SELECTIVE SOLDER FINE PITCH COMPONENTS ON HIGH THERMAL MASS ASSEMBLY

Gerjan Diepstraten
ITWEAE
Oosterhout, Netherlands
gdiepstraten@itweae.com

ABSTRACT

The number of through-hole components on printed circuit boards (PCB) has declined significantly over the last decade. Miniaturization in electronics has resulted in less THT (through-hole technology) and leads with a finer pitch. For this reason, the soldering of these components has also changed from wave soldering to Point-to-point selective soldering. Soldering these small, fine-pitch components is a challenge when surface mount components (SMD) are positioned very close to THT components on the PCB layout. This study, done in cooperation with a large automotive EMS customer, defines the process windows for through-hole technology for fine-pitch components. It determines what is feasible to solder and defines layout design parameter that make soldering possible with SMD areas and other components on the assembly.

Key words: fine pitch, point-to-point, selective soldering, THT.

INTRODUCTION

Point-to-point selective soldering has three main targets: good hole fill, no bridging and minimal solder balling. Many parameters in the board design influence the solder result. The hole diameter of the barrel is related to the lead dimensions of the component. If the diameter is too small, the pin can't be inserted smoothly and may be damaged. When the diameter is too large, the gap is too big to hold the solder and solder may drain out.

Bridging is influenced by the pad and hole diameter, the lead protrusion length, the lead diameter/dimensions, and pitch of the leads. The smaller the pitch the higher the challenge to solder bridge-free. Some leads are round while others are square. Whether the design will bridge depends on the capillary action of the solder. This is the ability of the solder to flow in narrow spaces with the assistance of external forces like gravity. The solder properties, like temperature and fluidity, have impact on the capillary action.

Solder balling is another challenge. Regardless of the root case, if the solder balls do not adhere to the solder mask when leaving the solder wave, the problem is mostly eliminated. Selecting the best solder mask is the best solution to making a board design robust. [1]

TEST-BOARD

The main challenge when soldering fine pitch components is to have no solder bridges. For some high thermal mass assemblies, the hole filling can also be difficult. To understand the impact of different design parameters, a test-board was made with different layers (2, 4, 6, 8, and 10 layers) to investigate the hole fill of the solder. This test-board included all the design features that may need to be supported to widen the solder process window. These features include the solder mask, solder thieves, different hole and pad diameters for five different pitches (1.00, 1.27, 1.50, 1.75, and 2.00 mm). Since solderability is affected by the condition of the metal surface, two different metallization's, immersion Sn and Cu OSP (organic solderability preservative) were compared with each other. The test-board dimensions were 285 x 184 x 1.6 mm. In total there were 3370 holes in the assembly. To keep the boards flat a pallet was used.

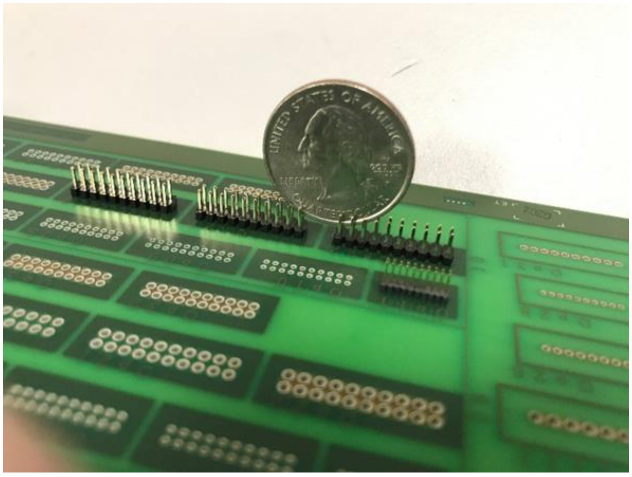

Figure 1: Test-board.

MACHINE AND CONFIGURATION

The tests are done on a selective point-to-point solder machine. The machine has a high frequency dropjet fluxer, an IR (infrared) heater, and a magnetic pump-driven solder pot. The solder nozzle is one of the parameters investigated. In the test, wettable nozzles are compared to non-wettable. To avoid bridging, an SDC (solder drainage conditioner) was installed behind the solder nozzle. This unit blows hot air between the leads of the connector. The gas temperature is well above the melting point of the solder and the flow is fixed at 7 litres per minute. The solder temperature was 300ºC during the experiments and the alloy was Sn3.0Ag0.5Cu. The preheater power was 45% for 51 seconds resulting in a topside board temperature of 120ºC.

DESIGN OF EXPERIMENT – HOLE FILLING

The first experiment focused on hole filling. A full factorial design of experiment with five different parameters that have historically proven influence on solderability was selected. These factors included fluxing and soldering parameters. Flux amount and type were selected at two levels. Solder drag speed (contact time), nozzle type and solder angle are the other factors. Although solder temperature is another factor that will impact hole fill this is kept constant at 300ºC. The preheat settings were also kept constant (see data above).

The test-board had different pitches, hole and pad dimensions, Cu-layers, solder thieves, and removed solder resist in soldering areas. The goal of this experiment is to give engineers the right tools to design boards and process conditions that enables sufficient hole-fill for fine-pitch connectors on high thermal-mass boards. The number of holes with a good hole filling according to IPC-A-610 were counted. There were 360 pins soldered per print.

Table 1: Parameters of Full Factorial Design of Experiment

Parameter	Level 1	Level 2
Board finish	OSP	Immersion Sn
Solder nozzle	Wettable 4 mm	Non wettable 4 mm
Drag speed	3 mm/s	5 mm/s
Solder angle	Flat	Tilted 10º
Flux amount	100 Hz	200 Hz
Flux type	REL0 - 2.5% solids	ORL0 - 3.6% solids

The board design was made to show differences. To achieve a 100% hole-fill on a print with 10 Cu-layers is very hard and may not be feasible for all components. The objective of this test-board was to find the limits. Different double-row pin connectors of 1.00, 1.27, and 2.00 mm were soldered as well as one 1.50 mm single-row pin connector with ten leads.

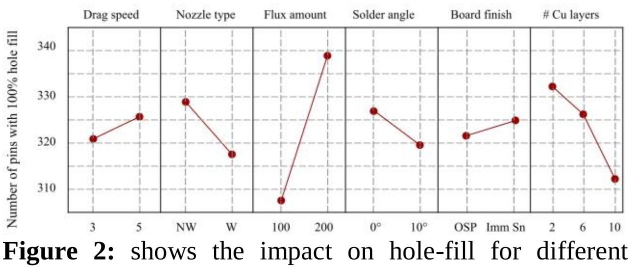

Figure 2: shows the impact on hole-fill for different parameters – the higher score the better hole filling.

There are two factors that had a high impact. The flux amount and the number of Cu-layers. There should be enough flux to support the solder to flow into the Copper barrels. The thermal mass of the Cu-layers absorbs so much heat that the solder solidifies before it reaches the topside of the board. Conclusion: a higher thermal mass requires a more active flux. There was also an interaction found between flux amount and Cu-layers. Figure 3 shows that with enough flux activation all barrels will have a good hole fill. Even the holes with ten Cu-layers.

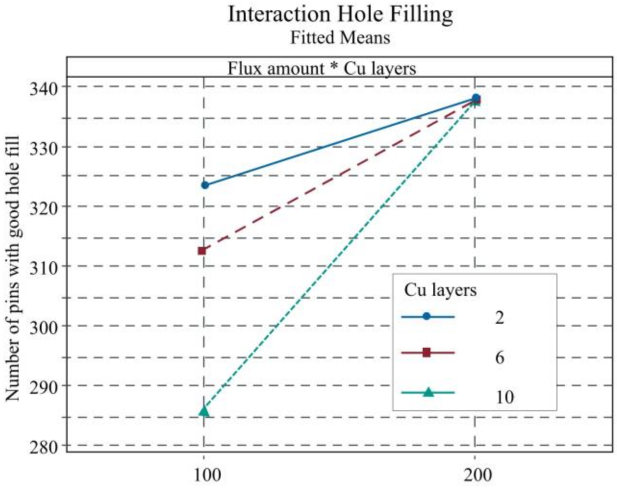

Figure 3: The flux amount is critical for the hole filling.

The non-wettable nozzle makes the solder flow in one direction. The contact with the board is longer at the same drag speed and there is more energy to force solder into the barrel. Therefore, the non-wettable nozzles shows better hole filling.

The immersion Sn is a better board finish with respect to hole fill. The wettability is slightly better than the Cu OSP. Since the boards are reflowed twice before soldering the Cu may have a small oxide layer that affects the wetting speed.

The hole diameter is also critical. The board had different diameters for the different pitches. For the 1.27 and 1.50 mm pitch the 0.80 mm diameter had the best hole fill. For the 2.00 mm pitch the preferred diameter is 1.10 mm.

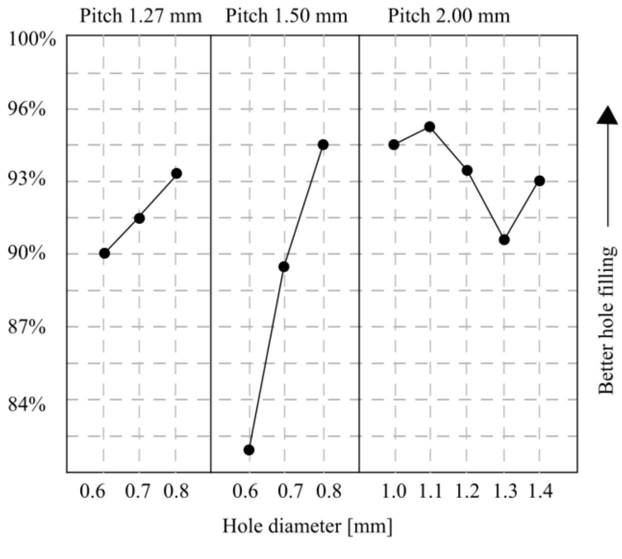

Figure 4: Hole filling for different barrel diameters (higher score is better).

All component had square leads. The dimensions were 0.35, 0.40, and 0.50 for 1.27, 1.50, and 2.00 mm pitch.

DESIGN OF EXPERIMENT - BRIDGING

Along with good hole-fill, it is critical to avoid bridging of the solder joints. Although bridging can be reduced by having a smaller protrusion length on the component, a de-bridge tool is required to eliminate this defect. Since users have no influence on the protrusion length and it is very costly to cut all components, the machine must deal with longer leads. Experience indicates that all components with pitches <1.75 mm requires an SDC unit. The SDC unit blows hot gas where the leads exit the liquidous solder.

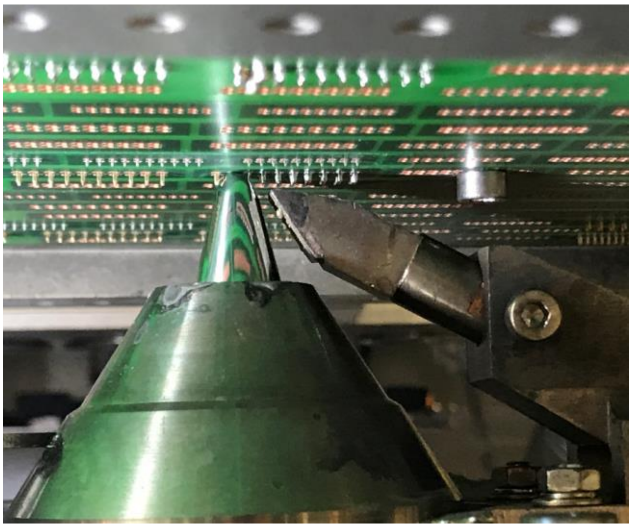

Figure 5: A wettable nozzle with SDC unit.

In the experiment there were some additional parameters that had an impact on bridging. Solder thieves are designed to eliminate bridges, but in some lead-free applications the benefit was not confirmed.

With data from the Design of Experiment, bridging can also be examined. The results are shown in figure 6 below. The higher the score the better. A score of 360 means no bridging.

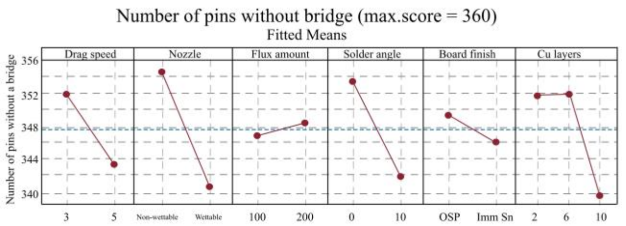

Figure 6: Impact of the different parameters on bridging.

The data shows less bridging with non-wettable nozzles. A drag speed of 3 mm/s was better. The tilting of the conveyor, which is good for hole-fill, had a negative impact on bridging. This can be improved by changing the SDC angle which is optimized for flat soldering.

The impact on the Cu-layers was remarkable. Obviously, the ten Cu-layers construction absorbs a lot of heat from the solder area making the solder solidify faster resulting in bridging.

A separate experiment was done to investigate the impact of the solder thieves and a different flux. Pad diameter is another factor that was investigated. Since the SDC is a powerful tool to eliminate bridging, the lead protrusion length is not significant. If no SDC is used the lead protrusion must be shorter to avoid bridging.

The pad diameter is critical for very fine pitch. A pitch of 1.27 mm has the lowest defects with a pad outer diameter of 1.00 mm. The wider the diameter the more sensitive to bridging. For the 2.00 mm pitch there is no significant difference between outer pad diameters of 1.50 and 1.70 mm. The 1.80, and 1.90 mm outer pad diameters are more sensitive to bridging.

The Design of Experiment shows that solder thieves reduce bridging at higher solder speeds. At lower solder speed the solder can drain by itself.

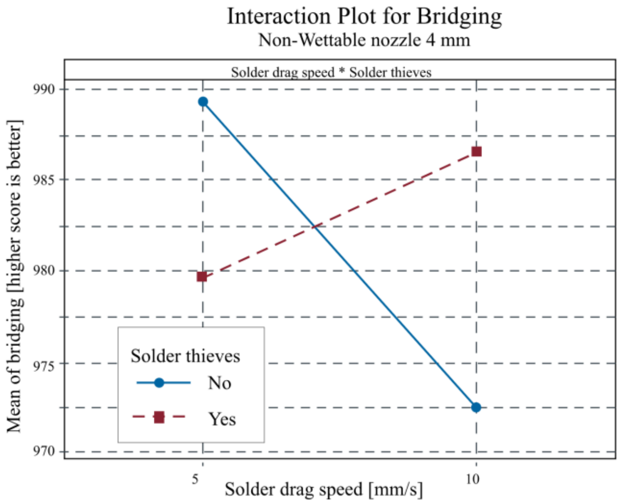

Figure 7: At high drag speeds (10 mm/s) solder thieves have a benefit (a higher score is less bridging is better)

Solder thieves hold the solder to the board for a longer time. Wettable nozzles are designed to peel the solder from the board and avoid bridging. The combination of wettable nozzles and solder thieves is not so good for some lead-free solder alloy applications. This experiment confirmed this.

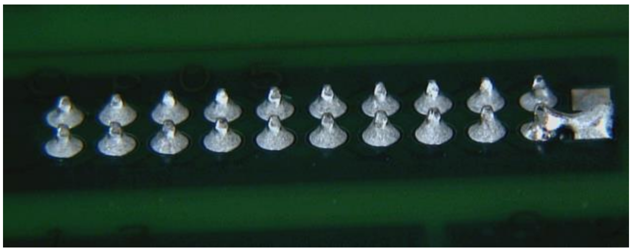

Figure 8: Fine pitch leads with solder thieve at the end,

Solder thieves hold the solder on the pad. As shown in the picture above the solder is not bridging between the pins and the solder thieves avoid rework. Solder thieves consume more space on the board. With miniaturization, adding solder thieves might be critical. A drag speed of 10 mm/s is exceptional. The experiment proved that with the right parameter settings the assembly doesn’t necessarily need solder thieves.

DESIGN OF EXPERIMENT – SOLDER BALLING

Although the focus of the soldering was on good hole fill and less bridging, avoiding solder balls is also important. Previous studies on solder balling showed the impact of the flux type and solder mask. On the test board there were three spots with identical hole and pad diameter but one with solder mask and the other one without solder mask.

Table 2: shows two 2.00 mm pitch positions (OP03/OP22 and OP02/OP23) and one 1.27 mm pitch (OP14/OP28) with and without solder mask

Position	Hole diameter [mm]	Pad diameter [mm]	Hole fill [%]	Bridging [%]	Solder balls [#]
OP03	1.20	1.70	98.4	97.3	36
OP22*	1.20	1.70	98.3	99.8	2
OP 02	1.30	1.80	98.5	95.4	15
OP 23*	1.30	1.80	97.0	91.6	0
OP 14	0.60	1.00	100	89.1	18
OP 28*	0.60	1.00	97.5	91.4	0

* Solder resist removed at solder area

In the table the difference between solder mask and no solder mask is shown. Flux A is used for this comparison. The 1.27 mm pitch component has 18 solder balls in the experiment with solder mask between the pads and no solder balls when the solder mask is removed.

For the 2.00 mm pitch components there is a similar difference. When the solder mask is removed the number of solder balls is reduced by 96%. Solder balls on a circuit board are the result of gassing and spitting of the flux on the surface of the solder side of the PCB.

The fact that solder balls are found on the board surface is only due to the adhesion of the solder to the solder resist in combination with the flux residues. Refraining from solder resist will in general eliminate the problem of solder ball adhesion, but that is not always a viable option. A good combination of solder resist and flux can also prevent this adhesion since the weakening of the solder resist during soldering might influence this solder ball adhesion. It is sometimes possible to reduce this adhesion effect by optimizing the machine settings. In general however, this problem can only be solved well by using the right selection of the materials.

Prevention is always better than trying to find a solution in the solder process settings. [2]

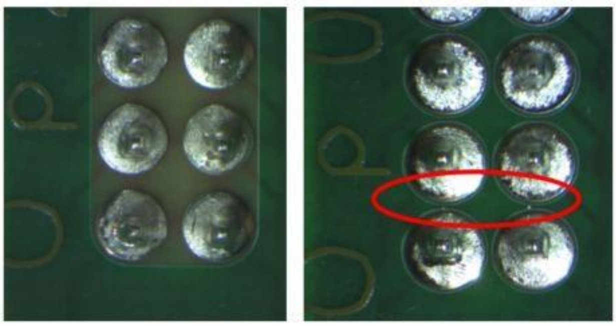

Figure 9: Left the solder mask removed, right with solder mask and solder ball.

Apart from the solder mask, flux has an impact on solder balls. In the Design of Experiment two different fluxes were compared.

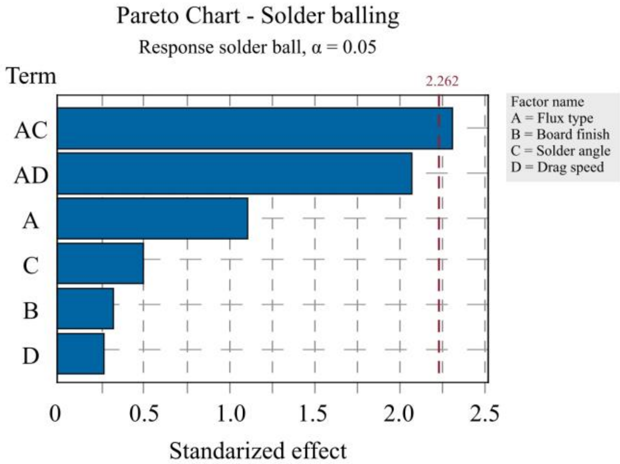

Figure 10: Pareto chart for solder balling. There are interactions due to the different flux properties.

The R-sq = 56% indicating that the data for solder balling is not consistent (should be > 80%).

The only statistically significant parameter is the interaction between flux and solder angle. Flux A is more consistent for all conditions. Whereas Flux B doesn't like the horizontal soldering at higher speed. When soldering under an angle the nitrogen out of the SDC may heat-up the board surface more just before soldering. The drainage of the solder in the pot is smoother and gives less splattering; solder balling. The tackiness of the solder mask is an important factor that might be influenced by the hot gas of the SDC.

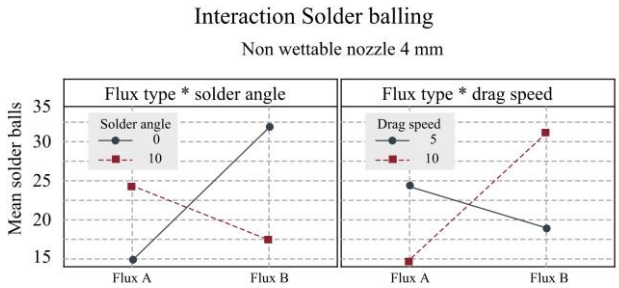

Figure 11: The average number of solder balls – the lower the score the better.

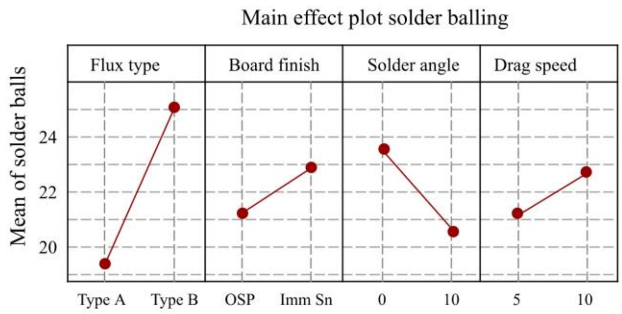

Figure 12: Overall analysis of solder balling showing that the flux type has a major impact.

BOARD WARPAGE

During the previous Design of Experiments the test-board was fixed in a carrier to keep it flat. Before the boards were soldered they were sent through a reflow oven twice. A typical application has double-side reflow technology followed by selective soldering of the through hole components that can't be processed in the hot environment of a reflow oven. When reflowed, the boards are warped and not flat anymore. The material and design (number of Cu layers and layout) will define how much it will be warped.

In the selective soldering process the contact time is a function of the wave height, z-position of the robot on which the solder pot is mounted, and the distance to the bottom side of the board. The board may warp, due to the heating cycles as described, prior to the selective soldering process. For the consistency of the process these parameters should remain constant. A board warpage compensation is an option that keeps the distance to the PCB consistent.

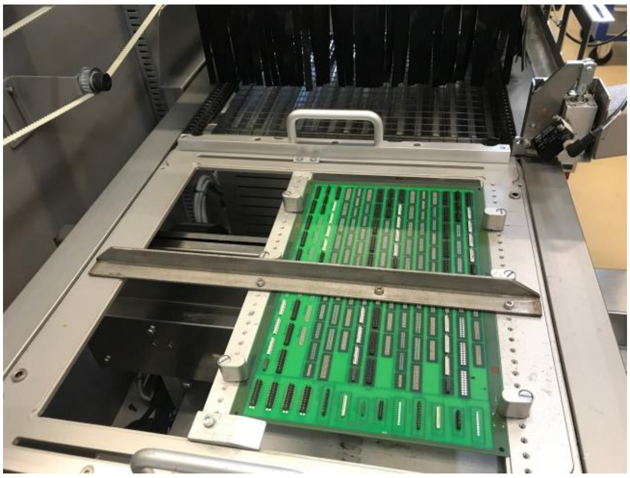

Figure 13: The test-board positioned in the pallet with a bar to keep it flat.

In the experiment the preheat temperature is 100 ºC measured on the topside of the test-board.

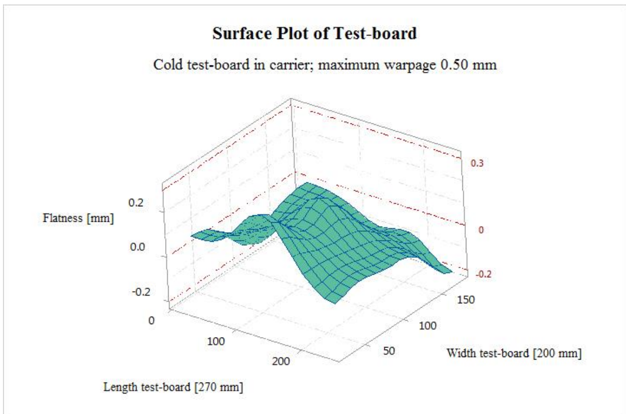

Figure 14: The warpage of a cold test-board after two times reflow.

Before soldering the test-board was placed in the carrier and the warpage was measured using an accurate laser sensor.

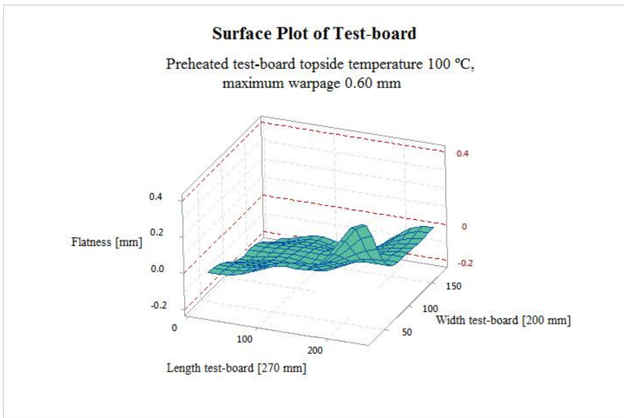

Figure 15: The test-board, although preheated (100 ºC), remains relatively flat due to the carrier.

The maximum warpage with 0.10 mm slightly increased because of the preheating. When the board is placed into the conveyor without a carrier there is significantly more warpage.

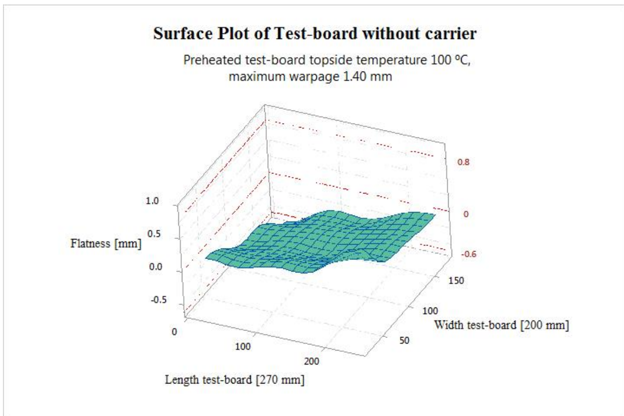

Figure 16: The test-board warpage when it is not placed into a carrier.

Although the test-board looks very robust with 10 Cu layers inside, it still warps significantly more than when it is held down in a carrier.

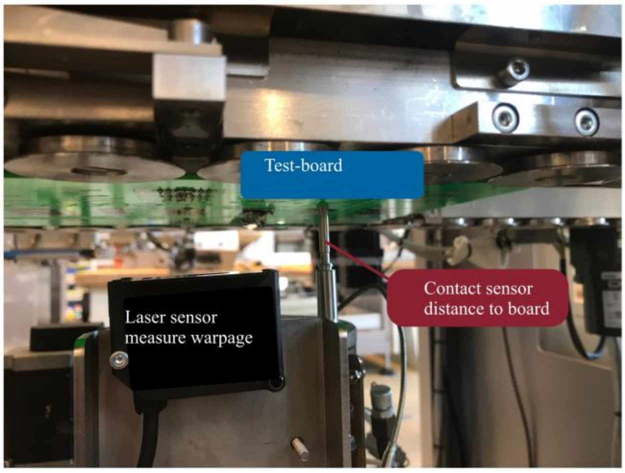

Figure 17: test setup with laser and contact sensor.

More than 1.00 mm height difference may result in open solder joints or it might be even worse when the board hits the solder nozzle. To overcome this the software should be intelligent and correct the z-height of the robot according to the warpage of the board.
In the next experiment 10 boards were preheated and the warpage was measured with an accurate contact sensor as shown in the picture above. In total, nine points are measured underneath the board.

Table 3: the warpage of ten different test-boards after preheating.

Warpage	WP1 [mm]	WP2 [mm]	WP3 [mm]	WP4 [mm]	WP5 [mm]	WP6 [mm]	WP7 [mm]	WP8 [mm]	WP9 [mm]	Range [mm]
Board 1	-0.3	-0.1	0.1	-0.6	-0.1	0.2	-0.7	0	0.6	1.3
Board 2	-0.3	0	0.2	-0.5	0	0.3	-0.6	0	0.6	1.1
Board 3	-0.3	-0.1	0.2	-0.6	-0.1	0.3	-0.6	0	0.6	1.2
Board 4	-0.3	-0.1	0.2	-0.5	0	0.3	-0.6	0	0.7	1.3
Board 5	-0.3	0	0.2	-0.4	0	0.3	-0.6	0	0.6	1.2
Board 6	-0.4	-0.1	0.2	-0.5	-0.1	0.2	-0.5	0	0.6	1.1
Board 7	-0.3	-0.1	0.2	-0.5	0	0.3	-0.5	0	0.6	1.1
Board 8	-0.2	0	0.2	-0.5	0	0.2	-0.5	0.1	0.6	1.1
Board 9	-0.4	-0.1	0.2	-0.6	0	0.3	-0.6	0.1	0.6	1.2
Board 10	-0.3	-0.1	0.2	-0.5	0	0.3	-0.6	0.1	0.6	1.2

The warpage is significant. Notice that the repeatability is good; most boards have a similar warpage shape. To eliminate the effect of the warpage on the contact time, the boards are run a second time. After preheating, the warpage is measured, and the software compensates the offset. The calculated distance is verified with the contact sensor.

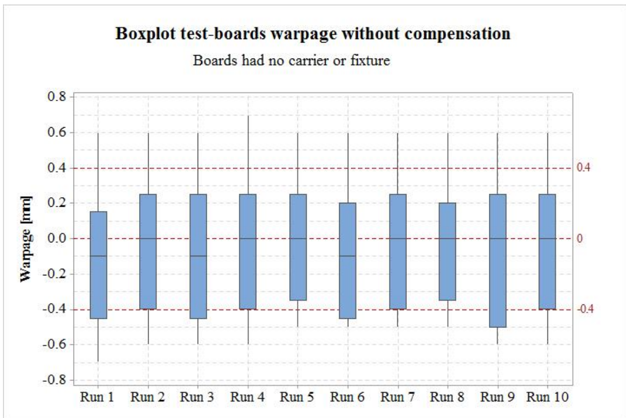

Figure 18: the distance to the bottom side should not vary more than ± 0.4 mm for a 1.6 mm thick board. [3]

The software compensation is capable to minimize the difference between nozzle and bottom side board.

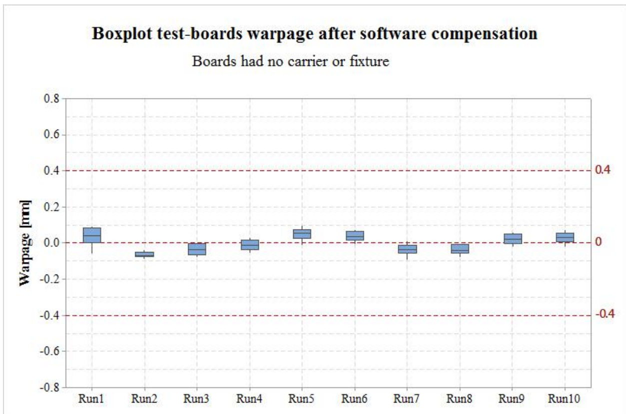

Figure 19: After compensation. The graph has the same scale as the previous one without software modification.

After the software compensation, the spreading is much smaller. All data points are within ± 0.10 mm.

Table 4: after correction the warpage is compensated within ± 0.10 mm spreading.

Warpage	WP1 [mm]	WP2 [mm]	WP3 [mm]	WP4 [mm]	WP5 [mm]	WP6 [mm]	WP7 [mm]	WP8 [mm]	WP9 [mm]	Range [mm]
Board 1	-0.06	0.04	0.01	0.04	0.06	0.09	0.02	0.08	0.09	0.16
Board 2	-0.04	-0.08	-0.07	-0.09	-0.08	-0.06	-0.07	-0.06	-0.04	0.05
Board 3	-0.08	-0.08	-0.05	-0.03	-0.03	-0.05	0.00	0.00	0.00	0.08
Board 4	-0.05	-0.01	-0.03	-0.02	0.00	-0.06	0.00	0.03	0.03	0.09
Board 5	0.01	0.05	0.04	0.05	0.05	-0.01	0.06	0.09	0.10	0.11
Board 6	-0.01	0.05	0.01	0.02	0.04	0.07	0.04	0.07	0.07	0.08
Board 7	-0.10	-0.05	-0.06	-0.03	-0.04	-0.02	-0.01	-0.01	0.01	0.11
Board 8	-0.08	-0.05	-0.06	-0.05	-0.04	-0.04	-0.01	-0.01	-0.01	0.07
Board 9	-0.02	0.02	0.00	0.02	0.03	-0.01	0.04	0.06	0.06	0.08
Board 10	-0.01	0.03	0.02	0.03	0.05	-0.02	0.02	0.07	0.08	0.10

The experiment shows that it is hard to solder a printed circuit board without warpage compensation if the board is not flat by itself. The design of the print and materials used play an important role. Also, the pre-selective solder processes like reflow have impact on the flatness.

CONCLUSIONS

The experiments showed that it is feasible to solder very fine pitch components on thick, high thermal-mass boards with good hole filling and no bridging. For the hole filling the flux amount is important. When there is enough flux activity, even ten Cu layer, barrels will have 100%-hole filling when the machine is setup properly.

To avoid bridging a de-bridging tool like the solder drainage conditioner is needed with a proper nitrogen flow and the gas at a temperature above the melting point of the solder.

Solder balls can be limited by removing the solder resist on the solder areas. Each flux has different properties and one flux will return more solder balls then the other. Solder parameters will influence the number of solder balls.

For a robust select-wave soldering process the contact time should be consistent. Software can minimize the distance difference to the bottom side of the board by measuring the warpage with a laser sensor and taking corrective action in the z-height of the solder robot. Maintaining this constant distance with a stable wave height, guarantees good hole fill and no open joints.
Another alternative is to use pallets with down-holders to keep the board flat.

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