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CHARACTERIZATION STUDY OF STRAIN GENERATED DURING PRESS FIT CONNECTOR INSERTION IN PRINTED CIRCUIT BOARD ASSEMBLY

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ABSTRACT
The wide use of press fit connector technology has made the assembly process the intersection of fine pitch, high I/O IC packaging, high density interconnect, and PCB materials performance. Press fit is a process where connectors with pins are inserted through the Plated Through Hole (PTH) of a Printed Circuit Board substrate to establish mechanical and electrical contact instead of the traditional soldering process. The clearance between the PTH and the connector pin diameters are intentionally made close to zero so that intimate contact is made between the connector pin and the PTH after insertion. A controlled force is used to push the connector through the PTH. One of the consequences of such a process is damage to adjacent solder joints due to strain generated during the press fit insertion process. Experimental investigation was conducted to characterize the impact of strain generated during connector press fit. Tri-axial rosettes were attached to adjacent solder joints located at 0 mm, 5 mm and 10 mm away from the press fit site.

Three PCB assemblies, one for each location were used for the study. The rosettes were placed at 4 corners of adjacent solder joints to capture all the strains. Strain gauge measurements were taken as the connector is pressed. The experimental results revealed that locations closer to the insertion site experienced the highest level of strain and the strain progressively decreased further from the insertion location. Furthermore, advanced x-ray inspection and computer tomography were demonstrated as a technique to evaluate and characterize failure sites.

Key words: Press fit, connector, CT, x-ray, strain gauge

INTRODUCTION

Interference fit or press fit connectors are used for applications requiring "high density" high I/O interconnections between PCBA's (Printed Circuit Board Assembly) and backplanes, other mother/daughter boards or system level integration. Press fit connector insertion of components on PCBA requires application of force. Press fit insertion operation is performed on an automated machine where the applied insertion force is controlled. Stress from pin insertion and due to intimate contact between pins and holes, cause the PWB to flex (or bend) during press fit insertion operation. This flexure of the PWB causes strain to propagate to the surrounding area adjacent to the press fit insertion points. The flexing of the PWB adversely impacts solder joints. Or simply, strain induced as a result of press fit insertion operation could cause solder joint damage (failure). Obviously, this is highly undesirable and measures have to be taken to ensure this adverse effect on solder joints doesn't occur. [2]. Press fit connectors are manufactured to meet a variety of PCBA interconnect applications and as such are usually installed at the EMS house after SMT and wave soldering , or generally as one of the last steps in circuit board assembly prior to system integration. A press (automatic or manual) a PCB frame or mount and a die combination are typically used for installation. An automatic electric press is preferred to install since the load is applied in a controlled and repeatable method. A manual press and an experienced operator can also install connectors reliably and with high quality.

The major factors that contribute to a quality PCBA assembly that incorporate press-fit connector technology into its design are the overall construction quality of the press fit product, the compatibility of the PCB layout, a well designed solid support for the PCBA (fixture), the tooling and die necessary to make the proper contact with the press. Aside from the known good practices about press-fit at the assembly stage , only expert the knowledge of experienced builders and engineers are available for consultation about how modern families of connectors perform in the long/ short term when used or processed outside of manufacturer's recommendations. It is difficult for hardware designers who need to use these connectors to predict how design rules are impacted by connectors with respect to other parts or final assembly processes. In comparison to the knowledge base available for troubleshooting assembly process problems for BGA type devices or other high volume IC packaging, there are not many tools available for design or post-production troubleshooting and process improvement, other than costly trial and error [2].

Study by IPC on impact of strain on solder joints on similar processes demonstrates there is a threshold strain that solder joints can withstand without incurring damage (or failure). Generally speaking, strain level exceeding 500 micro-strains can have detrimental effect on solder joints [1]. In this paper, principal strain measurements are taken at multiple locations adjacent to the component where press fit insertion is performed. A detailed analysis is made on the impact of the principal strain on solder joints. In addition, attempt is made to find correlation between the magnitudes and impact of the principal strain against distance as we move farther away along the diagonal of component from the press fit insertion area. How do we know or make a determination if the insertion process of a press fit component can crack or weaken an adjacent component by imparting excess mechanical strain on the PCB. Using stain gauges (a standardized, widely used technique), the amount of deflection on the PCB can be measured. However, for most applications, the strain measurements have no correlation to reliability without experimental evidence.

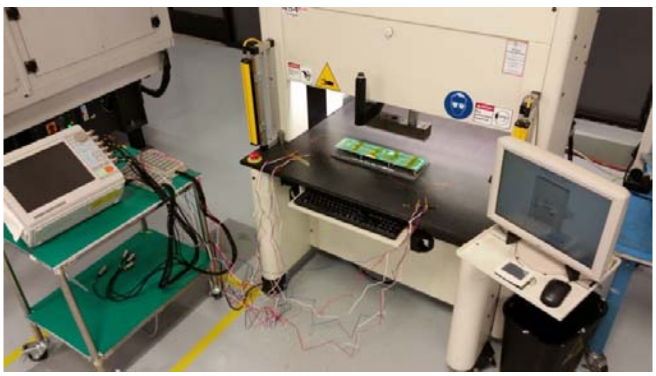

Figure 1. The test vehicle on the electric press attached to the data acquisition instrumentation.

The principle focus of this study is to broach the question of how to approach the framework of experimentation to determine or result in a set of a guideline for component proximity to a press fit connector location, and more broadly are there a standard set of best practices across all of the manufacturers and form factors that can be distilled into a working standard for lean, plug and play implementation? Many such guidelines, specifications and scholarly publications exist for most popular high volume electronics components, especially IC packages. There is information within easy grasp to advise or educate on solder alloys (Pb-free, high or low temperature, etc) PCB plating finishes, handling and environmental control, layout, coplanarity; basically, most material properties or interactions have been well characterized. Interference connectors are not new, (and neither are the experts who have spent their career making and installing them), now that know-how is needed en masse for a generation of highly interconnected, complex electronics. Modern larger scale computing and network systems need to match the volume of signals processed onboard to connect to networks of remote or dispersed nodes with high volume, high speed signals to process and transmit. Older, reliable connector technology is pushing into smaller form factors and the need for miniaturization of backplane style interconnection for a higher pin density is outpacing the technology for shrinking high aspect ration PTHs on the PCBs and backplanes. This is happening quickly and to the extent that new mounting methods incorporating high density SMT attach are mainstream. This burst of connector technology is creating a new paradigm of mixing generations of discordant, and customized engineering solutions that are not receiving the vetting and research to accompany their widespread availability and use. These connectors are at the forefront of any NPI discussion, displacing the hand wringing and troubleshooting that was traditionally reserved for high I/O, fine pitch IC packaging.

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As can be evidenced by Moore's Law, the density of electronic components on the PCBA have been continuously growing exponentially ever since the invention of the transistor. Improvements in device technology and ever miniaturization of electronic components dictate that more and more of them fit in an ever smaller surface area of the PCBA. The trend towards faster, cheaper and smaller electronic products demands a high level of miniaturization for high density interconnection. While miniaturization offers high interconnect density, the capability of the physical interconnect structure to withstand strain and stress forces generated during manufacturing processes as well as in use environment, is drastically reduced. Both design approaches and manufacturing techniques must be optimized in order to make these products robust to adverse use environment conditions. Controlling strain induced on adjacent solder joints during press fit operation is vital to ensuring fewer failures in interconnects on PCBA.

As a starting point, we have used the work and guidelines developed for assessing how strain on a PCBA can affect the reliability of a BGA component. There are two reasons for this approach: BGA devices are usually the most expensive component and are difficult to remove and replace. Considering those components will set the upper limit, providing the most conservative results. 2nd, strain is measured on or at BGA corners and therefore provides a precise point, a location based relationship reference for comparison of strain.

To perform a test to measure strain in an electronics application, small body size gauges, with bi- or tri-axial configurations are mounted to a PCB. For interpreting strain according to the experimentally determined guidelines published in IPC 9704A, triaxial gauges are necessary. Strain gauges have an electrical path whose resistivity changes as a function of its shape or length. A strain gauge is wired to a specific type of electrical bridge, and the bridge is connected to and powered by a data acquisition system, specifically setup up for both the resistance of the bridge and the type of gauge. There are many types of strain gauges and many types of applications, both the theory and practice of deserve a full treatment. Stress and strain are fundamental, but complicated concepts -even interpretation of the output of the strain gauges is a field of engineering itself.

Not all operations in the assembly of a PCBA generate strain, but some do. Operations, such as, handling, repair, testing and connector insertion, are among a few that can generate strain that can be detrimental to solder joints. One of the most challenging processes that generate high level PCBA flexing is press fit connector insertion. In press fit insertion process, pins of the connector are forcefully pushed into the plated holes of the PWB. The diameters of the plated holes and the connector pins are intentionally made to be almost of the same size, in order to ensure intimate surface contact after the pins are forcefully pushed through the plated holes. Although the application of the insertion force is controlled, this insertion force combined with the resistance force created due to the intimate contact between the holes and pins, causes the PCBA to flex, which in turn can generate significant strain that can adversely impact solder joints.

Based on IPC industry standard (IPC 9704), generally strain level that exceeds 500 micro-strain will likely cause damage to solder joints in the adjacent area. Consequently, steps have to be taken to ensure the PCB assembly process does not generate strain that exceed 500 μstrain. More specific to this study, we will show the press fit insertion operation causes the PCBA to flex (or bend) that results in strain to be induced on the surrounding area where press fit insertion takes place. As part of a typical reliability test plan, the amount of strain imparted on the PCB at the BGA corners will be measured and analyzed for conformance to IPC specification 9704A during a given manufacturing process step. This specification relates to the amount and upper limits of strain and strain rate that can be applied to a given PCB assembly during manufacturing or field use and not adversely impact the reliability of SMT BGA solder joints. No violations of IPC 9704A or unacceptable measurements of strain were observed or recorded in the test.

Table 1. Alloy Temperature Details

Strain Measurment Proprties			
Strain gauges	KYOWA 1503	triaxial	120 Ohm
Gauge length	1mm		
Orientation (degree)	0	45	90
Body Size	2mm		
Data Acquisition	Soltec TA-2300		
Sampling Rate	10ms		
Strain units	kμε	kilo- micro strain	
Wheatstone bridge	12 channel		

Strain signs

High strain rates with "too-high" principle strain on circuit boards can cause fracture of BGA solder joints [3]. Several factors are considered, a strain gauge measures the amount of deflection in a single dimension on the surface it is attached to. The gauge itself operates on the principle that it's body length changes size as the surface that it is bonded to is stretched or compressed compared to the original unconstrained length. In the case of a circuit board (PCB), a force on the broad can result in a deflection, resulting in a curvature of the surface rather than an elongation or stretching of the board material [1]. The shortest distance between two points is a straight line, however if a point in the plane on the line is deflected out-of-plane normally, the length between the points changes.

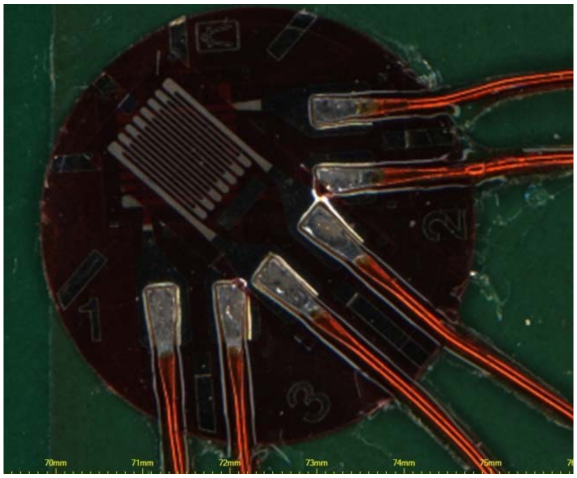

Figure 2. Triaxial strain gauge with 1mm path length

The gauge is a conductive path and functions as a dynamic resistor with respect to its length. The circuitry of the strain data acquisition system records monitors and records the changes in voltage of the signal through the path when the gauge is stretched or compressed, and represents it as strain, considering the known original path length (here gauge length is 1mm.) (see figure 2) We mount the gauge on one side of the circuit board. Deflections (with the gauge facing up) that make the board into concave shape shorten the gauge length and those that flex it into a convex shape increase the length and the resistance. With the gauge oriented on top of the PCB a concave deflection (frowning) is a displayed as a positive (+) strain. A negative strain (-) is a convex deflection of the PCB (smiling). Table 1 gives the details of the strain gauges used in the experiment here.

METHODOLOGY

The PCB used in this test has a thickness of 1.62mm (this size is an arbitrary choice where any other thickness smaller or bigger will produce similar result). Rosettes are used as strain gages to measure strain induced on solder joints in press fit insertion operation on PCBA. Rosettes are very accurate and convenient way to measure strain. Three stacked rosettes oriented at 0-45-90 degrees with each other are affixed on to the PCBA on specific locations and are connected to a data acquisition system though lead wires [4]. Triaxial strain gauges were attached in close proximity to a press fit connector location so that the strain on the PCB could be measured during the press process. This was repeated with increasing distance from the connector corners to characterize the magnitude and orientation of the strain.

The setup used a basic fixture to hold the assembly, with press fit die machined and bottom support fabricated according to the manufacturer's specifications from the product datasheet. Strain gauge testing is a typical step in a PCBA qualification program (to gauge the process against known limits, or when BGA is the component of interest). The procedure is as follows:

- Attach rosettes to assembly at BGA corners with cyanoacrylate adhesive.
- Set up data recorder, acquisition rate and normalize the strain gauge output.
- Perform process step (press fit connector insertion) according to manufacturing instructions
- Process strain measurement data
- Compare to specification in IPC test method 9704A. [2]

Strain gauges are mounted, attached, cemented or glued to the board, oriented as illustrated in figure 3, below. The gauges are oriented to a (x,y) Cartesian plane defined by the BGA and PCB, with gauges in the xy orientation to help characterize twist or "potato chip." In this experiment we substituted the press fit connector for the BGA to model the case of a delicate BGA corner that would be theoretically located at the gauge location during a press fit process.

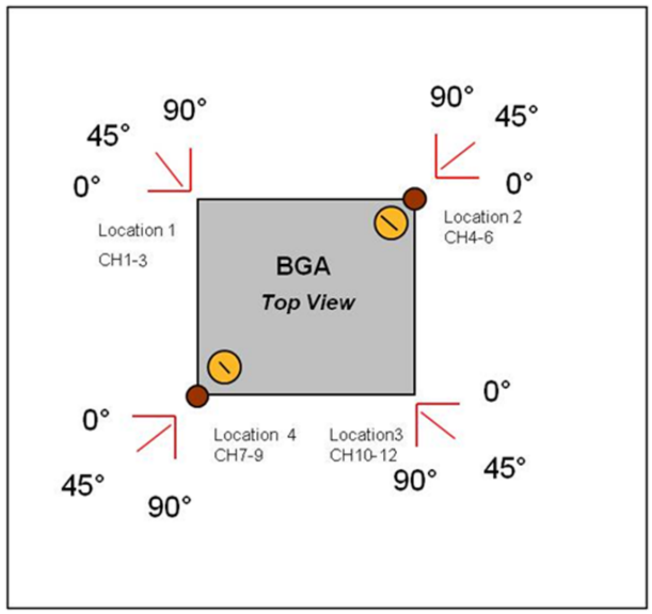

Figure 3. The 4 corner positions on the PCB shown in the preceding illustration have strain gauge rosettes attached at the corners. The strain is measured normal to BGA sides (0°, 90°) and parallel to the diagonals of the BGA (45°)

Rosettes are placed at equal distances from the four corner edges of the component where the press fit insertion takes place. The PCBA is then secured onto a fixture and placed onto the machine for press fit insertion operation (figure 4). One set of rosette strain gauges are placed around the edges of the component where press fit insertion is performed is shown in figure 5. In this test, the rosettes are affixed at three different locations of 0mm, 7mm, and 16mm away from the four corner edges of the component along the diagonal. The other sets of rosette placement take place in similar manner at the desired distances along the diagonal of the component. A 2-D illustration of the test setup to perform press fit operation is shown on figure 4. In the figure, the PCBA is ready for press fit operations placed on a fixture with strain gages attached at the desired locations.

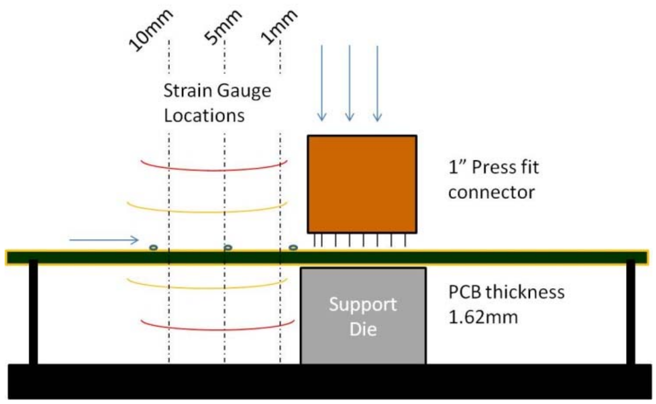

Figure 4. Cross sectional illustration of strain gauge test locations for one of four corner positions (not to scale.)

Using the basic geometry of our test vehicle, the first step was to create a program for the press fit machine. The principle variables to input here are PCB thickness, fixture height, pin height, and number of pins. The program was demonstrated on a test board for dimensional accuracy before the connectors on the test samples were installed [6]. The profile of the force is shown in the following figure for the 0.060" length pins. The graph indicates that as the pin is driven in at a constant rate, the force is variable, sharply increasing as the connector is fully seated. The connector has 60 pins in a 10 x 6 array, which are pressed in to a maximum total force of 600lbs (figure 5.)

We used an electrically driven press, pneumatic, hydraulic and manual types are produced for the same function [6]. The electrically driven types have the advantage of a force feedback loop and will abort the press pit process if the press fit resistance increases. A misaligned connector, tooling hole or bent pins can give increased resistance and difficulty seating the component. More advanced press fit programs can be created for applications that may require more or less sensitivity to force feedback i.e. wider process windows, or more sensitivity for smaller pins that are misaligned [6].

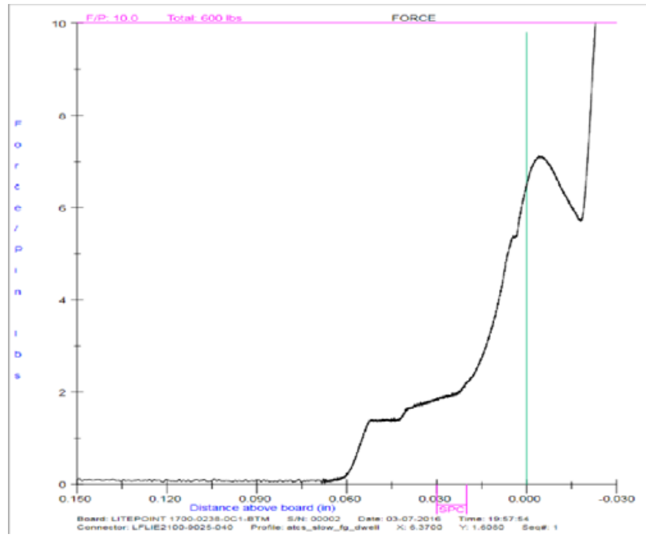

Figure 5. The force profile from the press fit equipment.

To characterize the strains generated on the PCB from the press fit process, the strain gauges were placed at increasing distances along the diagonals from the corners of the connector. PCBA design rules call for a 1-2mm keep out region from most other features where mechanical interference would prevent hinder assembly. For space saving and small form factor or high speed boards, 1 mm is important, we installed the strain gauges Establishing that a press fit installation close to small high pin count BGA is not a reliability risk in terms of PCB strain leaves only mechanical interference between the components as a design consideration see figure 6 below for gauge location placement.

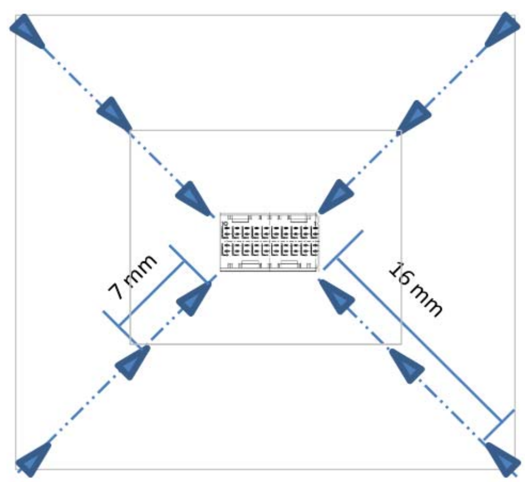

Figure 6. Strain gauge locations from press fit connector location

While the pins of the connector are completely supported by the lower fixture support pillow block, the gauges are placed outside the area supported by the lower press fit die. The aim was to gain insight into the PCB behavior near proximity to the press fit, somewhere on the span between the board's edges or supports. The application guidelines for creating a fixture available from the connector manufacturers can often leave it to the user to determine the bottom side support layout, and only indicate a minimum area under the pins for support. From the x-ray image in figure 7 the connector body overhangs the lower support. In the case of the present experiment, all of the strain measurement locations that are mounted on the top side are unsupported from the bottom side. The X-ray image is for reference to show the connector over the support, the measurements are approximations. 2D x-ray is good for showing the relative size and position of objects and has to be properly calibrated to make accurate measurements. Some parallax occurs between the detector, sample and x-ray source and results in some slight distortion in the 2D projection of the image.

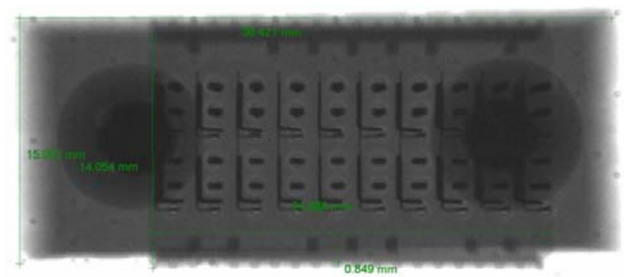

Figure 7. X-ray image (2D) showing the outline of the connector body slightly outside of the press fit lower support block. The measurements read [die length: 36.421 mm, width: 15.053mm; connector length 24.988, width: 14.054mm; offset 0.849mm]

Although it may seem arbitrary, when a very delicate component or device with an extremely small solder joint (pitch < 0.4 mm) is mounted on the PCB, its proximity to the pres fit connector may be questioned if a failure occurs. Conversely, consider the case of a complex two sided PCB, with the same delicate structures, and the accompanying decision to design a fixture that completely supports the bottom side to minimize risk. Without the benefit of a large trial of designed experiments it would be tempting to require a custom machined plate of aluminum or steel stock with pockets milled out for every component versus a simpler low cost jig with supports at the tooling holes and a block under the press fit PTH area. The results would be a short term or long term cost that could be made with less uncertainty with more research. The line of experimentation demonstrated in the present case would be an example of small set of the possible scenarios that should be explored.

The following images of the press fit test location show the strain gauges on the test vehicle placed at the greatest distance from the corners (figure) and at the middle location (figures 8-10). During press, the strains are recorded by the data acquisition system (shown previously in figure 1); a computer controlled instrumentation system that is programmed to convert changes in resistance on the rosettes into strain measurement.

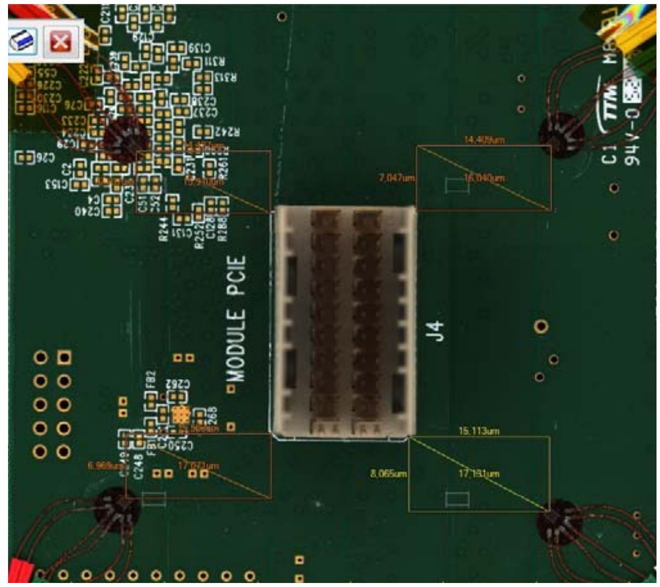

Figure 8. Four strain gauges mounted approximately 17mm from the corner of the connectors.

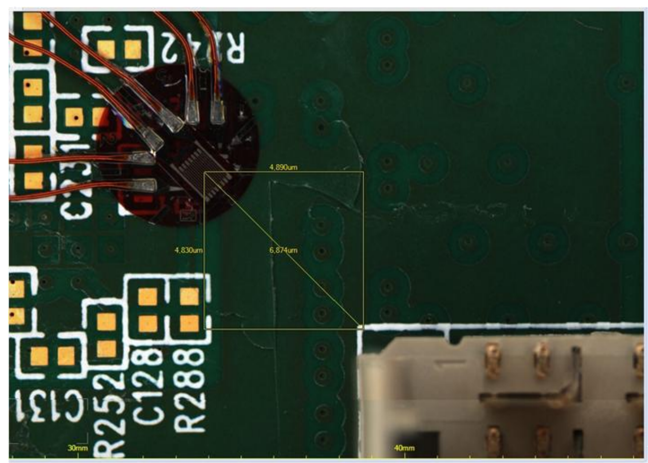

Figure 9. Strain gauge proximity to connector. The distance measurements read [x = 4.8mm, y = 4.mm, xy = 6.9] Gauges were located 0, 6.9 and 17 mm from the connector.

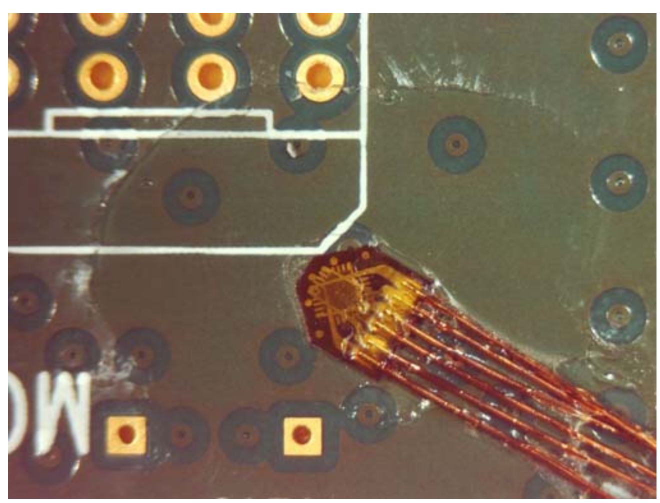

Figure 10. The placement of the "0 offset" gauge is actually 5mm from the center of the corner PTH to accommodate the

connector body. In this image, the connector has not been inserted.

The strains measured for this application while interesting, provide no frame of reference. However, much work has been compiled for strains near or on BGA devices. A general specification has been published, and even the strain recording equipment has the capability to post process the strain data using the formulas published by IPC in specification 9704A. The limited data that was collected during press fit, if viewed as a mechanical deflection at the corner of a BGA gives a profile of strain vs. distance that could be used as a guideline for placement proximity to the connector. Here, the imagined BGA device would be not only in close proximity to a press fit location, but it would in locations both supported and unsupported by the fixture.

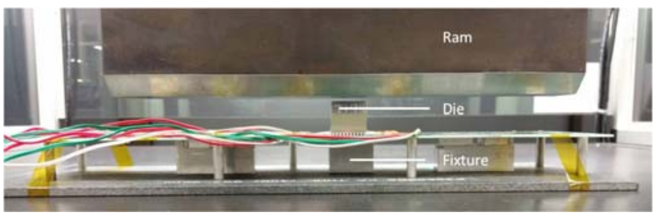

Figure 11. The test vehicle loaded with the die and press fit.

RESULTS

This round of experimentation came from a case study(studies) to investigate solder joint failures of fine pitch BGA components near press fit locations. As a first pass, we measured PCB strain during press fit process, used IPC spec 9704A to interpret the resulting data sets. The conclusion from a "typical" press fit board setup was that placing components near to a press fit location was that no violations of IPC 9704A or unacceptable measurements of strain were observed or recorded in the test.

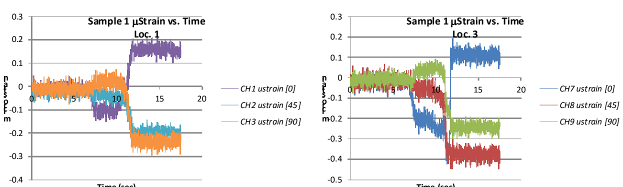

Figure 12. Experimental strain data displayed as *k*µstrain vs. seconds (y-axis reads µstrain/1000) for corners (1, 2).

The y-axis scale in figures 12 and 13 can also be interpreted as percent (%) dimensional change, in terms of the unit-less strain. For corner 1 in figure 12 then, the max strain would be about 0.2% total strain at the gauge location [4].

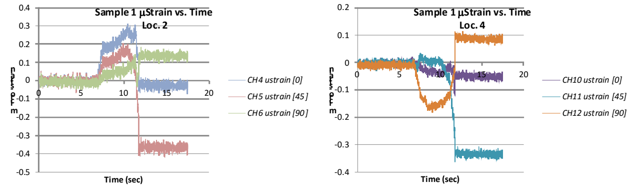

Figure 13. Strain data for corners (3, 4) in µstrain (y-axis reads µstrain/1000)

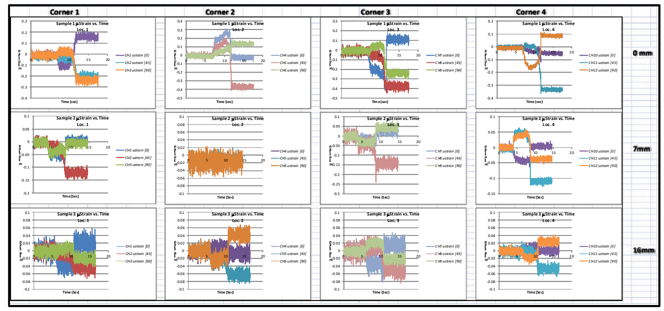

Figure 14. Comparison of all strain data, considering distance from press-fit location. Moving down the chart increases the distance to the connector.

At each corner and location, we can see a mix of signs on the strain curves, and an overall decrease in strain as we move away from the press fit location. Theses graphs of strain vs. time (in seconds) is the "raw" or un-processed data, as directly recorded during the test runs (all results collected in figure 14.) For general comparison, we collect descriptive statistics about the data, observe its overall shape, note the areas of gradual and periods of rapid dimension shift. The collection of calibration data in the IPC specification gives a look-up chart of strain versus strain rate, for various thicknesses of PCB laminates. The take home message is of the IPC chart is that if you flex a circuit board rapidly, do not flex it very much, and thicker boards are less forgiving than thinner ones, and there is an ultimate maximum strain that should not be exceeded [2]. The strain versus strain rate equation is fairly nuanced, and has a classic simplicity in its interpretation. The amount of data we collect for each test gives a fairly intuitive display of the warp and twist of the PCB, when it happens and how much. The IPC conversion function, calculates a running average of strain rate removes the negative strain and incorporates the orientation of the triaxial gauges from the output by combing the magnitudes into a series of RMS type test statistics. The output of a run can be compared against the IPC limit as a percent of total allowable strain (our test data is displayed this way in figures 15, 16 and 17.)

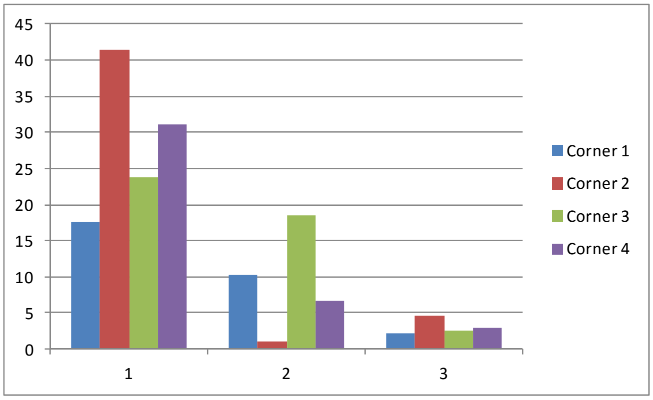

Figure 15. Results for each corner, we have captured the maximum % allowable at each corner vs. distance (3 locations.)

The bar graph in figure 15 illustrates the relationship of decreasing strain magnitude with increasing distance from the press fit location. Although no strain exceeds the IPC limit for a BGA corner, the nature of the strains is interesting. Since the PCB is supported from below, the amount of movement from the down ward pressing action is very small. The strain in the PCB could be indicative of lateral compression and rippling of the PCB material as the connector is forced flush to the board and the pin eyelets are compressed. As observed in the pre-process strain vs. time data (figures 12-14), the maximum strains occur as the largest forces are recorded on the press' force profile, some channels change signs, indicating cycling of tension to compression. For this case, the strain curves could tell us that if it were necessary it would be possible to reduce strain on the PCB by slightly under-driving the connector.

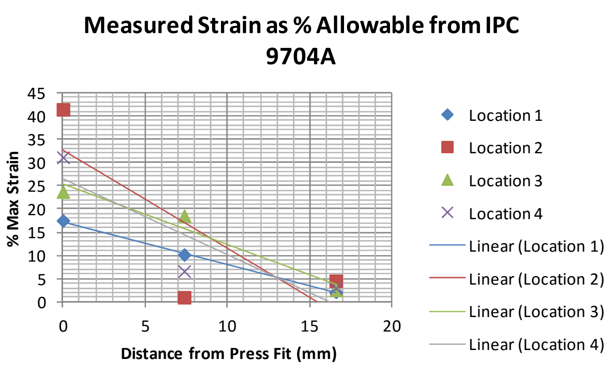

Figure 16. Results shown as a function of distance from the press fit location.

The relationship we determined in the experiment is illustrated in the figure below. Here IPC peak strain/strain-rate is plotted against distance from the press location (figure 16.) Linear curves were fit to the data, however with a greater number of test points or replications a more complex relationship may be discovered. Hundreds of data points were collected to create the IPC chart, the data collected here is but one run in a possible dataset of hundreds of data points. The number of variables that need to be included for the current generation of electronic assemblies is much greater now than when IPC 9704 was compiled because the number of connectors in use are greater and the types of assemblies that need to use them include fragile fine pitch components that may not have been considered for use on the type of system that would include a press fit connector type or other process induced strain.

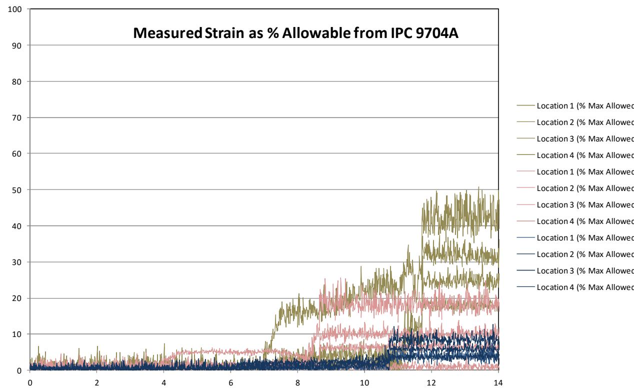

Figure 17. Overall, none of the locations measured strain that came within 50% of the guideline limits published in IPC 9704A.

Using the peak strain statistic does not give the high level view of the data. In (figure 17) all of the IPC strain data is overlaid, the distance from the connector is color coded. The test brings up several important possibilities, comparing times of the final leg of the press profile (figure 5) to our strain curves is important because the peak strains occur then, the strain data from each corner has both compression and tension data indicating a twist in the PCB or compression of the PCB laminate. Also observed in the experiment were residual strains that remain after the pressing force has been backed down. It is unknown if there is relaxation of this strain over time.

CONCLUSION

The lack of reliability data to make a proper correlation between experimental data and design rule guidelines hinder us without validation. Micro-strains are a unit-less metric, and this makes the experimental data mostly dependent on the PCB dimensions, especially thickness. Although press fit connectors are a mature technology, the IO densities are increasing and the materials and form factors are changing. PCB materials are also changing, and tradeoffs sometimes have to be made in PCB design between the ideal construction and electrical characteristics of the system being constructed.

Experiment illustrates the need for a comprehensive set of design rules and best practices for press fit and connector technology considering the need for high speed and high signal density on tightly populated, mixed PCBA technology using high performance PCB materials.

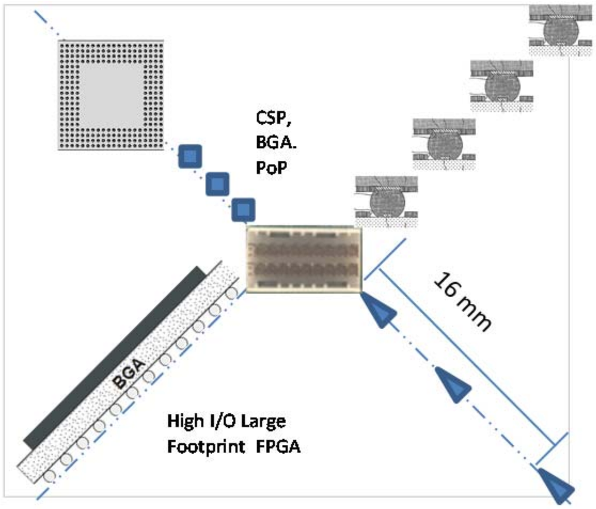

Figure 18. How much experimentation would involve answering all mixed technology design combinations.

We investigated a medium thickness PCB, with a 60 pin, rectangular press fit connector. The connector was an interference type pin collapsible eye, and measured the strain at increasing distances orthogonally from the corners. In defense of good ideas and half-baked in-vivo experimental execution, the setup has a number of flaws, including dimensional asymmetry and that it was not replicated. However, the ultimate intent was to establish a "trailhead" for using press fit (and "new" or other connectors) as designs and pin densities are outpacing practical working knowledge, at the expense of manufacturing costs. (See our “kickoff” road map of design rule guidelines in figure 18.) How our current test setup matches real world production usage of the connector is that the press machine is programmed without help of equipment or component suppliers (a resources typically available in proportion to sales volume.) the die (press) design is exactly from the manufacturer spec sheet, it was purchased from local machine shop. In this test, the fixture and support die are matched to manufacturer recommendation, using low cost materials, and we used a single PCB and press fit connector for every test run. In a high volume high yield environment, the process wrinkles may hay been ironed out and some “special sauce” may have been added to the recipe. Test was executed in factory floor settings (an advantage of strain gauge systems, they are designed for field-use.) Each run was a cost (as in the real world) where a PCB, connector and strain gauges are consumed. Removal and reinstallation is another topic for consideration also!

Strains in this configuration were within the limits of IPC 9704A. That is interpreted as “a BGA corner could be placed (within our framework) as close as possible to this connector, on this board, and the strain from the pressfit installation process would not cause a reliability concern.” It would be a sweeping overstatement to claim this in a design rule or or to even claim that the BGA would survive if it were moved off the orthogonal test path. It illustrates the time and resources to make any claim of reliability and poses a larger question how granular do we get?

FOLLOW UP

This follow up section includes the failure analysis techniques that form the basic toolbox for troubleshooting or qualification. Creating suitable test vehicles with dedicated, isolated traces performing circuit continuity checks and using event detecting test equipment during stress tests are how IC packaging and solder joints are evaluated for reliability. The extent of reliability testing and the development that goes into IC packaging with respect to their long term interaction with PCB laminate and solder structures is not as widely studied or standardized for many of the components used in electronics, including high density connectors. That is not to say that connectors are not thoroughly tested for reliability, but their interaction with the substrate and the properties therein are typically only explored for generic cases with ideal conditions. A possible use or direction to use the characterization the strain of a press fit process herein is to begin to design an experimental space to characterize the potential mix of PCB laminate and plating materials would eventually result in the installation and use of press fit connectors and the correlation to failures within the connector and other components.

Internally, press processes fail if the mating surfaces are not aligned; bent pins or folded pins can result. External to the connector it is observed that when a PTH has a blockage or an inner diameter that is smaller than the allowable tolerances, the resistance against the pressing force will increase. During assembly, increased press resistance will result in an aborted press operation if the press equipment force feedback process limits are reached. This is the best outcome, as the process gives an alert to stop. The alternative is escapes, as pins are delicate and bend laterally quite easily, a misalignment and can go unnoticed. Pins can be slightly skewed by handling and go on to bend or fold.

Table 2. X-ray inspection matrix for press fit connector inspection.

2D Planar View image Quality	Full CT	Off-Line PCT	In-Line PCT
Z (into board)	Excellent	Very Good	Good
X, Y (left to right and front to back through sample)	Excellent	Good to Acceptable	Very Poor or Not Available
Other Planes	Excellent	Good to Acceptable	Very Poor or Not Available or Shown
Limited sample size	Yes	No	No
Cut sample	Yes (unless very small)	No	No
3D Rendering of data?	Yes	Yes	No

Most PTH structures and connectors are designed and fabricated out very well by the designers, and give very good yields, but due to the increased presence, varying form factors and mix of components around them, characterizing what is happening on the periphery of dimensional tolerances, differences between sourced material, what affect small strains have on the reliability needs to be better understood and accessible to designers and manufacturers. Guidelines that consider plating finishes like ENIG, ENiPIG, and especially OSP; plating thickness tolerances; PCB panel dimensional skewing and connector handling and storage would be useful for engineering improved yields and process development at the assembly stage.

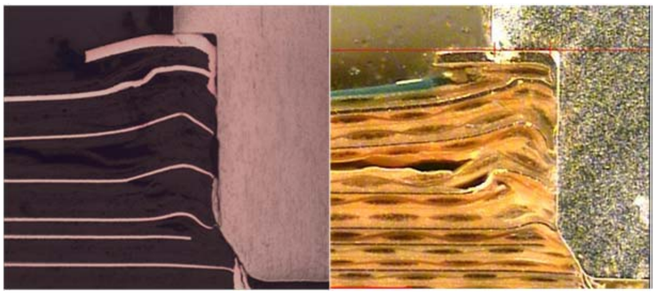

Figure 19. Press fit damage from a hardware insert, wrong part or mismatched specification between design revisions. The image is repeated in and dark field (left) bright field (right) images are shown.

Laminate thickness versus the overall stiffness of the board when PCBs were stacks of the same laminate material repeated and pressed together was predictable. However, buried capacitance layers (BC) and high resistivity dielectrics and asymmetrical construction may need final assembly process development that takes the substrate into consideration when developing a press fit design and fabricating . In the following images (figures 19-22), we cross sectioned some known good PTH with press fit pins installed. From the images, the pins are mostly unremarkable, but we can see that the pins curve out of their original plane, twisting slightly as the connector seats fully. Was the twist planned by the connector manufacturer, or is it a side effect? Would tighter tolerances produce more twisting, is the deflection necessary, and is it over stressing the laminate structures or is it a negligible indicator?

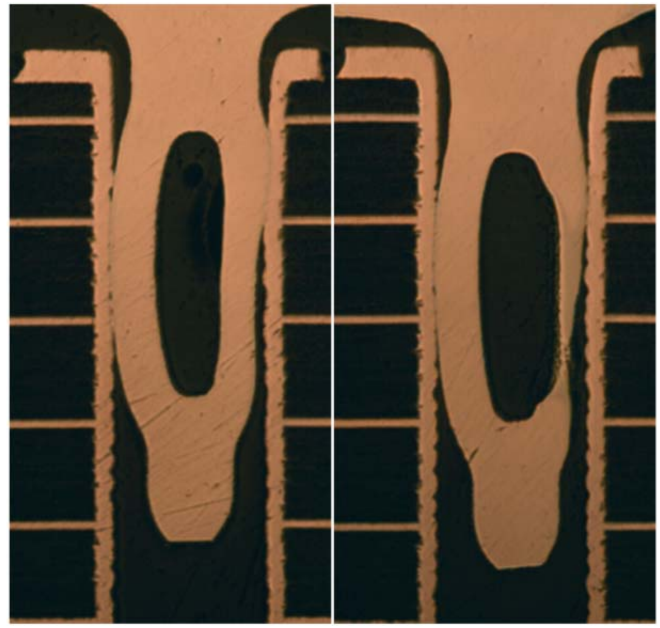

Figure 20. Composite of two pins that pass electrical test (images cropped) the pin on the right has slight twist out of plane (lower right side of pin).

Cross sectioning which is destructive and time consuming is not always desirable. X-ray analysis of the connector can be used for routine screening, but is often restricted by the lead frame of the connector, necessary to provide solid, functioning connectors that can survive multiple mating cycles. 2D X-ray will typically be the technique for inspecting for a possible connector pin open. We made detailed x-ray images using a general purpose x-ray inspection equipment to demonstrate the problems encountered when trying to observe a small pin buried in a thick PCB with multiple layers of 2 Oz copper and plated barrel walls, shadowed by the lead frame of the connector body.

Automatic x-ray can be a tool for detection, but it can also encounter into the same problem of shadowing where the cross sectional area of the pin is smaller than it surrounding features, and it is made of an alloy that has less density that the surrounding structures (especially if there are solder joints). Obviously, the area of interest on a PCB assembly needs to be destructively cut away for cross sectioning, and x-ray is considered the nondestructive alternative. Some structures were cross sectioned for failure analysis when open were found in a press fit PTH for a back plane system, (not the test board used for strain, but similar) and cracks were found in the copper plating. Since the locations of the cracks were known an offline x-ray CT analysis was setup for detailed inspection of the area. Using the CT mode, to be made compatible the sample area was cut-out PCBA, the cracks were able to be viewed using a standalone x-ray machine, demonstrating at least the possibility of finding known small defects in plated through holes using x-ray inspection. In the same vein of experimentation, press fit connectors with known bent pin locations were analyzed using offline full CT x-ray.

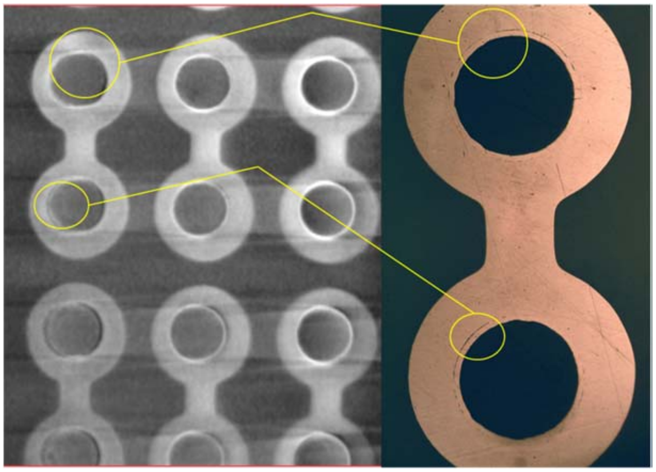

Figure 21. CT x-ray image of backplane PTH press fit vias showing a cracked plating structure, verified in cross section on right.

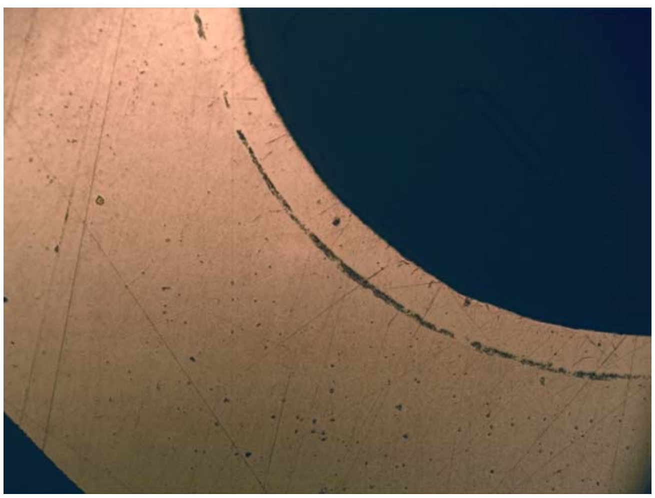

Figure 22. 200x magnification of crack

During the past two decades the importance for X-ray inspection for SMT process has been steadily growing. In most cases X-ray inspection is the only way to inspect optically hidden joints such as BGA, PoP, PTH, press fit connectors and other advanced packages.

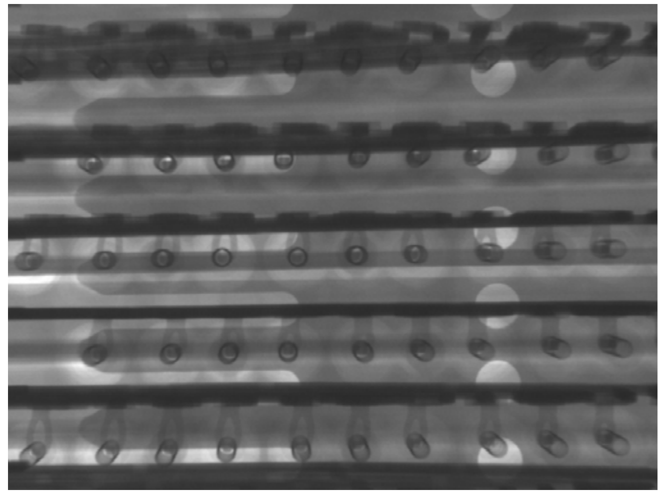

Figure 23. A connector body with lead frame shadowing (5x magnification).

Using an AXI (Automated X-ray Inspection) might seem to be a plausible solution to inspect all the optically hidden joints. In a high level description, an AXI works on the principle of comparing a series of concentric, vertical cross section images of structures against known or programmed contrasts. However, as per [1] it is very challenging to use an AXI for fine pitch BGAs, stacked components like PoP and critical components (like connectors) etc. Checking the press fit pins with AXI is difficult because of the pin's diameter sizes can be smaller than a fine pitch solder joint, the pin material is and surrounding PCB and connector lead frame material can often be copper or similar metals less dense than solder and as seen in (figure 23) the pins can be physically in different positions from sample to sample. AXI as an analytical tool to works well for sweeping an array of PTHs for missing press fit pin, but would not give a clear image of the condition of the structure if missing pin was identified.

In this study we selected some dense press fit connectors to look for defects like a bent pin, proper insertion of the pins etc. We started our inspection with a regular 2D Inspection. With careful manipulations we were able to see the pins and bent pin defects with an oblique angled view.

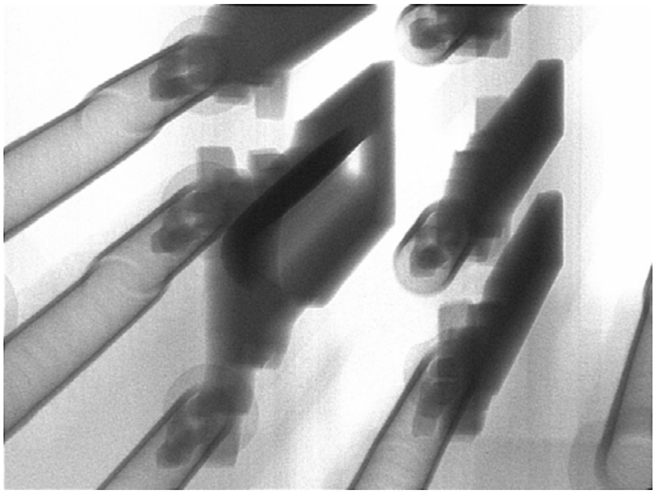

Figure 24. Pins inserted in a backplane application where there is low level of shadowing. (upper) (20x magnification) and the structures are visible

Computerized Tomography (CT) Technique

The continuing trend of subsystem integration, advanced 3D packages including CSP, PoP, SiP and flip-chip devices are widely used. Along with these packages an emerging mix of exotic connectors, utilizing press fit, wave and selective soldering, SMT and "paste in hole" interconnection methods are being used to meet the demand for greater circuit density and improved electrical performance. However, the increased complexity generates unique challenges for the inspection and quality control process during device packaging and subsequent assembly destructive testing and cross sectioning is a time and labor intensively analytical tool, but often the best method for collecting data for developing reliability and design guidelines. In the present case, we present the possibility that using manual x-ray inspection as an analytical tool. They have developed substantially in the last several decades and become more powerful in the resolution and magnification of electronics structures. Traditionally, the use of 2D X-ray inspection provides a vital and non-destructive method for investigating all aspects of device production and PCB processing. However, many dense connectors have a complex internal lead structure with a high PCB standoff, and 2D X-ray imaging may be limited since all layers within the device are seen at the same time, projected on a plane see figure 24. Analytically, this can be confusing to the operator because the SMT components and multiple PCB layers and PTH structures will appear to overlap each other in the x-ray image figure 23. For most commonly available electronic μCT x-ray systems this sample size limit is ~ 2" x 2" (50 x 50 mm), or smaller, and is typical of the size of a sample that is normally cut out from the circuit board from which to make a full mechanical cross-section. Obviously, cutting the sample will be the last resort when it comes to a production environment.

Off-line Angled CT generates very good views into the plane of the board without any cutting necessary and is available anywhere within the inspection area of the x-ray system. Off-line PCT does also provide valuable and useful information in the other planes but not as good as full μCT would provide because the dataset for the CT reconstruction only has limited information in the original 2D images compared to the data all around the sample gathered in full μCT. A comparison of the relative merits of all three CT techniques is shown in table 2.

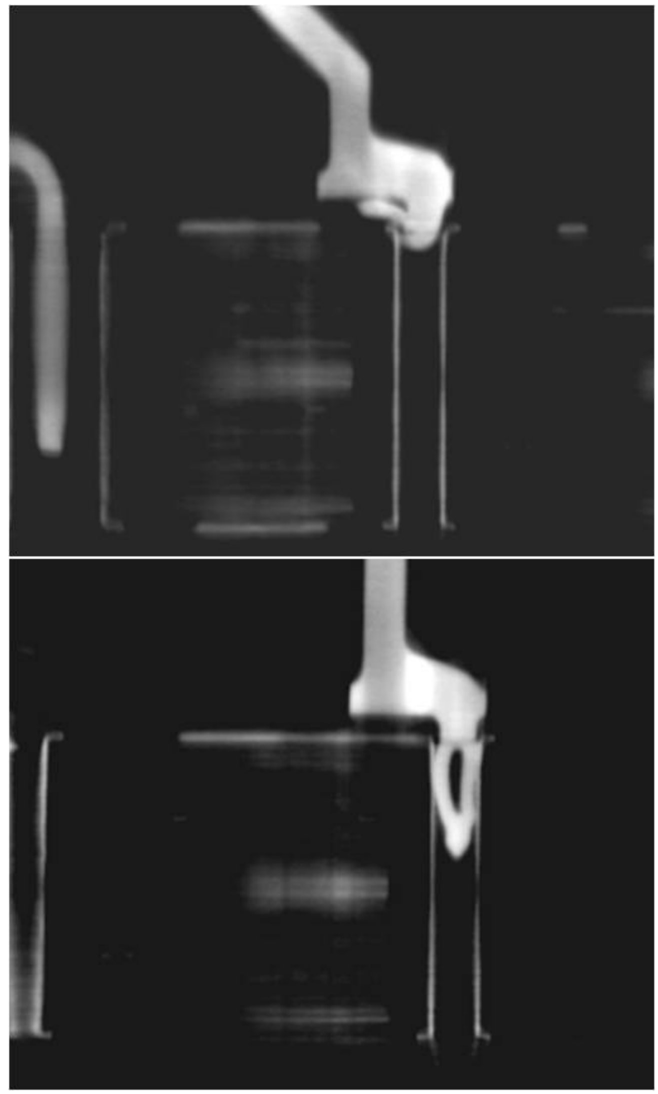

Figure 25. Two press fit pins show in a partial CT x-ray image, bent pin (upper) good pin (lower)

Off-Line Angled μCT

Although full μCT offers many benefits for failure analysis, the fact that it will almost certainly require the board to be cut up and destroyed makes it a technique that would usually only be used at the last resort, especially for printed circuit board assemblers. However, the need to have a μCT ability still remains, particularly as the complexity of today's double-side boards and stacked packages means that the 2D x-ray information is complicated and the features to be analyzed are obscured by other bottom side objects.

And so, being able to separate different board layers, for example, and de-clutter the 2D view for analysis is highly desirable, especially if the sample does not have to be cut up. This can be achieved using the angled μCT technique. The samples imaged in the CT images figures (25 & 26) were cut out from the PCB and the body of the connector s were cut away to remove shadowing and improve the quality of the image of the pins. Completely non-destructive analysis to the detail necessary for reliability analysis is not yet possible, as cross section allows access to more material properties than a virtual 3D x-ray image. However, the ability to observe defects in PTH plating using x-ray is a non trivial and a significant technique, even if substantial sample preparation is necessary. X-ray inspection techniques could potentially improve with time, whereas cross sectioning techniques have not improved significantly to where to complete areas can be "swept" through to analyze as is possible with CT x-ray.

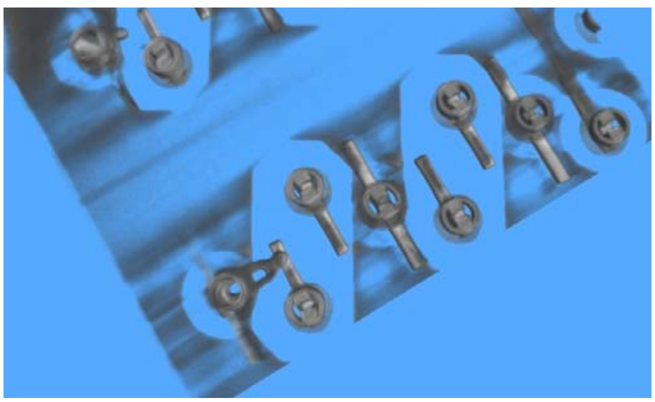

Figure 26. A Highly detailed CT x-ray image rendering showing a bent press fit pin next to good pins. The properly installed pins appear in cross section, the pin bent out of plane is visible in the lower left.

Prior to the availability of the tomographic approach to generating and separating various board layers for in-line Automated Inspection Systems (AXI), a mechanical approach to achieve the same end was available. This did not use any computational methods to achieve the separation but mechanical movements to highlight the slice at a critical depth in the sample and the other slices would be removed from the view. This was called laminography and can be seen as a 2.5D approach. It was only able to provide layer information into the board. There was no detail in any other plane. The production of these layers depended on a knowledge of any warpage on the board and ultimately the image quality of the result was compromised because of smearing and disappearance of the other layers was never perfect. As a result the image quality was poor and as this was used to make measurements at different layers to identify faults then the poorer the image quality then the greater the false call rate would become in order to offset the guarantee of an escape not happening in the tested samples. As a result, these systems generated many failing boards, especially as the board complexity grew, that had to be re-evaluated manually after automated inspection, often using a high end 2D x-ray system, requiring additional personnel. More recently these systems have been replaced with the in-line PCT approach where a highly computational approach is made much simpler but the resultant image. With off-line angled CT systems, there is less time pressure on the analysis compared to in-line. Therefore, there is the time to take more 2D images and each image can be better as averaging can be applied so as to improve the signal to noise ratio in each. The key for all CT techniques is to have precision and consistency for all the 2D images that are captured.

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REFERENCES

[1.] "Practical Strain Gage Measurements." Omega Web Technical Reference Agilent Technologies 1999. E94-130. http://www.omega.com/techref/pdf/StrainGage_Measurement.pdf

[2.] IPC/JEDEC-9704A Printed Circuit Assembly Strain Gage Test Guidline. IPC-Association Connecting Electronics Industries. February 2012. 3000 Lakeside Drive, Suite 309 S Bannockburn, IL 60015.

[3.] Low,Shin, Singh, Inderjit Hariharan, Ganesh Yip, Lauren Zohni, Nael Abtew, Mulugeta Solaiappan, Gowri Shankar Nair, Vineeth and Shane Lewis. Mechanical And Board Level Reliability Considerations Of Lidless Flip Chip BGA Packaging Electronics Components And Technology Conference (ECTC), 2013 IEEE 63rd. May 28-31 2013. 967-970.

[4.] "PCB Strain Gage Testing Using TA2200-2300. Simplified Generic Procedure To Do Strain Gage Testing On PCB Board". Equipment Handbook. Stress Investigators PI. Clearwater, FL. (n.d.) pdf. electronic document.

[5.] Ranack, Melissa. Portable Data Acquisition Recorders Falcon II Series TA2200-2300 ~ 16 channels. product manual. Soltec Corp. San Fernando CA. 2006

[6.] BMEP 3T / 5T Benchtop Manual Electric Press 3 or 5 Ton Operators Manual Part Number: 1398725-1, Rev E. E2010 Tyco Electronics Corporation, Harrisburg, PA TOOLING ASSISTANCE CENTER 1-800-722-1111