ENGINEERED FLUX FOR LOW TEMPERATURE SOLDERS

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ABSTRACT
Low temperature solders are becoming more common in surface mount assembly. Critical SMT components cannot handle the temperatures used for lead-free soldering which typically reaches 240 – 250 °C. Sensitive critical components might be damaged by these high temperatures. High temperatures can also cause warpage and other damage to the assembly. Low temperature solder alloys can be used in many forms including solder paste, wire solder, pre-forms, and bar solder. The main motivation of low temperature soldering is driven by faster technology scaling, reduced energy and emissions. Increasing demand in electronics assembly materials like low temperature solder paste to meet and fulfil the requirements of today's rapidly changing technology requires major innovation in developing new chemistry platform. A new and innovative chemistry platform needs versatile, multifunction capable chemical molecules as its building blocks to achieve desired solder paste processing properties. To achieve desired properties, a carefully engineered paste flux is used to study high speed printing and reflow properties of low temperature solders. The effect of viscosity and thixotropic index on high speed printability, reflow properties and other warpage defects like non- wet open (NWO) and head in pillow (HIP) were also compared to conventional flux system for low temperature solders. Fine feature printability is evaluated in both low (50mm/sec) and high speed (150mm/sec) printing methods to demonstrate the capability of newly engineered flux system.

Further, low temperature solders are finding its importance in fine feature application for advance packaging applications. The newly engineered flux is studied with finer particle size (Type 5) for printability, reflow ability and solder ability along with warpage defects and large area pad voids.

Key words: Engineered Flux, Low temperature solders, High speed printability, Critical properties

INTRODUCTION

Flux for solder paste technology came long way and needs lot of improvement to fulfil today's growing electronic market requirement. Consumer, domestic including automotive electronics are undergoing miniaturization. To successful solder smallest SMT components with low temperature solders requires flux. The required flux should be capable of fulfilling requirements such as better wetting, fine feature printability with excellent product stability. The flux also should be capable of minimizing warpage defects like non wet open (NWO) and head in pillow (HIP) defects with post reflow residue quality to meet in circuit test (ICT) requirement for all the needed electronic assemblies.

The final properties of the solder paste depend on the type of chemistry and flux constituents. Rosin/resin, solvents, activator and other additives as main constituents in flux determine several solder paste properties like wettability, rheology, stability and tackiness of the paste. As the electronic market advances mainly in miniaturization, manufacturers started seeing many defects such as head in pillow, non-wet open defects in case of very thin packages. Initially it was very difficult to solve these defects by adjusting processing parameters such as reflow profile and paste printing. These problems were solved to a certain extent by optimizing process conditions, but they could not be completely eliminated. So, a lot of research is under progress in solving these defects by chemistry by utilizing new molecules as building blocks in developing next generation flux. Solder paste printability is another biggest challenge when it comes to high speed printing as it increases productivity of manufacturing. High speed printing for fine feature applications in consumer electronic devices like mobile phone and tablet PC's is gaining more importance. SMT assembly manufacturers are looking for the solder paste which meets the requirement of high speed printing with other key properties of the solder paste.

To satisfy all the above said requirements of the market, there is a need of advanced and carefully engineered flux for low temperature solders. The authors have made an effort to study today's solder paste critical requirement properties with new chemistry platform

EXPERIMENTAL WORK

Considerations for selection of new chemicals for flux

General components of the flux are rosin, resins, solvents, organic activators and other compounds needed to achieve the targeted paste properties. A proper attention should be given when selecting a new chemical for flux development for low temperature alloys. The melting temperature of most of industry standard low temperature alloys (the high Bi alloys) is in the range of 138C to 160°C which is almost 70°C less than standard SAC alloys. Most of the chemical building blocks for developing flux for SAC alloys may not be suitable for low temperature alloys.

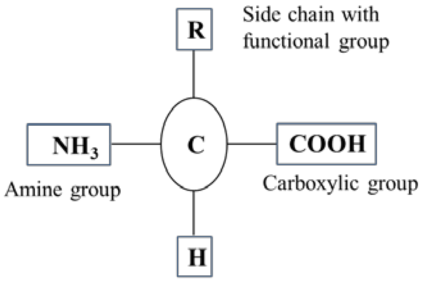


Figure 1. General chemical structure of Amino acid

Activators based on amino acids with lower melting temperature were selected and used to develop flux along with dicarboxylic acid activators. In addition, compatible organic solvents, rheology modifiers and other required additives were used to develop flux for low temperature alloy. General chemical structure of amino acid is presented in Figure 1.

Flux and solder paste preparation

All the required organic components were mixed and subsequently milled to ensure homogeneity of flux. The same flux is blended with low temperature alloy powder by using paste mixer. The powder particles size was in the range of 15-25 microns (Type 5). The different paste flux variations used for the current study are presented in following Table 1.

Table 1. Solder paste formulations

Flux components	Material	Formulations			
		Conventional paste	SP1	SP2	SP3
Rosins	Rosin 1	31			
	Rosin 2	13			
	Rosin 3		25	25	25
	Rosin 4		13	13	13
	Rosin 5				
Solvents	Solvent 1	22	28	28	28
	Solvent 2	21	12	12	12
	Solvent 3				
Activators	Activator 1	7	2		
	Activator 2		5	2	
	Activator 3		3	5	2
	Activator 4			3	5
	Activator 5				3
Aditives	Aditive 1	6	6	6	6
	Aditive 2		6	6	6
Total		100	100	100	100

Three paste fluxes SP1, SP2 and SP3 were prepared by standard flux manufacturing method and corresponding solder paste were prepared by blending with 88 % LTS powder HRL1 in paste blender. The viscosity and Thixotropic Index were measured by using Malcom viscometer. The viscosity and thixotropic index data for all the solder pastes are given in Table 2.

Table 2. Viscosity, Thixotropic index and metal content

Solder Paste	Viscosity	Metal Content	Thixotropic Index
SP1	M12	88	0.6
SP2	M14	88	0.61
SP3	M20	88	0.61

Solder paste stability

Solder paste stability is measured by continuous viscosity method using Malcom viscometer. The viscosity is measured up to 96 hrs to ensure there are no interactions that will lead to a rheology change.

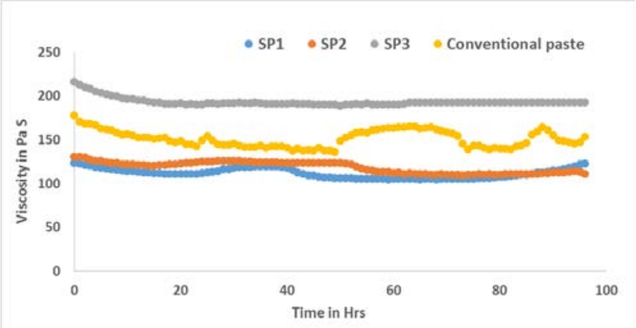


Figure 2. Continuous viscosity stability data

Three solder pastes SP1, SP2 and SP3 showed good stability over the period of 96 hrs continuous viscosity measurement test. The continuous viscosity measurement date up to 96hrs is presented in figure 2.

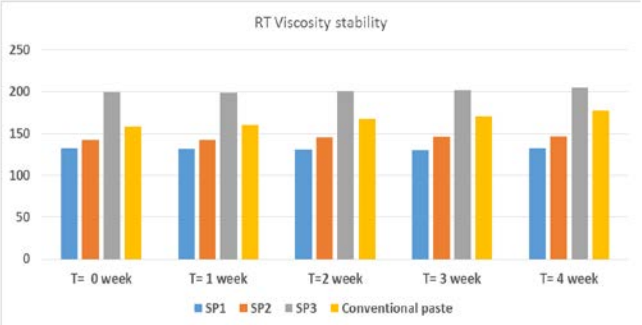


Figure 3. Viscosity stability at RT

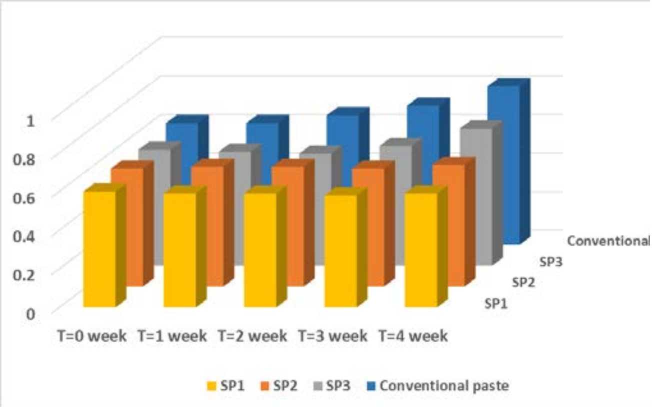


Figure 4. Thixotropic index stability at RT

Room temperature stability data of all the pastes were presented in Figure 3. It is evident from the data that the pastes with engineered flux SP1, SP2 and SP3 are found to be very stable at room temperature (28C) compared to the conventional chemistry platform based solder paste.

Thixotropic index (TI) of the conventional solder paste is found to be increased with time (Figure 4) whereas the solder pastes SP1 and SP2 found very stable. SP3 showed slight increment in TI from 3rd week onwards.

Solder ability performance

Solder ability performance of the solder pastes were measured by Random Solder Ball Test (RSB) as per JIS standard. Solder pastes with newly engineered flux showed improved coalescence performance compared to the conventional solder paste.

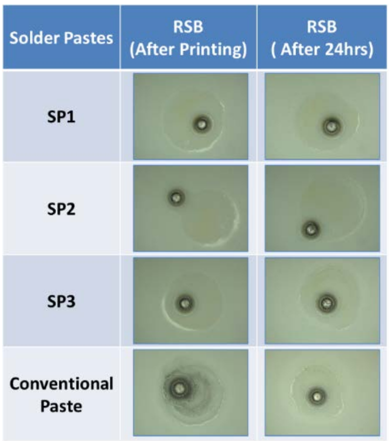


Figure 5. Solder ability comparison

Coalescence test for engineered solder pastes were tested on a ceramic coupon by printing with 8 mil stencil thickness and 6mm print deposit size. The results were found to be good compared. The conventional solder paste shows some solder balls. The coalescence results are given in figure 5.

Warpage defects

Organic flux in solder paste helps to remove the coatings on PCB's pads and make the metal surfaces active and wettable by the solder alloy. In the SMT process, flux promotes wetting of the surfaces to be joined by controlling the surface tension that determines the wetting process. Additionally, paste flux provides the right rheology for paste printability, tack, and slump characteristics.

When developing paste flux for LT solder paste, the rosins/ synthetic resins are generally chosen based on their softening temperature. Above its softening temperature, a rosins/synthetic resins will not be very tacky and the melt viscosity of the rosin/synthetic organic resins will drop significantly. To have proper tackiness and flexibility at both processing temperature and elevated temperature, synthetically modified organic resins were used. These organic resins can solve the expected warpage defects associated with LT solder paste.

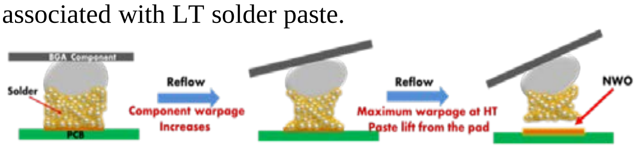


Figure 6: Mechanism of formation of NWO defect

When low softening temperature tackifiers with synthetic organic resin containing solder paste is printed and reflowed in reflow oven with assembled package, a large amount of warpage is expected at elevated temperature (at peak reflow temperature) and the thin package will be lifted from the pad along with the printed solder paste. The solder paste has affinity to stick to the solder ball of the thin package as solder material is having Sn as one of the major constituent. The formation of non-wet defect is due to the deficiency of tackiness and flexibility of the flux used for solder paste at elevated temperature. Low softening temperature rosins/resins does not possess high tackiness and also they exhibit lower viscosity at elevated temperature. So the formation of non-wet open defect is attributed to low tackiness and low flexibility of the solder paste at higher reflow temperature.

The mechanism of non wet open defect formation is presented in Figure 6.

When high softening temperature tackifiers with synthetic organic resin is used in solder paste, the corresponding solder paste will have minimum chances of exhibiting non wet open defects due to its high melt viscosity, high tackiness and high flexibility at elevated temperature. Solder paste is likely to hold firmly both pad and the component in reflow process at elevated temperature during components maximum warpage condition. At this stage the solder paste will stretch as the package undergoes warpage and the same paste stretching continues till the reflow process complete (Figure 7).

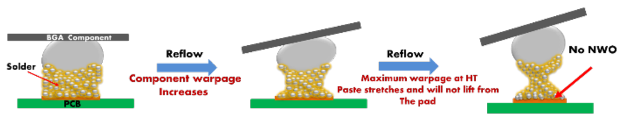


Figure 7. NWO minimizing mechanism with high softening temperature rosin

In the cooling zone the molten solder under goes solidification by forming a strong solder joint with the pad by eliminating the formation of non-wet open defects. Hence high softening temperature rosin with synthetic resins have the potential to minimize these defects when they employed in developing solder paste formulation.

Schematic representation of synthetic organic resins effect on minimizing non wet open defects in low temperature solders is presented in Figure 8.

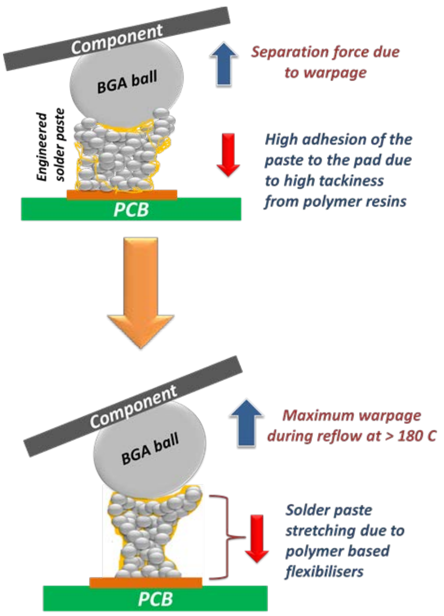


Figure 8. Schematic representation of minimizing non wet open defects

The non wet open defects were tested for both conventional and engineered pastes by using BGA 256 component. New chemistry platform based solder pastes SP1, SP2 and SP3 showed very minimum defects when compared to the solder paste with conventional chemistry platform. The results are presented in Figure 9.

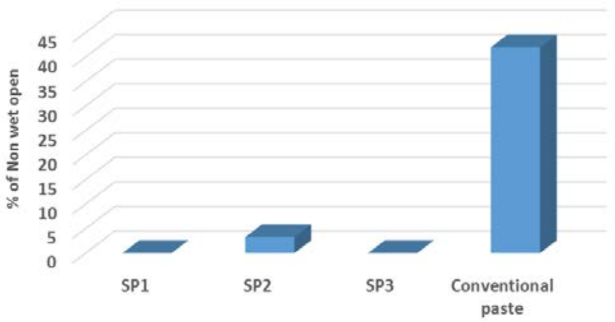


Figure 9. Non wet open defects

Pin testability

ICT (In Circuit Test) is very important to meet and qualify the solder paste for current market requirement. ICT is defined as In-circuit test (ICT) where an electrical probe tests a populated printed circuit board (PCB), checking for shorts, opens, resistance, capacitance, and other basic quantities which will show whether the assembly was correctly fabricated. It may be performed with a bed of nails type test fixture and specialist test equipment, or with a fixtureless in-circuit test setup.

The ICT performance is directly proportional to the amount of residue present on the PCB after reflow. If the residue present is more on the solder joint, the ICT is likely to fail. The residue on the PCB after reflow is formed from the organic flux and the amount of residue depends on the total solid content in the flux. As the rosin/resin is the major solid content of the flux, the amount of residue on the reflowed PCB depends on the content of the rosin/synthetic resin. The majority of the residue becomes hard/brittle after reflow and forms impenetrable residue on the solder joint. If the residue is not penetrable, the probe of ICT cannot make a contact with solder and may result in ultimate failure of the test. Though not much literature is available on the type of residue to achieve maximum probable or pin testable paste, the summary below presented is based on the in-house experience of achieving the best in class pin/probable paste.

No-clean flux residues do not vaporize completely in the reflow process. The solvent component of the flux system may be removed to some extent but the resins used in the make-up of the flux will remain. Resins could be rosin based, modified rosin or synthetic in nature. Higher temperature or long time above the liquidus of the solder will also tend to oxidize the residues and render them harder to probe. Often as time elapses, after reflow the residues will tend to harden in time. Flux residues can be categorized as soft, brittle, and sticky but this depends mostly on the formulation of the flux and the type of resins/rosins and the solvents used to make it. Flux residues will require specific probe designs and pin pressures to ensure penetration. A solid maintenance program to clean the probes needs to be developed also as to avoid false failures. Different solder pastes will have flux residues that will be more probe-able than others.

Hard and brittle type residue

This type of residue can occur by using any unmodified, disproportionate type of rosin. This type of residue can also occur by the chemical reaction with other ingredients of organic flux contents like activators, etc.

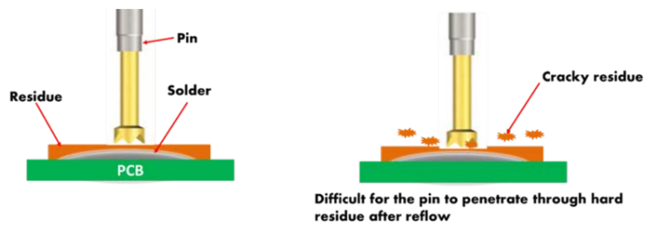


Figure 10. Impact of hard and brittle type residue on ICT

When the probe tried to make a contact with the solder joint, the hard and crack type residue (Figure 10) will not allow the probe to have a contact. Image (a) clearly shows the hard and crack type residue accumulated on tip of the pin. The hard residue on top of solder is also less brittle in nature and can cause ICT to fail instantly.

Soft and tacky type residue

This type of residue is the result of using any modified rosin in the flux formulations. The residue appears to be soft and penetrable by the probe but tacky in nature. The tackiness of the residue can also contribute in failing the ICT. The mechanism of ICT failure with this type of flux is presented in Figure 11.

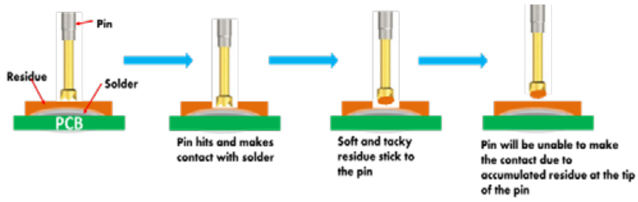


Figure 11. Impact of soft and tacky residue on ICT

Beginning of the test, the probe of ICT can easily penetrate and can make a contact with solder comfortably. As the test progresses the residue which is tacky can stick to the probe and further the probe of ICT cannot make a contact due to the accumulation of tacky residue at the tip of the probe as shown in image (b). This type of residue can also results in failure in ICT due to high tackiness of the residue. The high tackiness of the residue is due to the incomplete evaporation of the solvent and the presence of more VOC even after reflow process along with modified rosin residue.

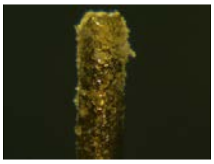


Image (a)

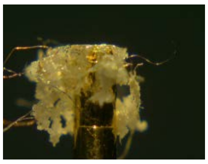


Image (b)

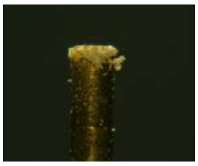


Image (c)

Soft, flexible and non-tacky type residue

This type of residue after reflow process is found to be soft. The best pin/probable residue can be further achieved by employing flexibilisers in the flux formulation. The mechanism of achieving best pin testable post reflow residue is presented in Figure 12.

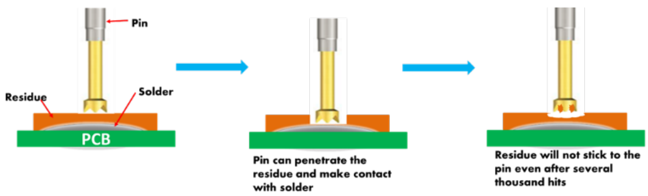


Figure 12. Impact of soft and non tack type residue

Soft and non-tacky type of residue have higher yield in ICT as the residue allows probe of ICT to make a contact without any difficult to achieve several thousand contacts by the same probe. Due to non tacky nature of flux, we observed less flux residue deposition on tip of the probe after testing which is presented in Image C.

Figure 13. Pin testing performance

The results of pin testability of both conventional paste and engineered pastes are presented in Figure 13. The solder pastes post reflow residues of SP1, SP2 and SP3 were found very less on the probe and non tacky in nature. The conventional chemistry based post reflow residue was more on tip of the probe and it was very brittle and non-tacky in nature. The brittleness is due the presence of conventional and non modified rosins in the formulation. The reason for having better pin testability of engineered paste can be attributed to the presence of several modified rosin along with synthetic resin.

The amount of post reflow residue deposited from all of the solder pastes after pin testability is presented in Figure 14.

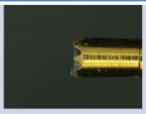
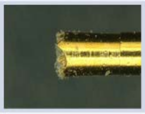
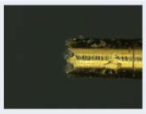
Solder Pastes	Top view of the probe	Side view of the probe
SP1		
SP2		
SP3		
Conventional Paste		

Figure 14. Probe images after pin testing

Printability

Printability of all the three solder pastes were studied at three different speeds at 50, 100 and 150 mm print speed per second. To compare, conventional chemistry platform based solder paste is also studied and the printability data for all the pastes are given below. For printability studies, DEK horizon printer is used with 4 mil stencil thickness. For measuring print volume of solder paste, Koh Young 8030 is used.

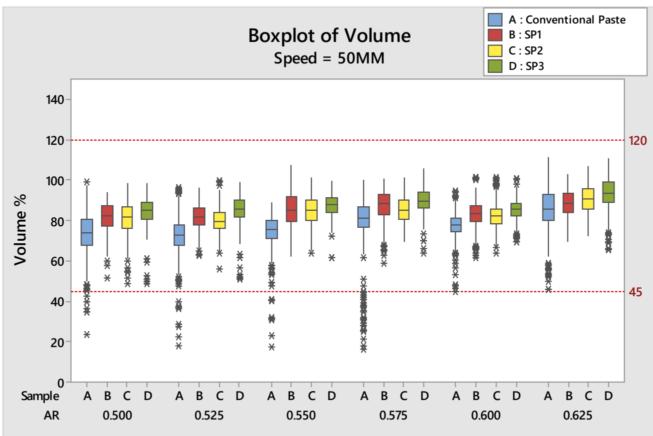


Figure 15. Printability at 50mm speed

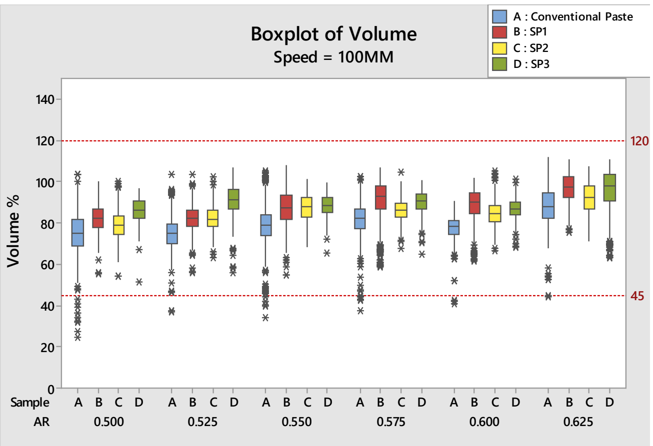


Figure 16. Printability at 100mm speed

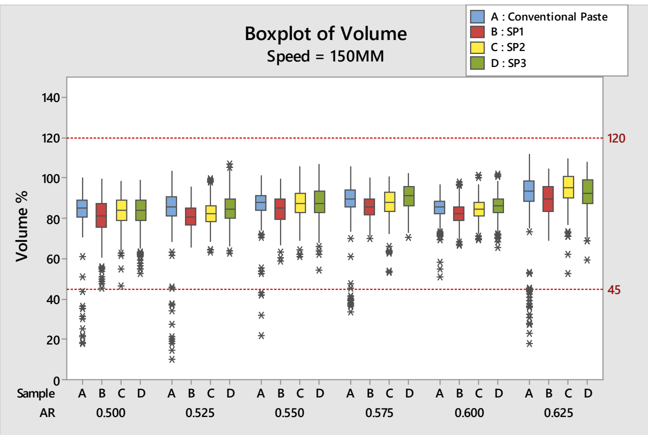


Figure 17. Printability at 150mm speed

From the above Figures (15, 16 & 17), it is evident that the engineered paste print performance is found to be better than conventional paste. In all the three print speed, engineered pastes transfer efficiency percentage was found to be better with different print speed and area ratio from 0.5 to 0.625.

Further the pastes were checked for print consistency and transferability for circle and square pads. The pad size of both circle and square pads were 0.2mm to 0.25mm. The results are presented in Figure 18. 19 and 20.

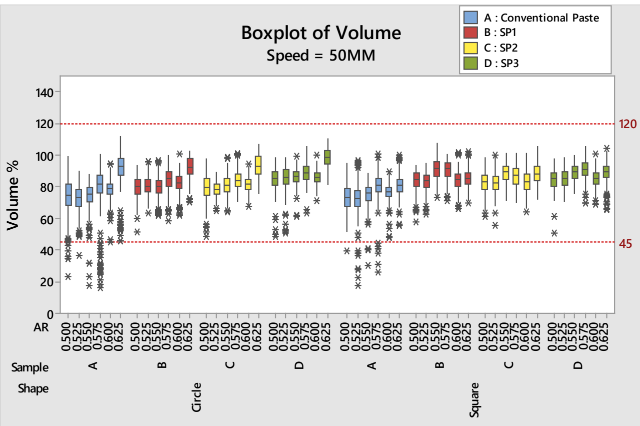


Figure 18. Printability at 50mm speed

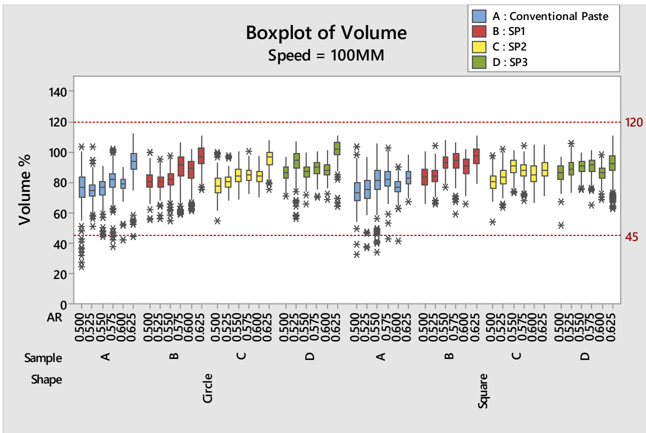


Figure 19. Printability at 100mm speed

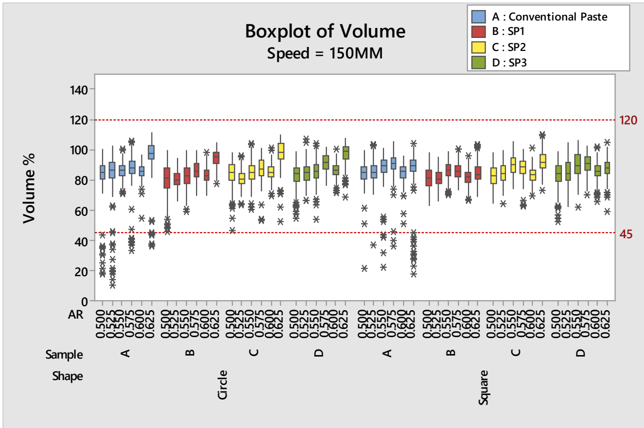


Figure 20. Printability at 150mm speed

The low temperature solder pastes SP1, SP2 and SP3 showed better printability and showed good transfer efficiency in all the three print speeds. It was also found that the transfer efficiency of the solder pastes was very consistent from area ratio 0.5 to 0.625 for both square and circle pads compared to conventional solder paste.

Large area pads voiding

Large area pads for engineered solder pastes and conventional solder paste is determined by using MLF-100. The voiding images all the solder paste samples are presented in Figure 21. We observed that the solder pastes SP1, SP2 and SP3 void percentage was low compared to conventional solder paste. New chemistry which we used for soldering low temperature alloy is found to be better for reducing void % of large area pads and the paste can make much better solder joints compared to conventional chemistry.

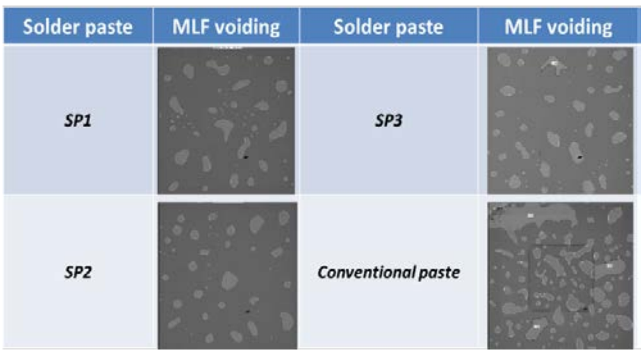


Figure 21. MLF-100 void images of solder pastes

CONCLUSION AND KEY TAKEAWAYS

In the current work, we have summarized the advantage of engineered flux for low temperature solders in achieving critical properties of the solder paste. The conclusions of this work is as follows

- Warpage defect (Non wet open) of solder pastes (SP1, SP2 and SP3) with engineered paste flux is minimum to zero compared to conventional chemistry based solder paste.
- Solder pastes with advanced chemistry platform showed good stability in terms of viscosity. Solder pastes SP1, SP2 and SP3 showed good stability at room temperature compared to conventional solder paste.
- Based on the pin testability data, it was evident that the new chemistry platform is found to be better than the conventional chemistry platform. It was observed that the residue generated by new chemistry platform is found to be non tacky and flexible which allows good yield in circuit test.
- On comparing the data of non wet open and ICT, It was demonstrated that the pastes with different viscosity with same metal % by maintaining same thixotropic index of around 0.6 has no effect on the performance of the solder paste.
- Based on the printability data, it was confirmed that the lower viscosity solder paste (SP1) can be able to achieve excellent printability and transfer efficiency by having right thixotropic index.
- Printability and paste transfer efficiency studies of the solder paste with engineered paste flux showed that the paste with any viscosity range can be printable by maintaining a proper thixotropic index of the solder paste.
- Newly developed chemistry platforms for low temperature solder alloy enable better assembly with very minimum defects compared to conventional chemistry platform. From our study, it is very evident that the new chemistry platforms with advanced chemical molecules are very much required to meet the requirements of SMT industry.

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