Risk Mitigation in Hand Soldering

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Abstract

Soldering is the bonding of metallic surfaces via an intermetallic compound (IMC). The interaction between thermal energy delivery, flux chemistry, and solder chemistry creates the solder bond or joint. Today, reliability relies on visual inspection, operator experience and skill, control of influencers e.g. tip geometry, tip temperature, and collection and analysis of process data. Each factor involved with the formation of the solder joint is an element of risk and can affect either throughput or repeatability. Mitigating this risk in hand soldering requires the identification of these factors and a means to address them. A new technology, which evaluates the quality of the solder joint by calculating the intermetallic compound formation and provides closed loop feedback to the operator, changes the way solder joints are evaluated in hand soldering. Validation of the solder joint requires the ability to identify the correct solder geometry, detect the transition of solder from solid to liquid, and calculate the intermetallic compound formation without adversely impacting throughput or repeatability. Additionally, to be effective, this validation of the solder connection provides real time feedback to the operator and prompts action based on the response. Implementation of this new technology represents a paradigm shift in the hand soldering industry changing the reliance on visual inspection to control of the formation of the intermetallic compound. The validation technology requires two components, software and hardware. The software component is an algorithm that executes the three-step process to calculate the intermetallic compound. The hardware component incorporates a system to store data at the point of use, process the calculations locally and provide feedback to the operator via a visual go/no-go indicator. The validation technology in concert with visual inspection represents a change to the status quo in hand soldering.

Introduction

Failed solder joints remain a constant source of printed circuit board failure. Soldering is the bonding of metallic surfaces via an intermetallic compound (IMC). The interaction between thermal energy delivery, flux chemistry, and solder chemistry creates the solder bond or joint. Today, reliability relies on visual inspection; operator experience and skill, control of influencers e.g. tip geometry, tip temperature, and collection and analysis of process data. Each factor involved with the formation of the solder joint is an element of risk and can affect either throughput or repeatability. Mitigating this risk in hand soldering requires the identification of these factors and a means to address them.

Soldering depends on the control of variables into the process, visual standards during the process and verification after the process. Engineers define variables such tip temperature and solder chemistry for each of the joints of a particular printed circuit board before soldering begins. Other inputs such as maximum component temperature, board composition, etc. influence the overall process. After the soldering process is complete, inspections performed by human or machine attempt to confirm solder joint formation to a standard. The highest point of risk during this process is the soldering activity.

The risk associated with the soldering activity takes the associated control of variables defined for the process and places success or failure entirely into the hands of the operator. The soldering activity relies on the skill and experience of the operator to judge whether each solder joint conforms to the visual standard. The visual standard and operator skill do not account for the correct formation of the intermetallic compound.

Background

According to the Institute of Printed Circuits (IPC), the fundamental goals and guidelines for a process are as follows:

- Non-destructive Process – During any assembly or rework process, no damage or degradation should occur to the board (both substrate and circuit elements), adjacent components, and the components to be installed or removed.
- Controllable, Reliable, and Repeatable Process – The process can be employed, and when necessary, modified by a trained operator in a repetitive fashion with consistently acceptable results.
- Process Appropriate to Particular Application – The process (or modification thereof) employed is appropriate to the particular application based on the relevant guidelines
- Operator Friendly Process – An operator of average ability can, with proper training and practice, become acceptably proficient in employing, and when required, modifying the process to suit any particular requirements of a given task.
- Efficient Process – The process can be done repeatedly in a production environment quickly and easily at minimal cost with little or no downtime. Set-up and training time must also be minimal. (IPC, 1998)

In order to meet the industry requirements and mitigate the risk associated with IMC formation, it is necessary to modify the operator's approach to the soldering process. The current soldering process is open loop. There is no indication to the operator that the process successfully meets any requirement other than visual. Validation of the solder joint requires the ability to identify the correct solder geometry, detect the transition of solder from solid to liquid (liquidus), and calculate the intermetallic compound formation without adversely affecting throughput or repeatability.

This three-step process begins with a preliminary validation of the solder joint to ensure the tip geometry and solder tip temperature match the load. The system compares the thermal characteristics of the tip geometry and the power delivered to the joint within two seconds of applying the tip to the load. The equation, $R_\theta = R_{\theta min} + \frac{R_{\theta max}}{\{1+[\eta_{th} * e^{-\Delta T}]\}}$ describes the process.

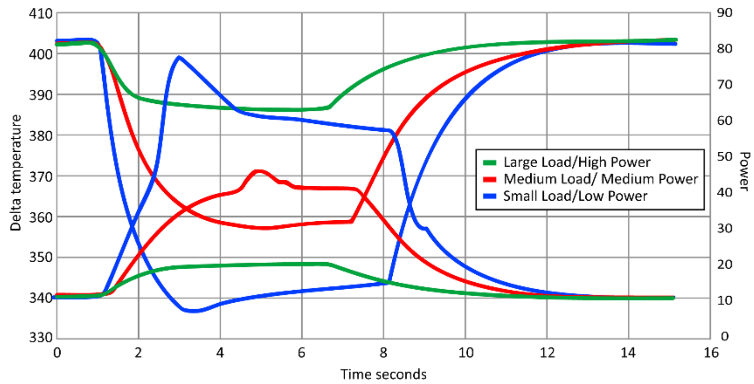

Figure 1 Preliminary Validation

Total thermal resistance is a function of minimum thermal resistance plus maximum thermal resistance as a function of a thermal efficiency of the tip geometry over time. Figure 1 shows the relationship between the load and temperature versus time. From this calculation, the validation moves into the second phase, liquidus detection.

Liquidus detection relies on the heat transfer equation, $\Delta T_{tip-load} = P * R_{\theta tip-load}$. During the soldering process, load temperature increases with an increase in power and a decrease in thermal resistivity as the tip and load approach equilibrium:

$$\Delta T_{tip-load} \Downarrow = P \Uparrow * R_{\theta tip-load} \Downarrow$$

Once liquidus occurs, thermal resistivity becomes stable resulting in a decrease in power as shown:

$$\Delta T_{tip-load} \Downarrow = P \Downarrow * R_{\theta tip-load} \Leftrightarrow$$

Detecting this change in state, signals liquidus. With the detection of liquidus, the process moves to the final phase of calculating the formation of the intermetallic compound. The intermetallic compound forms the bridge through which electricity flows and indicates the formation of a chemical bond at the substrate/solder interface. The role of intermetallic compounds (IMC) is critical to the successful formation of a solder joint. With too little IMC formation, typically <0.25 µm, the solder joint is cold or dry, which hinders electrical connection. Too much IMC, typically >4µm, solder joint embrittlement becomes a factor. Validation of the IMC formation during the soldering process mitigates the risk. The calculation of the IMC is $IMC = 1 + [\eta_{th}$*ln (t+1)]. As shown in Figure 2, the formula demonstrates a relationship between the thermal efficiency of the tip geometry and time. Each step of the process builds toward the successful formation of the IMC within a given timeframe based up on the tip geometry, load, etc. In order to perform the necessary calculations, the hardware must evolve.

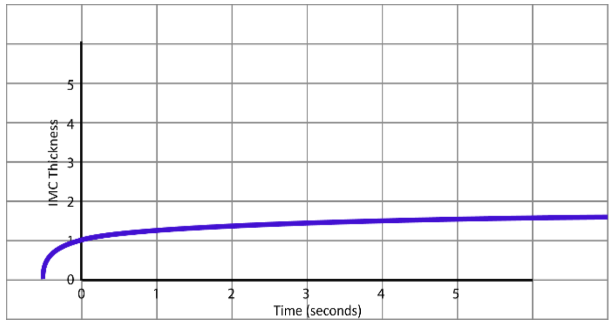

Figure 2 IMC formation

Implementation

The ability to calculate the intermetallic compound formation and the desire to provide closed loop feedback to the operator necessitates a change to the hardware. As explained, the thermal efficiency (η_{th}) of each tip geometry is key. Each tip geometry requires a unique thermal efficiency factor and the ability to provide this information in real time. Real time information processing requires a microprocessor-controlled solder system, a storage system for the tip geometry and thermal efficiency factors, and a means to communicate to the operator. The test setup consists of a modified, cartridge-based, inductive soldering power supply. A modified soldering cartridge, which incorporates a form of internal storage via EEPROM (electrically erasable programmable read-only memory). Lastly, a modified hand-piece provides feedback to the operator via embedded red and green LEDs (light emitting diodes). The embedded green and red LEDs indicate either successful IMC formation (green/Go) or a process failure (red/No Go). The choice of an inductive soldering power supply over a resistive soldering power supply or other technology resides in the inductive soldering systems ability to respond to the thermal energy demand of the pad and to apply power based on the pad temperature requirement.

Testing

Sample #1: Surface Mount Component, 0805 Resistor, Figure 3

Both solder joints exhibit proper wetting between lead and printed circuit board (PCB).

Table 1 Sample #1

	Avg. IMC Lead Interface	Avg. IMC PCB Interface
Sample #1	1.29	1.88

Figure 3 Sample #1

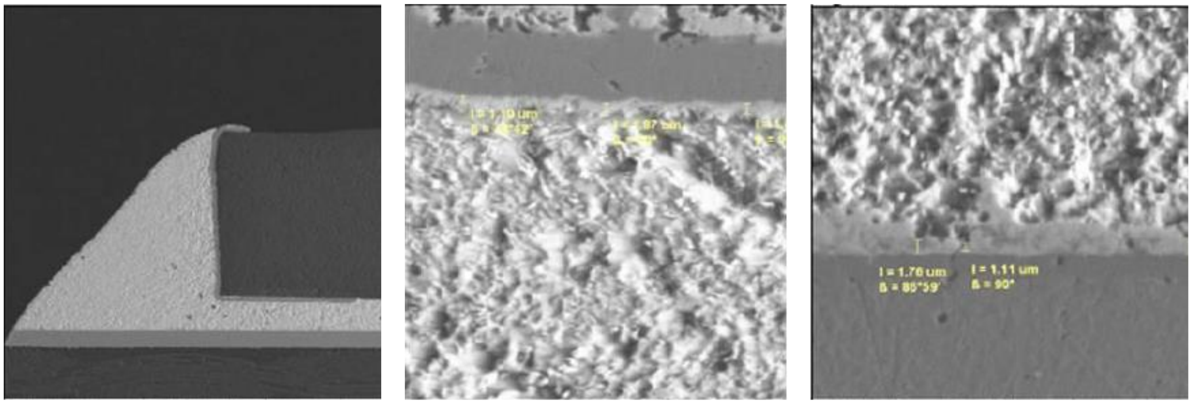

Figure 4 Sample #1 Cross sectional analysis performed by STi Electronics

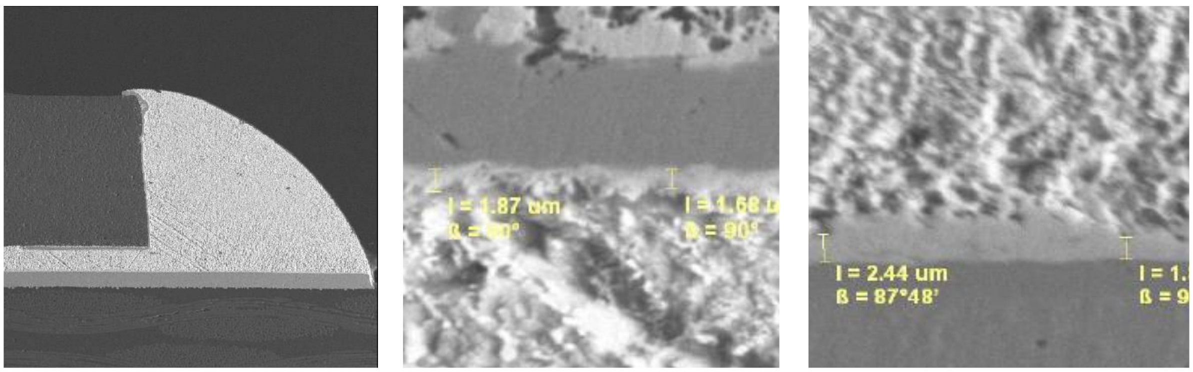

Figure 5 Sample #1 Cross sectional analysis performed by STi Electronics

Sample #2: Through-Hole Component, 1/4W Axial Lead Resistor, Figure 6

The solder joint exhibited proper wetting to both the lead and PCB interface as evidenced by the sufficient IMC formation. Resin recession and PCB delamination observed. Resin recessed can be described as a separation between the plated barrel of the hole and the dielectric material on the hole wall. Per IPC-A-600H-2010, section 3.1.9, it is acceptable for all three classes following thermal stress testing and meeting the dimensional and plating requirements of IPC-6010 performance series. Delamination is a separation between plies within a base material, between a base material and a conductive foil or any other planar separation with a printed circuit board. Per IPC-A-610E-2010, page 10-7, it is acceptable for all three classes, if the delamination does not bridge more that 25% of the distance between plated-through holes or internal conductors.

Table 2 Sample#2

	Avg. IMC Lead Interface	Avg. IMC PCB Interface
Sample #2	1.86	2.37

Figure 6 Sample #2

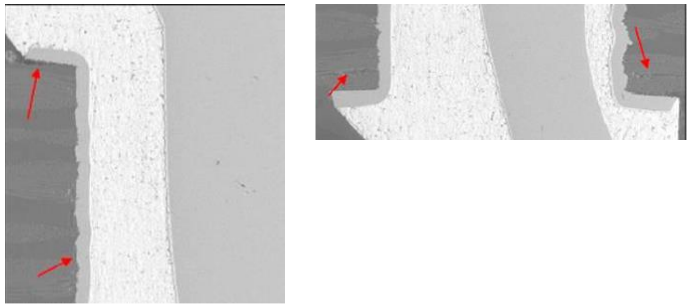

Figure 8 Sample #2, Minor board delamination

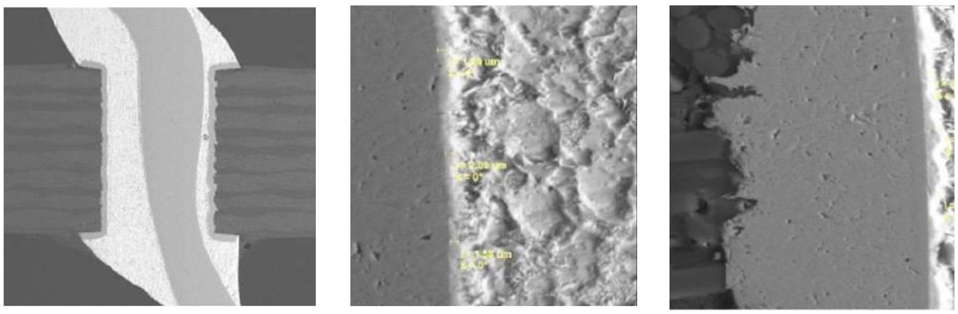

Figure 7 Sample#2 Cross sectional analysis performed by STi Electronics

Sample #3: Through-Hole Component, 1/4W Axial Lead Resistor, Figure 9

The solder joint exhibited proper wetting to both the lead and PCB interfaces evidenced by the sufficient IMC formation. PCB delamination observed. Delamination is a separation between plies within a base material, between a base material and a conductive foil or any other planar separation with a printed circuit board. Per IPC-A-610E-2010, page 10-7, it is acceptable for all three classes, if the delamination does not bridge more that 25% of the distance between plated-through holes or internal conductors.

Table 3 Sample #3

	Avg. IMC Lead Interface	Avg. IMC PCB Interface
Sample #3	1.86	2.71

Figure 9 Sample #3

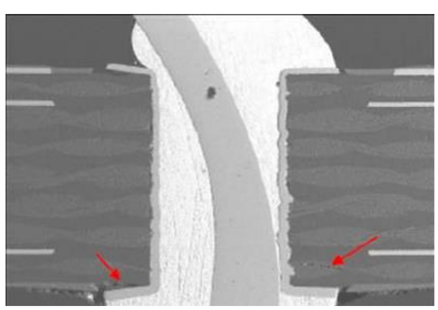

Figure 10 Minor board delamination

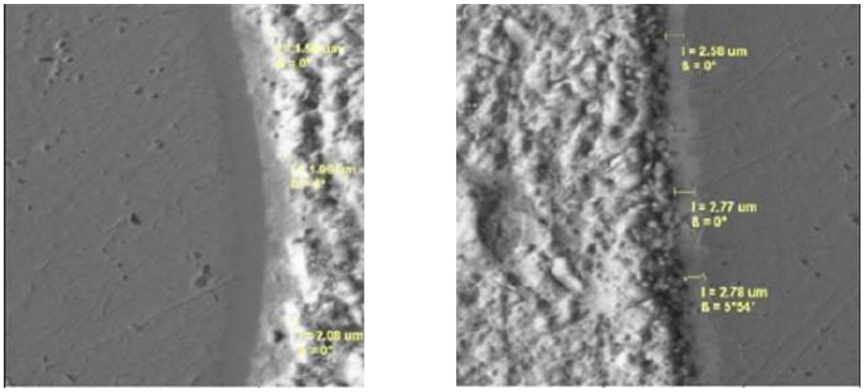

Figure 11 Sample#3 Cross sectional analysis performed by STi Electronics

Conclusion

Each factor involved with the formation of the solder joint is an element of risk and can affect throughput and repeatability. The industry relies on control of input variables and operator training to minimize risk to varying degrees of success. Intermetallic compound calculation compliments the visual inspection criteria with a tool that introduces repeatability into the process in real time. With the proper software and hardware modifications, IMC calculation provides a repeatable process that minimizes the variables associated with operator skill and individual assessment pertaining to the formation of a successful solder joint.

References

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