Defining the Correct Soldering Process

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The flexibility of the selective soldering process makes it a preferred method of soldering for new, innovative designs.

In the first two articles on selective soldering, we discussed the different processes ("Making Selective Soldering Work for You," September 2002) and how to keep track of the quality of the process ("Ensuring Reproducibility in Selective Soldering," October 2002). In this final article of our series, we focus on the correct characterization of soldering techniques for your new assembly.

Selective soldering is not only an alternative for wave soldering, but the process also offers new opportunities for designers and products. The process can solder displays, flat cables and various forms of odd components, as well as connect printed circuit boards (PCBs) to one another through soldering.

The automotive electronics industry has embraced selective soldering technology due to its excellent repeatability and high quality solder joints. The ability to have a robot system carry or position an assembly over a solder nozzle at different angles offers a new dimension in the soldering technique.

As the electronics industry moves toward miniaturization, reflow soldering has become the predominant mass soldering technology of choice; however, switches, connectors and some sockets must endure mechanical stresses that demand the robustness of a through-hole interconnection.[1] For some, the technique of pin-in-paste is inadequate or too expensive, and, for others, the temperatures required for reflow soldering are too high for particular applications.

While the soldering of certain through-hole components may be accomplished in many different ways, comparing the different processes and the costs involved is beneficial. Although soldering through-hole components may also be accomplished via hand soldering, this method often becomes irrelevant due to quality standard issues and costs. Today's assemblies are continuously changing, and engineers must review their processes with respect to new specifications, quality standards, lead-free introduction and miniaturization.

An assembly may be soldered in three ways: 1) wave soldering with pallets—pallets are specially designed for each assembly to protect the surface-mount device (SMD) components that have already been soldered; 2) drag soldering with the selective soldering machine—a robot grips the assembly and moves the board over a small, overflowing solder wave (selective wave); and 3) dip soldering with the selective soldering machine—the robot dips the assembly in a device that employs nozzles with flowing solder on the sites where through-holes are located (multiwave). All three in-line processes may be used for mass production, as well as for small batches.

Fluxing Techniques

Flux plays an important role in all three soldering processes. Flux prevents oxidation of the board during heating, and, at the end of the process, the flux still needs to have enough activity to prevent bridging when the assembly leaves the solder. To meet these requirements, certain issues must be considered regarding specific areas of the process:

- correct amount of flux to be supplied to the assembly
- equal deposition of flux over the area to be fluxed
- preheat temperatures needed to prepare the assembly for soldering
- solder temperatures and contact times
- cleaning after the soldering process.

Wave Soldering with Pallets

Many fluxes, with specific characteristics, have been designed for the wave soldering process. For a typical tin/lead soldering process, a no-clean flux with a solid content of approximately 2 percent is recommended. The flux should also offer good spreading characteristics and capillary action.

Flux spraying in wave soldering applications is accomplished with air atomized spray nozzles. Not all flux that leaves the nozzle will end up on the board. The spray patterns of the nozzles are

Alloy	Preheat			Solder pot		
	Zone 1	Zone 2	Zone 3	Solder temp.	Contact time chipwave	Contact time mainwave
Tin/lead	250°C	150°C	25%	250°C	0.5 sec.	2.9 sec.
Tin/silver/copper	450°C	180°C	25%	260°C	0.5 sec.	2.9 sec.

TABLE 1: Wave soldering with pallets machine settings.

Alloy	Preheat		Solder pot			
			Selective Wave		Multiwave	
	Zone 1 (% - time)	Zone 2 (% - time)	Solder temp.	Contact time	Solder temp.	Dip time
Tin/lead	80% - 40 sec.	-	280°C	1.5 sec.		
Tin/silver/copper	80% - 30 sec.	80% - 30 sec.	300°C	1.5 sec.		
Tin/lead	80% - 20 sec.	80% - 20 sec.			300°C	1.0 sec.
Tin/silver/copper	80% - 30 sec.	80% - 30 sec.			300°C	2.0 sec.

TABLE 2: Selective soldering machine settings.

round or elliptical—ensuring that any over-spray will occur at the front and rear sides of the assembly. Due to the atomization air, some flux will bounce back from the board.

For our tin/lead soldering experiment, a low solids, no-clean flux was selected. The flux required a preheat temperature of 70 to 100°C on the topside of the board just before soldering. The flux offered a density of 0.8 g/ml and a solid content of 1.5 percent. A VOC-free, water-based flux was chosen for the tin/silver/copper experiment. The flux required a preheat temperature of 100 to 130°C on the topside of the board just before soldering. The flux offered a density of 0.995 g/ml and a solid content of 1.8 percent.

The minimum amount of flux for the solder side of the tin/lead assembly is 1,600 µg/in^2. This amount was applied in the tin/lead experiment. For a no-clean, alcohol flux of 1.5 percent solids, the amount to apply on the test board is:

- Area board = 100 * 160 mm2 = 24.8 in2
- Amount of (wet) flux per board = solid content flux * area * required amount dry flux = 100/1.5 * 24.8 * 0.0016 = 2.645 g
- Amount of flux needed = density * (amount + 30 percent loss) * 2.645 = 0.8 * 1.3 * 2.645 = 2.751 ml/board

The amount of flux to be applied on the lead-free board is 40 percent less, as the chemistry of the flux dissolved in water is much more aggressive than when dissolved in alcohol:

- Amount of wet flux per board = 100/1.8 * 24.8 * 0.001 = 1.377 g
- Amount of flux needed = 0.997 * 1.3 * 1.377 = 1.784 ml/board

Selective Soldering

Selective soldering applications use drop-jet flux systems, since the amount of flux applied to the entire assembly is small. The sites to be fluxed are the areas of the board that will have contact with the molten solder—all other areas should not be fluxed. Since no typical selective soldering fluxes have yet been designed, and wave solder fluxes are also used in selective soldering, the same fluxes and amounts of flux used in wave soldering, per solder area, are used in selective soldering:

- Area to be soldered (tin/lead board) = 3 * (8*5) + 16 * 6 + 32 * 6 + 50 * 6 = 708 mm^2 = 1.097 in^2
- Required amount per board = 100/1.5 * 1.097 * 0.0016 = 0.117 g
- Amount of flux needed = 0.8 * 1.3 * 0.117 = 0.121 ml/board.
- Amount of flux needed (lead-free board) = 0.079 ml/board.

Soldering Processes

The next step in the soldering process is to dry the flux—evaporate the solvents in the flux and bring enough energy to the assembly to achieve good, filled solder joints. In one typical wave soldering machine, three zones of preheating, with a total length of 1,800 mm, exist. The preheat configuration of the machine is set up as follows: Zone 1: Calrod heater; Zone 2: forced convection heater; and Zone 3: infrared lamps.

The solder pot was fitted with a double wave former, and the solder temperature was set at 250°C for the tin/lead assembly. The wetting characteristics of lead-free alloys are less at the process temperatures than tin/lead due to the higher melting points of the alloys. To achieve good filling, the contact time and/or solder temperature should be increased. In this experiment, lead-free soldering was performed with SnAg3.8Cu0.5 at a temperature of 260°C. The higher temperature was enough to achieve good solder joint quality, so reducing the conveyor speed, which would have reduced the throughput of the assembly, was not required (Table 1).

The selective soldering machine was fitted with two zones of infrared lamps. The second zone is only used if the preheating defines the throughput. As long as the preheating time is not the bottleneck for the cycle time, the preheating may be accomplished with fewer units or power (Table 2).

In the selective wave tin/lead process, soldering takes longer than 40 seconds, so the preheating may be accomplished in one section or zone. In the multiwave process, the soldering time is shorter, so the preheating is split into two sections, reducing process cycle time.

Temperature profiles were made to identify the thermal effects of the processes to the components and materials used (Table 3, Figure 1). One thermocouple was mounted on the topside of the assembly, measuring the board temperature to verify that the flux requirements were being met (Table 4).

Process Throughput

In addition to quality performance, a process must deliver the required throughput. Although soldering is not the bottleneck in most assembly lines, soldering time is still important to the entire process. The test board contained 84 through-hole joints to be soldered (Figure 2). The average soldering time in hand soldering is 2.7 seconds. Due to a higher melting point and minor wetting, lead-free alloys are harder to solder by hand, resulting in an increase of the solder time to 3.5 seconds.

	Selective Wave		Multiwave		Wave Soldering	
Thermocouple	Tin/lead	Tin/silver/ copper	Tin/lead	Tin/silver/ copper	Tin/lead copper	Tin/silver/
Pin connector 1	136°C	151°C	132°C	151°C	145°C	166.5°C
Pin connector 2	159.5°C	178.5°C	161°C	182.5°C	168.5°C	185°C
Pin connector 3	128.5°C	148°C	139.5°C	161.5°C	137.5°C	161.5°C
Pin connector 4	186.5°C	177.5°C	-	-	164°C	184.5°C
Topside board	111°C	127°C	89°C	111°C	119.5°C	143.5°C
Elco	72°C	77°C	52.5°C	67.5°C	79°C	96°C

TABLE 3: Maximum temperature for the different thermocouples.

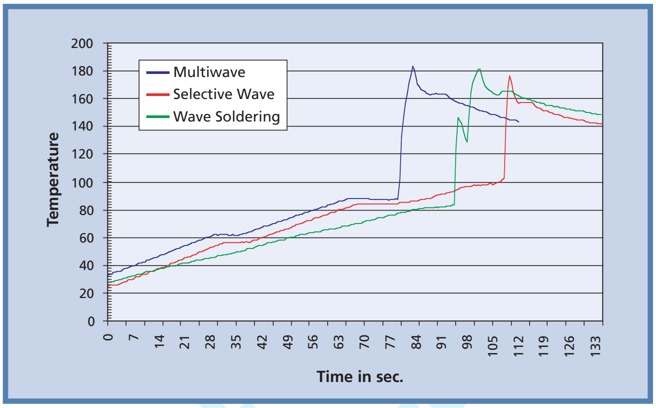

FIGURE 1: Time/temperature profile of a pin connector with the three types of lead-free soldering processes.

Selective Soldering

In the selective soldering machine, fluxing and preheating is performed in the conveyor area. Therefore, cycle times are defined by the section that requires the longest amount of time—the fluxing, the preheating or the soldering section (Figure 3).

In the tin/lead process, soldering takes the longest amount of time. For dragging over the selective wave, 59.3 seconds is required, and, for dipping on the multiwave, 27.4 seconds is needed. In the lead-free process, the solder time is still 59.3 seconds for the selective wave, since the assembly is soldered with the same speed (25 mm/sec.). For dip soldering, the preheating was extended (VOC water-based flux requires higher temperatures), resulting in a 36-second cycle time (30 seconds of preheat, plus 6 seconds of conveyor time).

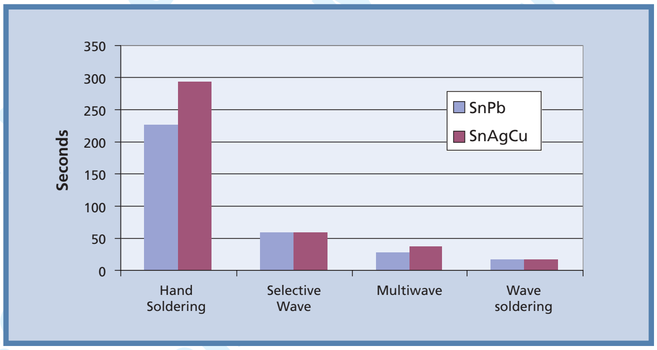

FIGURE 2: Cycle times for the test board (84 joints).

Wave Soldering

The conveyor speed during the soldering of the assembly is 20 mm/sec. (120 cm/min.). Leaving a space of 160 mm between each board results in a cycle time of 16.5 seconds in one wave soldering machine (Figure 3).

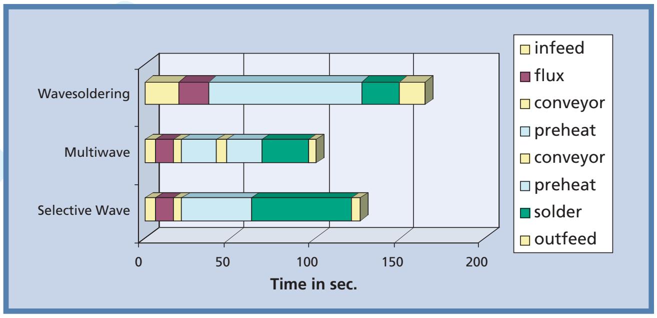

FIGURE 3: The time that an assembly is in process.

Cost Comparisons

Cost for the soldering processes can be divided into a number of categories: consumables (Table 5; flux, nitrogen, solder); labor (operators); investment (depreciation, interest for equipment and tools); and floor space. Numerous calculations are involved in this process, and the outcome depends on product-related labor costs and required cycle times. Special calculation modules may be made to determine the yearly cost versus the number of joints to be soldered for each process.

Cost of Labor and Operators

Labor calculations should include operator hours, programming time and maintenance time. For wave soldering with pallets, the logistic operation hours for the carriers (loading and unloading boards into the carrier, cleaning of the carriers) should also be included.

Cost of Investment

For a selective soldering machine, costs include: price of the machine; multiwave nozzle plate; selective wave nozzle and spare parts. For wave soldering, the cost of carriers should be included. One must realize that a minimum of carriers is required for every assembly. The lifetime of the carrier is also limited to approximately 20,000 cycles. Good pallets, depending on design and size, cost $200 to $1,000 each. The average handling time of a pallet is approximately 20 seconds.

Cost of Floor Space

The floor space needed for one selective soldering machine is about 5 m^3 compared to approximately 4 m^3 for a typical wave soldering machine. The floor space for one hand soldering station is about 2 m^3.

Making a general calculation of the breakeven point for the different soldering processes is not possible, as the cost of labor, nitrogen and floor space is region-specific. Nevertheless, in selective soldering, energy and labor costs are lower, as is the cost of flux, compared to wave soldering. The real savings, in comparison to hand soldering, are realized in defect reduction.

Topside Board Temp.	Preheat Zone 1	Preheat Zone 2	Preheat Zone 3	Soldering Maximum
Selective wave tin/lead	88°C	-	-	111°C
Selective wave tin/silver/copper	76°C	109.5°C	-	127°C
Multiwave tin/lead	59.5°C	87°C	-	89°C
Multiwave tin/silver/copper	78°C	110.5°C	-	111°C
Wave soldering tin/lead	36°C	65.5°C	90.5°C	119.5°C
Wave soldering tin/silver/copper	72.5°C	98°C	119°C	143.5°C

TABLE 4: Temperature of the thermocouple on the topside of the assembly for the different processes.

Material	Selective Wave	Multiwave	Wave Soldering
Flux $/100 test boards	$0.10	$0.10	$2.05
Nitrogen consumption l/min	50 l/min	120 l/min	120 l/min
Nitrogen $/hour ($0.15 /m^3)	$0.45	$1.08	$1.08
Solder/100 boards	$1.13	$1.13	$0.30
Dross (solder losses)/hour	$0.15	$0.30	$1.20
Power consumption, nominal	6.8 kWh	8 kWh	14 kWh
Power $/hour	$0.68	$0.80	$1.40

TABLE 5: Consumables found in tin/lead processes.

Conclusion

Selective soldering is a good alternative to wave soldering in pallets and offers a high degree of flexibility without the use of expensive carriers. Although wave soldering offers high throughput, the process has limitations in terms of the height of the already mounted and covered SMD components on the solder side of the board, which must be covered by the pallet. Separate from the high pallet and handling costs, the wave must be high enough to achieve adequate solder pressure in the apertures of the pallet. These wave heights, up to 12 mm, are more turbulent and result in increased dross—making a nitrogen blanket necessary.

Hand soldering is a manual operation and, therefore, prone to defects, such as excessive solder, inadequate hole fill, flux residues and thermal stresses at the solder joints. The high defect reduction justifies the higher price of the selective soldering machine when compared to the high labor costs of hand soldering.

The majority of products soldered on today's production lines contain, on average, 20 to 400 joints to be soldered. The high flexibility and programmability of the selective soldering process makes it a preferred method of soldering for new designs, while offering new opportunities for board designers. ■

Reference

1. 2002. Selective Soldering: Wave Soldering Redefined, Phil Zarrow, *Circuits Assembly*, February, p. 20.

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