

How to use the right flux for the selective soldering application

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Abstract

The selective soldering application requires a combination of performance attributes that traditional liquid fluxes designed for wave soldering applications cannot fulfill. First the flux deposition on the board needs to be carefully controlled: proper fine tuning of the flux physicochemical characteristics combined with a process optimization are mandatory to strike the right balance between solderability and reliability. However, localization of the flux residue through the drop jet process is not enough to guarantee the expected performance level. The flux needs to be designed to minimize the impact of unavoidable spreading and splashing events. From this perspective a fundamental understanding of the relationships between formulation and reliability is critical. In this application, thermal history of the flux residues (from room temperature to solder liquidus) is a key performance driver. Finally, it is necessary to conduct statistically designed experiments on industrial selective soldering machines in order to map the relationships between flux characteristics and selective process friendliness. In this area, multiple performance attributes will be considered: compatibility with drop jet dispensing (clogging effects, cleaning frequency, and satellite formation), spreading (in actual processing conditions, with multiple solder resist types) and soldering performance as measured by barrel filling and defect production in challenging thermal conditions. Therefore, a strong partnership between the flux designer and the equipment manufacturer is a key component of a robust flux design for selective soldering.

Introduction

The design of fluxes for a selective soldering applications pose unique problems due to the localization of the soldering process. Both the heat treatment and the scrubbing action of the flux residue by the solder wave are confined in the soldered area. In order to address this specific issue, the flux formulator follows two complementary strategies.

First, the physical characteristics of the flux are optimized in synergy with the application process to minimize its footprint on the board. The flux must work in concert with the drop jet dispensing head to flow seamlessly (e.g. no clogging) during the entire operation, localize the deposit and finally stay in place. The dispensing process parameters (Open time, Frequency, Robot Speed) as well as the board preheat temperature are critical parameters [1], and their optimal settings depend upon the characteristics of the flux (viscosity, surface tension, solid content, solvent). Assembly materials also play an important part, as the optimal surface energy of the solder mask is typically lower than that for the conventional wave soldering process (35mN/m vs >50mN/m) in order to prevent excessive bleeding of the flux on the board after deposition. Hence, the design of a selective soldering flux is a good illustration of the mandatory collaboration between the formulators, equipment and assembly materials manufacturers from the very beginning of the design process. We have partnered with tier-1 selective wave soldering equipment manufacturers to design a process friendly flux adapted to industry representative printed circuit board materials and layouts.

Second, the flux chemical package is formulated to minimize the impact of unavoidable spreading and splashing events. These will result in partially heated flux residues which won't be removed by the washing action of the solder. As such, they pose a serious threat to the reliability of the assembly, as ionic residues can induce electrochemical migration, corrosion and resistance losses, which will invariably result in the in-field failure of the assembly when exposed to a moist environment [2, 3]. It is therefore of paramount importance to establish a correlation of the thermal history of the flux with the reliability of the residues. From this perspective, a series of activator packages has been designed specifically to guarantee an optimal reliability when partially heated [4]. The reliability of the fluxes designed for the selective soldering application was assessed using well known industry standards, where the flux was subjected to various thermal conditioning conditions (Table 1).

Table 1 – Flux Reliability Testing Methods

Reliability Test	Method	Condition	
Copper Mirror	IPC 2.3.32D	23C; 50%RH	
Copper Corrosion	IPC 2.6.15	40C; 93%RH	
SIR	IPC 2.6.3.7	40C; 90%RH	Pattern Up & Down
			80°C Preheat only
			Room Temp
	IPC 2.6.3.3	85C; 85%RH	Pattern Up & Down
			80°C Preheat
			Room Temp
ECM	IPC 2.6.14.1	65C; 88.5%RH	

A statistically significant experimental protocol was conducted on ERSA’s selective soldering equipment, in order to evaluate the impact of materials and process parameters on the following response factors: Dispensing performance (clogging and satellites), flux spread and soldering performance. The learnings from these experiments are reported in the following paragraphs.

Flux Spread

The spread is influenced by the surface tension of the flux, as well as its temperature. Alcohol based fluxes will have a much lower surface tension than VOC-free fluxes, which are water based (22mN/m at 25C vs. 72mN/m). Also, the dispensing temperature will tend to favor spreading by lowering the flux viscosity. On the other hand, the impact of the board preheat will depend on the nature of the flux: VOC-free fluxes tend to spread more on warmer boards, while alcohol based board will show an opposite trend, as the temperature thinning effect competes with the high drying rate of the flux. Finally, the surface energy of the solder mask is another critical parameter: lower surface Energies are favored for selective soldering fluxes compared to conventional wave soldering fluxes (35mN/m vs >50mN/m) to increase the contact angle of the flux on the substrate. This is easily understood when looking at the balance of surface tensions modeled in Young’s equation: $\gamma_{SG}=\gamma_{SL}+\gamma_{LG}\cos\theta$. It should be noted that the preheating of the board may impact the surface energy of the solder mask.

We estimate the intrinsic spreading of our fluxes by deposition on a representative set of printed circuit boards with various solder masks types. In contrast, in-process optimizations of the flux spread are conducted by directing the drop jet on the shiny side of an aluminum foil, which presents a comparable surface energy, and measuring the dried deposits after preheat as illustrated in Figure 1.

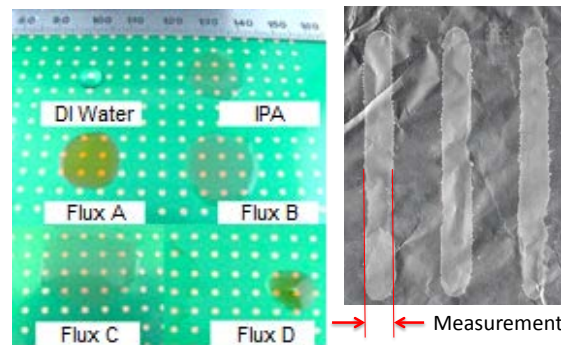


Figure 1 – Flux Spread measurement (Left: PCB, Right: Al foil)

Drop jet dispense: clogging and satellites

The high-frequency drop jet technology has been developed to narrow the spray pattern compared to atomizing-type aerosol spray heads or ultrasonic spray fluxers. The deflection of the flux droplets is minimized but occurrence of satellites is always a possibility: these very small flux droplets varying in sizes appear in random directions outside of the flux direct deposition corona. They depend on the flux physicochemical characteristics (viscoelastic properties, surface tension), hence its formulation, coupled with the jetting process itself. It is critical to mitigate the

formation of satellites, as these side deposits won't be exposed to the same heat cycle and solder scrubbing mechanism as the non-deflected droplets, and will therefore pose a serious threat of electrochemical migration under bias in a moist environment. Another processing issue frequently encountered during dispense is the clogging of the drop-jet fluxer, due to the narrow channels of the spray head (typically 130 μ m) combined with the high-volatility of alcohol-based selective soldering fluxes.

Both clogging and satellite formation are assessed during the same set of experiments, which enable us to screen our flux formulation efficiently on industrial selective soldering equipment. Fax paper is used to identify the location of geometry of droplets deposits. It should be noted that we typically avoid the use of fax paper for in-process spread measurement as the absorption of flux into the fabric of the substrate will result in an inaccurate representation of the flux spread data. The tests consist of successive deposition cycles executed at increasing time intervals. 20 dots are printed at 2s intervals in one cycle. This sequence is repeated 4 times, with 30s breaks between each cycle. The whole procedure is then repeated 4 times, this time with 15min breaks in between. The dot geometries and satellites positions are computed for the 500 dots deposited in total using an image analysis software. The successive breaks during the sequence make the procedure particularly aggressive: in our experience, a continuous flow of flux through the drop jet unit self-regenerates the head, while the breaks give time for the deposits to accumulate, ripen and create solid deposits on the side, which are more difficult to remove when the sequence is restarted. In consequence, fluxes can be efficiently discriminated through this experimental protocol. Figure 2 shows a representative set of deposition patterns obtained with various fluxes: the flux #2 deposition conditions were near perfect, while #10, #6 and #13 show multiple defects. One can observe that satellites and variations in surface area of the deposit often happen at the beginning of the sequence, where deposit concentration is at its maximum, which demonstrates that this effect is the major root cause for dispensing failures.

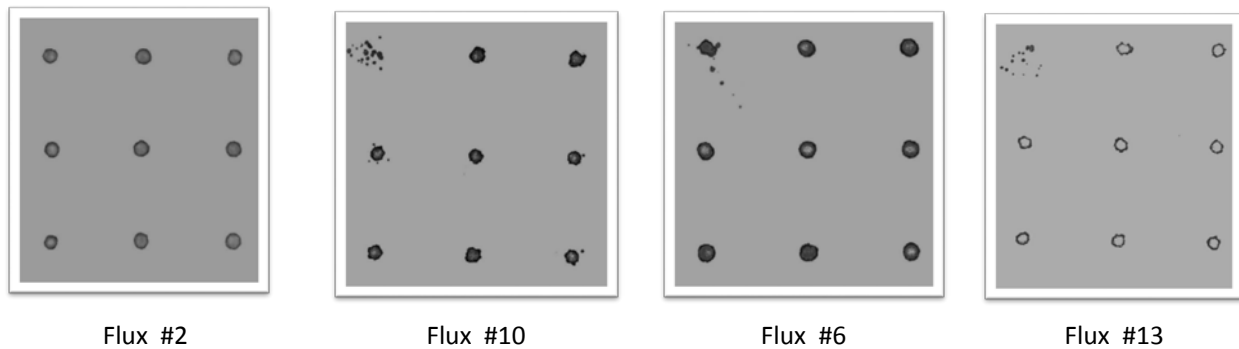


Figure 2 – Typical deposition patterns for the drop jet dispensing test

Overall, 15 Formulas were screened using the statistically significant set of data generated during these complex deposition sequences. Results of the deposition pattern analysis are reported in Figure 3. The efficiency of this screening method is confirmed, as large differences are observed between fluxes, in terms of uniformity of the deposits across the whole deposition sequence (Dot Area and Dot Circle), as well as the occurrence and spatial distribution of the satellites. Fluxes #1, 2, 3 and 4 present the best dispensing performance and were selected for the final soldering performance assessment.

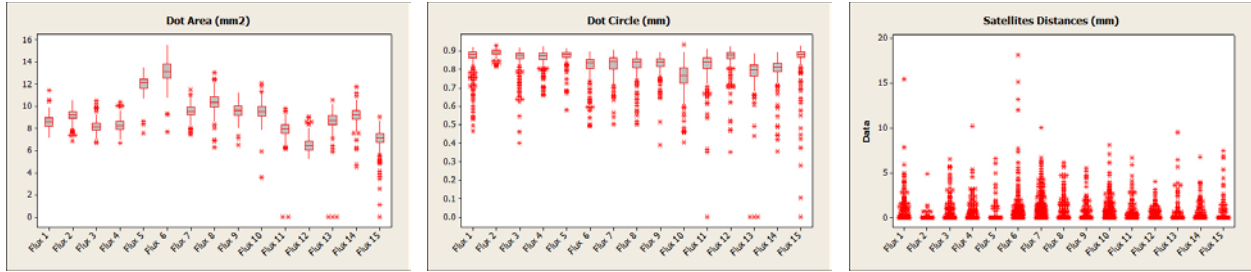


Figure 3 – Dispensing tests results for 15 experimental formula.
Statistical analysis of 500 data points per formula, collected through an image analysis software

Soldering Performance

A performance evaluation was completed on an industrial selective wave soldering machine from KURTZ ERSA (Figure 4), using 93 mils FR-4 boards made of 4 Copper layers (1/2/2/1 oz), solder mask over bare copper and an OSP finish (Figure 5). These boards were populated with 16 pins dual in-line packages (DIP) containing IC chips, and 96 pins Eurocard connectors.

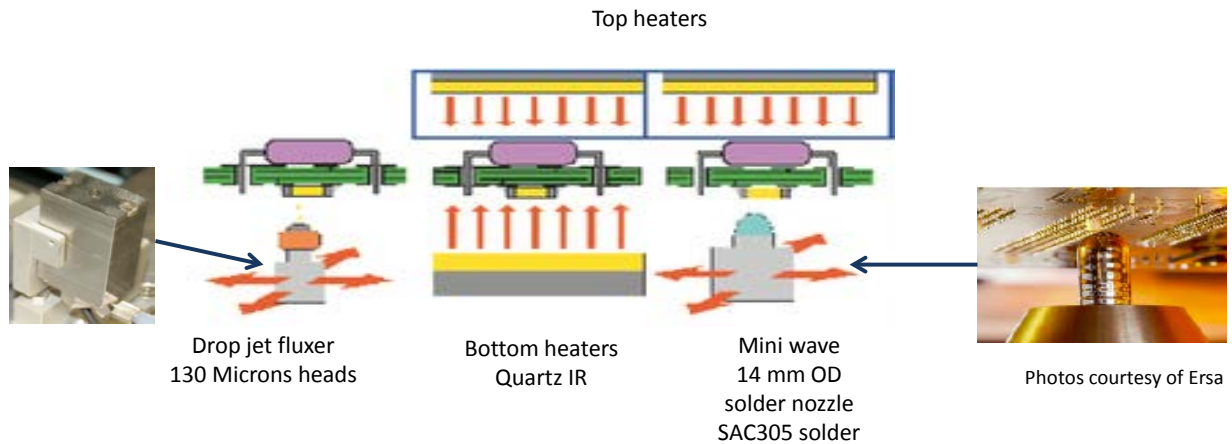


Figure 4 – Selective soldering equipment configuration

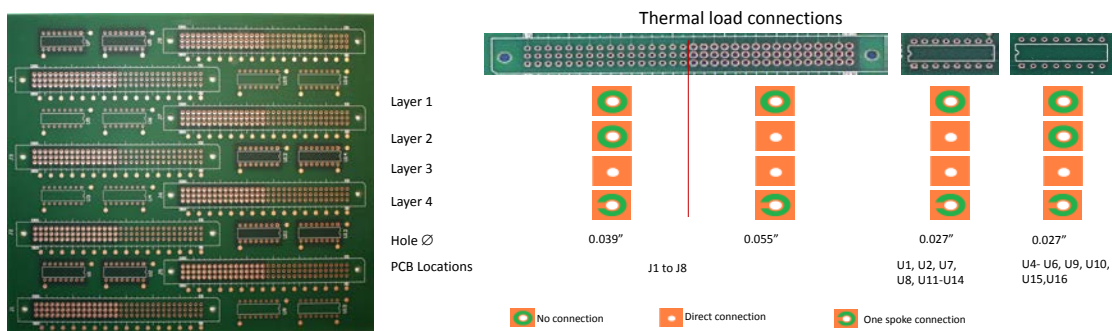


Figure 5 – Selective soldering testing board

To determine the soldering performances of the fluxes, the L16 Taguchi design of experiment reported in Table 2 was used.

Table 2 – Soldering Performance DOE parameters
Fixed Parameters: Solder bath: 290°C, Solder alloy: SAC305, Solder Nozzle: 10ID/14OD, wetted

Parameter	Level 1	Level 2	Level 3	Level 4
Flux Chemistries	Flux #1 10% solids	Flux #2 6% Solids	Flux #3 8% Solids	Flux #4 10% Solids
Flux Volume $\mu\text{l}/\text{cm}^2$	3	5.3		
Board Preheat Temperature	110°C	150°C		
Board Temperature Over the Solder Module	110°C	125°C		
Time In the Solder Module	300 sec.	720 sec.		

The response factors were flux spread (measured area), % hole fill (evaluated by X-Ray Diffraction), and the number of solder bridges and solder balls (visual count). The statistical analysis of the results is reported in figure 6: main effects are represented here, as second-order interactions were found to be statistically insignificant. All fluxes presented similar spreading results, the only impactful process parameter being the dispensed volume. Hole fill performance was found to be comparable between fluxes, while particular attention needs to be given to the board preheat temperature. This result is in good agreement with our background knowledge. Preheat times are relatively long in point-to-point selective soldering applications, which poses a challenge to the thermal stability of the activator packages. In this context, very satisfactory performance is found with all fluxes for a preheat temperature of 110C. More flux discrimination was found when considering soldering defects. Flux #1 clearly stands-out compared to the 3 other fluxes, with minimal defect rates observed in all conditions. The strong impact of board preheat temperature on defects confirms our initial interpretation on the activators thermal stability envelope.

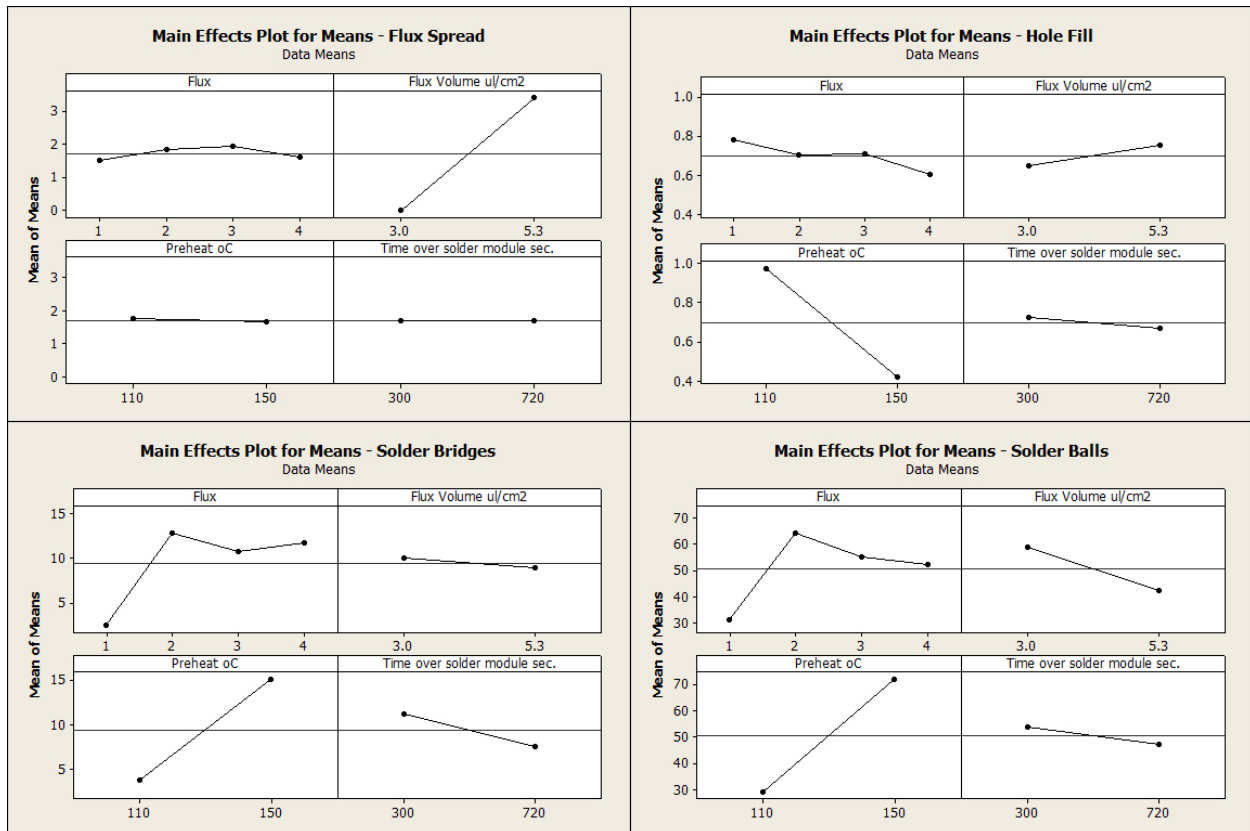


Figure 6 – Soldering Performance DOE results

Conclusion

The design of high-performance fluxes for selective soldering applications require a combination of formulation, application and equipment expertise which mandates a strong partnership between the flux designer and the equipment manufacturer. Multiple performance aspects have to be taken into account: the flux itself must have a proven reliability (corrosion, electrochemical migration) under various heat exposure condition, in particular when only partially activated. Having down selected a series of flux filling this requirement, it is necessary to conduct statistically designed experiments on industrial wave soldering machines in order to map the relationships between flux characteristics and selective process friendliness. In this area, multiple performance attributes will be considered: compatibility with drop jet dispensing (clogging effects, cleaning frequency, and satellite formation), spreading on the board (in actual processing conditions, with multiple solder resist types) and soldering performance (fluxing activity, thermal stability) as measured by barrel filling and defect production.

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