# Measles in Advanced Technology

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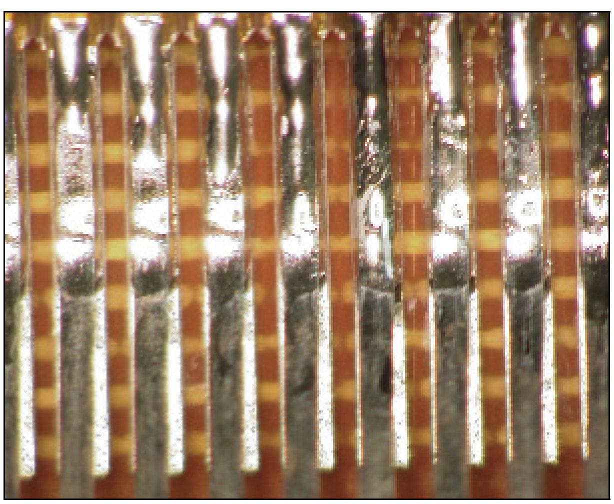
**Abstract**
Continuous measling, or unidirectional crazing, was observed in a multi-layer polyimide printed wiring board following assembly operations. Damage to the PWB preferentially followed the warp direction of the glass fiber reinforcement and extended beyond the region of localized heating. Further investigation revealed that glass fiber pullout in cross-sectional mounts is an indicator of laminate material that is prone to measling or crazing. Testing showed that boards with fiber pullout were significantly more likely to show damage in base material in subsequent process, especially when a drying bake was not recently performed. Damage to these PWBs consisted of cracks not between bundles of glass-fiber reinforcement, but within individual bundles. These cracks may produce reliability risks in PWB.

## Introduction

Measling and crazing have long been contentious subjects in the PWB industry. Originally believed to be serious defects affecting performance and reliability, measles were soon classified by IPC as cosmetic[1,2]. However, limitations were placed on the extent of crazing such that conductor spacing was not reduced by more than 50%[3]. All measles were allowed. Recently, both measles and crazing were prohibited for space and military avionic hardware[4]. As technology has advanced, conductor and laminate widths and spaces have steadily declined. The separations caused by measles and areas of crazing are becoming more important as conductor feature size approaches that of fiber bundle. This paper will present test data that assesses various means of preventing measling/crazing along with methods for screening for measling/crazing susceptibility. IST test data on measled and crazed coupons will also be discussed.

This investigation began with the appearance of anomalies in a multi-layer polyimide PWB during hand soldering of fine pitch edge connectors. The anomalies, shown in Figure 1, were first believed to be severe measling; however, unlike typical measles, the anomalies appeared as bright stripes in the PWB dielectric that ran fully across the connector solder pads. Further investigation determined that the stripes were continuous and were similar in appearance to a crazed PWB.

The striped anomalies followed the glass reinforcement bundles of the dielectric, but presented themselves in one direction only. Upon examination of coupon cross sections, it was found that all PWBs of the same manufacturing lot exhibited significant missing glass fiber reinforcement. Subsequent searches of coupons revealed additional lots of material, from different part numbers that also had significant fiber pullout. One of these additional coupons corresponded to an assembled PWB that exhibited discrete areas of measling following hand soldering using a point-tip iron.


PN A, SN 1, LDC I, hand-soldering with wide-tip iron

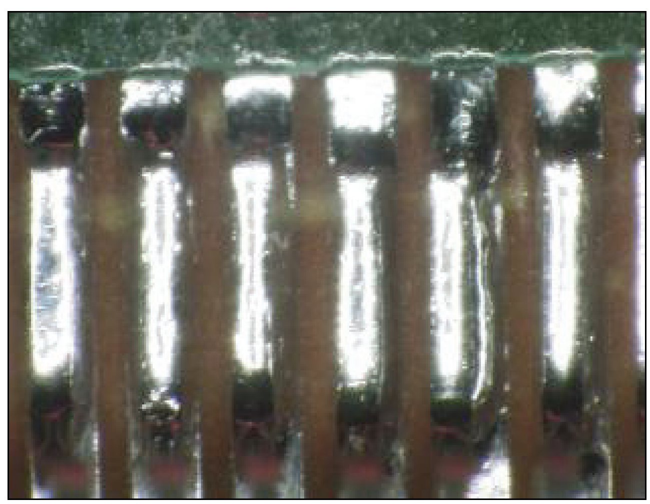

PN B, LDC IV, hand-touchup with point-tip iron

**Figure 1 – Crazing/Measeling below fine pitch leads of PWBs after hand soldering.**

**Testing of Coupons and PWBs with Measles or Crazing**

Following the initial observation of crazing, tests were performed on "M" coupons from four different designs. They will be called part numbers A, B, C, and D. Tests were also performed on bare board A, SN 1 and on populated assembly A consisting of bare board, SN 2. All test articles were polyimide with multilayer sequential lamination constructions.

M Coupons: The first test involved exposing several M coupons to a 340 ºC soldering iron with a wide-tip. The hand soldering simulation was performed following 2 passes through a convection reflow oven to simulate automated component assembly. The coupons were inspected for signs of measling and then were steam aged for 48 hours at 90 ºC to simulate prolonged storage in an uncontrolled environment. Following the storage simulation, the coupons were once again exposed to a soldering iron as above. Table 1 shows the results of the test.

**Table 1 – M coupon soldering test results.**

| Test Condition | PN (SN) | | | | |
|---|---|---|---|---|---|
| | A (1) | A (2) | B | C | D |
| Pre-existing Storage Condition + Soldering Iron, Wide-Tip | No Anomaly | No Anomaly | No Anomaly | No Anomaly | No Anomaly |
| 2x Convection Reflow Oven Exposure + Humidity Exposure + Soldering Iron | Anomalous Crazing | Anomalous Crazing | No Anomaly | No Anomaly | No Anomaly |

Prior to the convection-reflow heat and humidity exposures, no coupons showed any anomalies. However, after the introduction of moisture into the coupons, two of the five test coupons showed measling or crazing when heat was applied during hand soldering. A discrete measle that appeared in an M coupon following a second solder iron application is shown in Figure 2.

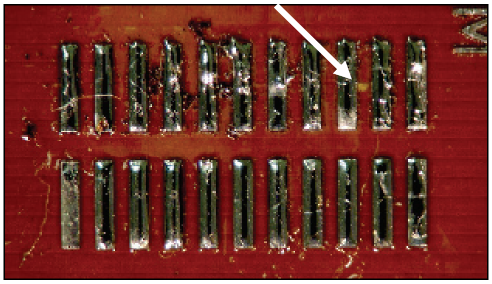
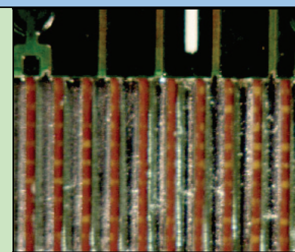
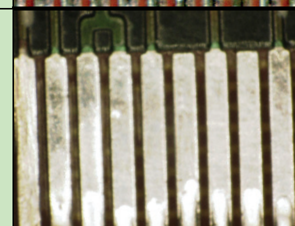
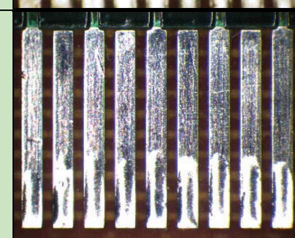
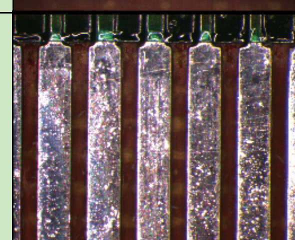
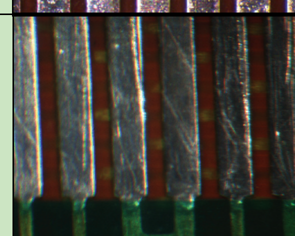
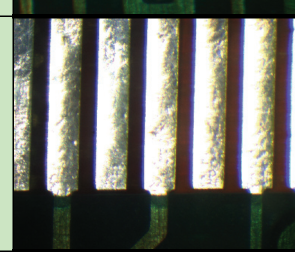


**Figure 2 – Measled M coupon after soldering following moisture exposure. Measle is shown with arrow.**

PWB PN A: The second set of tests involved soldering PWBs. Figure 1 shows the crazing observed in PWB A, SN 1 following soldering of a fine pitch edge connector onto the board. The crazed assembly had been exposed to ambient conditions for approximately 7 weeks prior to connector soldering. Due to the prolonged storage of the assembly, moisture was suspected as a driving cause of the crazing. The application of heat to a wide area was also deemed a possible contributor. To verify these causes, the remaining fine pitch edge connectors on the crazed assembly were soldered using a non-standard procedure. Instead of using a wide-tip iron, point-tip iron was used in a skip-lead soldering manner at 315 ºC following an 18-hour bake at 65 ºC. No measling or crazing was observed. It appeared that moisture, heat, or a combination of both was responsible for the measling/crazing.

To isolate moisture as the principle cause of measling/crazing, a test was constructed to evaluate the effect of drying time on a moisture saturated PWB exposed to a soldering iron. Bare board PWB A, SN 2 was used as the test vehicle. The fine pitch edge connector solder pads would be exposed to a 340 ºC soldering iron with a wide-tip following 2 passes through a convection reflow oven to simulate automated component attachment. Following this initial assembly simulation, the test PWB was steam aged for 60 hours at 80 ºC. Hand soldering was then performed different connector locations at various intervals following the initial humidity exposure. Soldering simulations occurred directly following the humidity exposure, after a 65 ºC bake for 6 hours, and then after two subsequent 65 ºC bakes, each for 6 additional hours. Lastly, a soldering simulation was performed on the test board after it was allowed to re-absorb moisture by exposing it to ambient conditions for 72 hours and then drying it for 18 hours at 65 ºC. Each soldering simulation consisted of one pass (except as noted) of the solder iron blade in direct contact with the PWB solder pads (i.e. without a connector). Following each simulation, the soldered connector location was removed from the test board with a jeweler's saw and cross-sectioned in two axes at the site of solder iron application. Table 2 shows the results of this testing.

**Table 2 – Soldering test results for PWB A, SN 2.**

| Test Step | Test Condition (Applied Accumulatively) | Visual Result | Photo of Result |
|---|---|---|---|
| 1 | As received – ambient exposure for 6 week duration. (Photo taken after 10 soldering iron applications) | Crazing |  |
| 2 | 120 ºC pre-bake for 6 hrs. + 2x convection reflow exposure + 100% humidity @ 80 ºC for 60 hrs. | Crazing |  |
| 3 | Above + Bake at 65 ºC for 6 hrs | Crazing |  |
| 4 | Above + Bake at 65 ºC for 6 hrs (12 hrs cumulative with 12 hrs ambient exposure between bakes) | Crazing |  |
| 5 | Above + Bake at 65 ºC for 6 hrs (18 hrs cumulative with 12 hrs ambient exposure between each bake) | Discreet Measling |  |
| 6 | Above + Ambient exposure for 72 hrs + bake at 65 ºC for 18 hrs. (18 hrs. continuous) | No Anomaly |  |

Cross-sections of the test PWB (SN 2) are shown in Figures 3 through 6. These sections showed significant damage to the glass fiber reinforcement. The fiber damage was continuous and ran the length of the mounts. The damage was also observed to extend beyond the connector solder pad areas into sections of the board with plated vias. The discovery of damage that extended beyond the connector area was cause for concern as it indicated that 100% bridging of the cracks was likely between conductors or plated vias/holes. This condition created a direct pathway between isolated conductors. In addition to the lateral reduction in dielectric, the dielectric spacing between layer 1 and layer 2 was effectively reduced to between 0.5 and 2 mils. This vertical reduction in dielectric was well in excess of 50%. Also of note was the condition of the glass fiber reinforcement in the sample that did not show visual signs of measling or crazing. The visually acceptable case showed significant cracking within fiber bundles as shown in Figure 6. These cracks were no less severe than those in the areas that visibly showed crazing. Cracks in the glass fiber bundles may provide an ideal pathway for fast conductive filament growth between closely spaced signal or power vias[5,6].

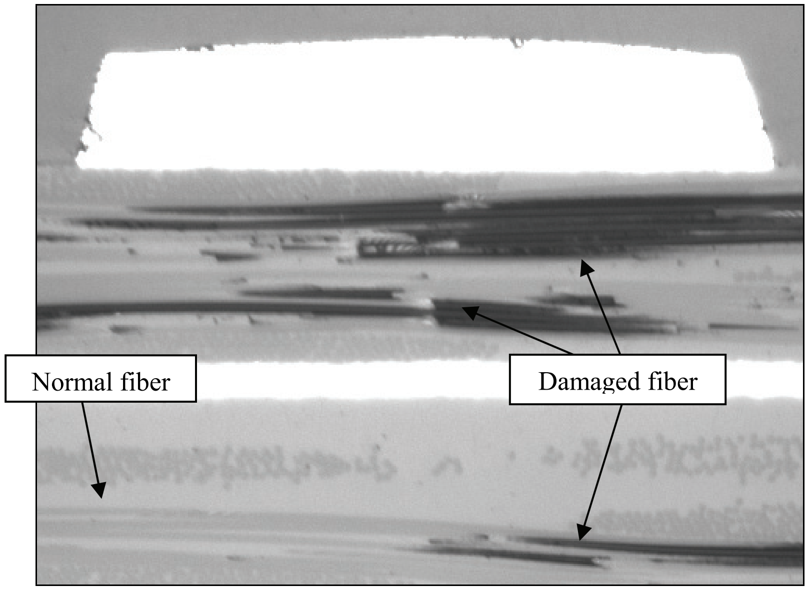



**Figure 3 – Longitudinal cross-section showing damaged glass fiber reinforcement of test PWB following humidity exposure and wide tip soldering simulation. Damage appears as black lines.**

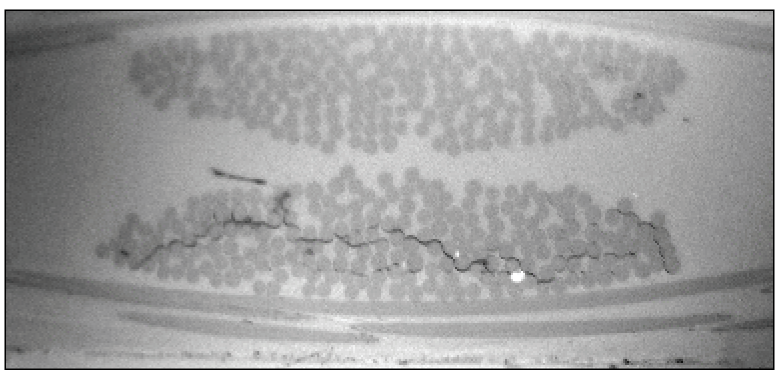


**Figure 4 – Lateral cross-section showing end view of damaged glass fiber reinforcement shown in Figure 3.**

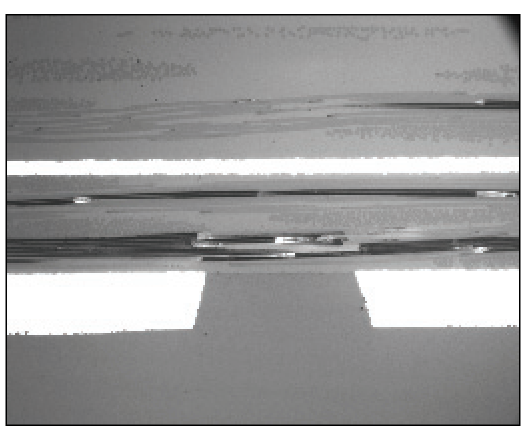


**Figure 5 – Glass fiber bundles are damaged even following an 18-hour continuous bake.**

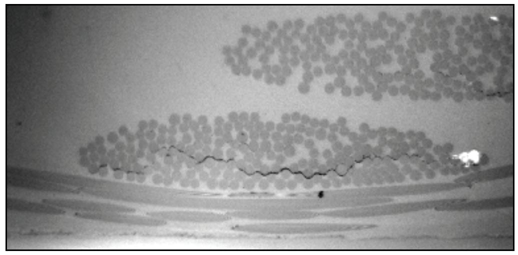


**Figure 6 – Lateral cross-section showing end view of damaged glass fiber reinforcement shown in Figure 5.**

**Evaluation of Acceptance Coupon Cross-Sections**

Acceptance coupon cross-section mounts of various multilayer polyimide part numbers and lot date codes were also examined for variations in appearance and construction. Cross-section mounts from 9 different part numbers and 12 lots were examined for fiber pullout. All had similar stackups and constructions. During this review of cross-sections, it was noticed that all coupons of PWB A LDC I (the crazed PWB lot) showed abnormally high amounts of missing glass reinforcement fibers. A few missing fibers due to pullout during cross sectioning is normal. However, coupons from the crazed assembly showed a significant amount of missing reinforcement fiber, well in excess of 50%. Figure 7 shows a cross-section photo of the crazed lot, LDC I, next to a photo of a normal lot of the same part number, LDC II. The acceptable lot has no glass-fiber reinforcement missing. Cross-sections also showed that the measled PWB B, LDC IV, also had missing glass fiber. Figure 8 shows a cross-section of an acceptance coupon from the measled board. It too had a large amount of glass fiber missing. Since all mounts were prepared per the same procedure, it is believed that there is a correlation between glass fiber pullout during cross sectioning and a weak laminate material that is susceptible to crazing.

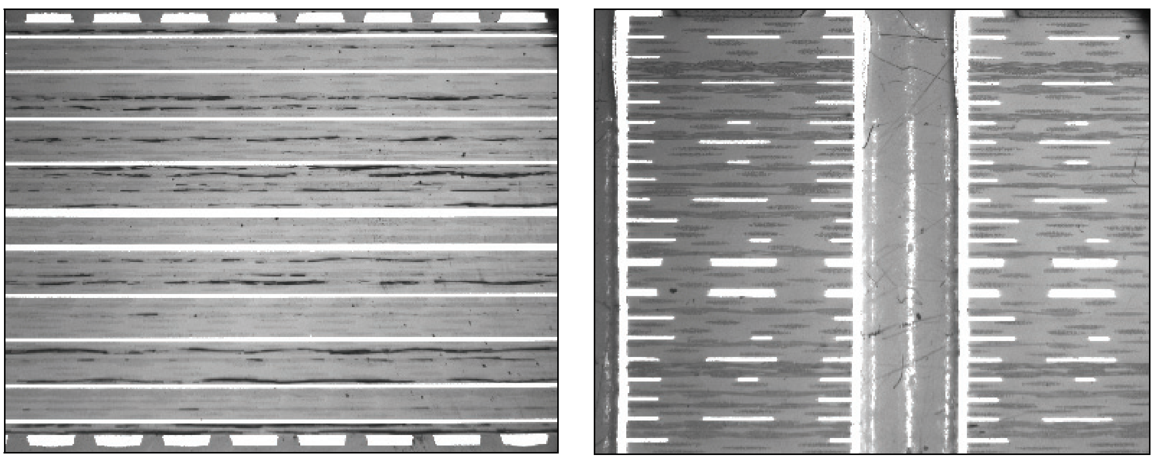


**Figure 7 – Two cross-sections of PN A. The photo on the left was taken of the crazed LDC I. The photo on the right was taken of a normal LDC II.**

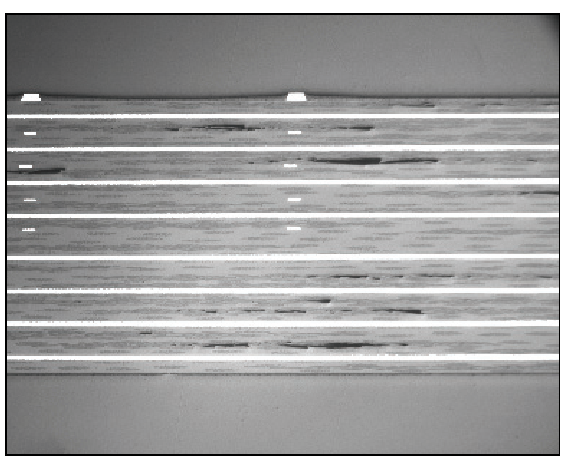


**Figure 8 – Cross-section of acceptance coupon for PN B, LDC IV, from a PWB that measled during assembly.**

It was further found that all cross-sections showing missing fiber were fabricated from laminate with a V-0 flammability rating. None of the cross-sections fabricated from V-1 rated material showed fiber pullout. Both materials meet IPC 4101 class 3 specifications. The cross-section observations are listed in Table 3. Among the lots that exhibited fiber pullout, pullout was only observed in one of the two planes of each bi-directional cross-section. It was determined that fiber pullout occurred preferentially in the warp direction of each woven glass ply. Table 4 compares the difference in appearance of the bi-axial sections of the measled/crazed lots with that of typical cross-sections from laminate with a V-1 rating. In lots of V-0 laminates, where fiber is intact, the cross-sections in both directions appear similar.

**Table 3 – Cross-sections examined for glass fiber pullout.**

| PN | LDC | Fiber Pullout Observed? | Measling/ Crazing in Assembly? | Flammability Rating of Laminate |
|---|---|---|---|---|
| A | I | Yes | Yes | V-0 |
| A | II | No | No | V-0 |
| A | III | No | No | V-0 |
| B | IV | Yes | Yes | V-0 |
| C | V | Yes | No | V-0 |
| D | VI | Yes | No | V-0 |
| D | VII | No | No | V-0 |
| E | VIII | No | No | V-0 |
| F | IX | No | No | V-1 |
| G | X | No | No | V-1 |
| H | XI | No | No | V-1 |
| I | XII | No | No | V-1 |

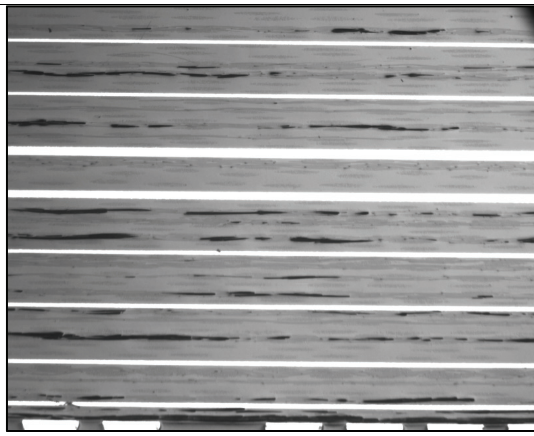
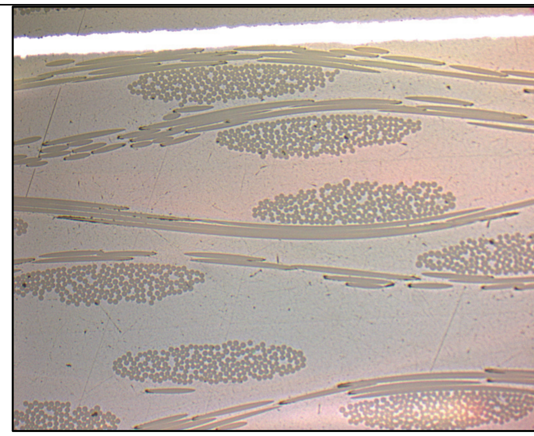
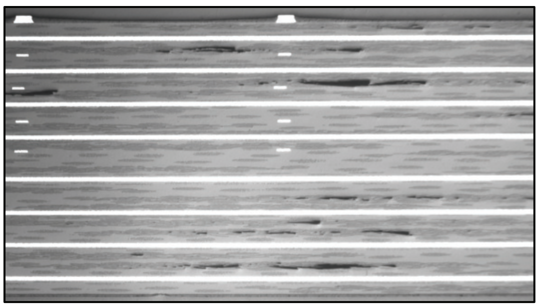
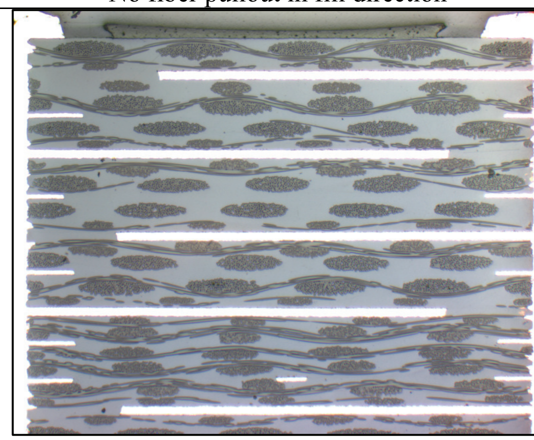
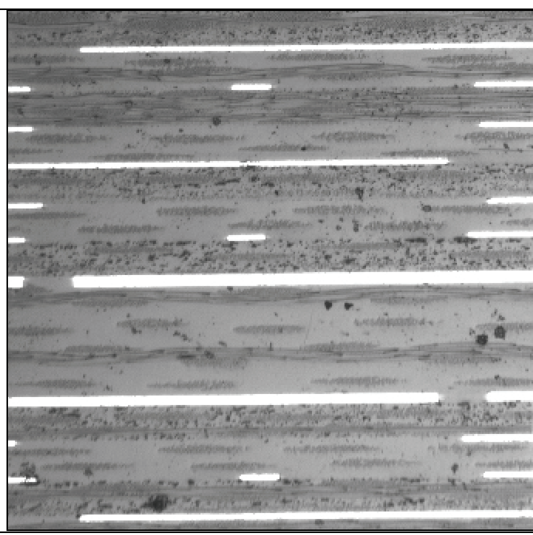
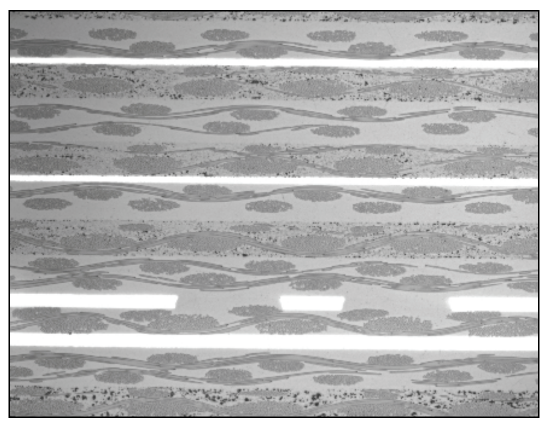
Some testing has been conducted to investigate the effects of fiber finish, yarn size in the woven glass fabric, and into the formulations of the polymers. At this time, sufficient data is not available to quantitatively differentiate these attributes and fully address why fiber pullout was found in some of the V-0 rated laminates. The significance of this investigation is not in fiber pullout itself. It lies in how to identify PWBs susceptible to measling or crazing and possibly prevent the scrapping of very expensive assemblies that measled or crazed during assembly. By screening out PWBs at the acceptance stage using "fiber pullout" as a differentiator, precautionary procedures might then be applied to susceptible PWBs to ensure success in assembly. Use of special assembly procedures in small isolated lots can help meet cost and schedule demands.

**IST Testing and Results**

Interconnect stress testing (IST) was performed to assess the PTH and laminate integrity of measled PWBs. A total of five IST coupons from PWB A and D were chosen. Four coupons from Lot I were tested (PWB A, SNs 1 through 4), while one coupon from a different material lot, Lot VII was also tested (PWB D, SN 5). Lot I material showed pullout of glass-fiber reinforcement during cross sectioning and is believed to be susceptible to measling and crazing. Acceptance coupons from Lot VII material did not show fiber pullout and serial numbers from this lot are not considered susceptible to measling or crazing. Although fabricated from different lots, the plating thickness measured on SNs 1 through 4 was nearly identical to that measured on SN 5. Since the design, construction, and fabrication of all five SNs was nearly identical, the only factor affecting reliability was the dielectric material lot.

All five coupons were forced to measle/craze by application of moisture and heat. SNs 1 and 2 were preconditioned by two passes through a convection reflow oven and then steam aged for 8 hrs. Measles were induced by five successive applications of a 1 inch wide, 370 ºC soldering iron to the coupon surface. SNs 3, 4, and 5 were identically preconditioned; however, measling was induced in a much more severe manner. To create a thermal shock, coupons were cooled to -65 ºC and then immediately touched by a soldering iron, as above.

**Table 4 – Comparisons among cross-sections**

| PWB ID | Cross-section parallel to wrap-yarn direction | Cross-section perpendicular to wrap yarn direction |
|---|---|---|
| PN A,<br>LDC I<br>V-0 rating<br><br>Sections reviewed for 6 SNs | <br>Fiber pullout in wrap direction | <br>No fiber pullout in fill direction |
| PN B,<br>LDC IV<br>V-0 rating<br><br>Sections reviewed for 2 SNs | <br>Fiber pullout in wrap direction | <br>No fiber pullout in fill direction |
| PWBs made from V-1 rating laminate<br><br>No fiber pullout in either direction |  |  |

All coupons were IST tested at the same time and resistance was monitored over 1500 cycles[7]. No meaningful resistance changes were detected in power nets over 1500 cycles. No post interconnect defects were expected to be detected as the power nets are typically very robust. Figure 9 shows the power net resistance changes, no more than 3%. The blind via sense nets also showed little resistance change as shown in Figure 10. No coupon's blind via sense net reached more than a 7% resistance increase before the test was ended after the 1500th cycle. Small fatigue cracks in the barrels were expected. Figure 11 shows the PTH sense net resistance changes. The PTH sense net did show increased resistance with thermal cycling. However, all coupons passed the 700 cycles with less than 10% resistance increase. All coupons are therefore considered to have passed reliability screening [8]. The elevated resistances of the PTH barrels began to rise after 100 to 300 cycles. PWB, SN 3 and SN 5 retained relatively low resistance changes beyond 1500 cycles when the test was stopped. SN 5 had the least resistance change. This is the coupon from a separate fabrication lot (Lot VII) where no fiber pull-out was observed coupon acceptance screening. Although suggestive of increased reliability, the small sample size precludes judgment. The resistance increases for all coupons were related to barrel cracking as confirmed by cross-sections such at that shown in Figure 12.

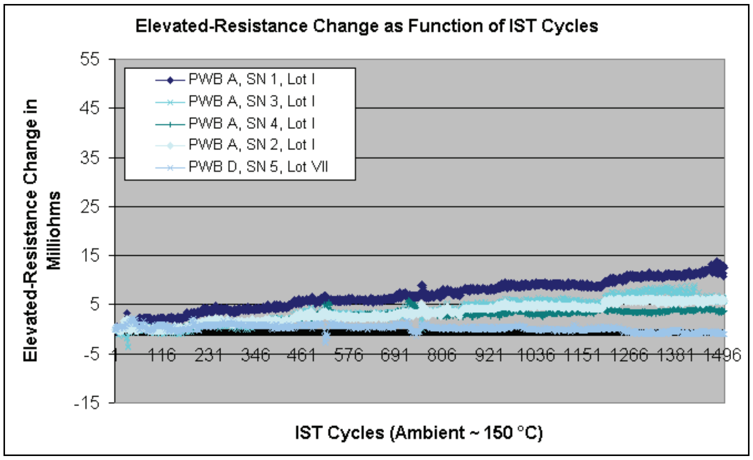



**Figure 9 – Plot of resistance changes in the Power nets. All coupons passed reliability screening.**

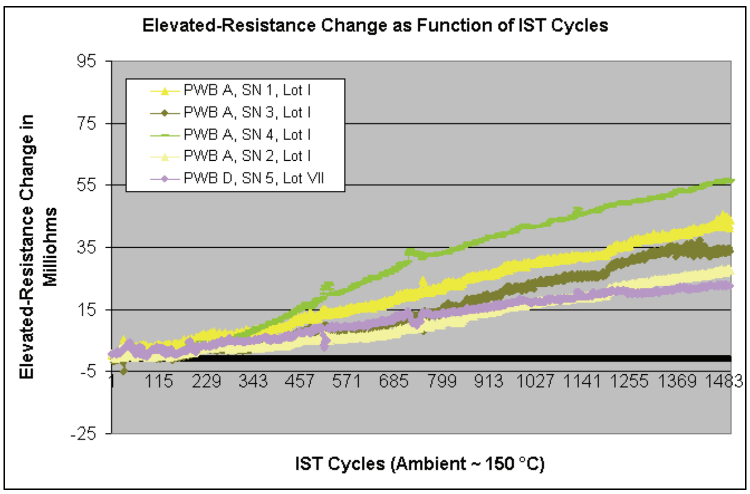



**Figure 10 – Moderate rising resistance trends were observed in test nets associated with blind via barrels. All coupons passed reliability screening.**

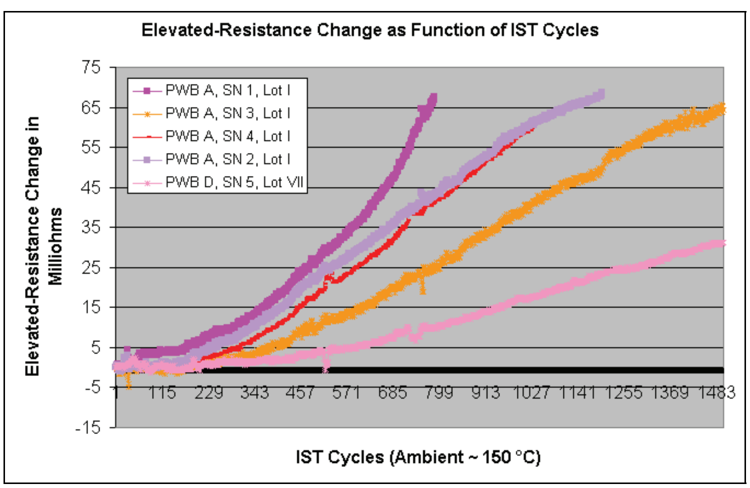



**Figure 11 – Plot of resistance changes in the PTH Sense net. All coupons passed reliability screening.**

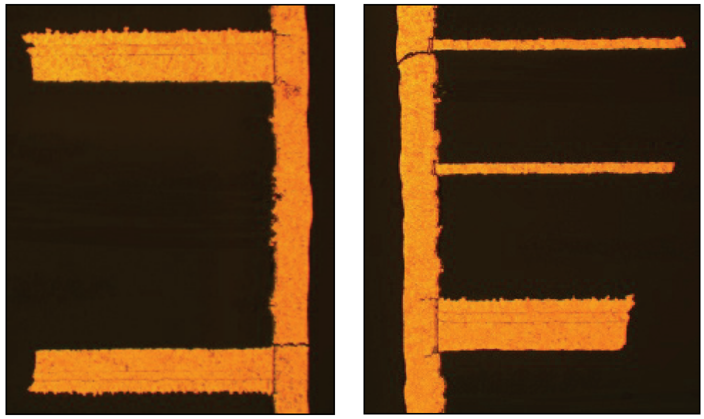


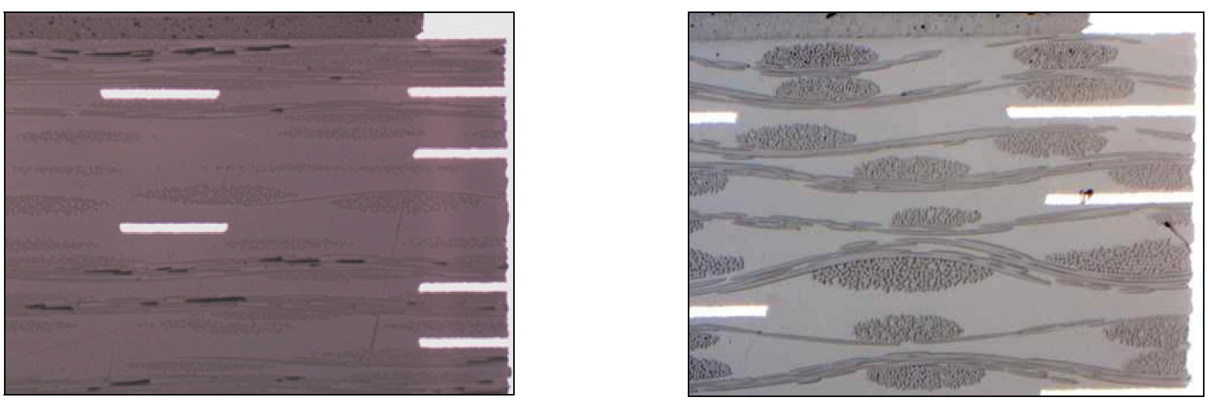
**Figure 12 – These cross-section images sections show the central or near central portions of the IST coupon PTH sense net barrels from SN 1.**

These cross-section images show the central or near-central portions of the IST coupon PTH sense net barrels from SN 1. SN 1 had the fastest resistance growth (Figure 11). All cracking appears to be fatigue-related, as signified by the rising IST curve. Copper plating in the barrels was measured to exceed 1.5 mils in PTHs. Some barrel cracks appear to be through the barrel wall. It is believed that these cracks correlate to the "bright spots" from the infrared images used to identify failure locations. Infrared images are shown in Figure 13.

SN 1 SN 4

**Figure 13 – Infrared images taken when the PTH sense nets (PTH barrels) were powered. The bright spots represent the worst damage locations.**

The cross sections taken to evaluate barrel cracking were also examined for signs of glass fiber pullout and cracking within or between fiber bundles. Both pullout and cracking was observed. Figure 14 shows fiber pullout from cross sectioning in the longitudinal direction of the IST coupon. When cross-sections were performed in the lateral direction, warp yarn cracks were not seen unless examined under much higher magnification.



Section along the longitudinal direction of the IST coupon Section along the lateral direction of the IST coupon

**Figure 14 – Cross-sections confirming the fiber pullout condition typical to PWB A, Lot I. The photos were taken from SN 1 after 1500 IST cycles.**

Fiber fall-out condition appears in one direction of the laminate only (the warp direction). This is again confirmed by one out of every two bi-axial cross-sections for all coupons from Lot I. When cross-sections are perpendicular to warp yarns, all fill yarns look normal and the wrap yarn condition is not apparent. However, unlike SN 1, warp yarn damage is still evident for SN 4 (same lot) coupons that are exposed sub-ambient shock of -65 ºC prior to contacts of hot soldering iron. The warp bundle cracks are confined within the bundles, and do not extend into the polymer as shown in Figure 15. The fill yarn remained intact under this severe test condition. This implies that fill yarn is much more robust than the warp yarn.

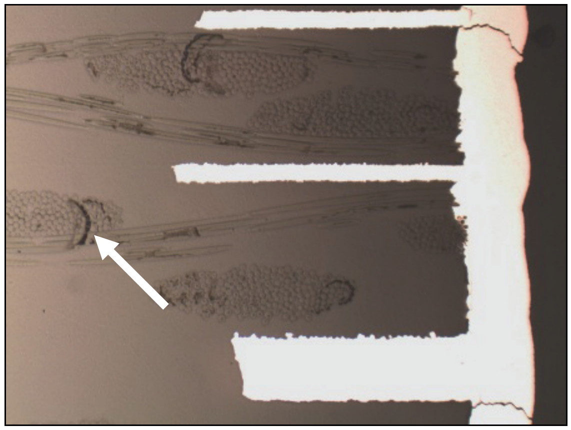


**Figure 15 – Cross-section showing the central portions of PTH sense net barrels from SN 4 with warp bundle cracks.**

**Conclusions**
Coupon testing showed that moisture clearly plays a large role in measling and crazing. When M coupons were tested, only those that had been steam aged showed crazing when soldered with a wide tipped iron. Moisture's role in measling/crazing was further confirmed by tests performed on PWBs. After 18 hours of continuous drying at 65 ºC, the test PWB (SN 2), exhibited no measling or crazing when soldered with a wide tip iron. The same PWB showed significant crazing when dried in multiple steps with prolonged ambient exposure between steps."

Cross-sections of the test PWB showed significant damage to the glass fiber reinforcement. The fiber damage was continuous and ran the length of the mounts. This damage was observed to extend beyond the connector solder pad areas into sections of the board with plated vias. The discovery of damage that extended beyond the connector area was cause for concern as it indicated that 100% bridging of the cracks was likely between conductors. This condition made the PWB susceptible to CAF formation between adjacent plated vias. CAFs could possibly grow through the cracked bundles and bridge adjacent plated vias causing an electrical short.

Examination of acceptance coupon mounts from several similar designs indicated that glass-fiber pullout was an indicator of possible measling/crazing susceptibility. Additionally, a correlation was found between material rated V-0 for flammability and fiber pullout. The fiber pullout occurred preferentially in warp direction of woven glass ply. Fill yarn appear to be significantly more robust.

IST testing demonstrated that although measling and crazing may impact the electrical reliability of a PWB (shorting risk) via electrochemical migration, reduced dielectric strength, or some other mechanism, it does not seem to significantly impact the mechanical reliability of the interconnects (open risk). There was some indication that material susceptible to measling and crazing may be less reliable than other material; however, no conclusive data was found.

**Acknowledgements**
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