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ELECTRONIC INTERCONNECTIONS

Electronic Assembly with Solder: an Unblinking Look at "The Devil We Know"

by Joe Fjelstad
VERDANT ELECTRONICS

Solder is unquestionably highly practical technology for joining metals, and carries with it a long history. Its roots go back more than 2,000 years. Somewhere in the distant past, one of our more clever and observant ancestors chanced to create an alloy of tin and lead that melted at a low temperature. They or someone who learned of their discovery found that this unique combination of elements could be used to join pieces of metal together. This combination of chance observation and applied imagination has proven a key development in the technological history of mankind. Those in the electronics industry of today are very familiar with this ancient technology and today it is still the method of choice for making electronic assemblies of every sort. The only fly in the ointment is that the EU parliament, in a mad rush to try to look "green," took the emotional and scientifically ill-advised position that lead needed to be banned from electronic solders.

Sadly, there was never presented a credible piece of scientific evidence that any user had ever been harmed by tin-lead solder in electronic equipment. Nor could they prove their assertion that it would be a risk to ground water. That said, it is true that greed and complete mismanagement of electronic waste boarding on criminal behavior, has resulted in physical illness and environmental harm in areas of the world where

uncontrolled recycling was being carried out by uneducated individuals. While all is not yet well in that regard, that "hole" in the system is being addressed by businesses, NGOs and governments around the world.

Not to be forgotten is the fact that the impact of the EU's decision has been significant and far-reaching and it has caused the industry to spend needlessly many tens of billions of dollars diverting the considerable talents of countless talented engineers and scientists around the world to make products that are unfortunately proving less reliable and arguably less environmentally friendly electronics than those built with tin lead solders.

The Devil We Know, Disrobed

While soldering (especially tin-lead soldering) holds many benefits in terms of offering a means of mass assembly of electronic components to printed circuit boards and is fundamentally simple, its application in the assembly and manufacture of electronic products of the present age is much more complex and fraught with opportunity for defects to be generated, but it is also the a demon we have elected to live with, for as the old saying suggests that "Better is the devil we know." The devil we know is at least familiar and the simple truth is that humans are creatures of habit and most of us abhor change. There is a lingering question in the current situation? Is dealing with the devil we know on a daily basis really worth the price we are paying?

Following is a recitation of some of the many types of solder and solder-related defects that test and inspection is tasked with finding before a product reaches market. Bear in mind as these defects are recounted and reviewed that the cost of defects rises as a product moves further from the manufacturing line.

a) Opens: Opens are discontinuities generated in the soldering process that can be manifest in assembly in a number of ways. For example, a bent or lifted lead on a QFP component, missing solder ball on a BGA, insufficient solder on an LGA or the warpage of the component during the high-temperature, lead-free reflow process can all result in an open circuit.

b) Shorts: Solder shorts are bridges of solder between one or more component leads on an assembly. As component lead pitch continues to drop, the incidence of short circuits increases. Presently, the threshold of pain for most assembly is experienced when the lead pitch drops below 0.5 mm.

c) Insufficient Solder: Insufficient solder is a condition where the amount of solder in a solder joint is less than desired or specified contractually through industry specifications or customer requirements.

d) Excessive Solder: Excessive solder is obviously the opposite of the condition of insufficiency and is again measured against agreements. It also introduces a wild card because it is not what reliability testing is based on.

e) Solder Cracking: Solder cracking is an obvious concern as it could result in a latent open circuit condition. Good during product test before shipping but then failing in the field.

f) Tin Whiskers: Tin whiskers are small metal projections emanating from a solder joint. They can grow up to 15 mm long and given the fine pitch of today's components, they are a significant concern. There are also challenging because they are typically a latent defect that shows up unpredictably. Past research indicated that the addition of lead to tin solder alloys would mitigate the formation of whiskers; however, with the ban on lead in electronic solders the incidence of whiskers is on the rise.

g) Poor Wetting/Dewetting: Good wetting is manifest by the presence of uniform coat of solder on both the leads of the component and terminations of the printed circuit to which they are joined. In areas of poor wetting or dewetting the solder thins appreciably in areas leaving only a thin silvery sheen.

h) Voids: Voids are defect which are often difficult to detect without use of special equipment such as an X-ray apparatus. The challenge with voids is that they represent potential weakness in the solder joint owing to their inconsistent nature. Voids can be found both in through-hole and surface mount components. In the case of surface mount components the voids are often extremely small and are sometimes referred to as champagne voids.

i) Blowholes: A term applied to a phenomenon where a small hole is observed in a solder joint. Typically, the defect is found to be the result of discontinuities in the plated through-hole wall, which may absorb flux and then explosively out gas during the soldering process.

j) Cold Solder Joints: Solder joints that did not form completely a good metallurgical bond. They are often the result of the joint receiving sufficient heat to cause complete melting and joining of the solder. Cold solder joints are often seen in cases where the component lead is connected to a large thermally conductive feature or element and insufficient heat is retained near the lead to assure a good solder joint. With lead-free solders, the phenomenon provides a greater challenge as the amount of heat which must be supplied is much greater than it might have been with a tin lead solder, thus potentially degrading device and assembly reliability.

k) Brittle Solder Joints: Solder joints wherein the alloy formed in the soldering process due to dissolution of elements within the finish or on the circuit board (e.g., gold), results in a solder joint that is less ductile than the solder used in the assembly process.

l) Head-on-Pillow: A new type of defect which was identified only with the introduction of lead-free soldering. It is an unsettling type of defect in that it is not easily detected but could result in an intermittent open in the operation of the assembly. The term was chosen because the phenomenon is reminiscent of an individual's head forming a depression on a pillow.

m) Graping: Another lead-free related defect wherein the small, often ball-like particles of solder in a solder paste do not reflow completely, leaving a surface that looks like the surface of a bunch of grapes. Like head-in-pillow, it is a defect that may not be easily detected.

n) Tombstoning: Tombstoning is a term that has been applied to the appearance of a defect related to discrete devices such as resistors and capacitors, wherein solder connections are not made simultaneously; the slight lag causes the first side to reflow to pull back and rotate up, resembling a grave marker (which is somewhat apropos given that the assembly will likely be dead if tombstones are present).

o) Component Cracking: Component cracking can have multiple causes, one being a situation where there is a significant mismatch in terms of coefficient of thermal expansion between the component and the printed circuit to which it is attached. It can also occur if the assembly is flexed in the area of the component, causing the device to crack.

> *"Component cracking can have multiple causes, one being a situation where there is a significant mismatch in terms of coefficient of thermal expansion between the component and the printed circuit to which it is attached."*

p) Popcorning: Popcorning is a phenomenon manifest when moisture entrapped within a component outgases during assembly, causing a blister to form in the encapsulation material. With the advent of lead-free soldering and its higher temperatures, the incidence of popcorning rises and in fact moisture sensitivity levels of components are degraded to reflect the new reality.

q) Solder Balling: Solder balling is a condition which happens during the reflow of a solder paste on a surface mount assembly. It is a result of the high temperature of reflow causing rapid volatility station of the flux and spatter of the solder particles that are part of the flux. While a viable solder joint may be created even as solder balls are being formed, they represent a risk to the long term reliability of the assembly as potential shorting elements.

r) Misregistration: Components with fine pitch leads, if jostled before or during the assembly, may be misregistered relative to the land pattern, resulting in a nonfunctional product.

s) Insufficient Cleaning Under Devices: As mentioned previously, insufficient cleaning under surface mount devices can result in latent failure through the formation of high resistance shorts or the growth of dendrites.

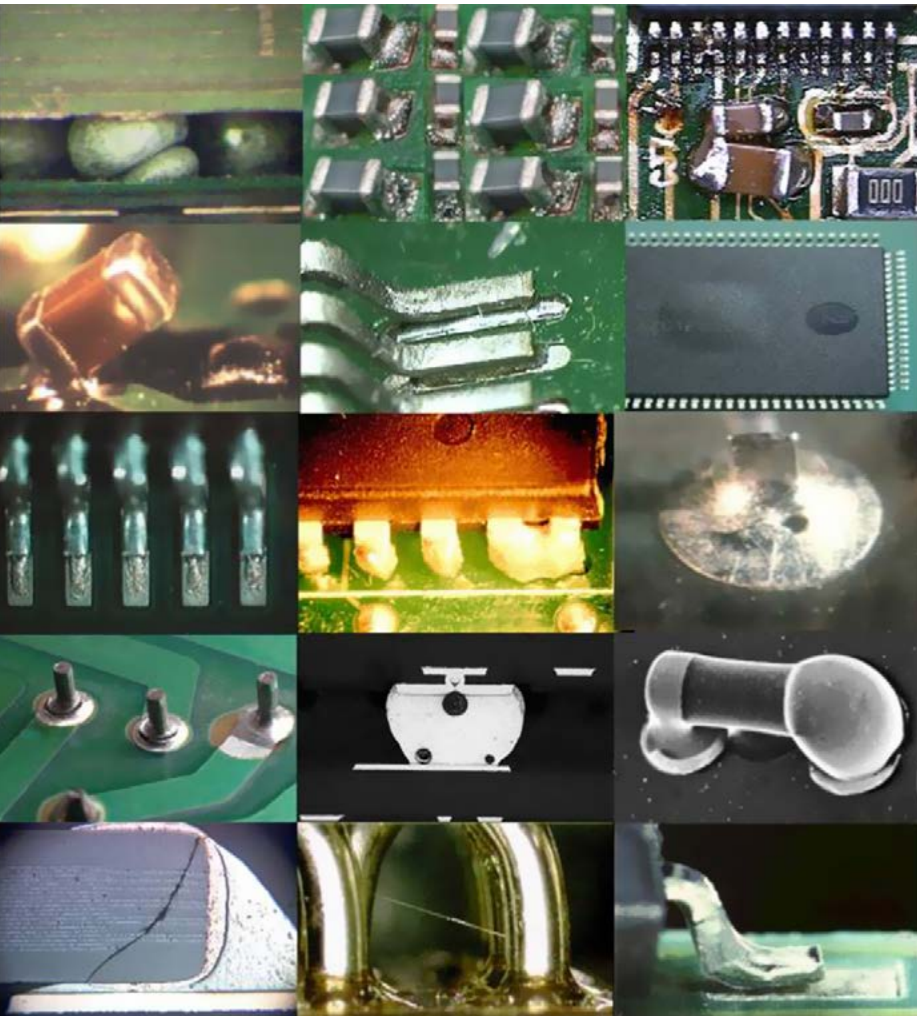

Figure 1: Representative images of some of the solder related defect found on printed circuit assemblies. Top row – left to right: head in pillow, graping, misregistration short and overheated flux. Second row, left to right: tombstoning, insufficient solder with open, popcorning. Third row, left to right: dewetting, blowhole, shorting between adjacent leads. Fourth row, left to right: cracked solder joints, voids, excessive solder. Bottom row, left to right: cracked component, tin whisker, open (lifted lead).

Clearly there is a great deal of nuance in the detection and identification of solder related defects; numerous books have been written over the last few decades that both characterize and suggest methods for eliminating or mitigating them (the devil is also "in the details" as another aphorism attests). It is not within the scope of this brief commentary to provide detail on all of the various types of solder related defects which can extend from the macro to the micro but for the benefit of the reader the following figure is offered providing representative examples of a number of the defects described above.

The "Devil's" Impact on the PCB

The importance of managing the soldering process is clear, but making a good solder joint is also just part of the story and there are a number of defects that can be generated within a printed circuit assembly because of the soldering process, including:

a) Corner Cracking: A crack that forms at the interface between the whole and the land that surrounds. It is normally the result of the Z-axis expansion of the PCB during the thermal excursions such as soldering.

b) Barrel Cracking: Another phenomenon associated with the soldering process; it is similar in some ways to a corner crack except that it is manifest near the center of the hole.

c) Post Separation: A separation of the plating in the through hole from an innerlayer connection

d) Hole-Wall Pull Away: Hole-wall pull away is manifest as a bulge in a plated through hole, which reduces its diameter.

e) Resin Recession: Roughly, the opposite of hole-wall pull away wherein a small gap is formed between the plated hole wall and a resin rich area of a plated through-hole

f) Delamination: A separation of the layers of a multilayer circuit. It is normally seen in cases where the glass transition temperature of the resins used in the multilayer structure is exceeded.

g) Pad Cratering: Another phenomenon unseen before the introduction of lead-free soldering. It is manifest as a circumferential tear of the copper land to which a component, normally a BGA, is assembled.

h) Decomposition: Decomposition of a PCB is a relatively new phenomenon associated with higher temperatures used with lead-free soldering. In fact, a new term was added to the industry lexicon, T_d, which is the temperature of decomposition representing a loss of a specified percentage of the weight of the printed circuit.

Clearly, printed circuit technology, like soldering technology, is fraught with its own vulnerabilities due to the complexities of processing. The demands on PCB technology foisted upon the industry by the imposition of lead-free soldering requirements have placed a heavy burden on the printed circuit manufacturing industry. The need for higher glass transition temperatures to assure a measure of survival through the elevated temperatures of lead-free soldering has required the printed circuit industry to qualify new materials. Simultaneously, there has been a demand placed upon the industry to remove halogenated flame retardants from its materials. This double-barreled challenge is one that the industry had not faced before. Moreover, the industry has been challenged to provide circuits with ever-finer features which operate at ever-increasing frequencies.

To their credit, printed circuit industry technologist, engineers and scientists have struggled admirably to address these challenges, including the challenge of finding solutions to defect modalities that were unknown to the industry just a few years ago. Unfortunately, a number of the defects described are related to soldering and its effects. The earlier problems have been exacerbated by the increased temperature required for lead-free soldering. Figure 2 offers cross-sections of representative printed circuit defects resulting from thermal excursions.

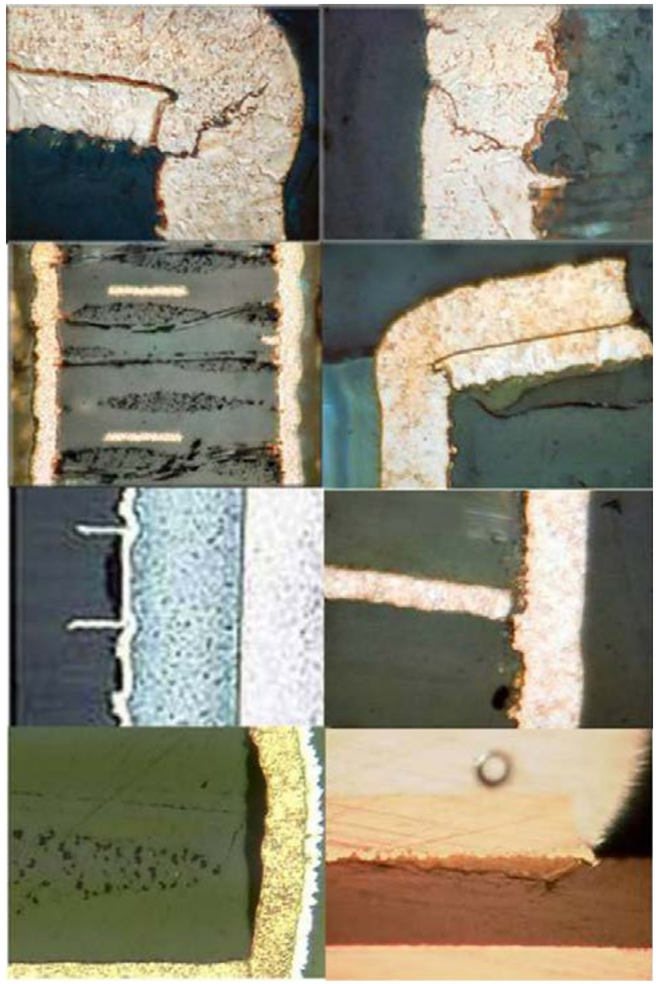

Figure 2: Cross-sectional micrographs of printed circuit defects caused by soldering are provided above. Clockwise from the upper left-hand corner: corner crack, barrel crack , pad lifting, post separation, pad cratering ,hole wall pull away, resin recession and delamination.

Solderless Assembly for Electronics (SAFE) Technology: A Simpler Approach?

Given all the challenges and risks associated with soldering, every thoughtful and prudent manufacturing engineer must constantly be seeking a way or ways to make assembly processing more robust. If one looks for inspiration on how they might end their dealing with the devil, they can find it in the Bible, where it is written: "If thine eye offend thee, pluck it out, and cast it from thee." Perhaps this is a bit extreme, but this seems to be where the industry is stuck today in dealing with the devil. Solder is by analogy an offending element of manufacturing and source of many if not most manufacturing problems. The industry will continue to have to deal with that devil as long as we persist in its use.

One can do their own research to test this assertion if they choose. They need look no further than the titles of papers in publications. Presently, this and other industry/academic journals and proceedings on electronic manufacturing are rife with articles, papers, commentaries and advertisements offering new materials, processes and equipment both for manufacture and inspection to try and beat lead-free solder into submission. Unfortunately, solder appears a wily and crafty adversary that always seems to offer another challenge to each new solution proposed. This situation begs the question: "Is there any alternative?" The answer, in the opinion of this author, is "Yes." The answer is to assemble electronics without solder.

The potential benefits of eliminating solder is significant in many areas of current concern or high interest in electronic manufacturing, including: cost , reliability, performance, environmental impact, design security, a means of addressing some elements of counterfeiting, sustainability, a means of sidestepping conflict metals concerns and others.

So how can it be done? It is really quite simple: Build assemblies in reverse and instead of placing and joining components on circuit boards with solder, build up circuits on "component boards" using copper plating, thereby bypassing the soldering process completely along with all of its many extra processing steps, ongoing challenges, and problems. The potential economic, environmental and reliability benefits are substantial as will be shown. The concept of SAFE assembly and its practicality will be examined in more detail in a future paper. **SMT**

Verdant Electronics Founder and President Joseph (Joe) Fjelstad is a four-decade veteran of the electronics industry and an international authority and innovator in the field of electronic interconnection and packaging technologies. Fjelstad has more than 250 U.S. and international patents issued or pending and is the author of Flexible Circuit Technology.