Reducing Defects in Hand Soldering Operations

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Abstract
Wire soldering operations are still widely accepted in the electronics assembly industry. When a product or the parts within cannot withstand the heat of oven reflow, the localized heat provided by a soldering iron has been the traditional solution. In high-volume operations, this can often require large labor pools to keep up with more automated assembly processes upstream or downstream. Soldering with wire and iron also leaves process judgments up to individual operators, and can produce a wide variety of defects, scrap, or long-term quality issues.

Despite the many improvements in automated soldering technology through the years, many soldering operations are best suited to manual production methods, which produce inconsistent results. Whether in low-volume custom operations or large-scale manufacturing processes, the quality of hand-soldered joints will exhibit a high degree of variation. Defect, scrap, and rework rates can be excessive, even when using skilled employees.

Higher temperature lead-free operations present an additional challenge. Because of the higher temperatures required, these processes have even smaller operating windows. Visual inspection of lead-free solder joints also presents new difficulties, and since most hand soldering rework occurs 'on-the-fly,' actual defect rates are difficult to measure.

There are other process solutions available which involve very little capital expenditure, but can significantly increase operator output. These solutions are effective in eliminating many of the process defects associated with wire solder. They will usually result in a faster and more controllable process that reduces scrap and improves overall product quality. In many applications where wire solder was once a requirement, a more automated approach can often be achieved using solder paste and localized heating methods.

Introduction
Manual soldering operations result in many types of defects. These defects are well documented in IPC A-610D, Acceptability of Electronic Assemblies. Within IPC A-610D, standards for acceptability were established based on the type of product being manufactured. For the purpose of this paper we will focus in on the six most common defects: too much solder, not enough solder, overheating, cold joints, contamination, and solder spikes. For those that are unfamiliar with IPC A-610D, the following synopses of these defects are provided as a review.

- Too much solder: Excessive solder can be caused by operator error and flux core solder wire quality variation. Even the best operator cannot get solder to wet when they reach a section of wire where the flux core is reduced or missing entirely. An excessive solder joint causes poor contact angles, stress concentration points, and can even result in bridging between components (Figure 1).

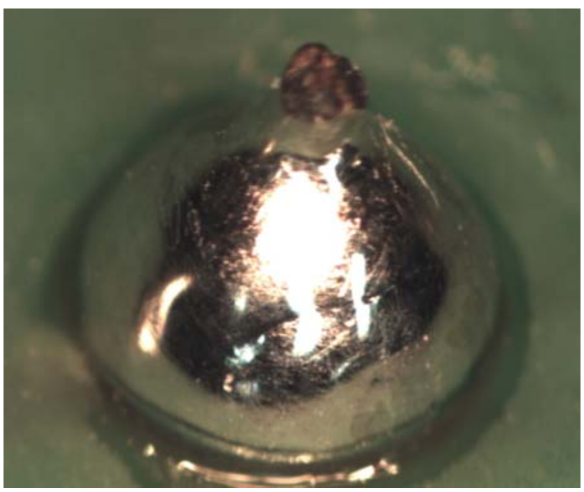

Figure 1 – Too Much Solder

- Not enough solder: An insufficient solder joint is at risk due to poor mechanical strength. In surface mount applications an insufficient joint can be difficult to see because so much of the solder joint is under the component lead. In through hole applications, there can be poor hole fill that is not visible (Figure 2).

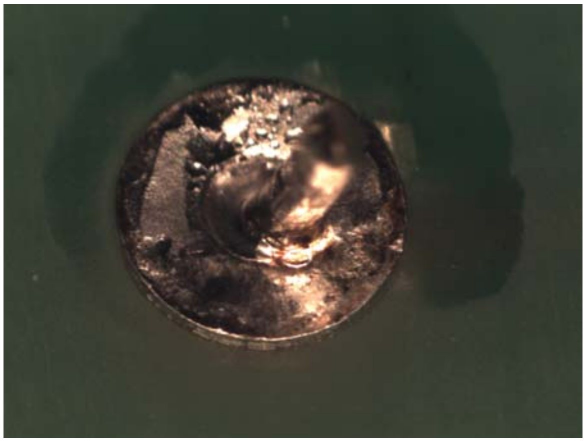

Figure 2 – Not Enough Solder

- Overheating: Leaving the iron in contact for too much time or having too high an iron temperature can damage components and circuit boards. The burns are the easy to see defect. Less easy to detect are cracked components that can easily make it to the field before making their presence known. Component cracking is caused by thermally induced expansion mismatch (Figure 3).

- Contamination: High iron temperatures and inadequate iron maintenance can leave behind burned flux and oxidized solder. Conversion to lead free solders typically requires higher iron temperatures that aggravate flux burning. Burned flux residue can contaminate joints, causing voids and interfere with wetting by covering surfaces that should be soldered (Figure 3).

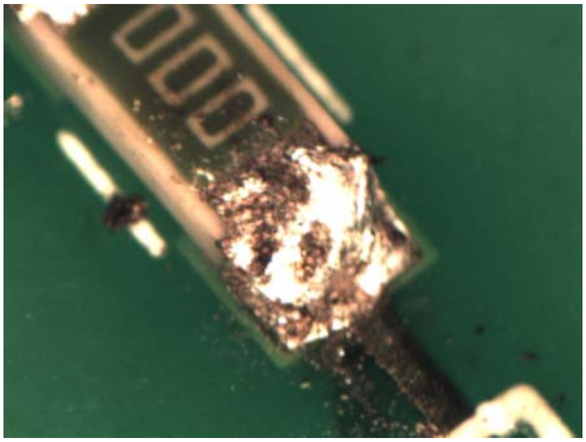

Figure 3 – Overheating & Contamination

- Cold joints: Insufficient heating and insufficient flux content in wire can both result in joints where the solder does not wet well. There is a minimum activation temperature below which the flux will not properly remove metal oxides. All the surfaces to be soldered must reach a minimum temperature for intermetallics to form. Putting a drop of molten solder on a piece of copper will not result in a joint unless there is enough heat in the molten solder to heat the copper to that temperature. Also, solder alloys wet and spread better the higher the soldering temperature. This improved wetting is caused by changes in surface tension and intermetallic growth rate. Poor wetting results in lower joint strength, voiding, and in some cases no joint at all (Figure 4).

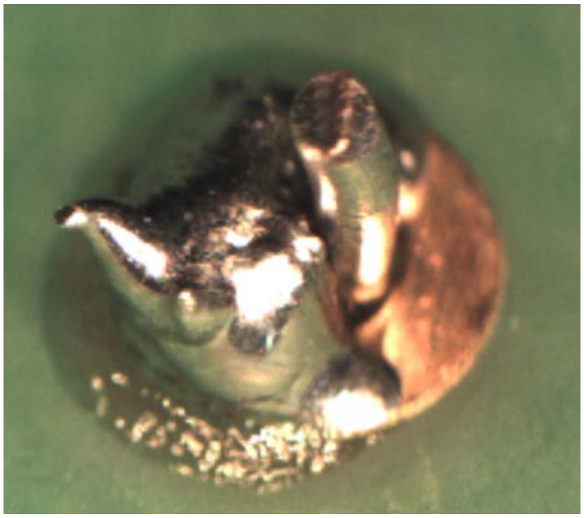

Figure 4 – Cold Joints

- Solder spikes and icicles: Solder spikes have been reported as the most common soldering defect. They are the result of several sources. Poor soldering iron technique can draw spikes of solder by allowing the joint to partially solidify before the tip is removed. Insufficient heating also causes solder spikes. Insufficient heating can be difficult for even a skilled operator to overcome. Many of the more inexpensive irons available have poor iron temperature control. Smaller joints often require a smaller tip that conducts less heat. The issue of flux consumption also produces solder spikes. Solder reoxidizes when heated and insufficient fluxing action results in an oxide shell that increases the probability of a solder spike. Solder spikes are vulnerable to touching other electrical components and breaking loose to fall onto the product (Figure 5).

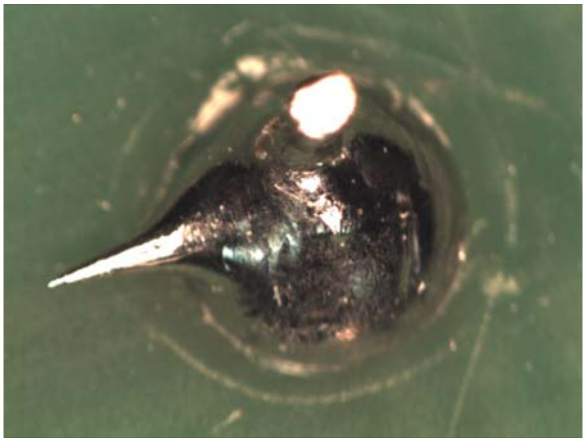

Figure 5 – Solder Spikes

All of these defects have a common root cause. They are the result of a manual operation, and manual operations by definition are more likely to cause variation. Handmade items have value when we are looking for unique products, but 'one-of-a-kind' is not a selling point for solder joints.

Employee training is essential to making good solder joints, but training courses cost money and take away from valuable production time. Even highly trained and skilled employees must deal with the effects of fatigue. High rates of employee turnover result in even more training expense, and smaller operations with fewer trained employees must find ways to deal with absenteeism and vacation time.

Evaluating the True Cost Quality

Many manufacturers do not have processes in place to calculate the total cost of quality. They have a good understanding of how to trim the cost of the bill of material and make their assembly operation more productive but not how to manage the soft costs associated with inspection, rework, training, and complaints and returns. Table 1 illustrates the relative quality impact and cost of each of these variables.

Table 1 –Cost of Quality

Variable	Quality Impact	Manufacturing Cost
Solder Material	High	Low
Inspection	High	Moderate
Rework	High	Moderate
Scrap	Low	High
Operator Training	High	High
Customer Returns	None	High

- Solder Material: Solder wire is sold as a commodity. The percentage of a product's cost from solder is usually quite low and may not even be on the bill of materials. The difference in performance between solders can result in yield loss change of 50% or more. Compare the cost of scrap to the cost of solder and you will usually find the solder cost is insignificant.

- Inspection Costs: These are the costs associated with lost productivity from time spent inspecting solder joints for defects. The operator may perform this inspection as the joints are manufactured, or it may involve secondary or even tertiary inspection operations. Inspection costs increase when there are customer complaints and returns that require corrective action.

- Rework Costs: This is the cost of time spent remanufacturing product and the materials consumed in repeating the soldering operation a second time. This rework can take place immediately as the joint is made, or can result from post-production inspection and rejection.

- Scrap Costs: Perhaps the most devastating cost is when a defective solder joint cannot be reworked, or results in damage to the product. This cost includes the cost of the raw materials and all of the value-added time invested.

- Training Costs: The manual production of solder joints requires skilled employees, and skilled employees require training. In addition to the actual hours spent in training and certifying employees, there are the costs of training materials and instructors. There is also the cost of 'on-the-job' training. Skill derives not just from training, but also from experience. Training continues on the production floor, and experience is making a mistake, correcting for it and learning from it. All this happens at the expense of effective production.

- Complaints and Returns: In addition to the direct costs of dealing with customer complaints and returns, there is the intangible cost of future business being lost because of poor quality. In some cases a customer will only require replacement which more than doubles your cost of manufacture for that sale. In others they require the implementation of corrective action which does much more than double costs in the short term.

Test Case 1
A printed circuit board manufacturer was using test coupons to perform accelerated life tests to determine circuit board quality. They had a problem. Accelerated life test results did not correlate with board manufacturing parameters or actual performance of the circuit boards in customer life testing.

Components used to attach the circuit board monitoring equipment were hand-soldered to the test coupons. After replacing the hand soldering operation with a semi-automated process, life test results finally correlated with actual circuit board performance. The life tests were exposing variability in hand soldering, not variability in the board manufacturing process.

Test Case 2
A manufacturer of electrical components had transitioned the soldering of fine wires to a thin printed circuit board (PCB) to lead free solder. Yield loss had become a problem due to overheating of the PCB and erosion of the thin wire due to excessive time exposed to molten solder. The use of convection heating was not an option due to other temperature sensitive materials in the assembly. After replacing the hand soldering operation with an automatic soldering process, yield loss due to component damage was eliminated.

Alternative Soldering Methods
Solder paste and paste flux are relatively simple improvements to implement, as they can be applied through a variety of deposition methods. For planar surfaces, it can be printed in place through stencils, and for non-planar surfaces and/or singular deposition points it can be deposited via syringe through a wide variety of needles and other apertures. Many

machines are available to automate deposition. These systems range from benchtop operator fed devices to inline, conveyor fed robotics. Some systems are even scalable to allow for a gradual process evolution from benchtop to automated assembly line.

Solder paste deposition is usually a more controllable process than wire. The actual amount of solder applied can be tuned to a fine degree. Add to this the increased flux levels found in solder paste as compared to wire, and a better solder joint is often achieved. Many find that they use far less solder per joint when moving to paste processes, while producing stronger, higher quality bonds. Process flexibility also increases, due to the incredibly wide variety of paste formulations. Flux type, paste viscosity, rheology, metal content and alloy are all customizable to a wide degree, allowing for non-standard processes, parts and materials to be soldered.

Comparing Solder Paste to Traditional Wire

In addition to the consistency and quality comparison, solder paste differs physically from traditional wire. These physical differences change the options available to the assembler.

Solder paste is a homogenous mix. Each alloy sphere is coated with flux, typically 85% metal content and 15% flux (Figure 6). Traditional wire contains approximately 2-3% flux and commonly experiences voids in the flux core that result in soldering defects, such as excessive solder, solder spikes and icicles. Paste flux is also more tolerant of heating that liquid flux. It stays in place and survives a longer heating process before running out of activity.

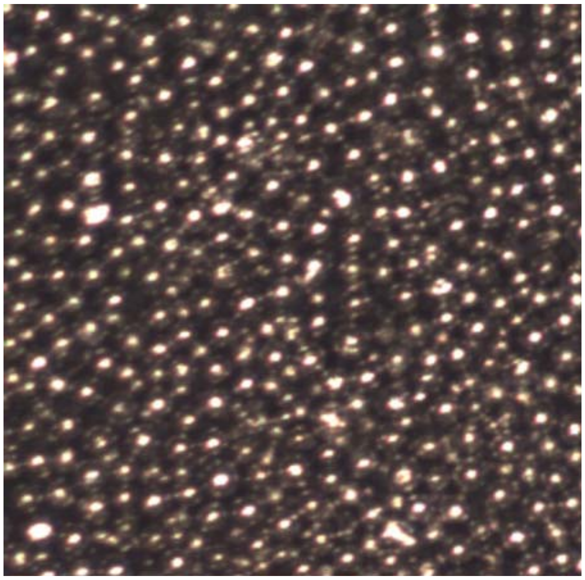

Figure 6 – Solder Paste

The additional flux in solder paste provides a better wetting surface when creating a joint. The flux cleans and prepares the surface to be soldered better than core wire, improving alloy spread and accelerating intermetallic growth. In comparison, wire solder must be fed into the joint until the desired wetting is achieved. With solder paste’s improved flux performance, less alloy is needed to produce the same solder joint.

Solder paste’s binding system prevents separation, and the tacky consistency allows for better part placement without the need to fixture the components to be soldered. Deposited paste stays where it is put and holds components in place for the reflow step (Figure 7).

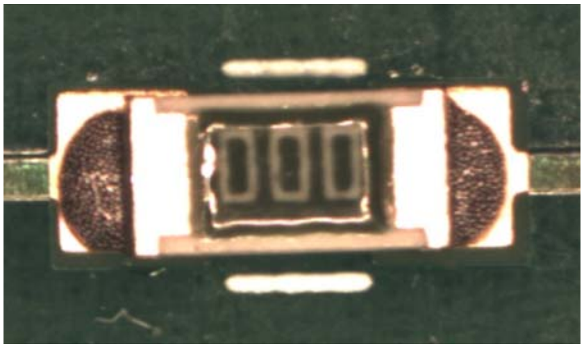

Figure 7 – Paste in Place

Solder paste can be deposited in hard to reach locations (Figure 8), allowing for easy assembly whereas positioning a wire and iron in place at the same time is a difficult and demanding exercise. By using a solder paste that is specially formulated for use with the rapid and high temperature heating of a soldering iron, greater care can be paid separately to placing the correct amount of solder and ensuring the best heating is achieved.

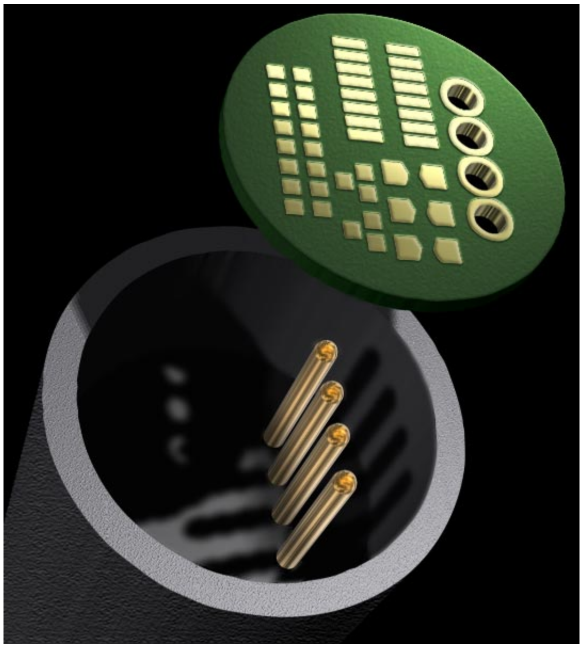

Figure 8 – Recessed Solder Joints

Solder paste is easy to transition to semi- and fully-automated assembly with many process options available; whereas wire is either manually or gripper roller fed.

Conclusion

The ideal solution to the problems associated with hand soldering would be independent of employee skill level so that any employee would be able to consistently produce high-quality solder joints. To avoid problems associated with soldering tip maintenance, it would also utilize a non-contact heating method. The heating method would provide reliable, even heating of the joint without any danger of overheating.

Solder joint volume would be uniform and the location of the solder joint would be consistent from part to part. The solution would include the ability to use a variety of solder alloys and fluxes, and would be easily transitioned between leaded and lead-free operations. And of course, the ideal solution would have a minimal investment cost.

Such solutions exist and do have a low investment cost. Solder pastes exist that serve a nearly infinite variety of heating and wetting needs. It is not necessary to tolerate the quality problems and expense associated with hand soldering in order to keep manufacturing costs down.

Reducing Defects in Hand Soldering Operations

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The Soldering Iron

Benefits of Soldering Irons

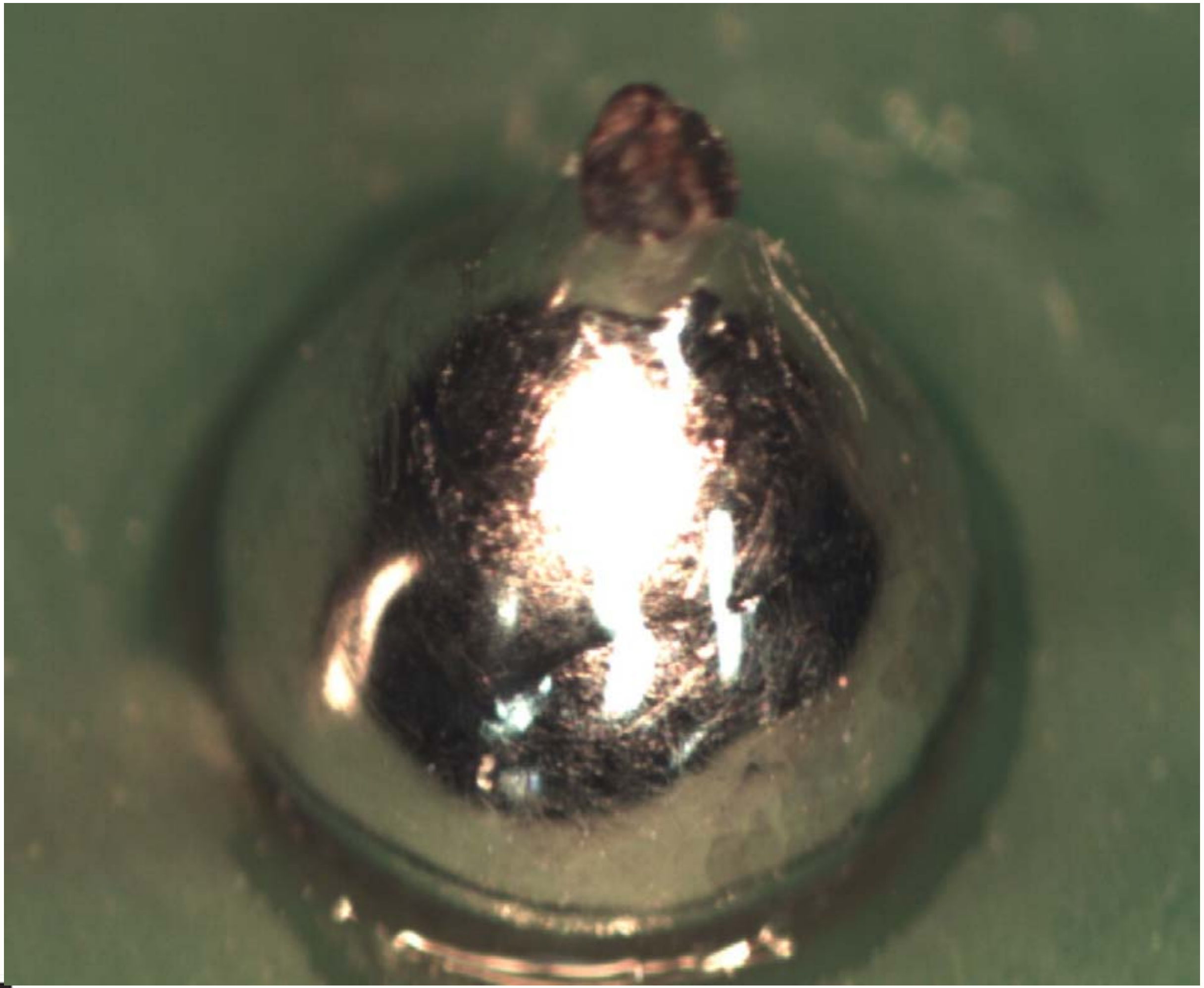
- High flexibility
- Relatively Inexpensive
- Good manual form factor

Hand Craftsmanship

Most Common
Hand Soldering Defects

- Excessive Solder
- Insufficient Solder
- Overheating
- Cold Joint
- Contamination
- Solder Spikes

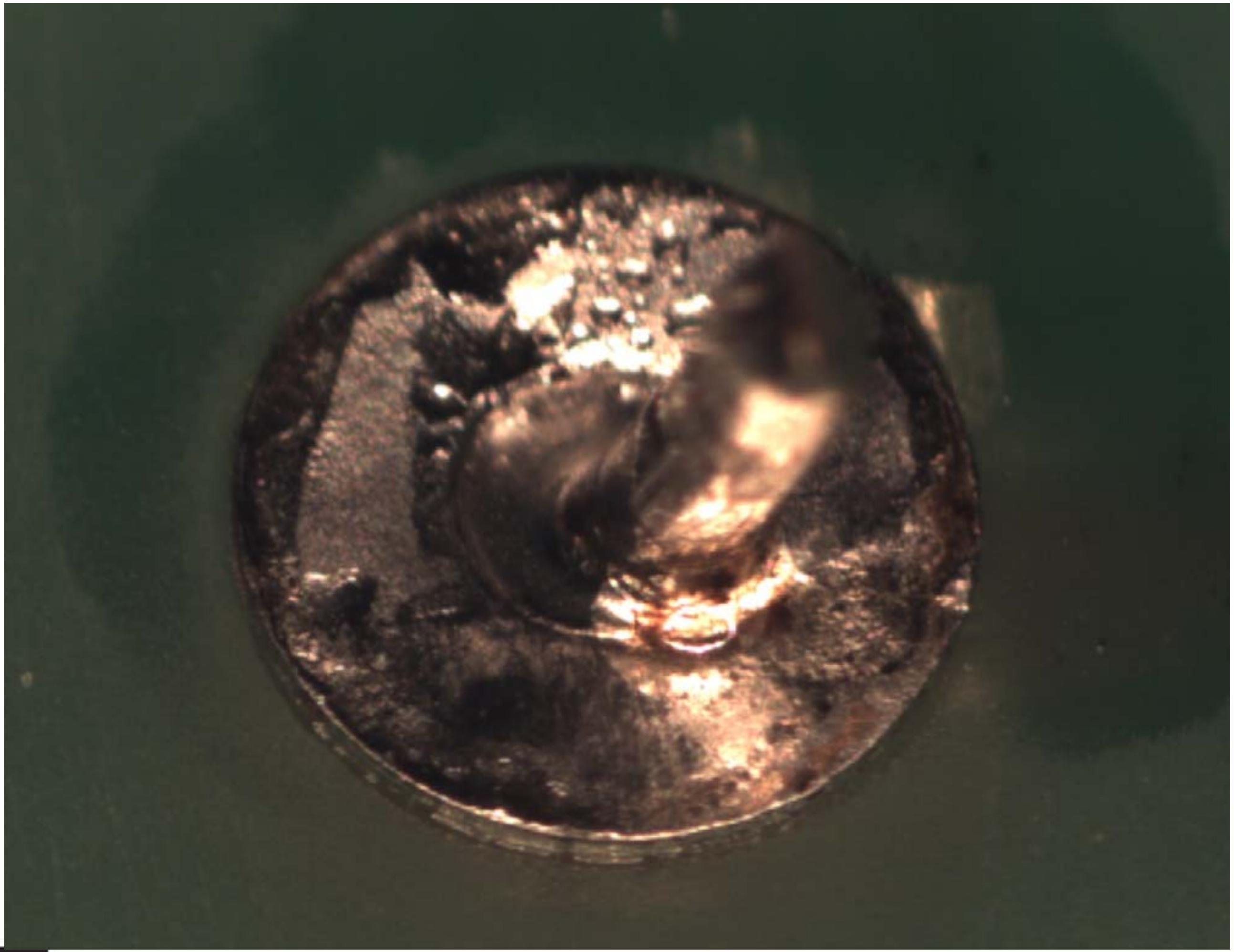
Excessive Solder



Too Much Solder

- Causes
  – Over feed wire
  – Need more flux action from flux core
  – Operator variability
- Solutions
  – Material metering
  – More reliable fluxing solution

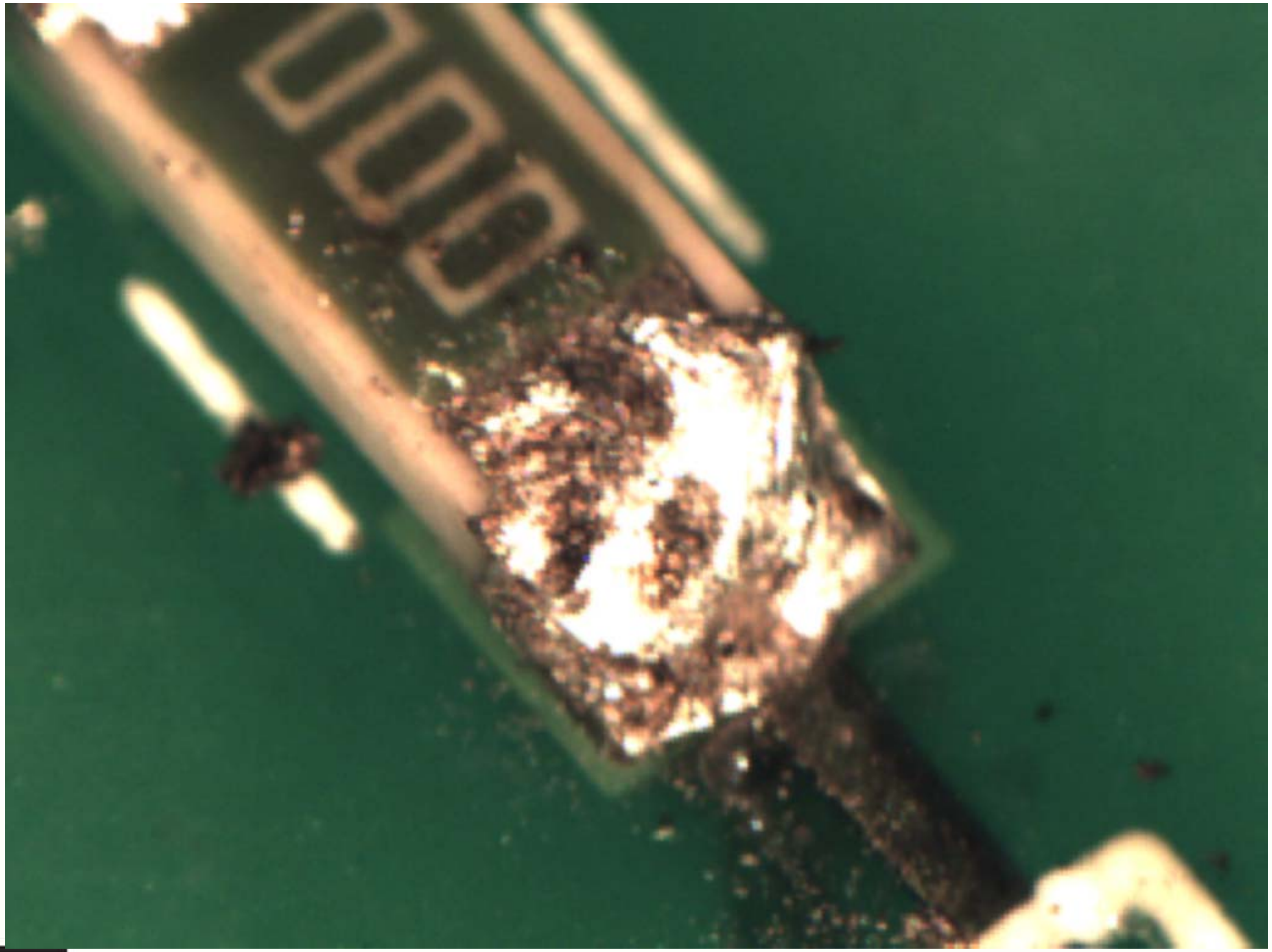
Insufficient Solder



Insufficient Solder

- Causes
  - Insufficient wire feed
  - Solder remains on iron tip
  - Difficult visual confirmation
  - Operator variability
- Solutions
  - Material metering
  - Obvious visual confirmation

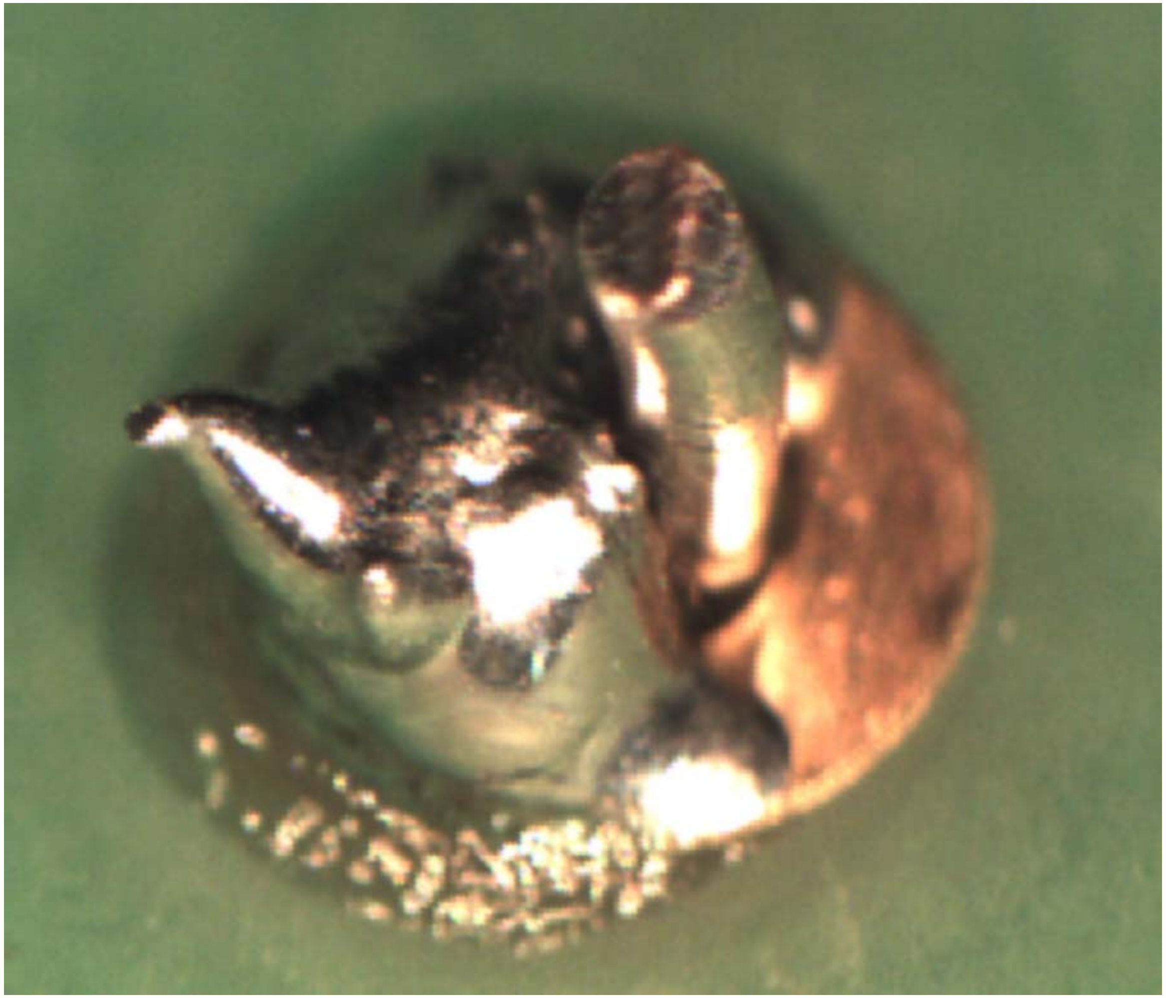
Overheating and Contamination



Overheating and Contamination

- Causes
  - Excessive iron contact fighting poor wetting
  - Flux char on soldering iron
  - Operator variability
- Solutions
  - Consistent fluxing action
  - Consistent heating cycle
  - Visual queue of heat cycle completion

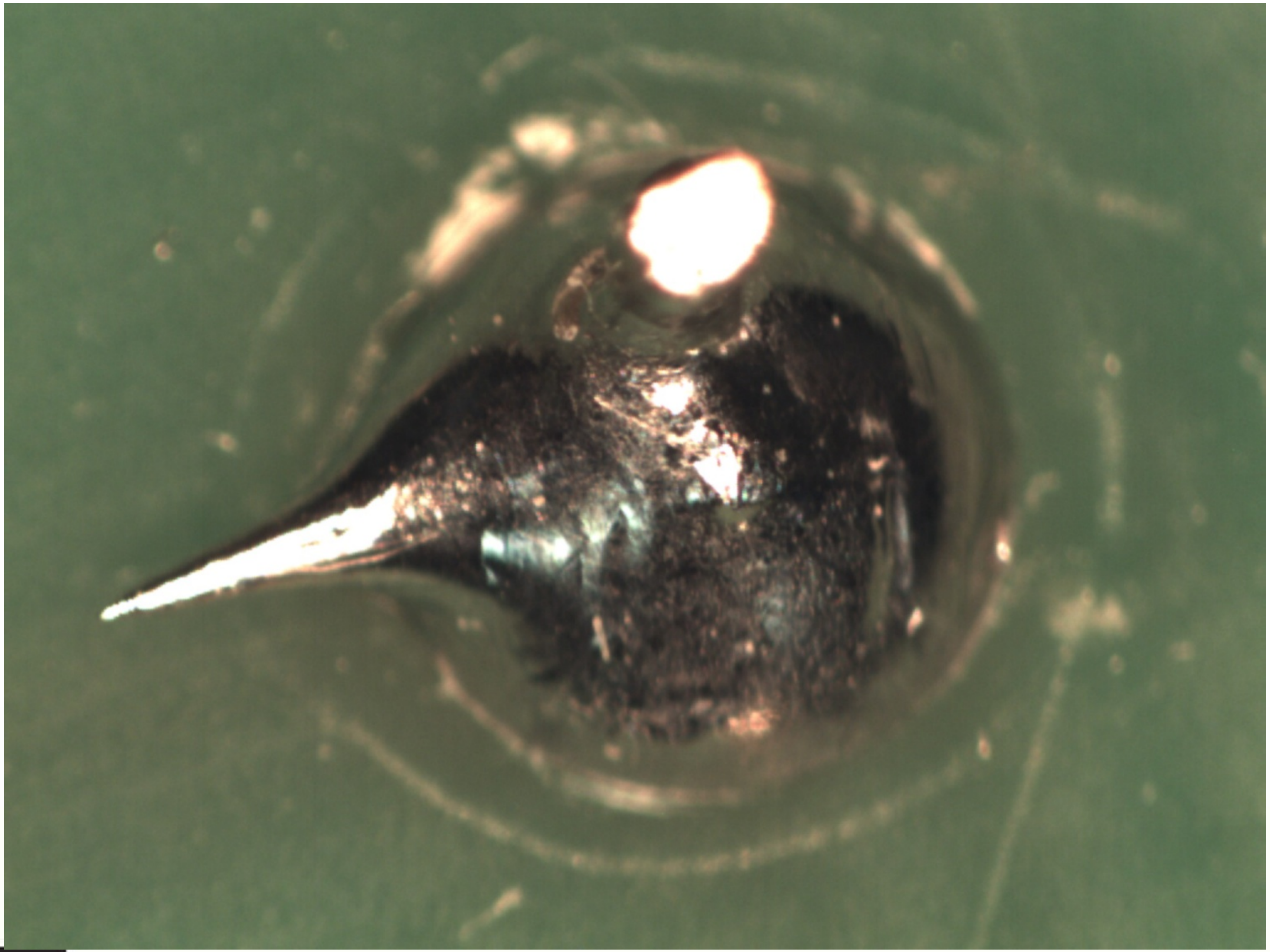
Cold Solder Joint



Cold Solder Joint

- Causes
  - Iron temperature fluctuation
  - Joint to joint heating requirement differences
  - Operator variability
  - Poor fluxing action
- Solutions
  - Consistent heating cycle
  - Consistent fluxing action

Solder Spikes / Icicles



Solder Spikes / Icicles

- Causes
  - – Poor soldering iron technique
  - – Insufficient heating
    - Operator variability
    - Equipment variability
  - – Insufficient fluxing action
- Solutions
  - – Consistent heating cycle
  - – Consistent fluxing action

True Cost of Ownership

Variable	Quality Impact	Cost
Solder Material	High	Low
Inspection	High	Moderate
Rework	High	Moderate
Scrap	Low	High
Training	High	High
Returns	None	High

Solder Material

- Sold as a commodity – Low unit cost
- % of product cost is very low
- Performance affects yield directly

Inspection Costs

- Lost productivity
  - Inline Inspection
  - Secondary Operation
  - Inspectors “Find Defects”
- Drivers
  - Process Yield
  - Customer returns
  - Corrective Action Requests

Rework Costs

- Inline and Secondary Operations
- Duplicate labor costs
- Rework staff touch up good joints too
- Second opportunity to damage product

Scrap Costs

- Cost direct to bottom line

Training Costs

- Training expense
- Lost productivity
- Employee turnover
- Skilled labor

Customer Complaints and Returns

- Cost of processing return
- Cost of increased inspection and CAR
- Lost future business

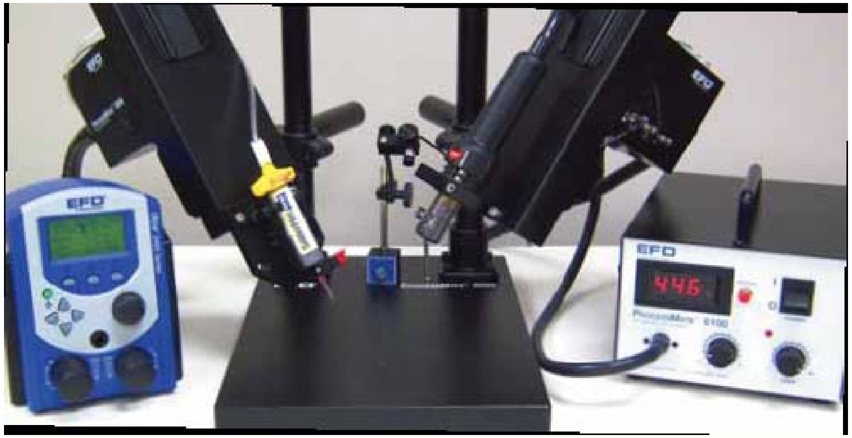
Test Case 1: PCB Test Coupon

- Before
  - Manual soldering with wire and iron
  - Test results do not match actual performance
- After
  - Semi-automatic solder paste dispense and hot air reflow
  - Assembly time cut by 75%
  - Test results match actual performance

Test Case 2: Lead Free Conversion Soldering thin wires to PCB

- Before
  - Manual soldering with wire and iron
  - Pad lifting due to overheating and wire erosion
- After
  - Manual solder paste dispense
  - Semi-automatic timed process with iron
  - Elimination of pad and wire damage

Alternative Methods



Comparing Solder Paste to Wire

- Solder Paste Features
  - 10-20% flux by mass
  - Even flux distribution
  - Flux lasts longer
  - Safe no-clean residue
  - Dispense on joint prior to heating
  - Digital dispense control
  - Requires 1 hand
  - Can hold parts in place
  - Allows for mass reflow

- Solder Wire Features
  - 1-3% flux by mass
  - Sections with no flux
  - Feed into joint while heating
  - Operator feed control
  - Requires 2 hands

Conclusions

- Ideal soldering solution
  - Independent of operator skill
  - Repeatable heating requirement
  - Wide variety of flux options
  - Clean transition from leaded to lead free
  - Minimal investment cost