THE RISK AND SOLUTION FOR NO-CLEAN FLUX NOT FULLY DRIED UNDER COMPONENT TERMINATIONS

Fen Chen and Ning Cheng Lee, Ph.D.
Indium Corporation
Clinton, NY, USA
nclee@indium.com

ABSTRACT
The miniaturization trend is driving industry to adopting low standoff components or components in cavity. The cost reduction pressure is pushing telecommunication industry to combine assembly of components and electromagnetic shield in one single reflow process. As a result, the flux outgassing/drying is getting very difficult for devices due to poor venting channel. This resulted in insufficiently dried/burnt-off flux residue. For a properly formulated flux, the remaining flux activity posed no issue in a dried flux residue for no-clean process. However, when venting channel is blocked, not only solvents remain, but also activators could not be burnt off. The presence of solvents allows mobility of active ingredients and the associated corrosion, thus poses a major threat to the reliability. In this work, a new halogen-free no-clean SnAgCu solder paste, 33-76-1, has been developed. This solder paste exhibited SIR value above the IPC spec 100 MΩ without any dendrite formation, even with a wet flux residue on the comb pattern. The wet flux residue was caused by covering the comb pattern with 10 mm × 10 mm glass slide during reflow and SIR testing in order to mimic the poorly vented low standoff components. The paste 33-76-1 also showed very good SMT assembly performance, including voiding of QFN and HIP resistance. The wetting ability of paste 33-76-1 was very good under nitrogen. For air reflow, 33-76-1 still matched paste C which is widely accepted by industry for air reflow process. The above good performance on both non-corrosivity with wet flux residue and robust SMT process can only be accomplished through a breakthrough in flux technology.

Key words: No-clean, flux, Surface Insulation Resistance (SIR), SAC305, halogen-free, soldering, low standoff components, wet flux residue

INDUSTRY TRENDS
The electronic industry is obviously driven by miniaturization and cost reduction.

The highly favorite thin, small portable devices such as smart phones are the strongest driving force pushing the continuous thinning down of devices, component profiles, and boards. In order to support the advancement in getting thinner, low standoff components such as QFN and LGA become a popular choice in product design, as shown in Figure 1. The shift toward a thinner profile is further augmented with designs encompassing components assembled in the cavity of substrate, as schematically shown in Figure 1 as well.

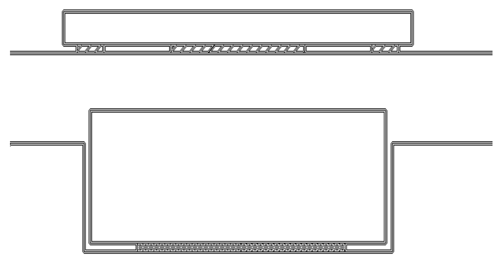

Figure 1. Schematic drawing of low standoff components and components assembled in the cavity of substrate.

On the other hand, for telecommunication devices, in order to reduce the cost, the assembly of components often is conducted with the simultaneous assembly of electromagnetic shield with few or no venting holes on the shield, as shown in Figure 2. This way, the labor cost needed for assembly of clip-on type shield can be eliminated. For simultaneous assembly process, a proper number of venting holes on the shield are definitely needed for escape of flux fumes. Those holes often are tape-masked after reflow assembly for integral shielding effect.

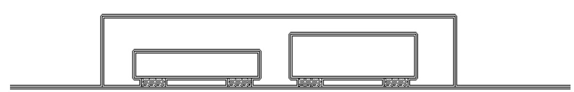

Figure 2. Components sealed within electromagnetic shield

FLUX BEHAVIOR
The flux typically comprised of solvents, activators, resins, and rheological additives. Examples of activators may include organic acids, organic bases, and halogenated compounds. In the case of resins, depending on the nature of flux being water soluble or no-clean, the resin chemistry may be highly hygroscopic polar compounds or non-polar rosins or resins. At conventional SMT board reflow assembly, the flux residue typically dried out well. Figure 3 shows the flux vaporization behavior under open environment [1]. The solvent escaped first, then followed by solid escape at a higher temperature.

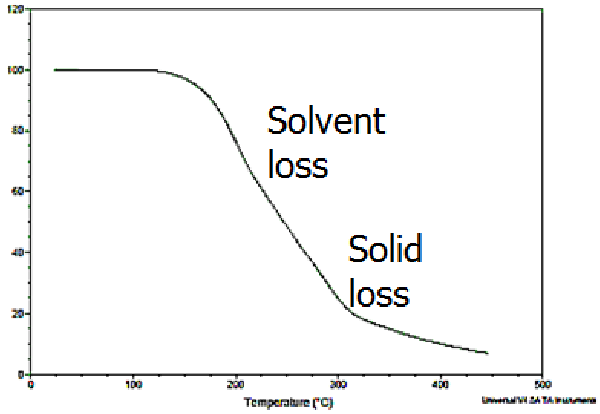

Figure 3. Flux vaporization behavior [1]

In general, flux is formulated with sufficient flux capacity so that it can provide adequate fluxing performance over a wide processing window, such as what shown in Figure 4. A short profile (profile 1 in Figure 4) consumes less flux activity than a long profile (profile 2 in Figure 4) does. In other words, the flux will have more or less remaining activity or activators after reflow, depending on the reflow profile utilized.

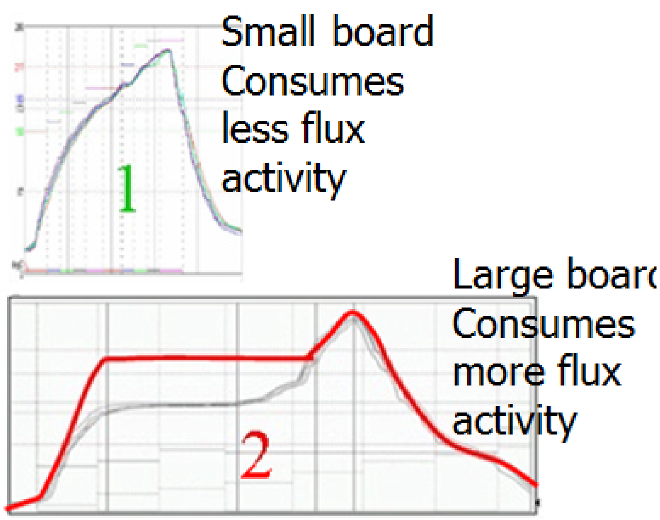

Figure 4. Flux activity consumption varies with profile type [2]

For a good no-clean system, any remaining activators are encapsulated within the non-polar rosin/resin, thus poses no reliability concern. For water soluble system, the flux residue can be easily removed by aqueous cleaners, hence also poses no issue on reliability.

CHALLENGE

The low standoff components and components in cavity are indispensable in manufacturing thin profile devices. However, a new issue emerged associated with those flimsy fashionable electronic gadgets. The small clearance between components and substrates greatly hampered the venting of flux volatiles at reflow soldering. As a result, considerable amount of flux ingredients got entrapped under the components, including solvents, vaporized activators, rheological additives, and fluxing reaction products [3]. On the other hand, for many designs with components sealed within the electromagnetic shield, the venting hole number may be too few or the hole diameter may be too small, the venting of flux volatiles can be hampered as well.

When venting of flux volatiles is significantly impeded due to configuration factor described above, the reliability immediately becomes a concern. Obviously, for aqueous cleaning system, the smaller clearance or holes would not allow easy access and removal of flux residues, thus results in immediate corrosion problem.

Even for no-clean system, where the flux residue used to be benign, the entrapped solvents and activators start to create corrosion problems which were never experienced before. For instance, organic acid activators in dried flux residue are not capable of undergoing corrosion reaction when encapsulated by solid rosin. This holds true even under hot humid environment, since water cannot penetrate through the non-polar rosin protection layer. However, in the presence of entrapped solvent, the flux residue becomes liquid or semi-liquid, and activators can move around engaging corrosion reaction, particularly under hot humidity and biased condition.

Figure 5 depicts the behavior of activator RCOOH under different process conditions. When the venting path is open, not only the solvent can be dried out, but some of the activator can also be vaporized and escaped from flux residue. When the solvent is retained in the flux due to blocking of venting path, the wet flux residue is more prone to pick up moisture under humid environment, and consequently results in corrosion, particularly under elevated temperature and biased condition.

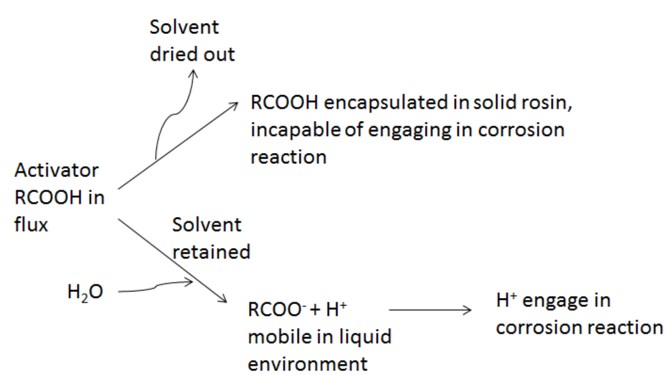

Figure 5. Activator RCOOH behavior under different process condition

The corrosion problem caused by lack of venting path can be detrimental. Figure 6 shows dendrite formation around a large pad of a bottom-terminated component. The flux expelled from solder paste at large pad could not dry out due to very limited venting space. Figure 7 shows dendrite formation for chip capacitor covered by an electromagnetic shield without venting hole. The solvent was not able to vent out, consequently resulted in dendrite formation.

WHERE DO WE GO FROM HERE

The emergence of "low standoff components" or "components in cavity" is driven by human's craving for convenience. The assembly of components and concurrent sealing is driven by desire of cost reduction. The assembly of components and concurrent sealing is driven by desire of cost reduction. Apparently both driving forces are here to stay. Facing the resultant corrosion and dendrite formation, the question is: where do we go from here?

The first potential solution is removal of flux residue. This will be very challenging, since the cause "small venting space" of having wet flux residue will also be the barrier for cleaner to remove the flux residue. To make situation worse, the residue is getting more and more difficult to remove with new flux chemistries needed for supporting further miniaturization [4].

The second potential solution is to develop flux which is non-corrosive and non-conductive even if flux residue drying is not possible. In other words, develop a flux which is benign wet or dry.

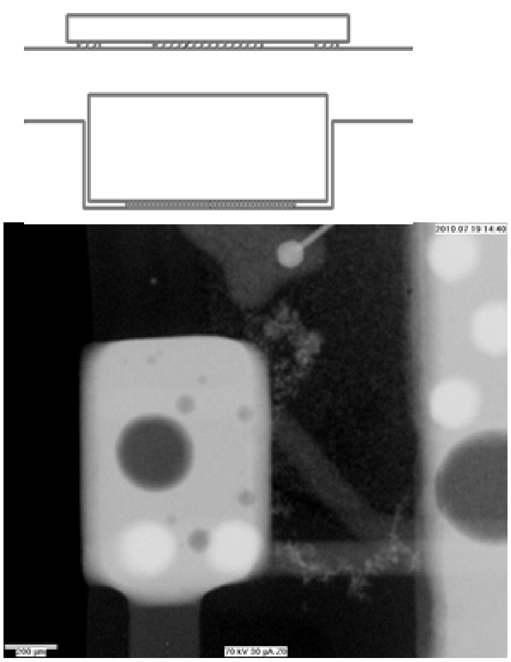

Figure 6. Dendrite formation around the large pad of a bottom-terminated component

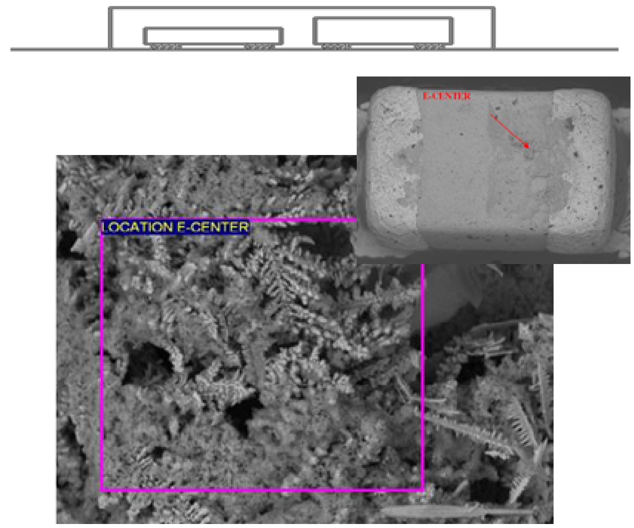

Figure 7. Dendrite formations for chip capacitor covered by an electromagnetic shield without venting hole

However, in principle, a wet flux residue being non-corrosive and non-conductive should contain very low amount of activators and exhibit very low activity. Such type of flux would be poor in wetting, which in turn would be poor in voiding [5, 6] and HIP performance [7], hence would not be adequate for SMT assembly applications.

The challenge is: can a flux be developed, being benign with wet flux residue, but still perform well at SMT assembly process, including reflowed under air?

QUEST FOR BENIGH WET FLUX

A major developmental effort has been conducted for this quest. As a result, a new halogen-free no clean solder paste, 33-76-1, was developed. The performance assessment, including the SIR behavior with hampered venting of flux fume, wetting, voiding, and head-in-pillow, are presented and discussed below.

EXPERIMENTAL

1. Materials

Six solder pastes were tested, including the newly developed halogen-free no-clean solder paste 33-76-1 and five conventional solder pastes as controls. The characteristics of those six solder pastes are shown in Table 1. All solder pastes employed 96.5Sn3.0Ag0.5Cu (SAC305), type 4 (20-37 microns) or type 4.5 solder powder. Pastes A, B, and C are standard products well received by market as SMT no-clean lead-free solder paste. Paste D and E are commercially available materials, the powder size of E was not available.

Table 1. Characteristics of solder pastes evaluated.

Flux	Characteristics
A	Halogenated, no-clean, T4
B	Halogenated, no-clean, T4.5
C	Halogen-free, no-clean, T4
D	Halogen-free, no-clean, T4
E	Halogenated, no-clean
33-76-1	Halogen-free, no-clean, T4

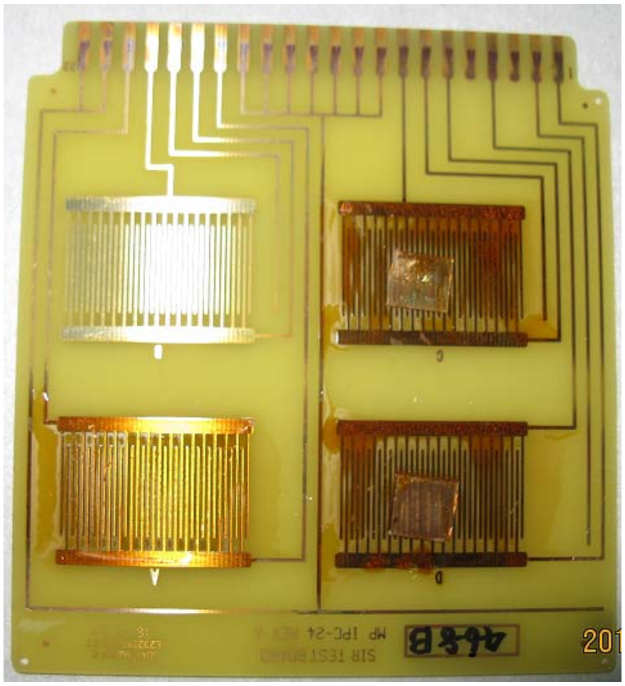

Figure 8. Example of reflowed SIR board with glass slide, with 3 comb patterns printed with flux, and 2 of these 3 comb patterns were further covered with glass slides.

2. Surface Insulation Resistance (SIR) Test

Standard IPC B-24 SIR board was used for this experiment. The flux vehicle of each of the solder pastes was printed onto 3 of the 4 comb patterns in the SIR comb pattern using a 0.10 mm (4 mil) thickness stencil. A 10 mm × 10 mm glass slide was placed onto part of the printed flux of a comb pattern. Two comb patterns received this glass slide coverage treatment, as shown in Figure 8. Each of the glass slide was further secured onto the SIR coupon with a 3M high temperature tape to avoid slide movement during subsequent air reflow. The reflow was conducted via a convection oven with a peak temperature of 244°C, with profile shown in Figure 9. Other than the coupon preparation, the SIR testing was performed in accordance with J-STD-004B.

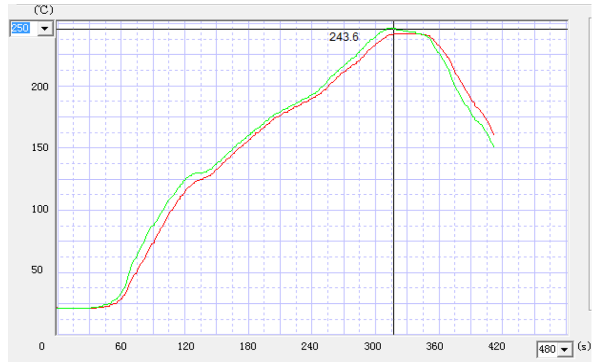

Figure 9. Reflow profile used for fluxed SIR boards with or withou glass slides attached.

The SIR performance of those fluxes on SIR coupon without glass slide coverage (Standard SIR Test) was also evaluated for comparison purpose. Here all flux fumes vaporized with dry flux residue left behind on the comb pattern.

It should be noted that during the preliminary trials, solder paste was printed onto comb pattern followed by placing glass slide. After reflow, the flux residue under the glass slide was found to be dry despite the glass slide coverage. This was due to too high a standoff caused by the solder rim formed on comb pattern. In order to mimic the hampered venting of flux fume, printing flux vehicle instead of solder paste was found to be effective and resulted in wet flux residue.

3. Wetting Test

Use a three-hole stencil, with hole diameter of 6.35 mm (0.25 inch), and thickness of 0.12 mm (5 mil), print each paste onto 4 types of substrates with surface finishes described below: substrate OSP, Oxidized OSP (by pre-conditioning OSP substrate in 200°C oven for 2 hours), Immersion Ni and Alloy42. The substrate with printed paste was then sent through oven both under air and under nitrogen atmosphere with reflow profile shown in Figure 10. The reflowed coupon was then examined for wetting behavior.

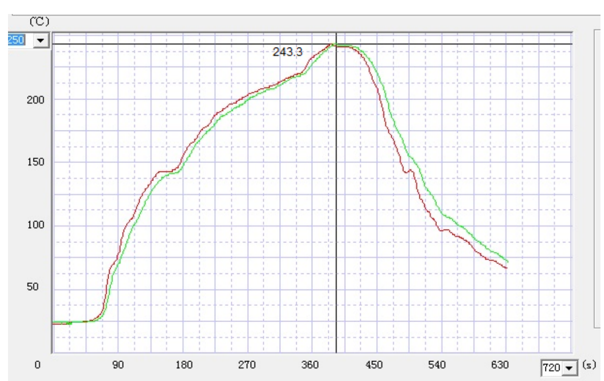

Figure 10. Reflow profile used for paste wetting test.

4. Voiding Test

A dummy coupon representing QFN was assembled as below (see Figure 11):

1) Prepare 30 mm x 30 mm FR4-OSP with 10 mm x 10 mm Cu pad in the center.
2) Print the paste onto the Cu pad using a 0.3 mm (12 mil) thick stencil with 10 mm x 10 mm aperture size.
3) Place a 12 mm x 12 mm QFN coupon with Immersion Ag surface finish onto the paste
4) Send the sandwich through convection oven with profile shown in Figure 12 and air reflow atmosphere
5) Examine the voiding with X-ray inspection equipment.

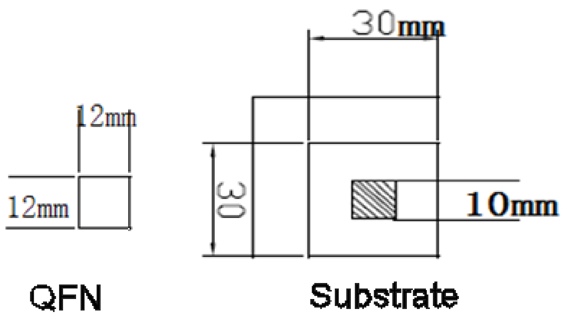

Figure 11. Schematic drawing of QFN coupon and substrate.

5. Head-In-Pillow (HIP) Test

The propensity toward HIP was evaluated with Ball-Onto-Paste method [7], as described below.

Figure 12. Reflow profile used for QFN voiding test.

Ball Onto Paste test

Ball Onto Paste method is used to assess combined capability of oxidation resistance and excessive fluxing capacity of fluxes. In this method, both paste and solder ball are subjected to oxidation prior to putting them together. Figure 13 shows the schematic drawing about the test method, which can be described with the following procedure.

1) Precondition 2.3 mm diameter solder ball at 200°C under air for 30 min, then put it aside.
2) Print 3.0 mm diameter solder paste onto Cu coupon using a 125 µ thick stencil. Precondition the printed solder paste at 200°C on hot plate with 2 min under air.
3) Move the preconditioned specimen onto 240°C hot plate under air. Once the paste melted, hold the coalesced solder at 240°C, with time varies (e.g. 0, 20, 60, 80 seconds).
4) Drop a preconditioned solder ball onto the liquid solder dome. Hold the specimen on 240°C hot plate for 20 more seconds under air. Remove specimen from hot plate.

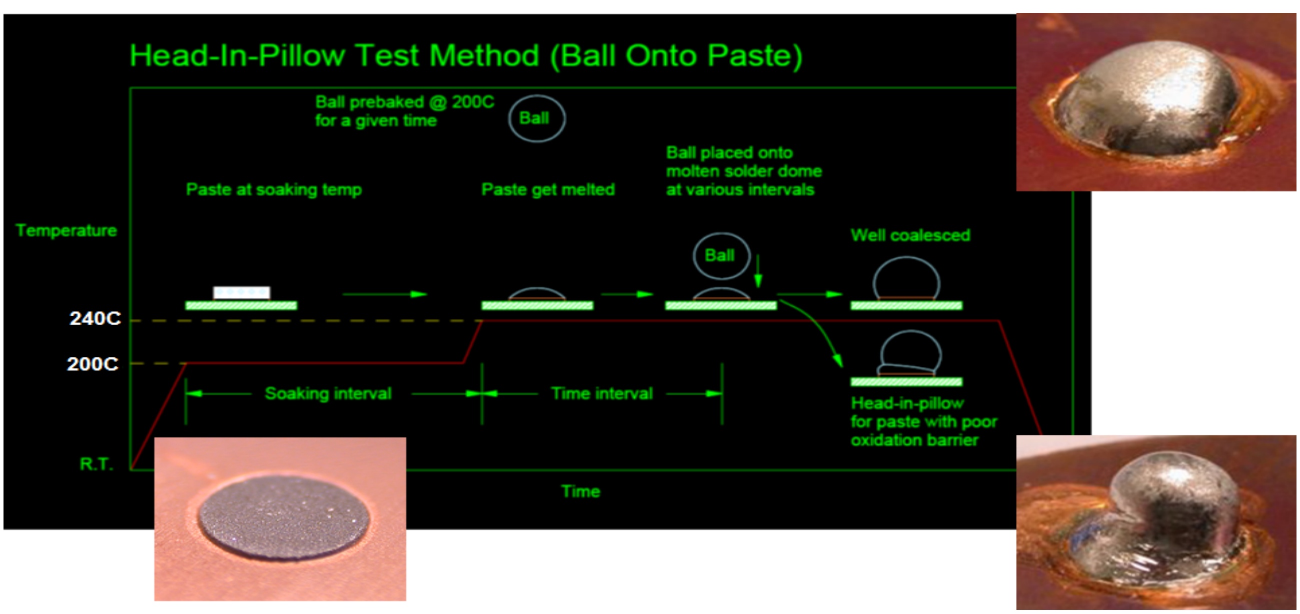

Figure 13. Ball Onto Paste method for HIP propensity evaluation.

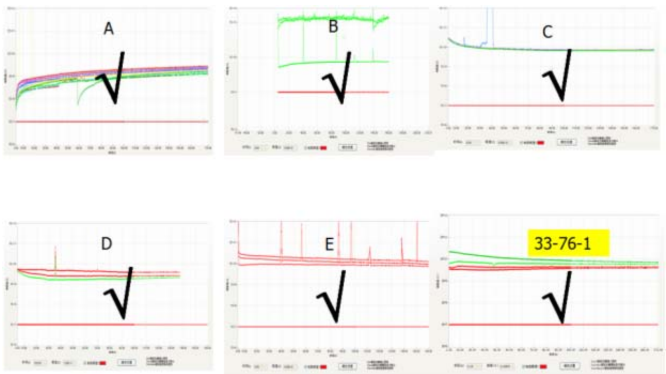

Figure 14. SIR standard test data of various fluxes shown in Table 1.

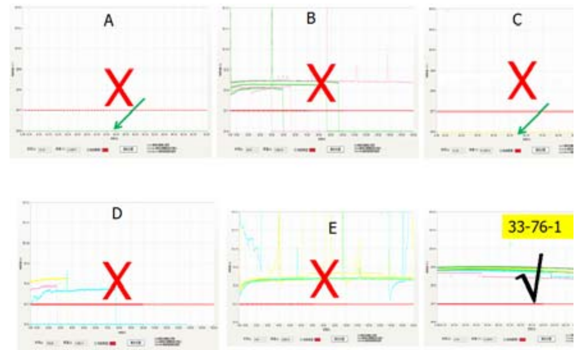

Figure 15. SIR data with glass slide on of various fluxes shown in Table 1.

5) Examine the specimen under 40X optical microscope for incomplete coalescence, which reflects propensity of HIP.

Example of printed paste (lower left), full coalescence between ball and paste (upper right), and partial coalescence (lower right) are exemplified in Figure 13.

RESULTS

1. SIR

Table 2 shows the key data points on results of SIR standard test and SIR with glass slide on for all fluxes. Figure 14 shows the original data for SIR standard test, while Figure 15 shows the original data for SIR with glass slide on for all fluxes. For standard SIR test, no significant difference can be discerned between various fluxes, with most of fluxes being above 10^9 Ω except flux A.

However, when the glass slide was placed on test coupon, most traditional fluxes failed badly and the resistance was under 1 MΩ. Here all readings below 1E+6 Ω were reported as 1 MΩ due to the inserted current limiting resistor in the circuitry. Flux E was close to pass, with good portion reading above 100 MΩ, except at the beginning, near the end, and a number of blips. Flux 33-76-1 was the only one exhibiting a clean pass through whole test.

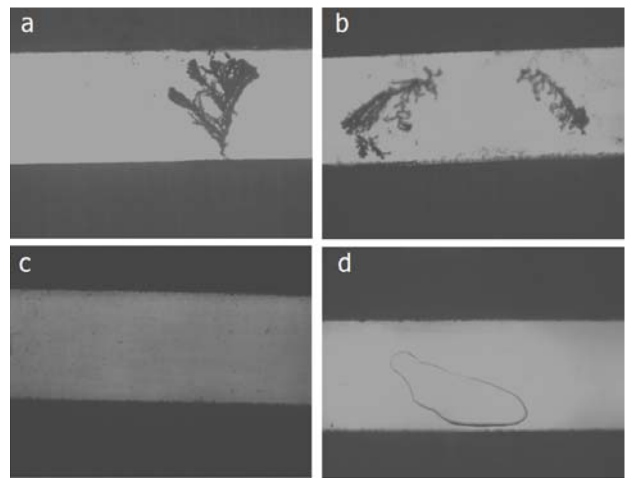

Figure 16. Close up look of SIR coupons after SIR test with glass slide on (50X), with a, b showing dendrites, and c, d free of dendrites.

The coupons with glass slide on were examined with 50X microscope. The dendrite was clearly observed in flux A, B, C and D, as exemplified in Figure 16 (a) and (b). No dendrite could be discerned for flux E and flux 33-76-1, as exemplified in Figure 16 (c) and (d).

Flux A, B and E are halogenated and flux C, D and 33-76-1 are halogen-free. For the SIR test with glass slide on, with flux 33-76-1 being the only one passed the spec, flux E nearly passed, and the rest fluxes all failed, it is obvious that

Table 2. SIR standards and SIR with glass slide on for various fluxes. Expressed as log of resistance ohm.

Flux	SIR standard				SIR with glass slide on			
	0	24 hours	96 hours	168 hours	0	24 hours	96 hours	168 hours
A	8.2	8.8	9	9.2	6	6	6	6
B	9.2	9.4	9.6	9.6	8.2	8.3	6.4	6.4
C	10.5	10	9.9	9.9	6	6	6	6
D	9.7	9.4	9.4	9.4	6.8	6.7	6	6
E	10.3	10.2	10.1	10	7.6	8.3	8.4	8.7
33-76-1	9.9	9.8	9.8	9.7	8.7	8.6	8.5	8.3

removing halogen from flux did not promise a pass, and a major breakthrough in flux chemistry formulation is needed to accomplish this.

2. Wetting

When reflowed under nitrogen, all solder pastes wetted well on all substrates, and no difference can be discerned.

When reflowed under air, the wetting behavior of those pastes can be differentiated. Figure 17 shows the solder spread appearance on various substrates. The halogenated pastes A, B and E showed full wetting of the prints on all 4 substrates. For the halogen-free solder pastes C, D, and 33-76-1, D showed dewetting on all substrates. C wetted regular OSP and oxidized OSP well, showed some dewetting on Ni and considerable dewetting on Alloy 42. Paste 33-76-1 wetted regular OSP and Alloy 42 well, showed slight dewetting on oxidized OSP and Ni.

Considering that paste C is very well accepted by industry for air reflow process, Paste 33-76-1 wetted comparable with or slightly better than C, thus is expected to meet industry need for air reflow.

3. Voiding

The voiding performance of each paste is shown in Table 3. The halogenated paste B shows the lowest voiding rate among all pastes studied. The halogen-free paste 33-76-1 exhibits the second lowest voiding, and is better than all halogen-free pastes.

4. Head-in-Pillow

The head-in-pillow behavior of various pastes is shown in Table 4. The resistance against occurrence of HIP can be ranked below: B > A > 33-76-1 > E > C > D. Paste 33-76-1 is not only better than all halogen-free pastes, but also better than the halogenated paste E.

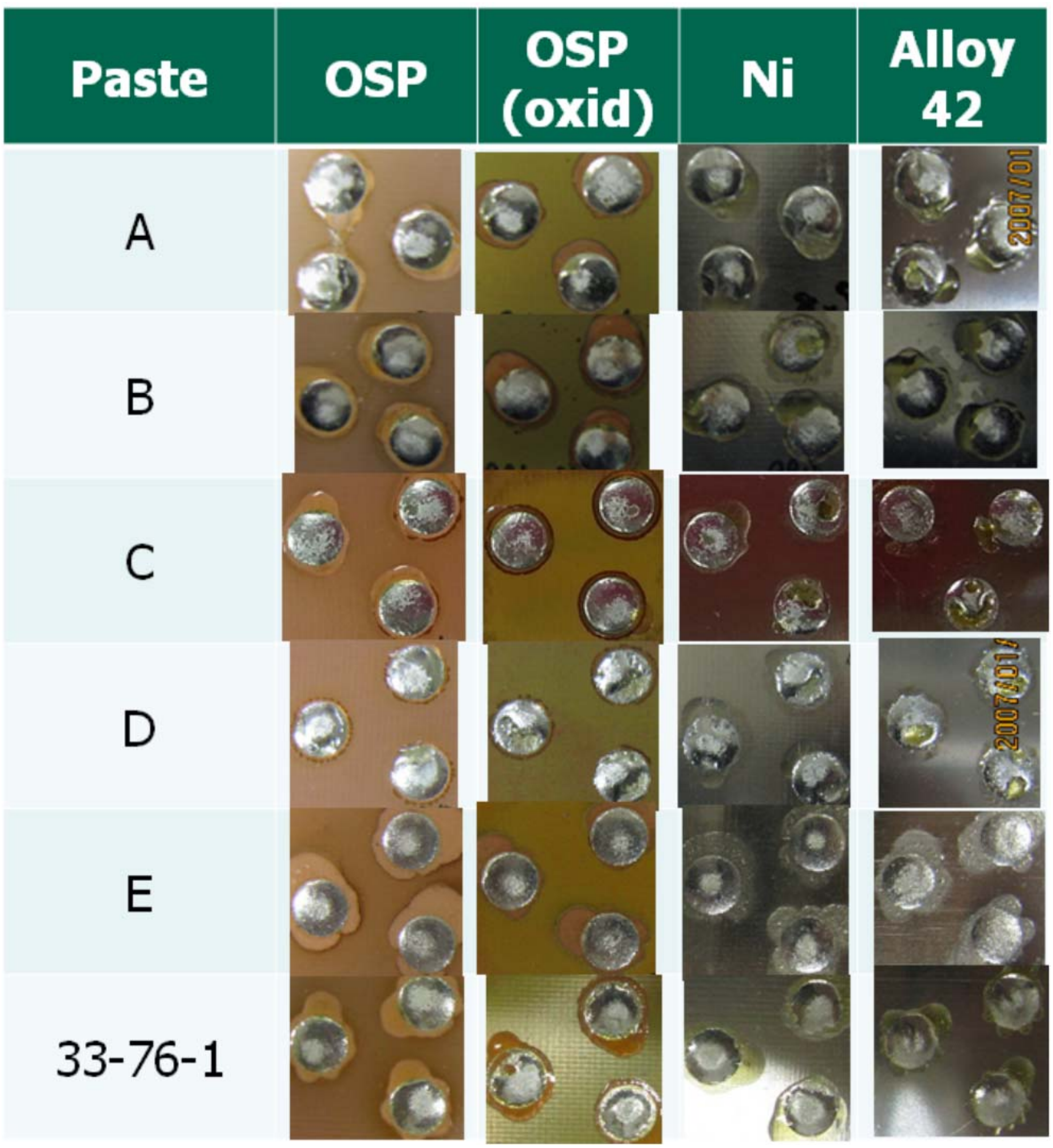

Figure 17. Wetting of solder pastes under air on various substrates.

Table 3. Voiding performance (area %) of various solder pastes.

No.	Largest void (%)	SD	All voids (%)	SD
A	2.6	1.4	19.6	5.8
B	1.1	0.7	8.0	7.4
C	3.0	1.5	20.3	7.2
D	1.7	0.6	19.7	5.8
E	1.5	1.1	24.1	8.4
33-76-1	2.9	1.0	13.8	4.0

Table 5. Summary of solder paste performance

Paste	SIR-G	SIR-Std	HIP	Void	Wet (air)	Wet (N2)
A T4	x	√	√	x	√	√
B T4.5	x	√	√	√	√	√
C T4	x	√	x	x	√	√
D T4	x	√	x	x	x	√
E	x	√	x	x	√	√
33-76-1 T4	√	√	√	√	√	√

Legend: good; acceptable; unacceptable

DISCUSSION

The paste 33-76-1 performed very well at voiding and HIP under air. Good voiding demands good wetting [5,6], and good HIP need good oxidation barrier capability plus good fluxing capacity [7]. The good wetting and good fluxing capacity is consistent with the wetting performance results observed. In the mean time, the good SIR performance with wet flux residue demands low activator concentration or low corrosivity in the flux residue. The dilemma between good soldering performance and low corrosivity can only be resolved with a breakthrough in flux technology, as demonstrated by 33-76-1 here.

SUMMARY

The performance of those pastes can be summarized in Table 5. For SIR - glass slide on, 33-76-1 was the only one performed well. All solder pastes had at least two features unacceptable, except 33-76-1. This newly developed paste performed very well on all features, and marginally well on wetting under air.

Even for that feature, 33-76-1 still matched paste C which is widely accepted by industry for air reflow process.

CONCLUSION

The miniaturization trend is driving industry to adopting low standoff components or components in cavity. The cost reduction pressure is pushing telecommunication industry to combine assembly of components and electromagnetic shield in one single reflow process. As a result, the flux outgassing/drying is getting very difficult for devices due to poor venting channel. This resulted in insufficiently dried/burnt-off flux residue. For a properly formulated flux, the remaining flux activity posed no issue in a dried flux residue for no-clean process. However, when venting channel is blocked, not only solvents remain, but also activators could not be burnt off. The presence of solvents allows mobility of active ingredients and the associated corrosion, thus poses a major threat to the reliability. In this work, a new halogen-free no-clean SnAgCu solder paste, 33-76-1, has been developed. This solder paste exhibited SIR value above the IPC spec 100 MΩ without any dendrite formation, even with a wet flux residue on the comb pattern. The wet flux residue was caused by covering the comb pattern with 10 mm × 10 mm glass slide during reflow and SIR testing in order to mimic the poorly vented low standoff components. The paste 33-76-1 also showed very good SMT assembly performance, including voiding of QFN and HIP resistance. The wetting ability of paste 33-76-1 was very good under nitrogen. For air reflow, 33-76-1 still matched paste C which is widely accepted by industry for air reflow process. The above good performance on both non-corrosivity with wet flux residue and robust SMT process can only be accomplished through a breakthrough in flux technology.

Table 4. Head-in-pillow test for various solder pastes.

Sample	After preheated at 200C/2 min, time of paste at 240C before placing ball						
	0 s	20 s	40 s	60 s	80 s	100 s	120 s
A					coalesced	marginal	HIP
B						coalesced	marginal
C	coalesced	HIP			—	—	—
D	marginal	HIP			—	—	—
E		coalesced	marginal	HIP			
33-76-1					coalesced	HIP	

Legend: coalesced; coalesced with oxide film impression discernible; failed to coalesce, HIP

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