

# Reliability Threats Fine Pitch Through Hole Soldering

Gerjan Diepstraten,  
Vitronics Soltec  
Oosterhout, Netherlands  
[gdiepstraten@vsww.com](mailto:gdiepstraten@vsww.com)

## ABSTRACT

Miniaturization continues in all kind of electronic assemblies and thus also in the different soldering processes. Not only consumer electronic assemblies become smaller, but also in other areas like automotive, industrial and medical parts reduce in size where functionality increases. No matter if products are assembled in high or small volumes soldering technology has to deal with finer pitch and higher accuracy of the soldering process. Small electronic assemblies contain mainly SMD components that are soldered with solder paste in a reflow oven. Traditional through hole soldering is replaced by surface mount devices nevertheless there are still some reasons to have through hole components instead of SMD's. The main two reasons are strength (reliability) and heat resistance. Some components like flex cables, LCD displays and other plastic parts just cannot withstand the high reflow temperatures of ~ 250 °C for a longer time. In order to meet the high temperatures of reflow special high temperature resistant plastics are required; making the parts more expensive.

This paper will discuss how this small through hole components can be soldered when assembled together with SMD's, either in a reflow oven or in a wave or selective soldering process.

Key words: Fine pitch, pin in paste, selective, wave soldering, bridging.

## INTRODUCTION

How assemblies should be soldered depends on several conditions. Apart from the selection between reflow and liquid soldering there are certain factors that defines the soldering method. The preferred method to solder a mixed assembly with SMD and through hole components is pin in paste (also called intrusive) reflow soldering. This process requires a dedicated stencil to print the solder paste.

If liquid soldering is selected there are more methods. In case of some prototyping hand soldering or better selective soldering with a small dedicated nozzle (fountain) is a fast method that doesn't come with additional tools.

In case of high volume processing fine pitch through hole mixed with SMD components there are 3 processes:

1. Reflow pin in paste
2. Wave soldering with pallets
3. Selective soldering

In hand soldering a consistent quality and process robustness fails and machine soldering is a must for many industries. Automotive also focusses on no rework. All different soldering methods have their challenges soldering the small fine pitch THT components especially avoiding rework.

## PIN IN PASTE REFLOW:

The first advantage using a pin in paste process is that all soldering processes are done in one step or in other words in approximately 4 minutes. Depending on the oven and PCB length typically every 20 seconds a board is soldered with mixed components.

What materials are needed to reflow solder THT components?

Basically similar solder paste can be used as soldering fine pitch SMD components. This includes a fine solder powder. Most likely powder type 4 is the best selection for fine pitch THT pin in paste. The solder paste has to meet some additional requirements.

For making a proper solder joint that meets IPC-A-610 requirements a good hole filling is one of the critical issues. This can only be achieved by overprinting solder paste (= solder paste is printed on solder mask and will coalescence into the barrel when melted).

The paste must have some properties to make it compatible with fine pitch pin in paste soldering. Two characteristics are critical:

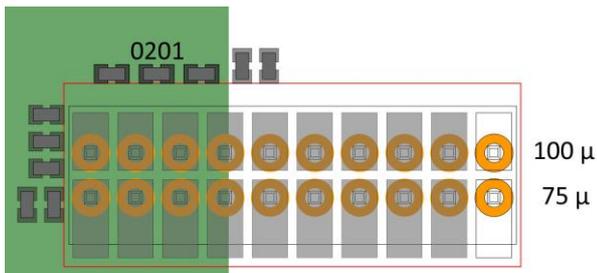
1. It should be a tacky paste (paste may drop of the component lead which makes it critical).
2. It should have excellent hot slump properties and ability to coalescence during time above liquidus.

Both characteristics will define the hole filling but also remaining solder balls is a phenomena that is not wanted. When the solder is not tacky during transportation in the oven solder paste may drop off the assembly and contaminate the oven. Because some solder paste is missing also the barrel will not be completely filled, result: the joint is not meeting the standard. If the solder paste coalesces not properly parts will remain on the solder mask and solder balls remain.

How much space is required for a 1.00 mm pitch THT for pin in paste applications?

Pin in paste requires a certain solder paste volume to fill the complete barrel with solder. Keep in mind that solder paste is only 50% alloy in volume. In order to fill a complete barrel 2x the amount of solder paste is therefore

required. Figure 1 shows the space for a 1.00 mm pitch 2 row 10 pins connector.



**Figure 1.** Schematic spacing for solder paste. Shown is the copper barrels (orange) with leads and the squares (grey) is solder paste. The red line shows the required free space.

The paste volume is defined by the aperture in the stencil and stencil thickness. For a 100% hole fill solder paste overprint over an area of 10.20 x 4.10 mm will be enough. More space is required if fine pitch is combined with large components. For these types of assemblies a step stencil might be necessary which requires additional space.

Requirements for fine pitch through hole components in a reflow process:

1. Used materials should be compatible with high reflow temperature conditions.
2. Protrusion length should be limited. Longer protrusion length will make it more difficult to get solder paste in the barrel. Solder paste might drip off or wet the pin and not the barrel.
3. Wettability of the lead finish should be compatible with lead-free alloy. Higher temperatures should not de-wet the surface.

Pin in paste reflow soldering fine pitch components up to 1.00 mm is feasible. To overcome poor hole fill design and stencil dimensions are critical. THT fine pitch components should have a limited lead protrusion length.

### WAVE SOLDERING WITH PALLETS:

Wave soldering is a most common method to solder THT components. Starting mixed applications (SMD and THT) many companies will use their existing equipment to manufacture and make dedicated pallets that cover SMD's on the solder side of the assembly.

Using pallets comes with some challenges. Each board requires its own designed pallet. For production one need more pallets since they need to cool down after soldering and one has to clean them after multiple soldering runs. In wave solder lines the complete pallet will be fluxed and contaminated. There is a demand to have only the solder areas covered with flux which requires a dedicated spray concept and software to do so.

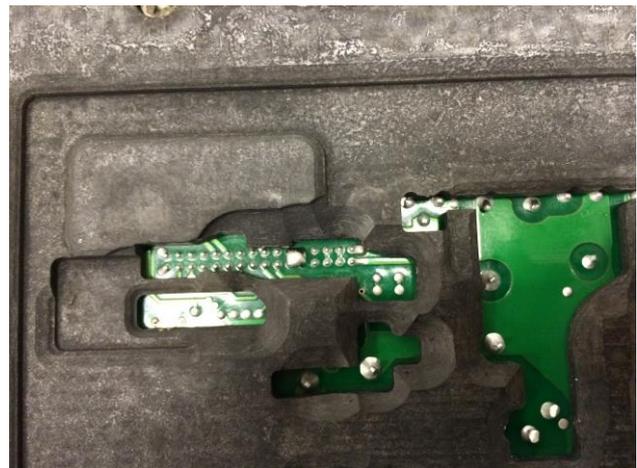
To cover the SMD's the thickness of the pallet will increase. If the small THT is surrounded by a lot of SMD components the aperture will be small and it will be hard to fill it with flux. With walls close to the barrels there is a risk that it will have insufficient flux because of shadow effects. To avoid this flux pressure needs to be high enough. If the board is not flat or when there is a small gap between the board and the pallet the flux will penetrate in the SMD areas. This will cause a potential

risk for electro migration, solder balls or excess of solder on the assembly.

The second problem using pallets is to get enough heat into it during the preheating. When only small components are used this will not be an issue, but in case of multilayers and a lot of copper layers it might get difficult. Once the board temperature is approximately 100 °C it is not difficult to get a sufficient hole filling for the small THT fine pitch.

The hole filling does very much depend on the design of the pallet. A small aperture is very hard to fill with solder and solder channels are required in the pallet. A larger opening will not only bring more heat into the solder area, but the solder can flow more laminate resulting less solder bridging and balls.

Small apertures may be better off with a turbulent wave former like a Wörthmann wave. This type of wave former will force the solder into these small apertures and doesn't have the shadow effect properties of a laminar wave former.



**Figure 2.** Typical selective wave solder pallet with small apertures with bridging on connector.

When all these problems with flux, preheating and getting solder to the barrels are overcome there is another challenge with the fine pitch THT connectors and that is the risk for bridging. The small pitch distance and longer leads makes it very difficult to eliminate bridging. Solder thieves as known for tin lead soldering applications doesn't work well with lead-free alloys. More successful will be soldering the connector under 45° angle towards the wave, but not all applications and designs makes this possible.

There are companies soldering 1.27 mm pitch THT connectors in pallets in today's production lines. The way they are successful is by limiting the lead protrusion length to maximum 0.5 mm. Shorter leads reduce the risk for bridging. The problem that may occur with very small lead lengths is that the solder end is not discernable in the solder. Manufacturers can cover this in the agreement with their customers.

Wave soldering fine pitch components up to 1.00 mm is feasible. To overcome bridging issues the protrusion length should be limited. The pallet design is the most critical factor.

### SELECTIVE SOLDERING MINI WAVE:

The most efficient method to solder small THT components in between SMD's is a selective soldering application using a small mini wave. Apart from the nozzle no dedicated tooling is needed.

Selective soldering processes require nitrogen. A small nozzle system consumes only 25 liters per minute enough to maintain an inert soldering environment that is required to prevent oxides on the solder.

Soldering with a mini wave contains three different solder methods:

1. Wettable nozzle (nozzle material attaches to solder making an intermetallic)
2. Non-wettable nozzle (stainless steel repels solder)
3. Non-wettable nozzle with PCB under an angle

So far soldering with wettable nozzles under an angle has not shown any additive value, but there might be some applications where this method is applied.

#### 1. Wettable nozzle:

Soldering with a wettable nozzle makes it possible to use very small nozzle diameters and enabling to come closer to small surrounded SMD components. There is a risk that the solder of the mini wave hits the solder paste of surrounded SMD's and re-melting of the paste may result in defects (drop off SMD's – missing components).

Dedicated nozzles are designed (so called bullet nozzles) for soldering small parts. Smaller diameters make the solder height less stable.



**Figure 3.** A bullet type nozzle made of wettable material.

Major advantage of a wettable nozzle is that the solder flows in all directions out of the nozzle. Therefore the PCB can be soldered without any rotation. The nozzle can approach the leads from any wanted direction.

Wettable nozzles need maintenance. Once the pump is switched off environment might become less inert and an oxidation layer may built up on the nozzle. Flux or special chemistry can be used to make it wettable again. The intermetallic layer that is formed between base metal of the nozzle and solder will grow overtime and finally result in wear.

A wettable nozzle is a part that needs to be replaced periodic which makes its performance critical – wear must be monitored continues as well as wettability. There is a potential risk for de-wetting of the nozzle during the process making the wave instable.

Many studies have been done to minimize the wear and still have good wetted material. The focus here is on the Carbon % in the steel. High quality materials can extend the lifetime of the wettable nozzles.



**Figure 4.** Nozzle showing de-wetting

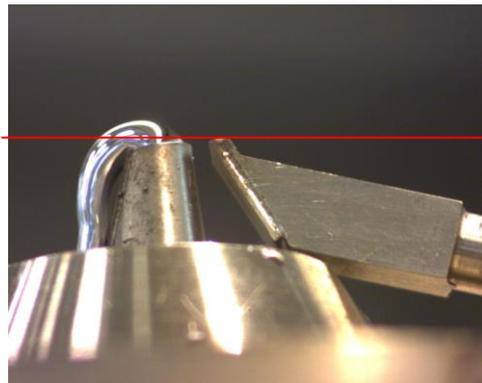
Selective soldering fine pitch components up to 1.00 mm using a wettable nozzle is feasible. To overcome bridging the protrusion length should be limited. The critical factor is the robustness of the wettable nozzle.

#### 2. Non-wettable nozzle:

Soldering with a non-wettable nozzle is a very consistent soldering process. The solder flows to one direction similar to a wave solder unit. Therefore the PCB or the solder pot must be able to rotate in order to solder the THT components that can be parallel or perpendicular mounted.

The nozzle materials are compatible with lead-free alloys. In general there is no wear concern and maintenance is limited. Because the solder flows only to the front side, this system requires more free space on the assembly to avoid contact with surrounded SMD components. The nozzle diameters are limited to 4 mm. For smaller nozzles it is very hard to get solder through without having an inconsistent wave height.

The bridging is an issue, but this can be avoided when there is an SDC (Solder Drainage Conditioner) installed on the opposite side of the flow direction. This small gas flow acts like an air knife; disturbing the solder that intends to bridge in between two or more leads. The gas temperature should be above the melting point of the solder otherwise the solder would freeze and bridge.



**Figure 5.** Non wettable nozzle with SDC unit.

3. Non-wettable nozzle with PCB under an angle. Similar to wave soldering the PCB is soldered under an angle. Typical this would be a 7 or 10° angle that supports the drainage of the solder. In order to be able to solder like this the PCB should be tilted by the conveyor or a robot system. Soldering with a tilt has two advantages:

- The gravity will help to eliminate bridging
- It makes it possible to solder closer to surrounded SMD's or components

Selective soldering the fine pitch with non-wettable nozzles is feasible if there is enough space surrounds the component. Soldering with the PCB tilted is preferred.

**DESIGN OF EXPERIMENT:**

The next experiment was done to define what parameters affect the soldering of the fine pitch connectors using a selective mini wave application. The boards are soldered with a 4 mm wettable nozzle using a magnetic pump system.

The test-board is a FR4 1.6 mm thick with HAL finished barrels. The components used in this DoE are a 10 row 1.00 and 1.27 mm pitch connector. The solder is SAC305. The test-board contains different pad diameters for the 1.27 mm connector. The barrel diameter was 0.60 mm.

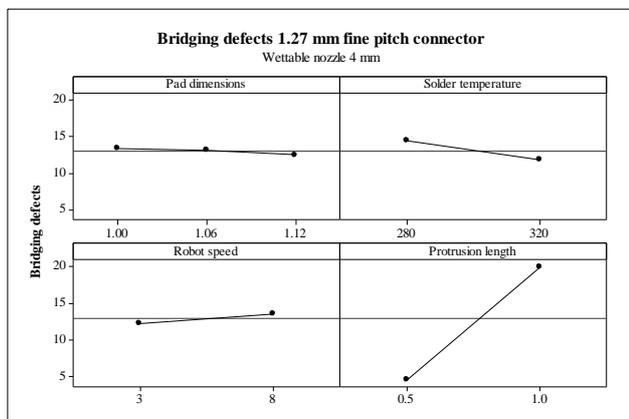


Figure 6. The bridging defects for the 1.27 mm connector; a lower score is less defects and thus better.

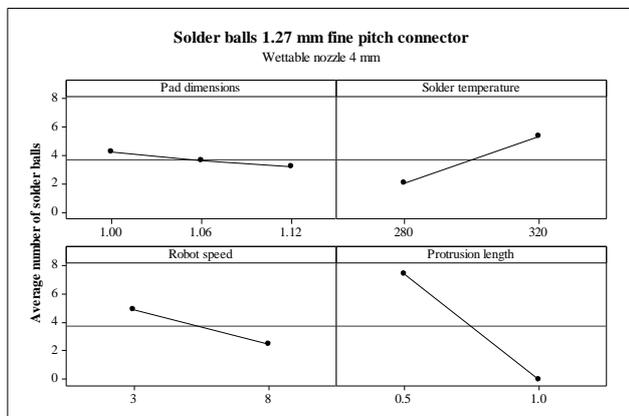


Figure 7. Number of solder balls for the 1.27 mm connector; lower score is better.

The protrusion length of the connector is the most dominant factor. Shorter lead length gives less bridging, but more solder balls. Lower solder temperature gives also less solder balls because at lower temperatures the solder

mask is less sticky. For the pad diameter there are no significant differences. A larger pad (diameter 1.12 mm) gives the best results.

For the 1.00 mm pitch connector the results were identical. The pad diameter was 0.85 mm and could not be varied because of the small size. Barrel diameter is 0.50 mm.

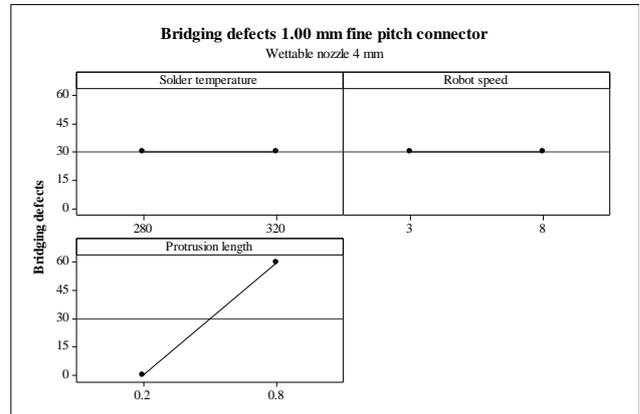


Figure 8. The protrusion length of the component is determining whether there is bridging or not.

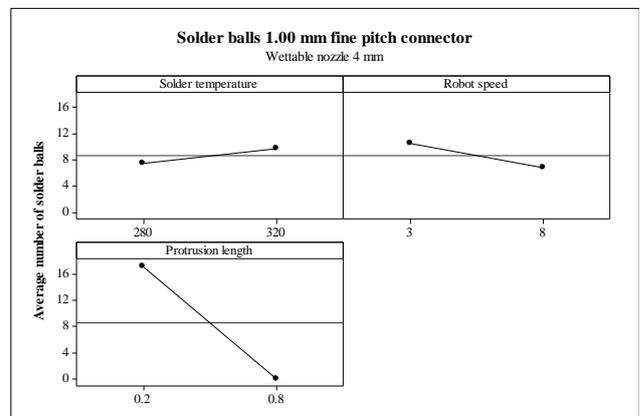


Figure 9. Similar results for solder balling as for the 1.27 mm pitch connector.

More solder balls are observed for the shorter leads. The larger number of bridges for the longer leads may explain this number (Where there is a bridge there are no solder balls).

Recommendations from this experiment:

- Short lead length
- Solder temperature 280 °C

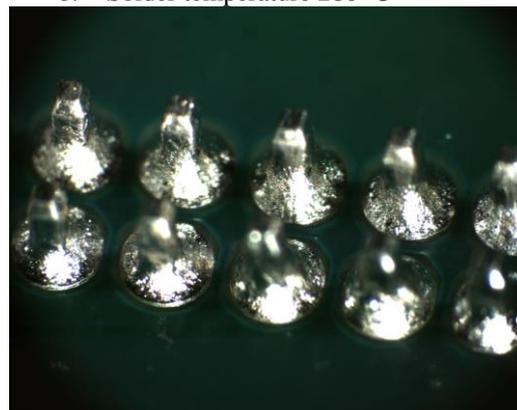


Figure 10. A nice soldered 1.27 mm pitch connector.

### SOLDER EXPERIMENT LONG LEAD FINE PITCH

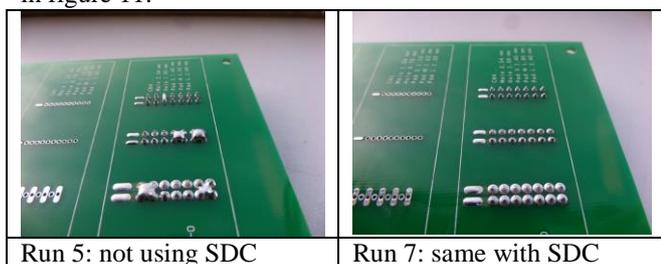
Previous experiments showed the difficulty to avoid bridging when soldering fine pitch with lead protrusion length > 1.00 mm.

Non-wettable nozzle using a solder drainage conditioner (SDC) is a more efficient method to solder components that are sensitive for bridging. To illustrate the performance of this technology first 2.54 mm pitch connectors are soldered and later 1.00 mm. The protrusion length for the 2.54 mm pitch connector is 2.00 mm. The IPC-A-610 limits the protrusion length to 1.50 mm for class 3 products.

The experiment is done on a selective soldering machine that has a robot to move the print and the non-wettable nozzle will rotate when soldering in another direction. Soldering is done horizontal; so no tilting.

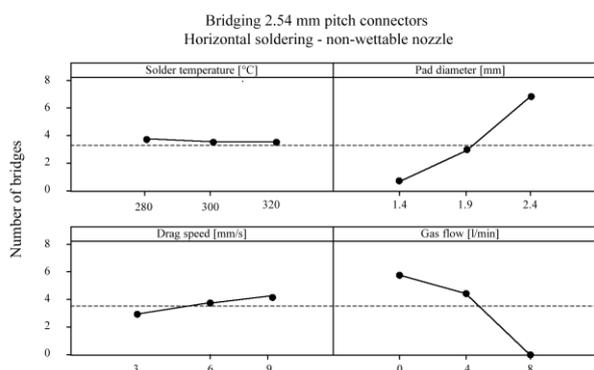
For the experiment a Box Behnken layout is selected. Solder temperature, robot drag speed and the gas flow rate are the parameters to eliminate bridging.

The best way to show the impact of the SDC is visualized in figure 11.



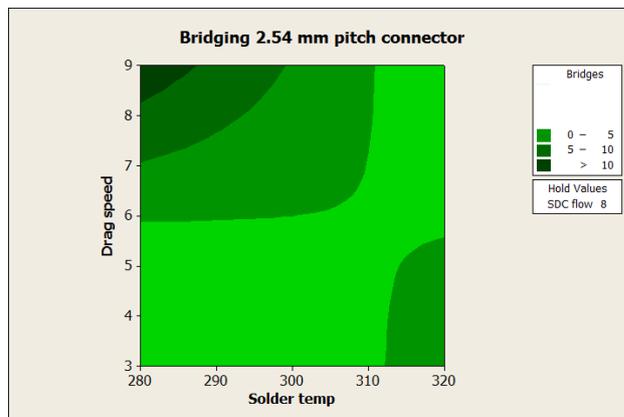
**Figure 11.** Using SDC at the same settings eliminated all the bridges.

The outcome of the experiment for the 2.54 mm component was that the solder temperature and the drag speed had minor impact. The pad diameter (smaller diameter less bridging) and the gas flow had a bigger influence. The gas flow must be equal or greater than 8 LPM. The row data of the runs is listed in Appendix 1.



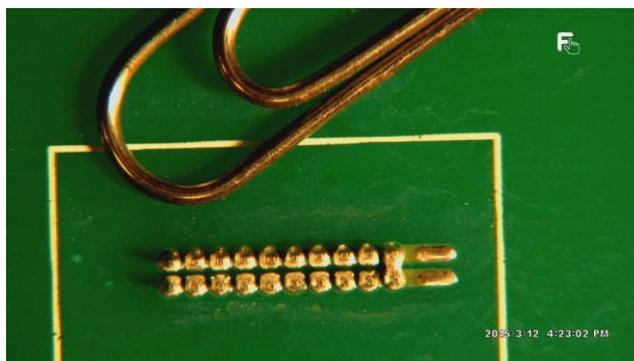
**Figure 12:** Recommended pad diameter 1.4 mm. The smaller number the better.

A similar test was done with the very small fine pitch component. The 1.00 mm pitch connectors were soldered in a hole of 0.5 mm in diameter. The pad diameter was fixed at 0.9 mm. The pins were 0.3 mm square.

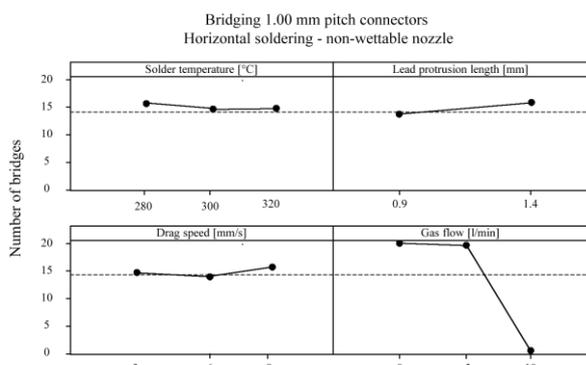


**Figure 13:** Solder temperature and drag speed at flow of 8 LPM.

The lead protrusion length was 0.9 and 1.4 mm. Between the both there was no significant difference. The major parameter was the gas flow. The flow needs to be strong enough to remove the excessive solder in between the leads. With a flow of 10 LPM no bridging was seen.



**Figure 14:** The 1.00 mm pitch THT connector together with a paper clip to indicate how small this component is.

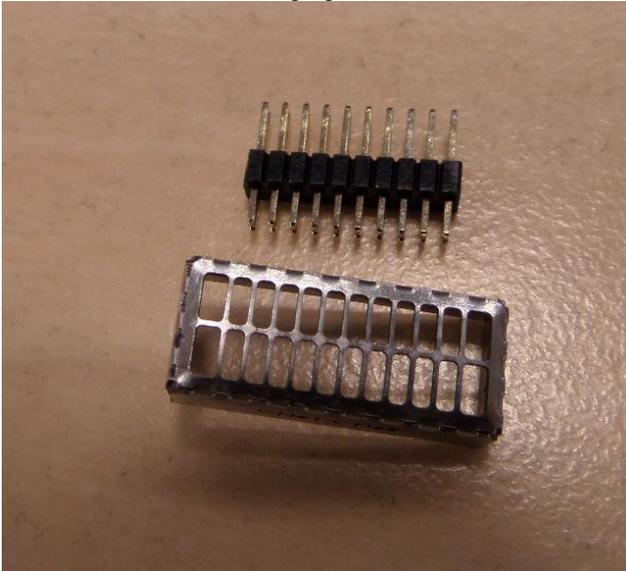


**Figure 15:** Gas flow of 10 LPM is required to remove the bridges.

## SELECTIVE SOLDERING MULTI WAVE

For high volume selective soldering a dip process where all pins are soldered in one dip is the preferred method. With this process cycle time of 20 seconds or less can be achieved. This application contains a solder pot of approximately 200 kg solder and a special dedicated tooling plate with nozzles on the soldering areas. All connectors are dipped at once in vertical direction. The solder is covered by a window to keep the environment inert. Typical a nitrogen amount of 80 liters a minute will keep the soldering area inert and free of oxides. Dipping fine pitch components without bridging is not that easy. A nitrogen environment is not enough and dedicated tools are required.

Two possible solutions are available to eliminate bridging. One is to install a wettable strip in the small nozzle that acts similar as a wettable nozzle. The solder will be pulled off between the pins because of the adhesive force of the wettable strip. For these small fine pitch components this option may not work properly. Dimensions are too tight to get the alloy through the nozzle and the strips are very sensitive for de-wetting and wear. More likely a laser cut screen is able to avoid bridging.



**Figure 16.** The 1.00 mm fine pitch pin connector with its corresponding screen.

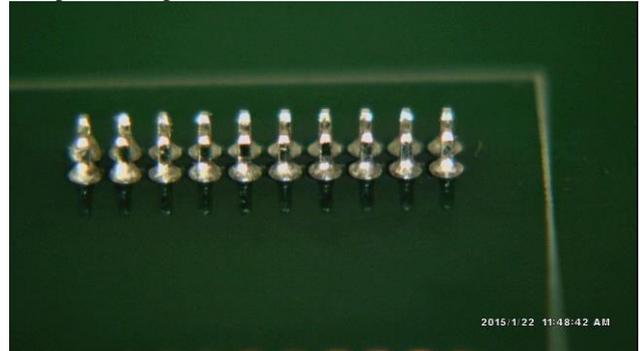
The screen is mounted on top of the nozzle. When the PCB is placed on the nozzle and the solder is pumped up, the screen sits in between the solder mask of the assembly and the solder. When the board is lifted the solder will not bridge because of the presence of the screen. An additional advantage using screens is that the screen avoids the contact of the solder with solder mask and this eliminates solder balls.

The process requires a placement accuracy of  $\pm 0.1$  mm when using these fine pitch connectors. The robot with its controls and fiducials is able to handle this accurate positioning.

The apertures in the screens are very small. This makes it very hard to get the solder through it. With the 1.27 mm pitch it is possible to get solder through the screen into the barrel. The protrusion length is also here playing an important role. A longer protrusion length is required because that will guide the solder to flow through the screen into the barrel. Once the board is positioned above

the nozzle the pump speed should be increased more than for other applications otherwise the solder will not touch the barrel and open solder joints will be the result.

The high force of the solder might lift the light fine pitch pin connector. To avoid lifting during soldering a dedicated hold down unit might be necessary to keep the component in place.



**Figure 17.** A nice dipped 1.27 mm pin connector.

More difficult is to keep a robust soldering process. After soldered a number of boards there might form some small oxide film in the nozzle. In a typical multi wave process a flush cycle (let solder overflow with high pump speed to remove small oxide films) will do its job. The screens make it hard to get all the contamination out. As a result some hairline bridges were found after soldering.



**Figure 18:** Fine pitch component showing hairline bridges after soldering.

In order to avoid this phenomenon periodic maintenance of the nozzles is required. Screens may have to be removed and nozzles have to be cleaned inside to avoid this.

Selective multi wave dip soldering fine pitch components is much more difficult than  $>2.00$  mm pitch. Open joints are critical and the process requires a high pump speed with long protrusion length of the pins to get the barrels filled with solder.



**Figure 19.** Nozzles with screens installed on a multiwave plate.

**CONCLUSIONS:**

All different soldering processes have their own specific challenges with respect to solder fine pitch pin connectors. Where for most assemblies a proper hole fill is an issue to solder fine pitch THT connectors bridging, open joints, solder balls and required space are more critical. A short summary of the challenges:

<b>Pin in Paste Reflow</b>	<b>Wave soldering</b>	<b>Selective multi wave</b>	<b>Selective mini wave</b>
Hole filling	Bridging	Bridging	Bridging
Solder balling	Solder balling	Open joints	Solder balling
Flux residues	Open joints	Tin oxides	Tin oxides
Short lead length	Short lead length	Long lead length	Short lead length

The IPC Roadmap predicts that in 2021 the smallest pin connector in the PCB assembly will have a 1.00 mm pitch. Today's soldering processes need optimizations to solder these components in a robust process.

## APPENDIX 1

Number of Bridges (total pins with bridge)				Pad diameter section 1			Pad diameter section 2			Pad diameter section 3		
Run	Solder temp	Drag speed	SDC flow	1.4	1.9	2.4	1.4	1.9	2.4	1.4	1.9	2.4
1	300	3	0	0	7	12	0	2	14	0	8	8
2	280	6	0	2	6	8	6	8	8	2	8	10
3	300	6	4	0	3	12	0	3	12	0	4	14
4	300	3	8	0	0	0	0	0	0	0	0	0
5	320	6	0	2	8	8	2	8	8	2	8	10
6	280	6	8	0	0	0	0	0	0	0	0	0
7	320	6	8	0	0	0	0	0	0	0	0	0
8	300	6	4	0	4	4	0	4	8	0	2	14
9	300	9	8	0	0	0	0	0	0	0	0	0
10	320	3	4	0	0	8	0	0	13	0	0	14
11	300	9	0	2	6	6	4	12	4	4	8	4
12	280	9	4	0	8	12	2	8	6	3	6	10
13	320	9	4	0	4	8	0	4	10	0	2	10
14	280	3	4	0	0	4	0	0	4	0	0	12
15	300	6	4	0	4	4	0	2	10	0	6	14