VAPOR PHASE REFLOW'S EFFECT ON SOLDER PASTE RESIDUE SURFACE INSULATION RESISTANCE

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ABSTRACT

Surface insulation resistance (SIR) is a critical material property for electrically reliable assemblies using a no-clean surface mount technology process. It has been shown in recent studies that the reflow profile and atmosphere used can have significant effects on the SIR properties of no-clean solder paste. In this study, multiple reflow profiles were used in a vapor phase reflow process.

Vapor phase reflow is the process of subjecting an assembly with unreflowed solder paste and components to a temperature equal to the boiling point of the liquid used in the reflow process. This type of solder reflow process offers several advantages, especially for assemblies with a large amount of thermal inertia. Differences in temperature at different locations on the board can be reduced. In addition, lower peak temperatures can be used versus a typical reflow profile in a convection reflow oven. This can reduce the thermal stress on smaller components that otherwise could reach higher temperatures in a conventional convection oven process.

Another advantage is that the reflow liquid vapor is extremely inert, reducing any potential for excessive oxidation which can increase the incidence of head in pillow defects. It is well known that an inert atmosphere also increases the spread and wetting of lead free alloys. This also contributes to the reduction in voiding under bottom terminated components.

INTRODUCTION

Vapor phase reflow has created a niche in the surface mount technology (SMT) industry for several fundamental reasons. Assemblies with large thermal mass that contain small discrete components are excellent candidates for vapor phase reflow.

In this reflow process, a populated circuit board is preheated using one of several methods, then immersed in a chamber containing evaporated solvent with a boiling point temperature sufficiently high enough to reflow solder paste, and create intermetallic compounds with component IO's and metallic pads on the printed circuit board. The basic principle behind vapor phase reflow is shown in Figure 1.

In theory, the maximum temperature of the solder paste, components and board is limited to the boiling point of the vapor phase solvent that is used. Some have argued that the boiling point could rise or fall if the vapor phase fluid is contaminated, or if the location of the assembly house is well above sea level.

In order to reduce the thermal shock of an assembly being immersed in a 230°C chamber, preheating is generally recommended. This can be done with an in-line convection heater, or by managing the time and distance that the assembly spends above the vapor phase chamber**.** Both types of preheating were used in this study

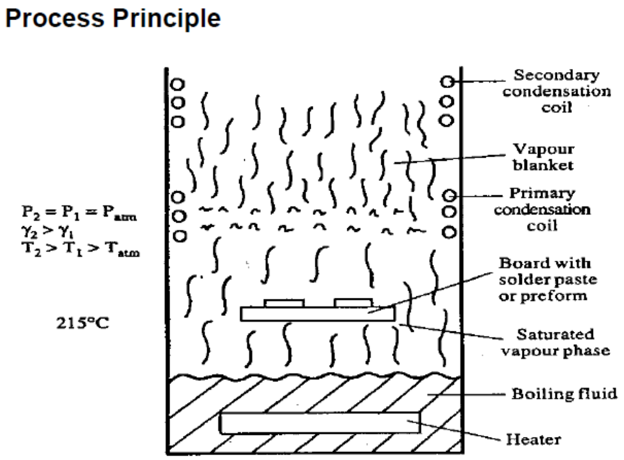

Figure 1. Vapor Phase Reflow Process Principle

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One issue is that if an assembly has regions where the temperature is below the boiling point of the solvent, the solvent will precipitate onto the colder regions. The fluid will evaporate as soon as it reaches the boiling point again This raises the issue of interaction with unreflowed solder paste and the vapor phase fluid, and what if any effect does this interaction have on the Surface Insulation Resistance of the final assembly.

The other question that promoted this study was the vaporization of weak organic acids, a key to high reliability no clean solder paste. Excessive amounts of weak organic acid in the solder paste flux residue could create an opportunity for dendritic growth, if exposed to moisture and a voltage bias. How is the vaporization of weak organic acids affected if the reflow is carried out in a high vapor pressure environment of solvent, versus the hot, dry conditions associated with a conventional convection oven?

EXPERIMENTAL PROCEDURE

Assembly Performance Evaluation

Two test vehicles were used for process evaluation: the Reference coupon (Figure 2) and the Wuerfel coupon (Wuerfel is German for cube) (Figure 3) were used to evaluate 14 different solder paste combinations consisting of 9 flux types, 7 Alpha and 2 competitors, 4 lead free alloys (2 with improved mechanical properties, HR1 and HR2, SAC305 and SAC0307, and 3 powder size types, 3, 4 and 4.5. Only 6 of the 9 solder paste fluxes were evaluated on the Reference board, while all 9 solder paste fluxes were evaluated on the Wuerfel board. Performance criteria for this study included voiding, tomb-stoning, wetting on pads and components, and residue appearance.

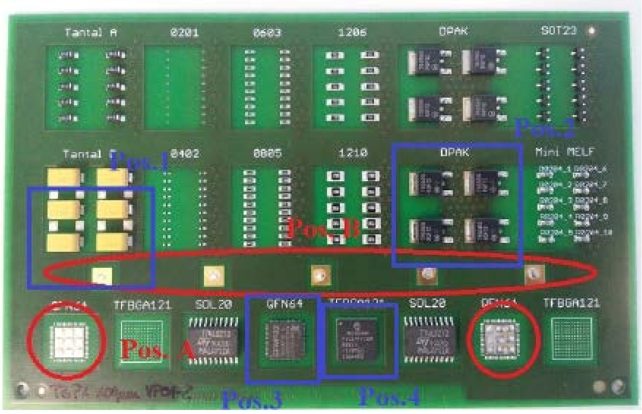

Figure 2. Reference test vehicle.

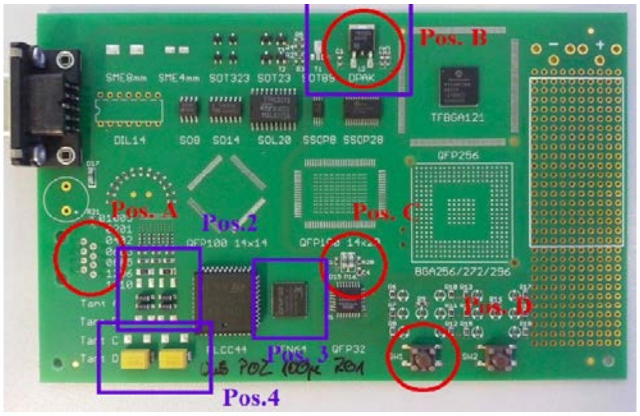

Figure 3. Wuerfel Test Vehicle

The test vehicles used all had the same **E**lectroless **N**ickel, **I**mmersion **G**old (ENIG) surface finish. All boards were printed using the same printer and print settings, but with different stencil thicknesses, 80 and 100µm for the Wuerfel board and 100 and 150 µm for the Reference board. A single pick and place machine placed the components.

Three reflow systems were used for the study. One was a vapor phase unit with no external preheating; see Figure 4. Preheating in this system is accomplished by holding the board at designated heights above the vapor phase chamber.

The second system used a convection oven, inerted with nitrogen, in line with the vapor phase chamber. Figure 5 shows this machine

The third reflow method was a conventional convection reflow oven. An air atmosphere was used with this method.

Figure 4. Vapor phase reflow machine – internal preheating.

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Figure 5. Vapor phase reflow machine with in-line convection preheating.

Because of the vast differences in the configurations of the two vapor phase machines, the reflow profiles were not exactly the same. Figures 6 and 7 show the profiles used with the internally heated and an in-line inert convection pre-heated vapor phase ovens respectively.

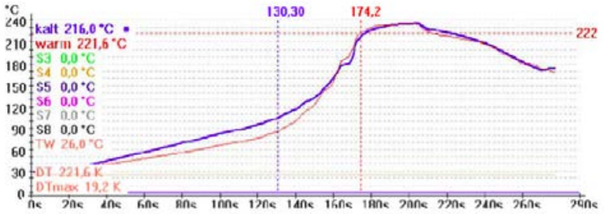

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Figure 6. Internally pre-heated vapor phase reflow profile used for VP 1.

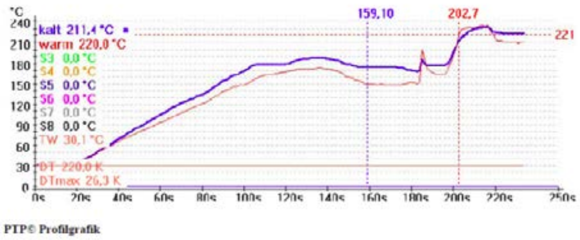

Figure 7. In-line inert convection preheat vapor phase reflow profile used for VP 2.

Evaluation of Performance Criteria

Voiding was evaluated by qualitatively comparing X-ray micrographs of large passive components and DPAK's, see Figure 8. Three ratings were used, 1 for little or no voiding, 5 for moderate voiding and 9 for extensive voiding.

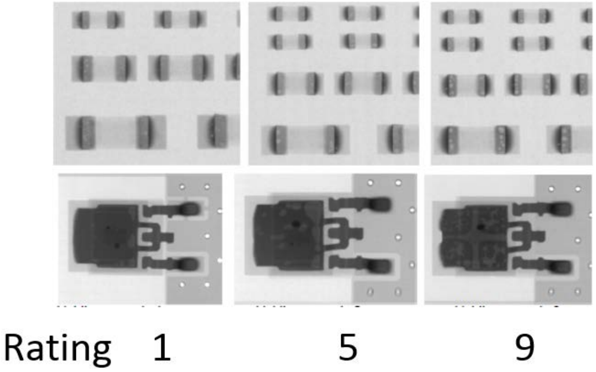

Figure 8. Qualitative voiding evaluation criteria

Wetting on pads, wetting on components, tomb-stoning, and residue appearance were evaluated using a qualitative comparison of the visual appearance of the test vehicles, as shown in Figures 9 through 12. Again, the results were divided into three categories, 1 for the best, 5 for moderate and 9 for the worst results.

SIR Testing

Four solder pastes, P1, P2, P3 and P5, were tested with three reflow conditions that were previously used in an SIR study of convection reflow profiles in both nitrogen and air atmospheres, and a fourth paste that was considered to provide the best results using vapor phase reflow.

Pre-cleaned IPC-B-24 coupons were sent to SmartTech for solder paste printing and reflow using the same conditions used for assembly performance evaluation, except that the convection reflow used a nitrogen atmosphere. The previous study mentioned above showed that a nitrogen reflow atmosphere yields higher SIR values than coupons reflowed in air. The solder paste was printed using a 150µm stencil; then reflowed by one of three methods previously discussed. Two or three coupons were processed per paste/reflow condition. Figure 13 shows a close-up of a printed and reflowed comb pattern. The processed coupons were then sent back to Alpha for SIR testing.

Teflon-insulated, 28AWG hook-up wire was soldered with 63/37 SnPb ROL1 solder wire to the SIR coupons. The leaded boards were mounted in temperature humidity chamber set at 40°C and 90% RH, per IPC-TM-650 method 2.6.3.7. [2]

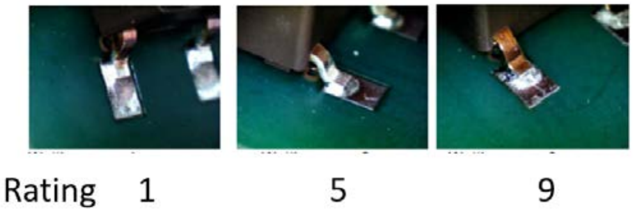

Figure 9. Qualitative component wetting evaluation criteria

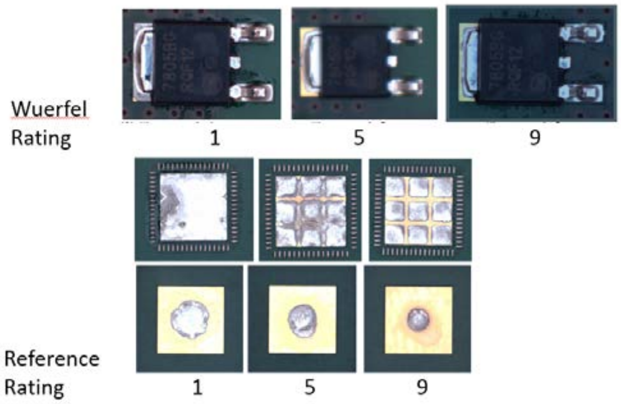

Figure 10. Qualitative pad wetting evaluation criteria

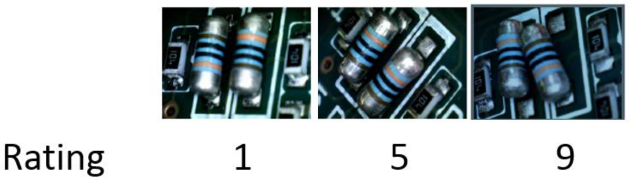

Figure 11. Qualitative tombstoning evaluation criteria

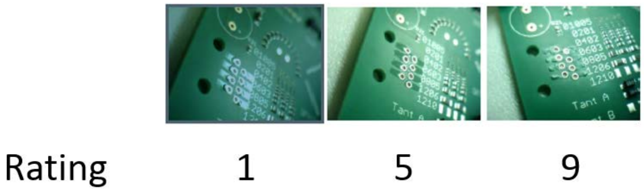

Figure 12. Qualitative residue appearance evaluation criteria.

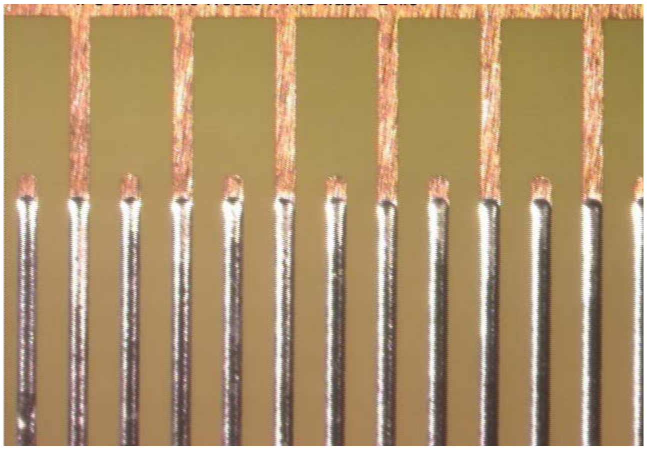

Figure 13. Close up of IPC B-24 coupon comb pattern with reflowed solder paste.

The coupons were connected to a GEN-3 AutoSIR The AutoSIR was programmed to apply a 12 V bias and make SIR measurements at bias voltage every 20 minutes for a total of 7 days.

After exposure to SIR testing, the coupons were examined with a microscope for evidence of electrochemical migration and corrosion.

RESULTS AND DISCUSSION

Assembly Performance Evaluation

A large quantity of mostly qualitative evaluation data was collected:

- 14 Pastes
  - 9 fluxes, 7 Alpha and 2 competitors
  - 4 alloys
  - 3 powder types
- 3 reflow conditions
  - 1 convection
  - 2 vapor phase
- 2 test coupons
  - Wuerfel and Reference
- 3 stencil thicknesses
  - 80, 100, 150 microns
- 5 qualitative reflow responses
  - Voiding, tomb stoning, component wetting, board wetting and residue appearance

In order to make sense of the data, it was entered into a popular statisticical analysis program, to help evaluate it. A comprehensive main effects plot of all the factors studied vs. all five responses evaluated is given in Figure 14. Solder paste flux has a strong effect on voiding and wetting of both pads and components, but a lesser effect on tomb stoning and residue appearance. The HR1 and HR2 alloys had better wetting and less voiding than the two SAC alloys, but poorer tomb stoning and residue appearance. Powder type does not seem to have an important effect on any of the responses evaluated. Stencil thickness seems to have a larger effect on component wetting and residue appearance, but test vehicle type also has an effect on these responses. Because thicker stencils were used with the Reference board than the Wuerfel board, perhaps stencil thickness should be looked at separately for the two types of test vehicles. Vapor phase reflow had better voiding and wetting than the air convection reflow, but poorer tomb stoning and residue appearance.

Because fewer paste types, (combinations of flux and alloy) were processed on the Reference board than the Wuerfel board and because thicker stencils were used on the Reference board than the Wuerfel board, separate main effects plots were made for each test vehicle. Figure 15 shows a main effects graph for the Reference board, and Figure 16 shows a main effects graph for the Weurfel board. Solder paste flux has a strong effect on voiding and wetting on the on both test vehicles. Flux has a strong effect on tomb stoning on the Reference board, but only a moderate effect with the Wuerfel board. Residue appearance did not seem to be strongly affected by flux for either test vehicle, but perhaps this is because reflow conditions had such a strong effect on residue appearance.

On the Reference board with only two alloys studied, the effect on all five responses was small, however, for the Wuerfel board, wetting was better and tomb stoning worse for the high reliability alloys than the SAC alloys. Powder type and stencil thickness had a moderate, but somewhat confusing, effect on all five responses for both test vehicles. Stencil thickness had a very small effect on all responses for both coupons.

Reflow conditions had a large effect on all responses for both coupon types, except tomb stoning. Voiding was considerably better for the vapor phase reflows than convection reflow in air for the Reference board, only showed a modest improvement for the Wuerfel coupon. Wetting was much better for vapor phase reflow conditions. Flux residue was more noticeable for vapor phase reflow than convection reflow.

Finally, Figure 17 shows a main effect plot for solder paste 3. Because the Reference and Wuerfel boards were processed with different stencil thicknesses, Reference 100µm and Wuerfel 80µm thick stencils were classified as **L**ow and Reference 150µm and Wuerfel 100µm thick stencils were classified as **H**igh. Here any extraneous effects from different paste flux chemistries are removed, and the effects of process conditions are clearer. Wetting and voiding are better for the high reliability alloy than the SAC alloys, but tomb stoning and flux appearance were worse. Finer powder had less voiding and better wetting than the coarser powder, but poorer tomb stoning. Vapor phase reflow gave much better voiding and wetting than convection reflow, but tomb stoning and flux residue appearance was worse. Thicker stencils showed modest improvements in voiding, wetting and tomb stoning.

In summary, solder paste flux has a large effect on all five responses, as expected. The flux's effect was more pronounced for voiding and wetting. The most important finding was that vapor phase reflow gives better voiding and wetting than convection reflow, but poorer tomb stoning and residue appearance results. Finally, thicker stencil prints can provide a modest improvement in voiding and wetting.

SIR Testing

Our previous paper showed that reflow conditions can have an important effect on SIR values [1]. Figure 18 shows the summarized data from that previous study, where we showed that SIR is generally higher with hotter reflow profiles, particularly those with higher peak temperatures and that SIR is generally higher after reflow in nitrogen atmospheres than air. These effects of reflow conditions are more pronounced for some solder pastes than others.

Figure 19 shows a plot of SIR vs. time for solder paste 5 that was reflowed using the vapor phase reflow condition with no

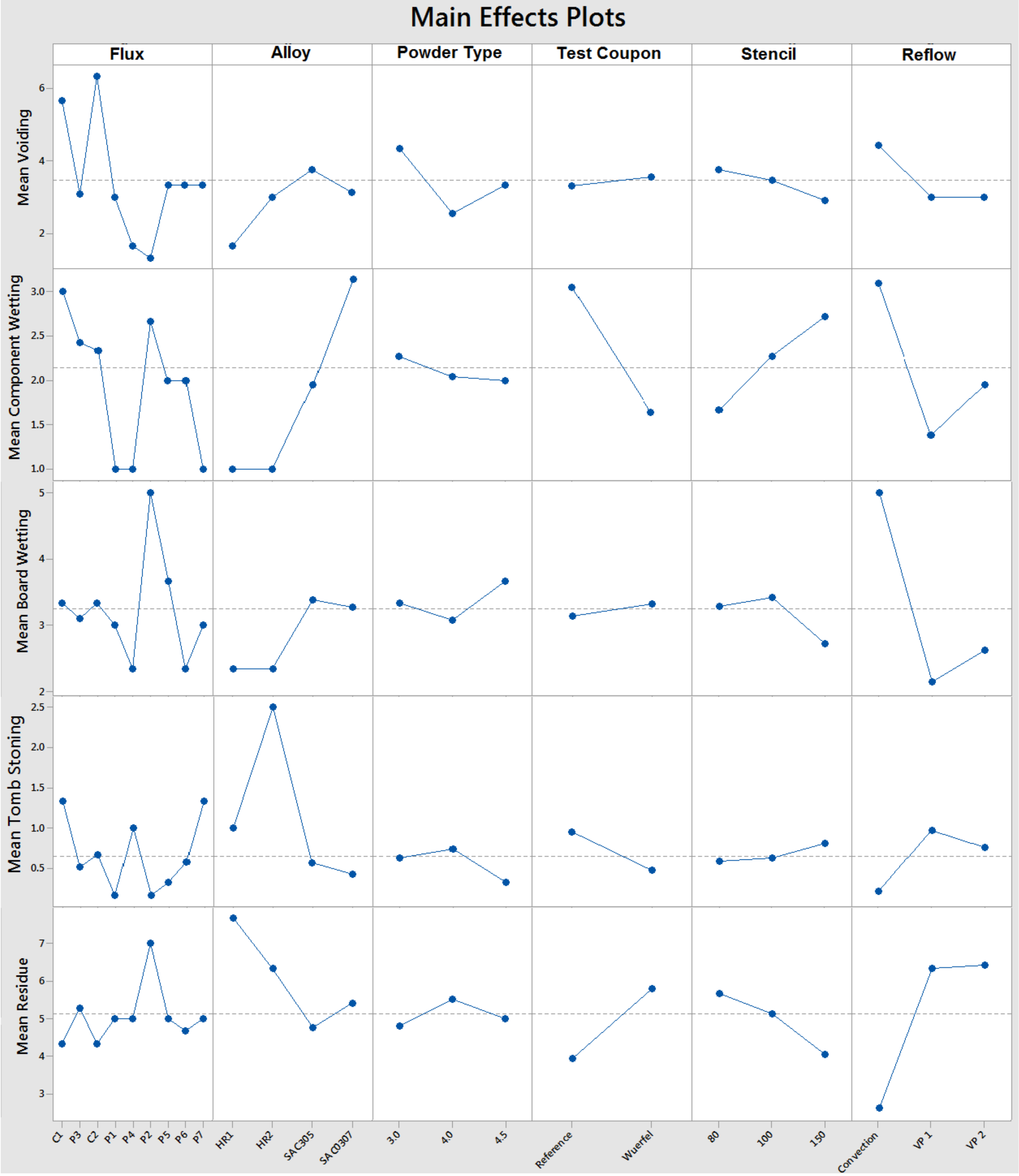

Figure 14. Main effects plot for qualitative evaluation of voiding, component wetting, board (pad) wetting, tombstoning and residue appearance for all factors studied, including solder paste flux, alloy, powder size, test vehicle, stencil thickness and reflow type.

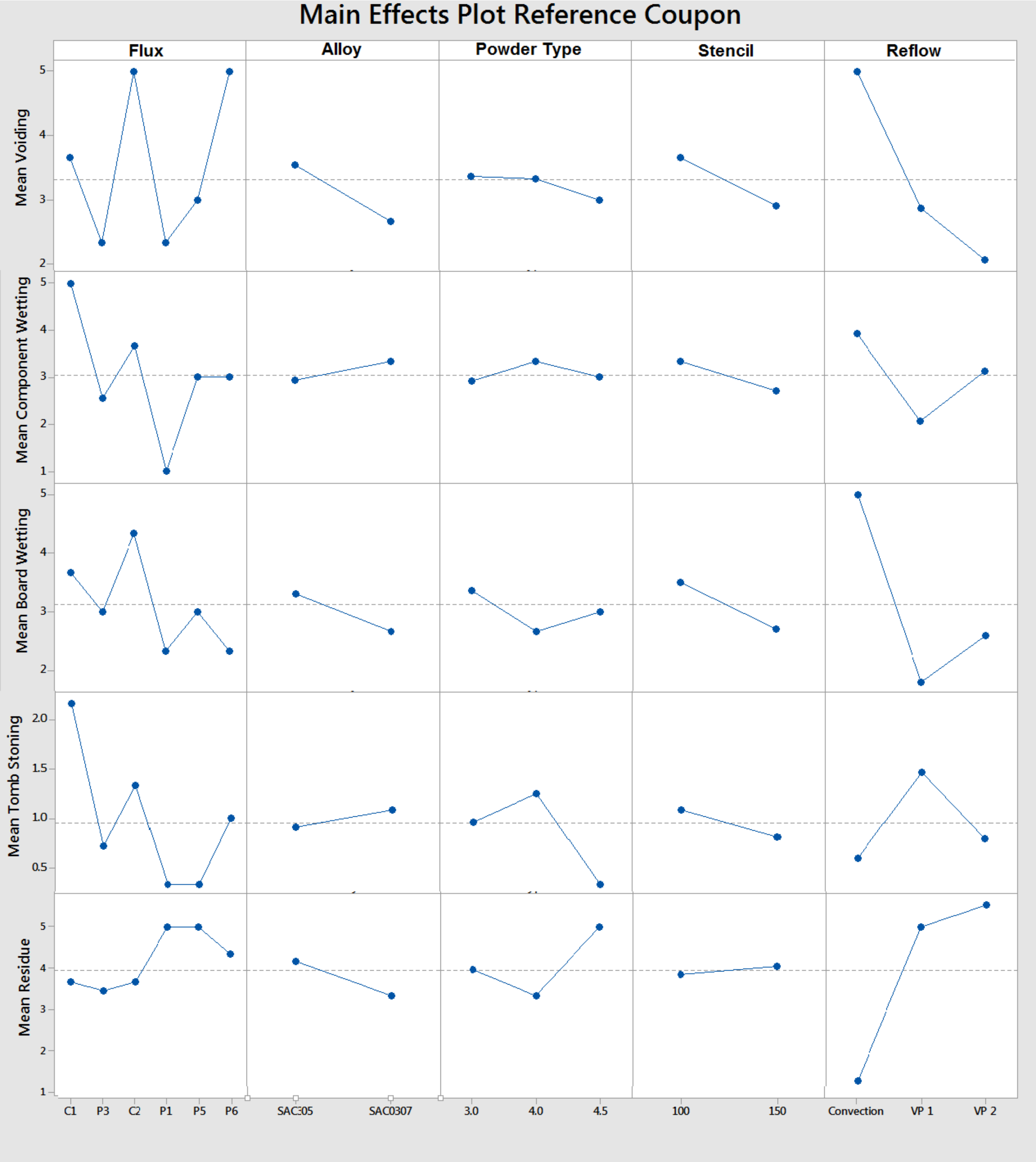

Figure 15. Main effects plot for the Reference test vehicle for qualitative evaluation of voiding, component wetting, board (pad) wetting, tombstoning and residue appearance for factors studied, including solder paste flux, alloy, powder size, stencil thickness and reflow type.

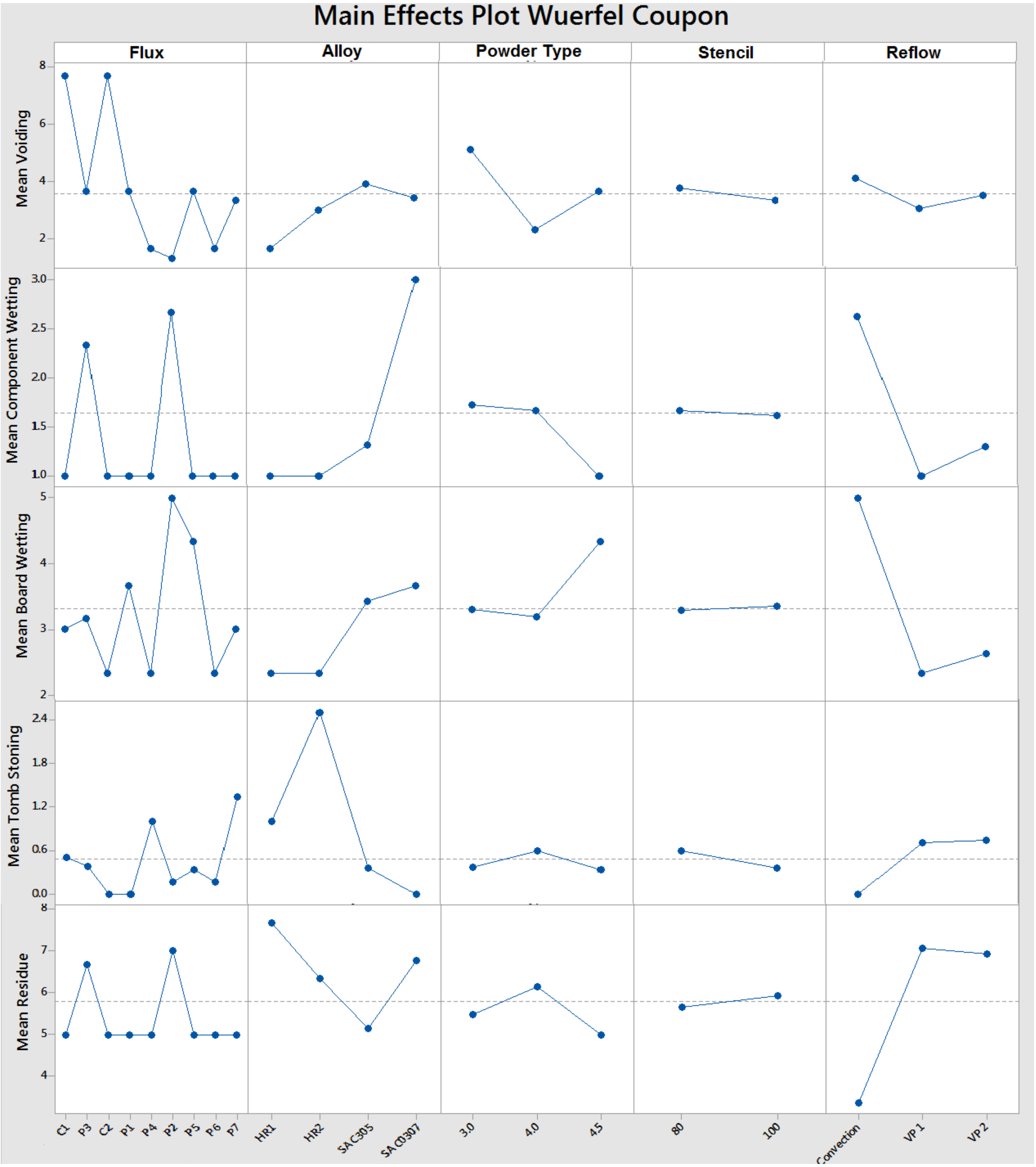

Figure 16. Main effects plot for the Wuerfel test vehicle for qualitative evaluation of voiding, component wetting, board (pad) wetting, tombstoning and residue appearance for factors studied, including solder paste flux, alloy, powder size, stencil thickness and reflow type.

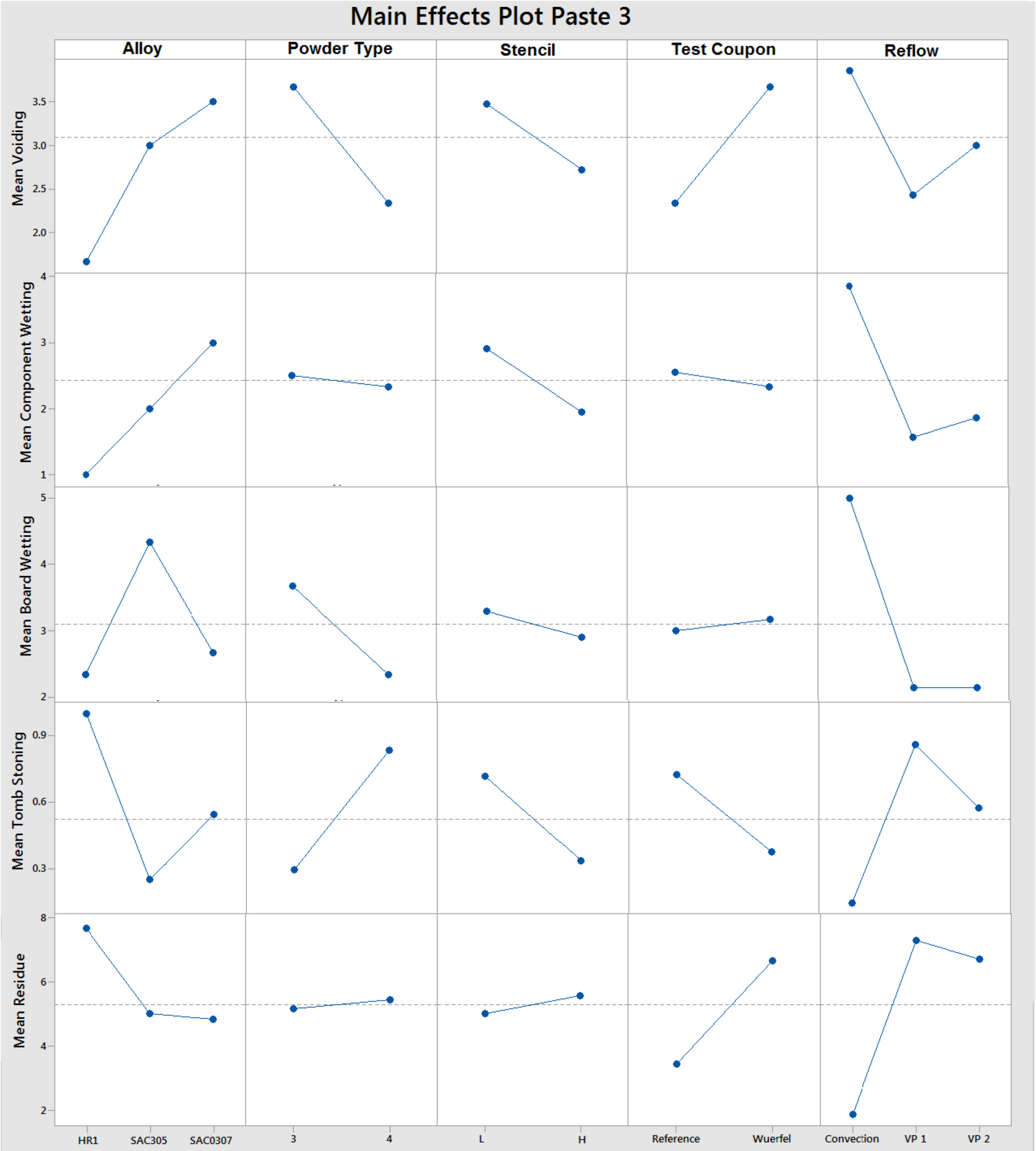

Figure 17. Main effects plot for solder paste 3 for qualitative evaluation of voiding, component wetting, board (pad) wetting, tombstoning and residue appearance for factors studied, alloy, powder size, stencil thickness and reflow type.

external preheat. The SIR per IPC TM 650 method 2.6.3.7 clearly passes the electrical requirements given in J-STD-004C ("All SIR measurements on all test patterns **shall** exceed the 100 MΩ requirements") [3]. All four solder pastes reflowed using both vapor phase reflow conditions met the visual and electrical requirements given in J-STD-004C. Post SIR testing microscopic examination showed no visual indication of any electrochemical migration or corrosion. From this result, the concern that weak organic acids not evaporating because of the vapor pressure of the solvent used, to the extent that TM-650-2.6.3.7 testing would fail, is unwarranted.

Paste 3 was also reflowed using the convection profile in nitrogen so the SIR results in this study could be compared to those in the previous study; the results were similar to those found in the earlier work. Average SIR vs. time for paste 3 processed with all three reflow conditions in shown in Figure

20. The SIR for VP2, shown in blue, is similar to that for that for the convection reflow in nitrogen. The SIR for VP1, shown in red, is a little less than an order of magnitude higher.

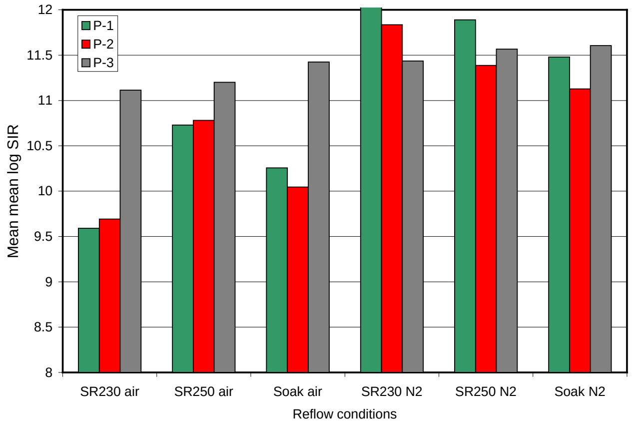

Figure 18. Summarized SIR data from previous study [1].

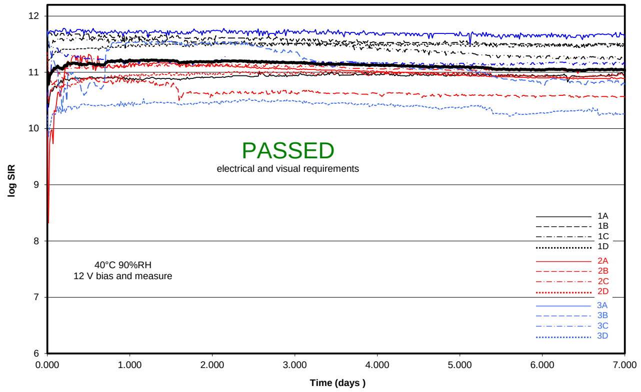

Figure 19. SIR vs. time for solder paste 5 reflowed with VP1.

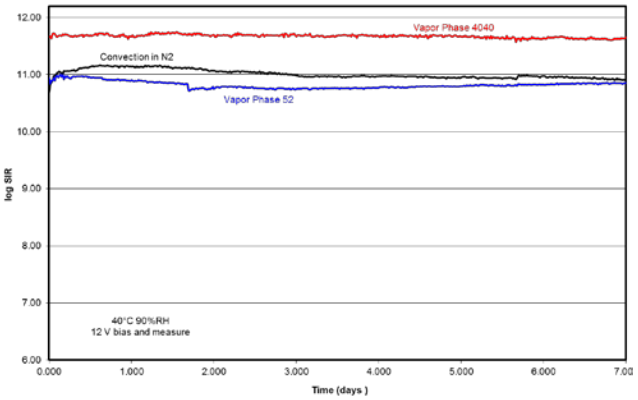

Figure 20. Average SIR of Paste 3 processed using all three reflow conditions.

Figure 21 shows average SIR vs time of all for pastes processed with both vapor phase reflow conditions. Paste 5 had relatively high SIR values similar to those found for paste 3, however the VP1 condition without the external preheat gave somewhat higher SIR for paste 3 than paste 5. Pastes 1 and 2 had lower SIR values for the vapor phase reflow profiles than paste 3, just as they generally had lower values than paste 3 when processed with convection reflow in the previous study.

Another interesting result was that the SIR readings of all 4 pastes appeared to be higher when the internally pre-heated vapor phase reflow, VP1, was used than that for VP2, the externally pre-heated reflow. This could be an effect of the reflow profiles used. This observation would require further confirmation with a reflow profile/SIR doe, but the pattern from this set of experiments seems to be consistent.

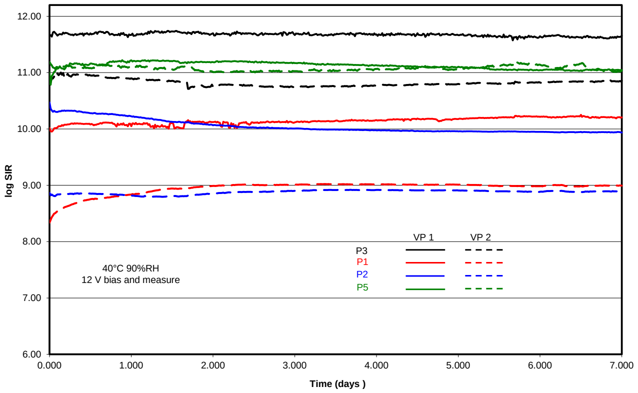

Figure 21. Average SIR of all four solder pastes under both vapor phase reflow conditions studied.

CONCLUSIONS

Vapor phase reflow is a mature process that solves the issue of preserving small discrete components on large thermal mass assemblies. It has shown in this testing, and previously reported work [4] to afford superior wetting and less voiding to convection oven reflow.

The SIR data also indicates that vapor phase reflow, like nitrogen inertion in convection reflow, increases the SIR results of a no clean solder paste.

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[4] T. Lewis et al., *Inclusion Voiding in Gullwing Solder Joints*, APEX EXPO 2012