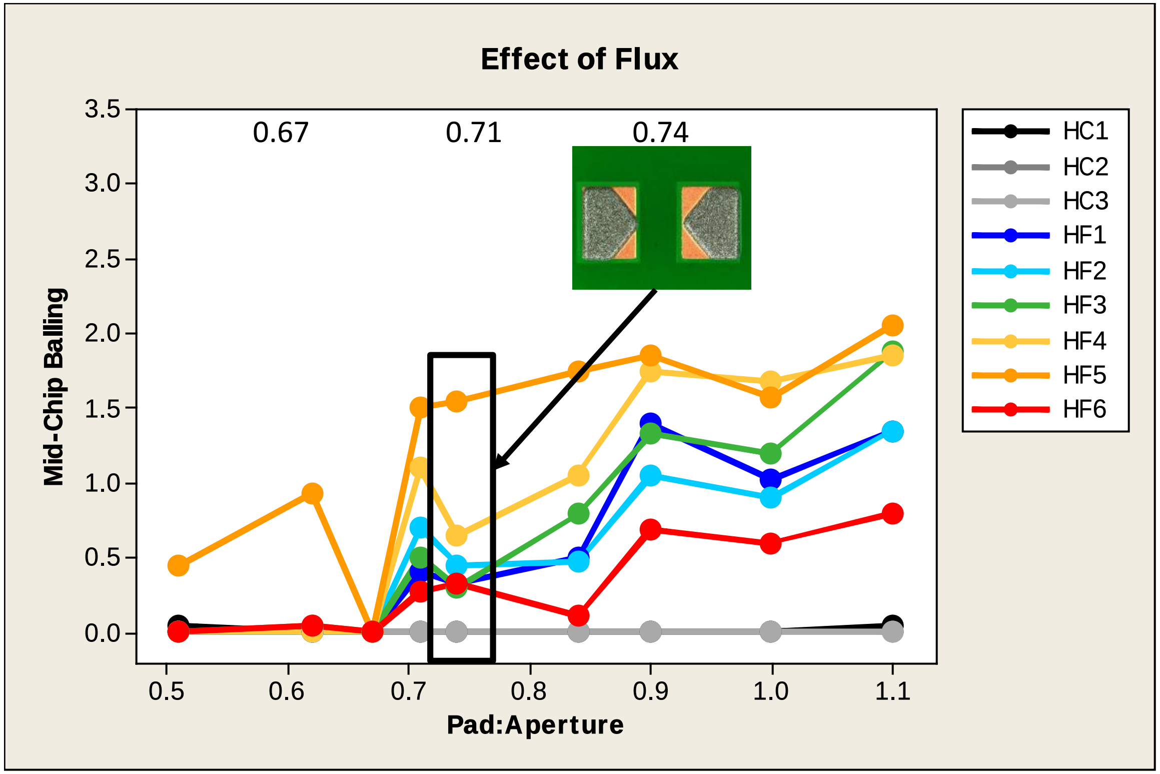


Effect of Flux



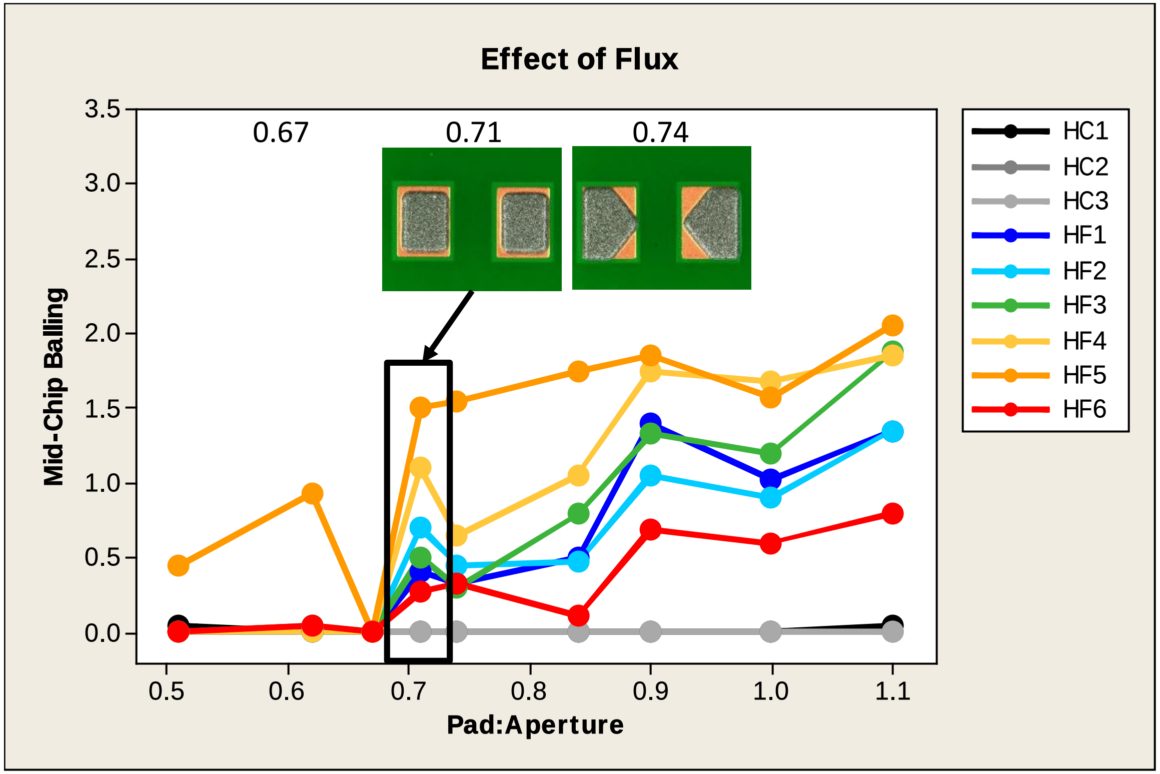
- Flux can have a significant effect on mid-chip balling
- Not a simple solution

Effect of Flux



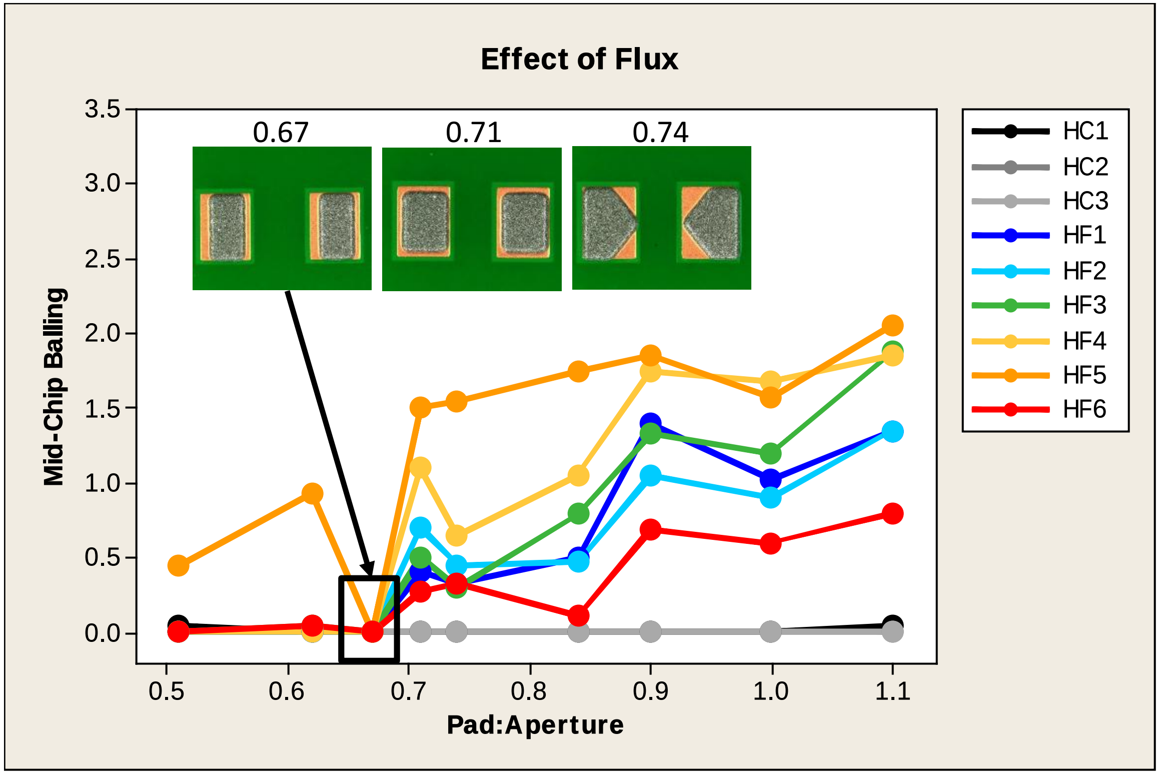
- Aperture shape can override the effect of flux

Effect of Flux



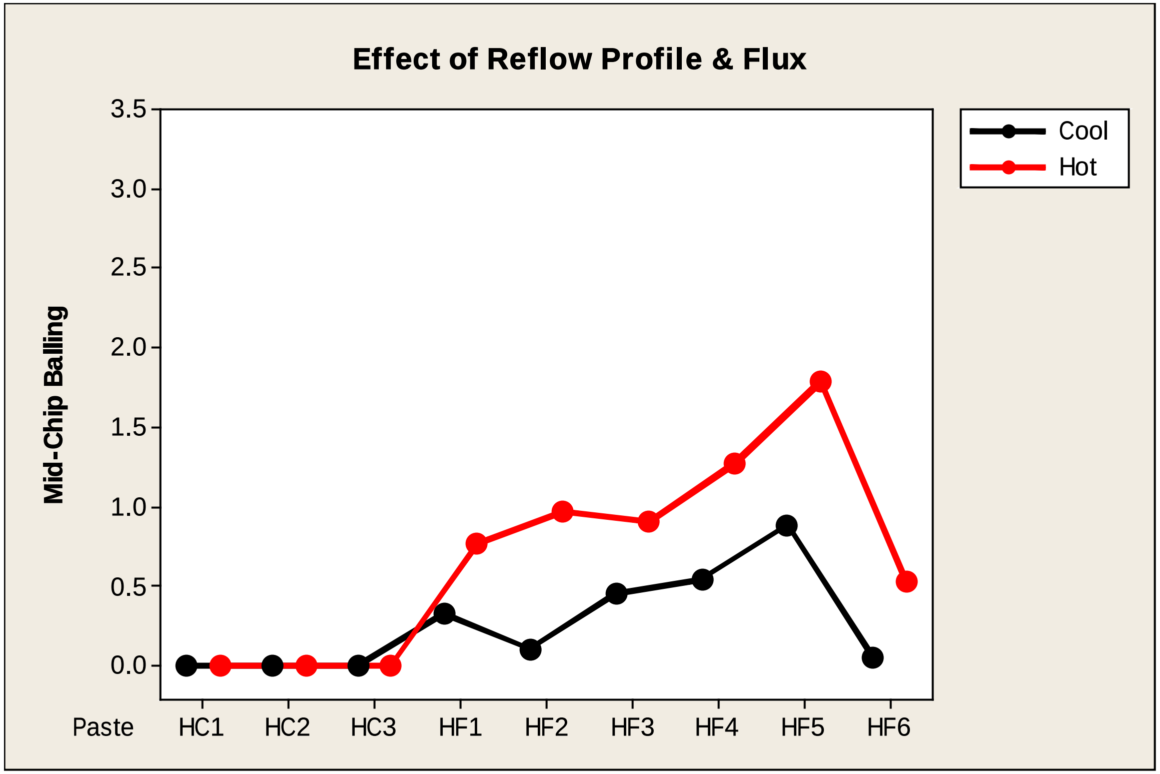
- Aperture shape can override the effect of flux

Effect of Flux



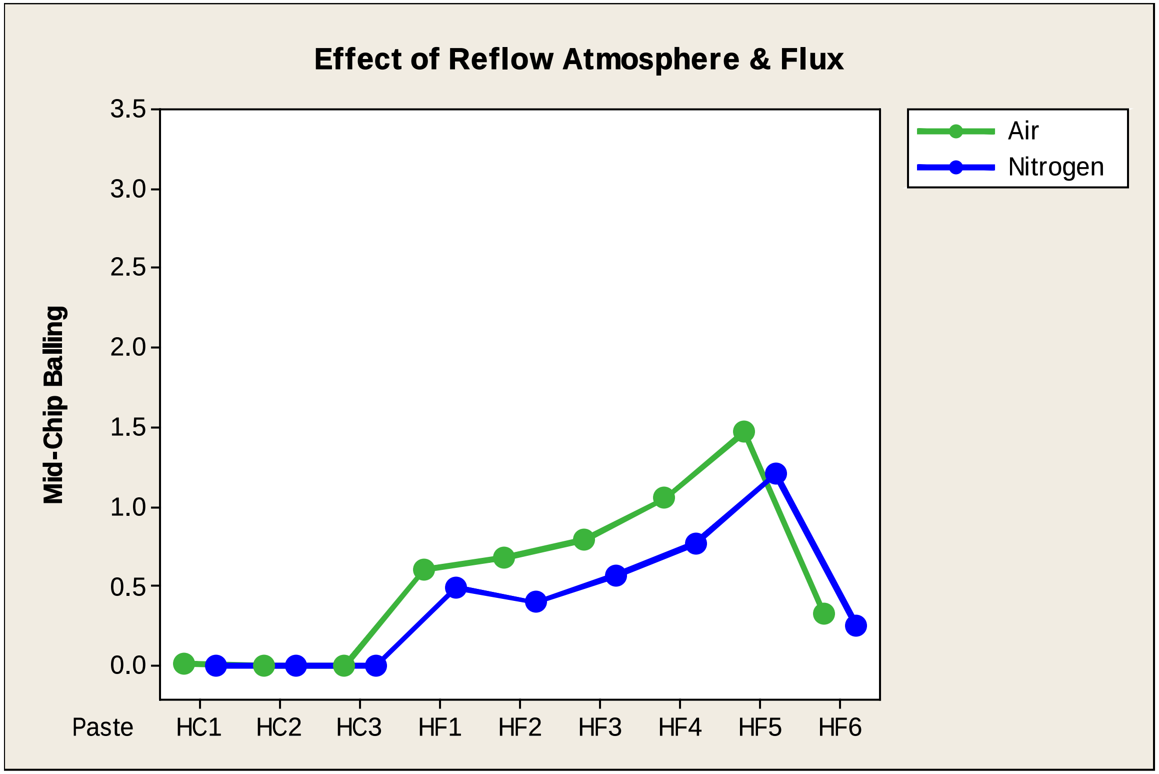
- Aperture shape can override the effect of flux

Effect of Reflow Profile



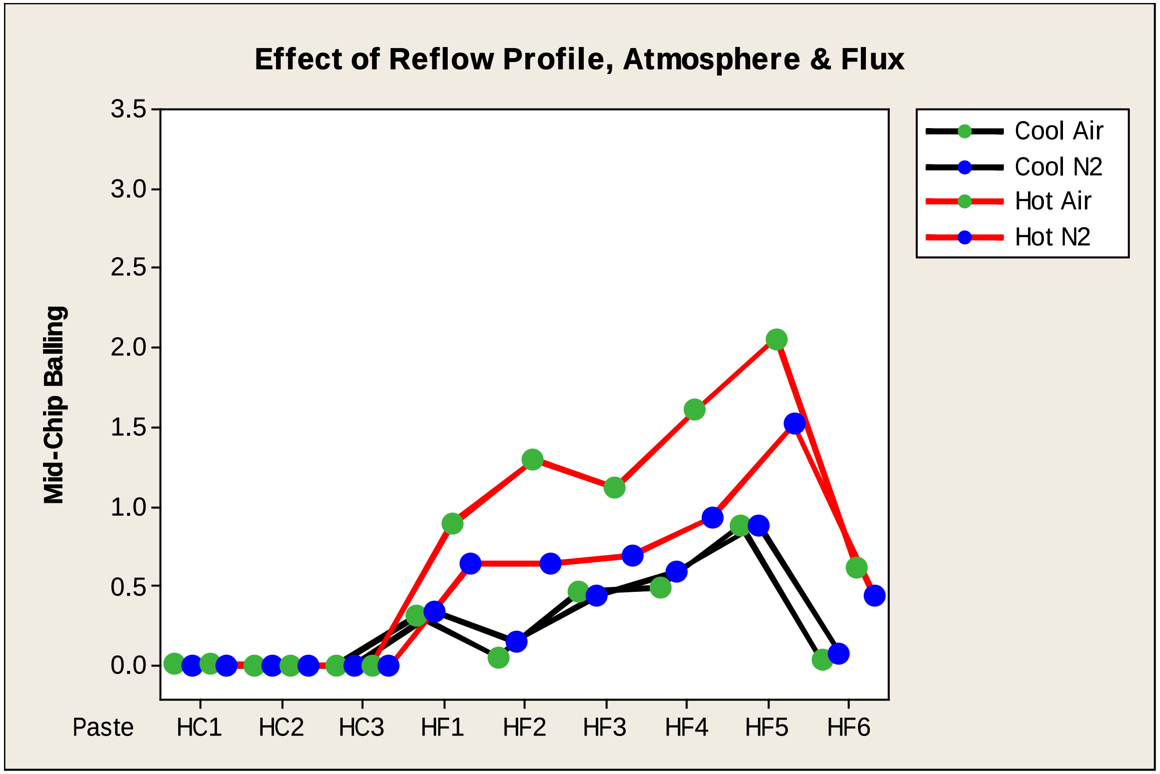
- Hot soak profile increases potential for paste to slump during reflow
- Effect seen with all flux types tested

Effect of Reflow Atmosphere



- Less mid-chip balling was observed when reflowed in nitrogen
- Less of an impact compared to changing profile

Effect of Reflow Profile & Atmosphere

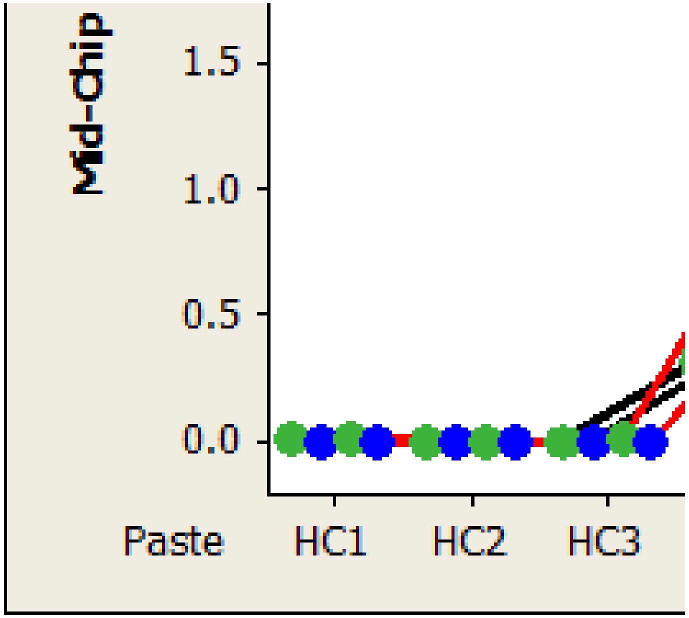


- Hot air profile produces poorest results
- Significant decrease in mid-chip balling in hot nitrogen – improved wetting

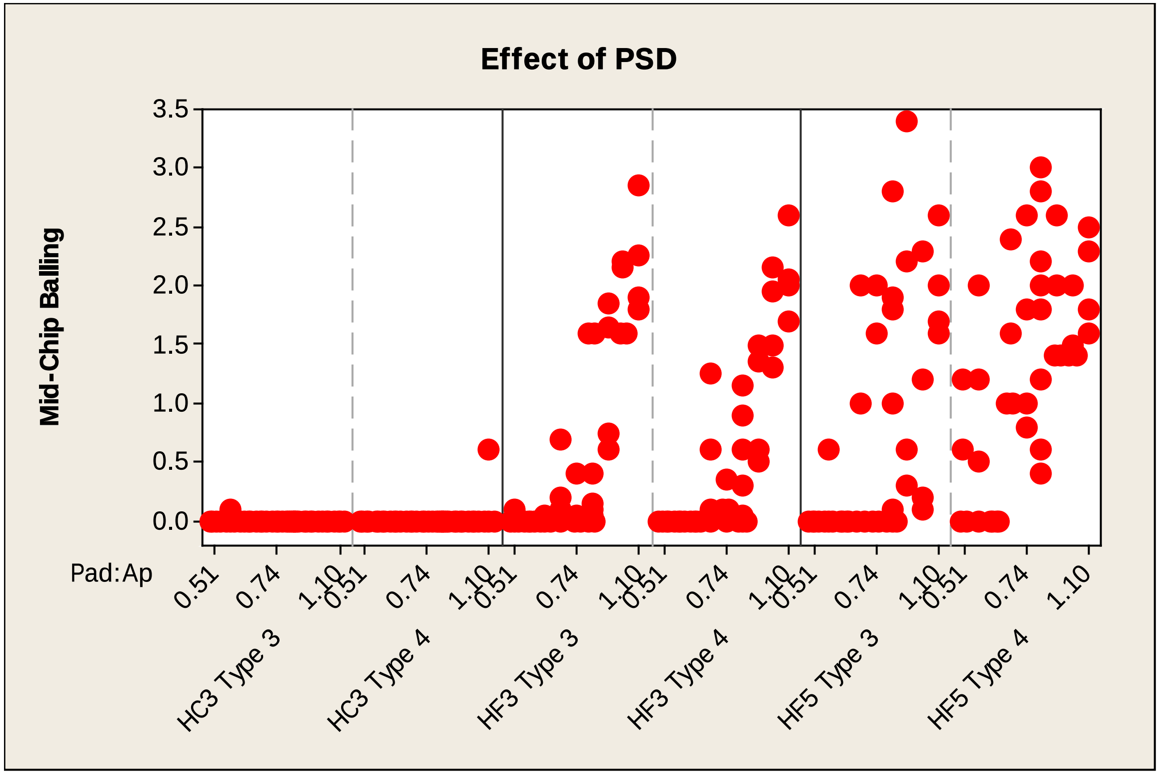
Further Investigations

- Very low levels of mid-chip balling seen in HC pastes
- All made with Type 3
  - All HF pastes made with Type 4
- All halogen containing

- Are these factors influencing the results?

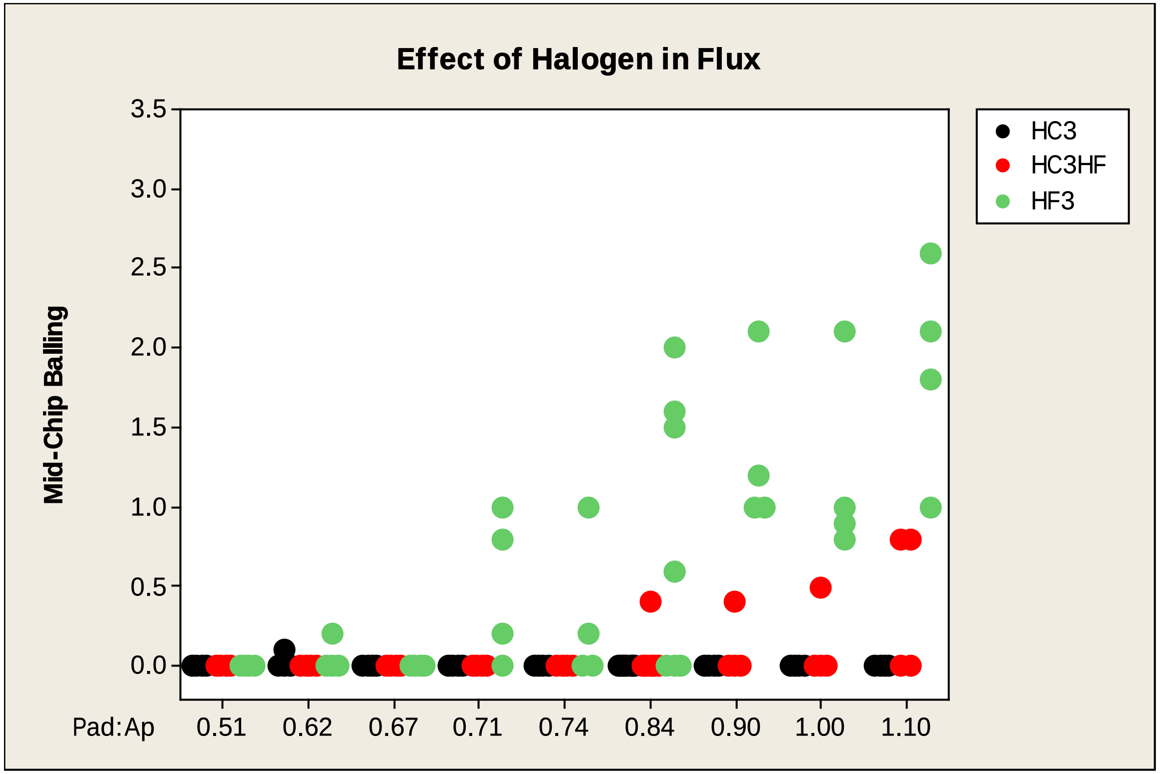


Effect of Particle Size Distribution



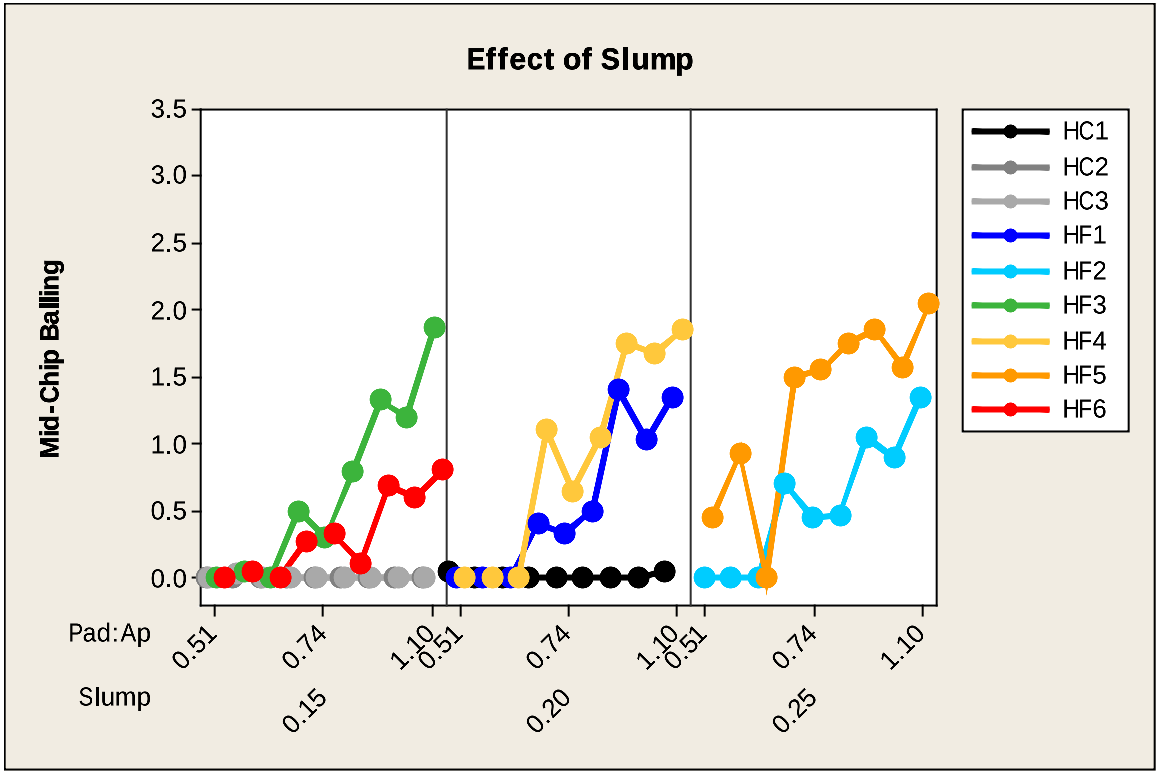
- Changing PSD did not appear to effect mid-chip balling
- Other fluxes may produce different results

Effect of Halogen



- Removal of halogen did appear to increase mid-chip balling
- Further work required to fully understand this

Effect of Slump



- Slump only has a minor impact on mid-chip balling
- Not necessarily primary contributing factor

Conclusions

Conclusions – Effect of Process

Mid-chip balling can most effectively be reduced by the following process changes:

Printing

- Changing aperture shape
- Reducing stencil thickness

Reflow

- Changing to a cooler reflow profile
- Reflow in nitrogen if a hotter profile is required

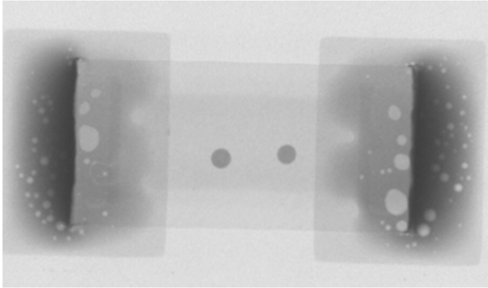
Conclusions – Effect of Flux

The flux chemistry can also have an impact on the mid-chip balling:

- Considerable variation between different fluxes
- Halogen appears to eliminate mid-chip balling
- Can get zero mid-chip balls with halogen-free when process is right
- Hot slump has only a minor impact when process is right
- Further work required to identify potential contributors to mid-chip balling

Further Work

- Improved understanding of effects of process and flux chemistry
- IPC does not have a test method
- Only looked at number of mid-chip balls
- Effect of size? Position?
- At what point do they actually become an issue?
- Mid-chip balls also detected **under** components
  - Invisible defects
  - Impact?
- Tip of the iceberg…



Any Questions?

katherine.wilkerson@henkel.com