Process Control of Rework Used in High Reliability World

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ABSTRACT
Working in a Class 3 manufacturing facility requires high reliability processes, process controls, and the understanding of the control effects. Each board is unique in design and can result in unique component placement making rework difficult, forcing production agencies to get creative in reflow processes.

Understanding the rework equipment and proper use can greatly impact the success of a solder reflow process while maintaining heat sensitive requirements and part safety. Board thickness, component location in relation to heat source, and the presence of an ionizing fan are a few of the various control factors that have been identified to solidify a repeatable rework process.

The conducted experiment comprised of 2 bare boards, a 13 layer 3"x 3.25" board and a 20 layer 2.5"x 6.5" board, at 2 different heights from the hot plate. The bare boards help determine a general heat range without component heat blockage or absorption. Measurements of the board temperatures were taken in various increments in multiple locations on both sides of the board. The temperature of the hot plate was kept constant but was interesting to see how it fluctuated based on the board thickness, board height from the hot plate, and the distance from the ionizing fan. These results can be used to better maneuver the reflow equipment to protect components and boards against thermal shock and damage.

Identifying the controllable vs. un-controllable factors can help reduce inconsistency in reflow results. Some un-controllable factors can also be manipulated in a way to benefit the solder reflow process. This process is not solely contained to rework but rather to precise solder reflow in a general sense. As rework and solder reflow become ever present as a part of normal processing, it must be accepted that hand installation is still an important method to improve and design into the manufacturability of a board.

INTRODUCTION
The ever present need to innovate and improve processes lead us to evaluate the way in which we do rework and have been for decades. New technologies bring advancement, new capabilities but also new unknowns. We considered 2 different unpopulated boards of different thicknesses (13 and 20 layers) and different sizes to determine a baseline of the operating temperatures, controls, and constraints of these new rework systems. The rework equipment used in the study consisted of a hot air pen with a rework arm, a hot plate and the manufacturer provided board stand. Given the equipment standards, there were 3 operating heights to hold the board from the hot plate surface: high (2.75"), medium (1.83"), and low (0.92"). For the board to preheat to a reasonable temperature to allow reflow without exhibiting the board to thermal shock when the hot air pen was turned on, the medium and low heights were chosen in the study. To fully understand the integration of the combination of the hot plate and the hot air, studies were completed with each system individually, then together to determine the thermal signatures in certain locations on the board in comparison from each system. Electrostatic Discharge precautions were assessed, and it was determined that an ionizing fan should be used for all trials to mitigate the chances of an ESD event occurring. Type K thermocouples were used in various locations on both sides of the board. An 8 Input Portable Thermometer Data Logger was used to capture the temperature read outs. The side with the direct heat was the main priority but gauging the temperature on the opposite side provided valuable data for future studies and allowances. With unpopulated boards we were able to determine the heat dissipation at half inch increments from the heat source, this information better explained how we can shield sensitive components from excessive heat just by adjusting the setup of the rework station.

ANALYSIS
Hot Plate
To understand the connection between the hot plate and the hot air station, they were first observed independently of each other. Starting off first with the hot plate, 9 thermocouples were used on the 20-layer board at the lowest height of 0.92 inches. The 9 thermocouples were adhered with kapton tape in the configuration shown in Figure 1. The 9^{th} thermocouple was read out using one of the hot plate TC inputs.

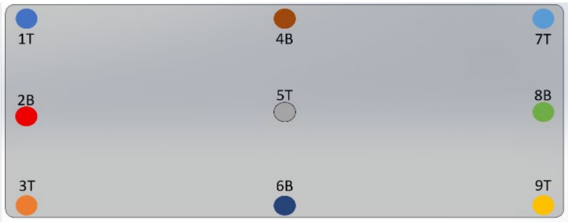

Figure 1: 20-layer board with thermocouple locations on both sides of board for hot plate study.

With 5 thermocouples on the top side and 4 on the bottom side closest to the hot plate. An ESD fan was placed approximately 5 inches away from the hot plate on the Northwest corner of the board, this fan remained in this location for the remainder of all the trials. The hot plate profile was set at 130C, and data was collected every 30 secs for 17.5 minutes.

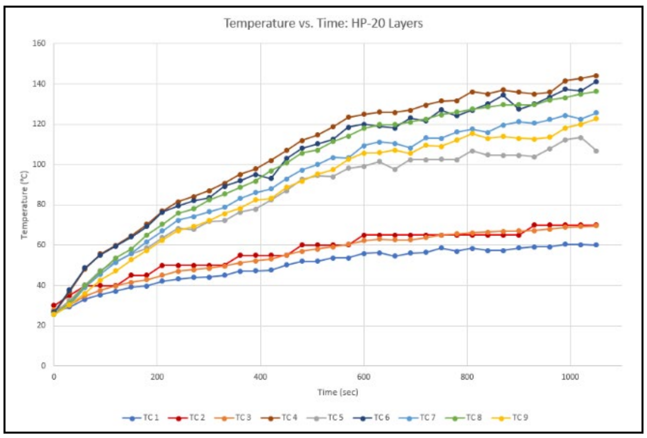

Figure 2: 20-layer board results for hot plate study.

The 20-layer board saw a max temperature of 93.6C at 16 minutes, with temperature variability between groupings of thermocouples. It is obvious that the thermocouples closest to the ESD fan experienced the least heat. From left to right, the heat increases the further away from the fan and as the fan pushes the heat to the right. The 13-layer board had a similar thermocouple setup.

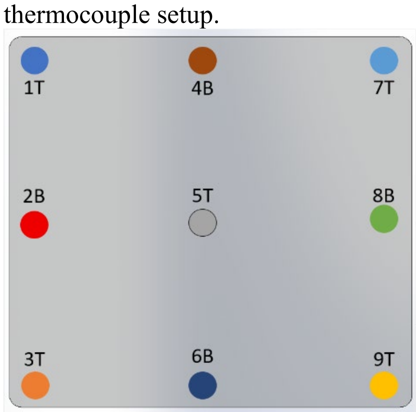

Figure 3: 13-layer board with thermocouple locations on both sides of board for hot plate study.

The highest temperature on the 13-layer board reached was 124.5C at 14.5 minutes in the Southeast corner of the board, this thermocouple was on the top side of the board and the same assumption can be made that the fan forced the heat to the right side of the board, as shown in Figure 4.

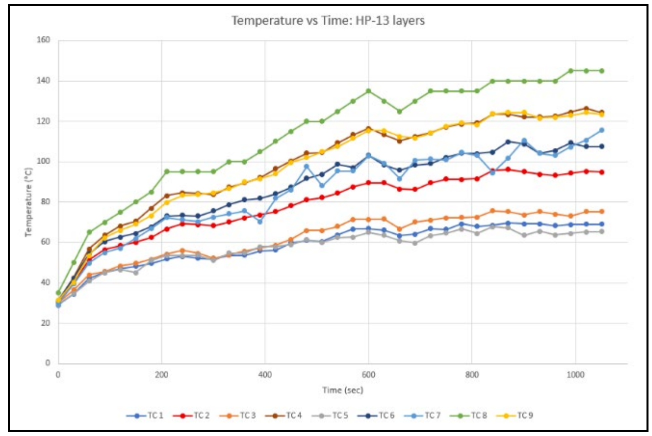

Figure 4: 13-layer board results for hot plate study.

Figure 4 shows a similar picture where the thermocouples closest to the ESD fan exhibit the coldest temperatures compared to the other thermocouples. A medium height trial for both boards were conducted but due to the high variability in the temperature readings and the lower overall temperatures, it was chosen to continue the rest of the study with the lower stand setting.

Hot Air

Next, the hot air station was studied, a temperature of 400C was chosen as the heating temperature and an air flow of 40%. Far above the eutectic point for the solder to become molten, but not excessively high as to not damage components and boards. The time for the heat to be applied was 40 seconds, this allows for solder to become molten, component removal, solder reflow, then new component installation. Although, there are no limits on the times that process may happen, the trial was conducted to ramp multiple times to 400C for 40 seconds, total time of 11.5 minutes with data captured every 20 seconds. To allow for "operator" time between each ramp up, a ramp down time of 40 seconds was established. Process follows as (1) ramp up to 400C, (2) dwell for 40 seconds, (3) ramp down for 40 seconds, (4) repeat 1-3. The heat source nozzle was placed 2.5cm from the board for both trials of 13- and 20-layer boards. This height was chosen as an arbitrary height and helped in protecting the boards from damage during all trials. Only 6 thermocouples were used in these trials, adhered using kapton tape in the configuration shown in Figure 5.

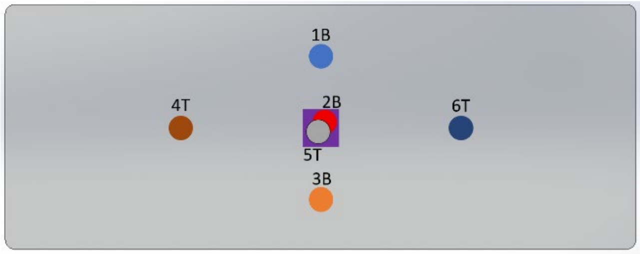

Figure 5: 20-layer board with thermocouple locations on both sides of board for hot air study, where the purple box is the hot air nozzle location.

The 20-layer board saw a maximum temperature of 243C during its 6th ramp up cycle, the ramp peaks are consistently around 200C from the thermocouple on the top side of the board, directly under the heat source, as shown in Figure 6. Similar to the hot plate only trials, the heat increases across the board from left to right as an effect of the ESD fan, either cooling the board or pushing the heat in one direction.

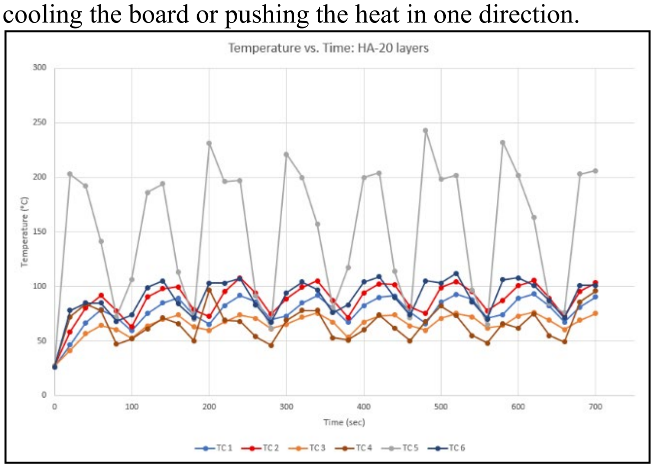

Figure 6: 20-layer board results for hot air study.

The three thermocouples on the bottom side of the board remained constant with consistent variances between the locations, the spot directly under the nozzle saw the highest temperature compared to the other two locations. The 13-layer board did not see temperature spikes as high as the 20-layer board, with a maximum temperature of 214C during the 4th ramp up cycle, although more locations rose above 120C during each cycle.

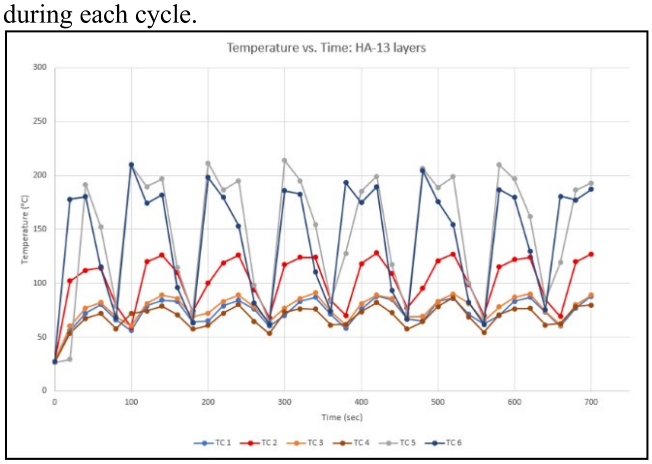

Figure 7: 13-layer board results for hot air study.

The dimensions of the boards are different and therefore the distance to the center of the heat source in relation to the edge of the boards were not the same.

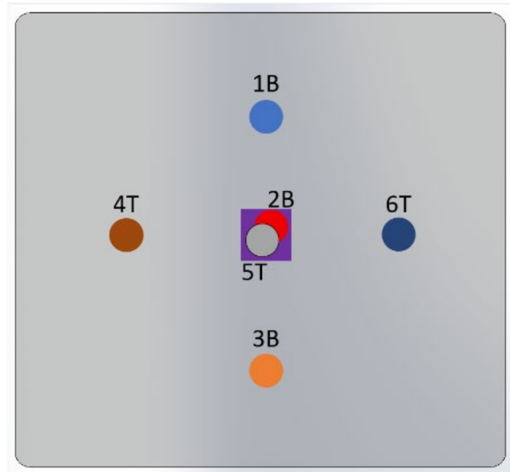

Figure 8: 13-layer board with thermocouple locations on both sides of board for hot air study, where the purple box is the hot air nozzle location.

With a smaller width, the thermocouples were placed closer to the center, closer to the heat and thus exhibiting more higher temperatures than the 20-layer board thermocouple locations. The 7-layer difference between the two boards was prominent when looking at the thermocouple directly below the heat source, seeing peaks of 120C during each ramp cycle, the heat better penetrated the thinner board by roughly 20C at each peak.

Hot Plate and Hot Air

From the hot air study, seeing how the different thermocouple placements changed the temperature tremendously with only an inch or so difference, the next study was conducted to determine heat dissipation in relation to the heat source in half inch increments. The same two boards were used with a hot plate low stand height. Seeing how the heat penetrates through the boards, at a higher rate in the thinner board, the studies were conducted independent of side. Each configuration was tested on both sides of the board at different trials. To simulate the actual rework process of these boards without inducing the board to thermal shock, the hot plate was set at a temperature of 130C, after a 5-minute warm up for the board, the hot air was turned on using the same cycling as before. Hot air cycling as follows as (1) ramp up to 400C, (2) dwell for 40 seconds, (3) ramp down for 40 seconds, (4) repeat 1-3. The hot air nozzle remained 2.5cm from the board center, and data was collected every 30 seconds for 17.5 minutes. To start, the 9 thermocouples were placed as shown in Figure 9.

Figure 9: Thermocouple locations on one side of board for full study of hot plate and hot air, where the purple box is the hot air nozzle location. Same set up for both the 13- and 20-layer boards.

Shown in Figure 9, 1 thermocouple was placed directly below the hot air nozzle, then 2 thermocouples in each direction 0.5" away from the center. The 20-layer board was done first comparing the thermocouple placements on the top side of the board independently.

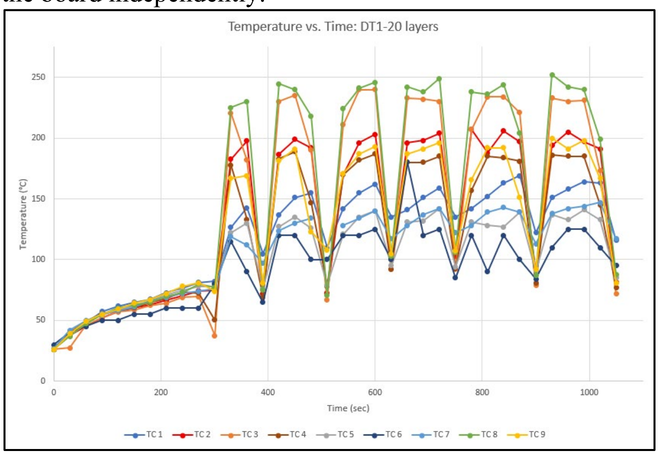

Figure 10: 20-layer board top side results for full system study.

As shown from all the previous studies, the lowest temperature read out was the thermocouple closest to the ionizing fan, and the highest read outs are the thermocouples furthest from the fan. All thermocouples in the vertical set up had very consistent and similar ramp cycles. During the 5-minute pre-heat, almost all thermocouples read approximately 75C.

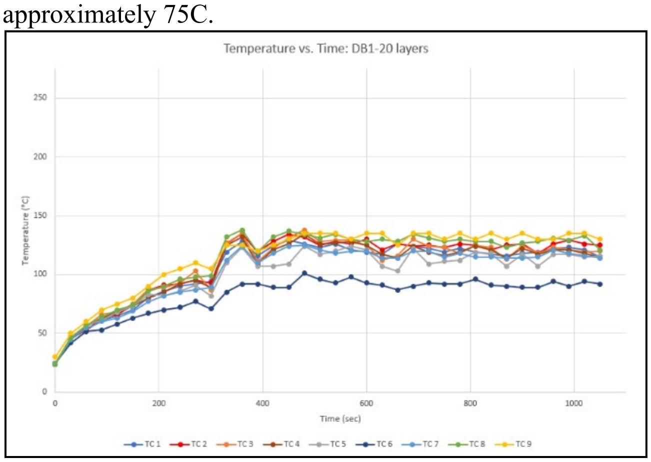

Figure 11: 20-layer board bottom side results for full system study.

When the same study was conducted with the same thermocouple placements but this time on the bottom side of the board, the variability of the temperatures decreased, all 9 thermocouples saw very consistent temperatures but significantly lower than on the top side of the board. The top side study saw temperatures around 200C-245C, on the bottom side, the temperatures were around 110C-130C during the ramping cycles. The 13-layer board saw very different results using the same TC placement and side independent studies.

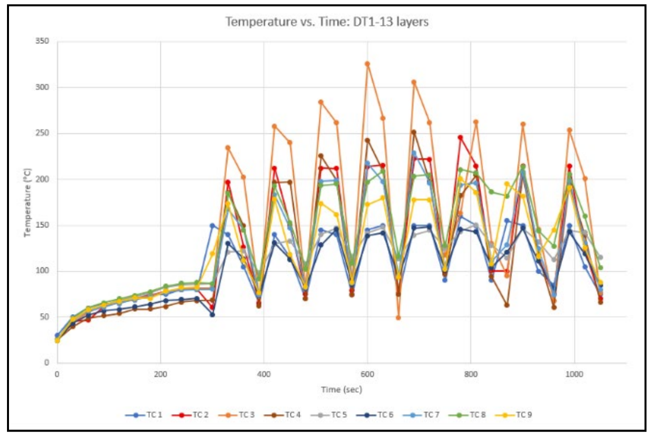

Figure 12: 13-layer board top side results for full system study.

The ionizing fan did not seem to cause much of a temperature difference in the thinner board, the results seemed to jump more with the ramp ups, but each thermocouple was very similar in temperature read outs. Most noticeable was the TC directly below the hot air nozzle, reaching a temperature of around 325C at one point. These higher temperatures could be attributed to the thinner board and the hot plate heat source penetrating through the board better than the 20-layer board, again the boards are also significantly different in width and length, so that could also be a contributing factor. Less overall surface area to heat, the quicker it will heat up. The bottom side saw similar results to the previous studies where the thermocouples furthest away from the fan saw the highest temperatures.

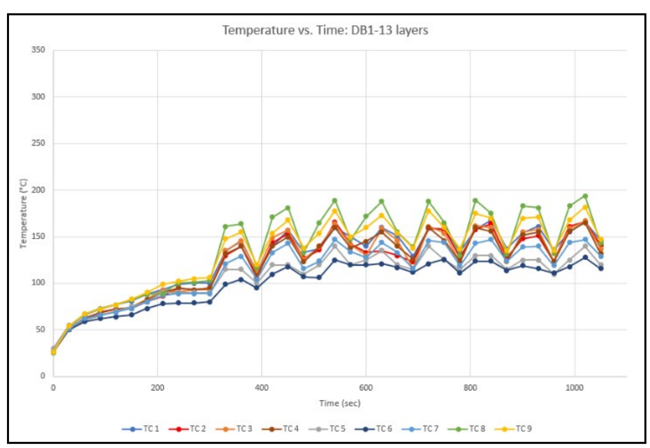

Figure 13: 13-layer board bottom side results for full system study.

The ramp ups were very consistent with the settings on the hot air nozzle reaching peaks of approximately 180C. Comparing the 13-layer board bottom side to the 20-layer board, the temperatures are approximately 10C higher on the thinner board, as discussed before the heat can better penetrate through the thin board and the smaller sized board.

CONCLUSION

The main control determined from this study was that the placement of the ionizing fan greatly affected the temperature read outs, a lower temperature near the fan but also sort of pushing the heat away from the fan. An assumption that was found true was that the heat from the hot air penetrates better through the thinner boards. The low board stand height was chosen to be the best option for its consistency of heat throughout the trials. The fan did not affect the convection the bottom side of the board and hot plate were creating when using the low stand height. The height chosen for the hot air nozzle was too far away from the board for normal production reworks, it will need to be explored more for an accurate and precise distance. Upon completion of all trials, the decision was made that the method in which the data was captured should be improved from single point to continual temperature monitoring. It was also noticed when using the 9th thermocouple input on the system that there was a built-in temperature control feature. When first using the 9th input a temperature max of 200C was set and therefore would decrease the heat on the hot plate when the thermocouple read higher than 200C. For this study, it was a hinderance and therefore not discussed, but has the potential to benefit future production and processes. Another round of trials will need to take place to fully understand how the heat dissipates across the board when the board is fully populated, applying heat shields to heat sensitive components, and how the placement of the ionizing fan could help protect heat sensitive components where the design cannot be changed.