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CONVERTING CABLE ASSEMBLY MANUFACTURING TO LEAD FREE SOLDER

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ABSTRACT:

Lead free soldering presents many challenges to cable assembly manufacturing. Many assembly issues were easily solved with a little tin lead solder. However, the higher temperatures and lower ductility associated with lead free solder presents assembly challenges requiring adjustments to existing processes.

This paper will review the various soldering applications associated with cable assembly. The focus will be on process modification and qualification with lead free solders. The processes reviewed will include soldering of crimp terminals to enhance reliability, automatic or semiautomatic bulk cable solder attach to printed circuit boards, soldering of copper tape for shielded cables, soldering of splices and braid or drain wires.

Some process and design modifications are required when using lead free solder in cable assembly manufacture. Most are associated with temperature. High performance cable assemblies that have printed circuit boards exhibit changes in electrical performance with lead free solder but the variation is relatively minor. The more pressing issues are manufacturing and process control. The forces transmitted to the solder joints from relative motion of the high performance bulk wire pairs have been a long standing concern. Lead free solder is stronger but that is not necessarily an advantage. Consistency is more critical to the quality and reliability of these cables. Handling during the process is also critical.

Converting processes to lead free solder is not without challenge. Accelerated reliability testing is not required for most cable assembly families. If proper cable assembly designs, cable manufacturing process designs and process controls are established, a wide variety of cable assemblies can be built using lead free solder without impact to the end customer.

Key words: cable assembly, lead free solder, cable assembly qualification, wire termination

INTRODUCTION:

Cable assemblies consist of two main components (the wire and the connector) that must be connected together. The first wave of changes to cable assemblies brought about as a result of EU RoHS legislative restrictions, resulted in the removal of lead from wire insulation and from tin lead coatings. These changes were relatively minor technically. The server exemption allowed OEM's in the Server and Storage segments to continue using tin lead solder. While the life expectancy of the server exemption is not definite, many suppliers were anxious to move immediately to lead free solder in their manufacturing plants. In addition, a common goal for many companies including IBM is to begin compliance activities for anticipated environmental regulations in advance of the requirements. A review of the applications using lead free solder in cable assemblies in Server and Storage products was conducted. Each application was reviewed and qualification plans created and executed to move these to lead free solder.

Cable assembly reliability is important to the over all success of server products. High reliability can be achieved with lead free solder as long as the design and process allow for the higher temperatures and reduction in ductility associated with lead free solders.

QUALIFICATION:

There are numerous applications of solder in cable assemblies. Table 1 presents a list of some of the more common uses of solder in cable assembly manufacture.

Table 1: Solder Application in Cable Assemblies

Solder Application	Cable Families Impacted
Light Crimp and Solder	Harness, Molded
Solder Cups	Harness
Splices	Harness, Molded
Shielding *	Molded
Drain wire to Shield	Ethernet
Bulk Wire to PCB	High Performance
Connector to PCB **	High Performance

*Includes copper tape seams, braid to shield ** Typically done in a card assembly type process outside of the cable assembly process.

Qualification plans for most cable families focused around the ability to successfully manufacture the cable using lead free solder and meeting the necessary quality requirements. Quality requirements can be found in IPC and IBM specifications [1] – [7].

High performance cable assemblies require more than just continuity to function properly. A more comprehensive test plan was developed. Many high performance cable assemblies use printed circuit boards (PCB). This cable assembly family represents the greatest risk due to the change in solder material and processing temperatures. Samples were made with lead free and tin lead solder using the same lot of bulk wire. Electrical and mechanical data were gathered before and after reliability testing. The environmental test sequence is shown in table 2.

Table 2: Lead Free High Performance Cable Assembly Environmental Test Sequence

Test Description	Sequence
Measure High Performance Electrical parameters	1
25 plug cycles	2
Measure Impedance	3
Thermal ship shock	4
Measure Impedance	5
Thermal Cycling	6
Measure Impedance and Cross Talk	7
Thermal Aging	8
Measure Impedance	9
Flex Testing	10
Measure Impedance	11
Vibration	12
25 plug cycles	13
Measure High Performance Electrical parameters	14

There were two cards used for post environmental visual inspection, cross sections and peel testing. The cards went through a pretreatment for 10 days at 125ºC. This is intended to determine if solder embrittlement is an issue. Impedance measurements were also used to determine the impact of the environmental sequence. The cards were processed through sequence 3 through 9. Testing was done on InfiniBand™ [9], Serial Attached SCSI (SAS) and PCI Express® [10] cables with three different suppliers. The PCIe cables were only done with lead free solder and compared to the specification after testing.

Table 3: High Performance Electrical Parameters

Parameter	Description
Imp	Transient Impedance/bulk wire Impedance
SDD21	Attenuation/Insertion Loss
SDD11	Return Loss
Within Pair Skew	The difference in time for a signal to travel down each of the two wires in a pair.
Pair to Pair Skew	The maximum difference in time between the best and worst pairs in a bundled cable.
NEXT	Near end cross talk
FEXT	Far end cross talk
Eye Height	The height maximum height of the eye opening pattern in mV.
Eye Width	Maximum eye width in time of the eye pattern in ps.
Jitter	Noise/1 - eye width

High performance electrical parameters tested depend on the requirements for each cable assembly family and part number drawing. Some requirements come directly from industry standards such as InfiniBand™ others are defined by the cable assembly drawing. Table 3 lists the high performance parameters examined in this paper.

RESULTS AND DISCUSSION:

Light crimp and solder is required when a wire terminal combination fails to demonstrate stability (fails to pass the testing in reference [8] or if the combination has not been tested). The visual inspection requirements for this process are shown in Figure 1 from reference [1]. Unfortunately, this criterion proved to be too stringent for lead free assembly.

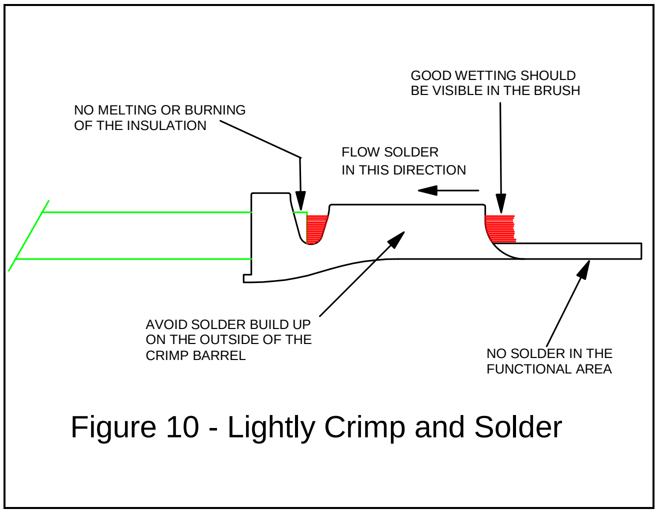


Figure 1: Crimp Light and Solder Criteria per EC G42804 [1]

Experiments included standard wire with 80ºC and 105ºC insulation materials. It was determined that wire gauges 20 AWG and smaller can meet the new slightly relaxed requirement from reference [2] (or [3]). The updated criterion allows some small amount of heat impact on the insulation, see Figure 2. Figure 3 shows an acceptable sample that would indicate the supplier may need to adjust the process to continue to produce acceptable product. Figure 4 is an unacceptable sample. Insulations under the bare wire crimp can result in intermittent opens. For larger wires, 18 AWG and larger, a long strip and shrink tubing must be used to meet requirements.

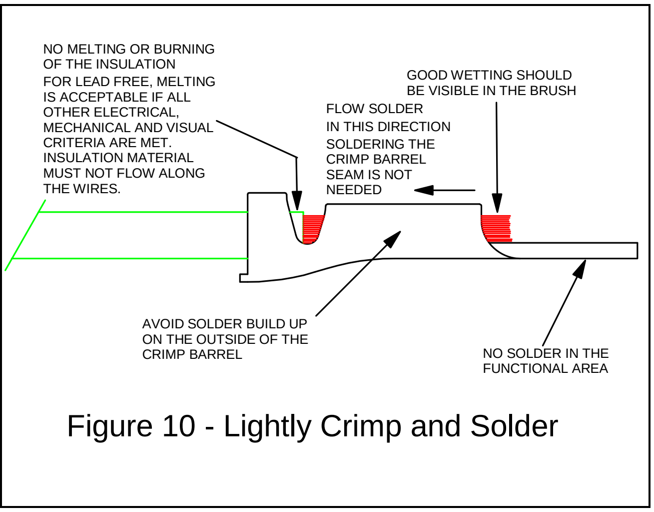


Figure 2: Crimp Light and Solder Criteria updated for lead free processing [2] and [3]

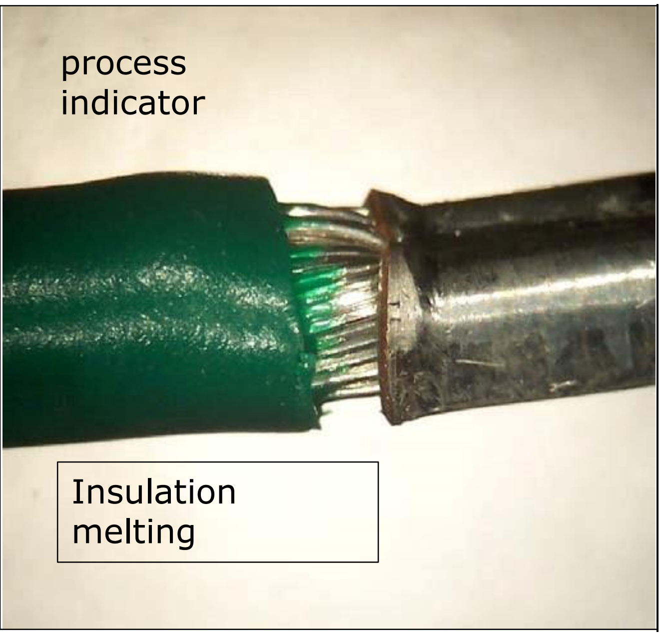


Figure 3: Acceptable but process adjustment is needed.

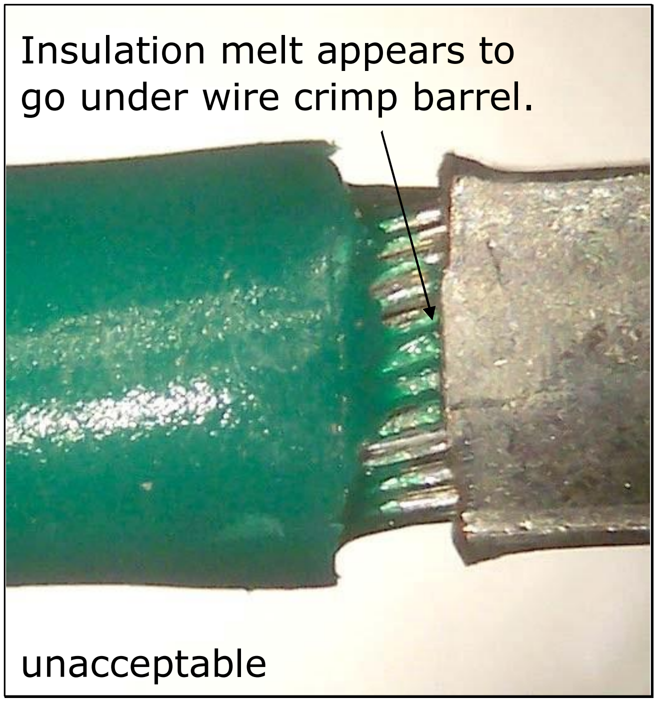


Figure 4: Unacceptable due to insulation under the bare wire crimp.

Other processes were accomplished using lead free solder without significant issues identified.

High performance cable assembly testing was much more extensive and did result in some lessons learned. The first difficulty was in actually building the cables.

The first supplier was able to achieve acceptable results and still meet all the requirements of reference [4]. A tin silver solder alloy was used.

The second supplier was not able to achieve acceptable results for more than 6 months. Experimentation included several DOEs (Design of Experiments) and multiple solder alloys. The biggest issue was pad peeling at very low values. Solder peel test does not represent a method to evaluate pad adhesion on a card. However, soldered wires that peel at very low forces do not indicate a robust assembly either. These early results did not represent a product that would be considered customer shippable. Supplier 2 eventually realized positive results but declined to share their lessons learned. In this case, the supplier was also able to meet the requirements of reference [4] using a Sn-Ag-Cu (SAC) solder with no pad peeling.

Figure 5: Pad peel

After years of experience with tin lead solder and high performance cable assemblies containing PCB, it was known that it was possible to avoid peeling pads. However, there was no body of knowledge with regard to lead free solder assemblies.

The reason for not allowing pads to peel is two fold. First, if the pad peels, there is no information gained about the quality or strength of the solder joint. Second, if the solder process window can be adjusted to prevent pad peeling, it provides immediate indication of overheating during the solder process.

Unfortunately, the third supplier was not able to eliminate pad peels. Solder mask/resist over the back edge of the pad has been used to eliminate solder pad peels for tin lead soldered cable assemblies in the past. However, given the higher strength of lead free solder, this approach does not always prevent pad peeling. Using digital photography, it was shown that even with the solder mask in place, the pad did peel. The position of the wire on the pad can also be tweaked to help the solder joint to fail rather than the pad to peel. To date, it has not been possible to eliminate pad peeling 100% of the time when using lead free solders.

This presented a new problem, while soldering wires onto PCB could be accomplished with lead free solder using automated or semi automated processes, there was a serious problem with how to establish process control.

Reference [5] has been updated with a section on pad delamination. From reference [5], section 2.1:

"Pad Delamination is not acceptable for tin lead soldered cable assemblies.

The goal for lead free solder cable assemblies is to eliminate or minimize pad delamination. Sometimes conformal coating over the edge of the solder pad can reduce the amount of pad peels. If pad delamination can not be eliminated, process control becomes challenging.

Only solder failure data points can be used for statistical process control (SPC).

If there are pad peel failures, an attribute chart for number of pad peels is needed in addition to the peel force xbar and R or s charts.

Cross sections must be used to establish that the process does not overheat the card or damage the bond between the solder pad and the printed circuit board. This will be needed as a part of qualification to establish that the process is acceptable.

There is no specification on the force at which the pad peels up. If there is a concern regarding pad adhesion, proper testing for this attribute must be done on cards that do not have wires soldered on them."

Once we were able to build parts, the reliability testing was completed by all three suppliers.

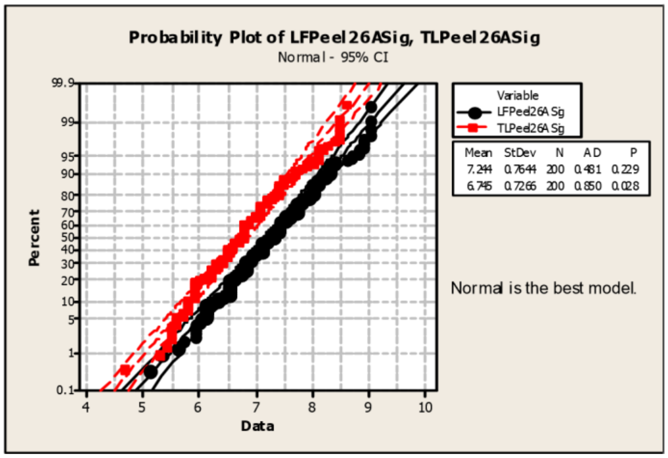
The testing generated a tremendous amount of data. The analysis matrix in table 4 was used to organize the results.

Table 4: Analysis Matrix (Mechanical and Electrical)

Time Zero Lead Free vs. Tin Lead	Post Environmental Lead Free vs. Tin Lead
Lead Free Time Zero vs. Post Environmental	Tin Lead Time Zero vs. Post Environmental

Mechanical Results

Supplier 1, time zero, analysis showed that the peel strength for lead free solder was higher than for tin lead solder, see Figure 6. This was an expected result. However, when the pad and the wire are close to the same size, the peel test results were fairly close. This is likely due to the nature of the peel test. While a straight forward tensile test will show the lead free materials to have superior strength, a peel test can also be influenced by the ductility of the material. As is typical when working with metals, if the strength is higher, the corresponding ductility will be lower. The peel test is also strongly influenced by solder volume.

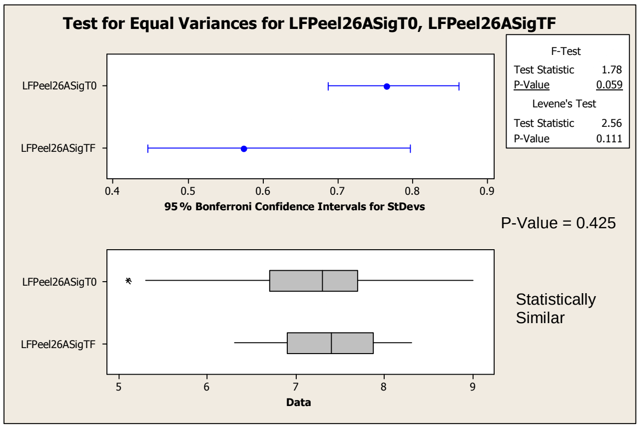


Normal is the best model.

Figure 6: Time zero peel test data. Red is tin lead and black is tin lead solder.

For Supplier 1, the post environmental test results were statistically similar to the time zero results for lead free solder but not for tin lead solder, see figures 7 and 8. The tin lead results did not compare statistically. This appears to be the result of higher variation in the time zero data.

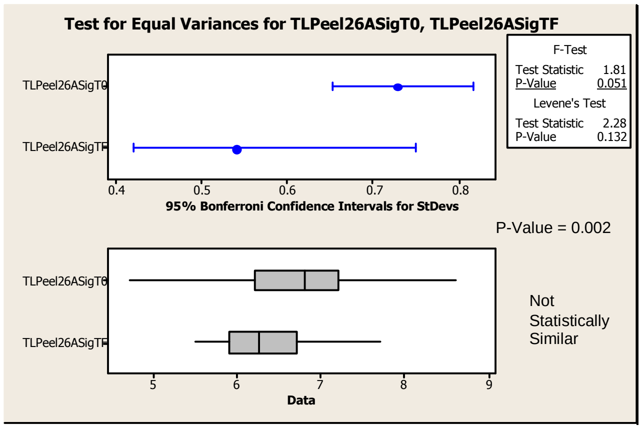
Supplier 2 data showed a slight degradation in peel test values in the post environmental data for both lead free (see figure 9) and tin lead solder. The observed differences are minor and within the normal variation of the process.



P-Value = 0.425

Statistically Similar

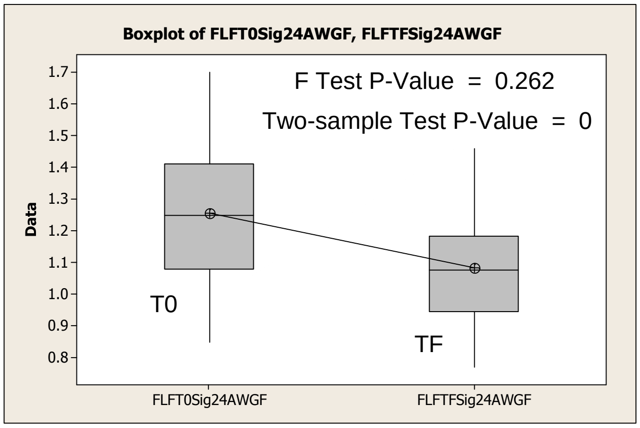
Figure 7: Supplier 1 lead free solder peel test data time zero and after environmental testing.



P-Value = 0.002

Not Statistically Similar

Figure 8: Supplier 1 tin lead solder peel test data time zero and after environmental testing.



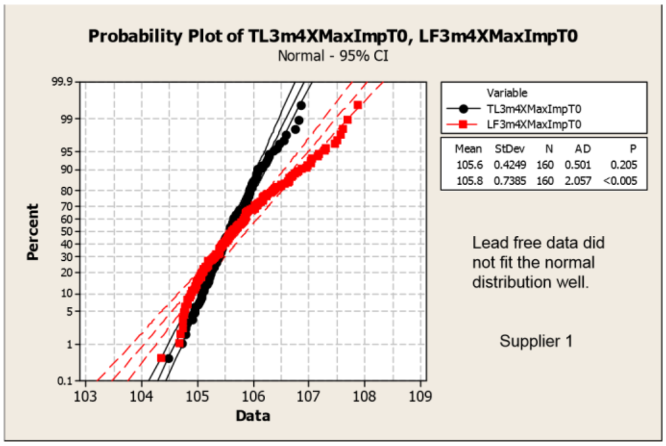
F Test P-Value = 0.262

Two-sample Test P-Value = 0

Figure 9: Supplier 2 lead free solder peel test data time zero and after environmental testing.

Electrical Results

Supplier 1 time zero data showed higher maximum impedance values than tin lead assemblies built with the same bulk wire lot, see figure 10. Supplier 2 also showed higher maximum impedance for the lead free assemblies, see figure 11.



Lead free data did not fit the normal distribution well.

Supplier 1

Figure 10: Supplier 1 time zero maximum impedance tin lead solder (black) lead free solder (red).

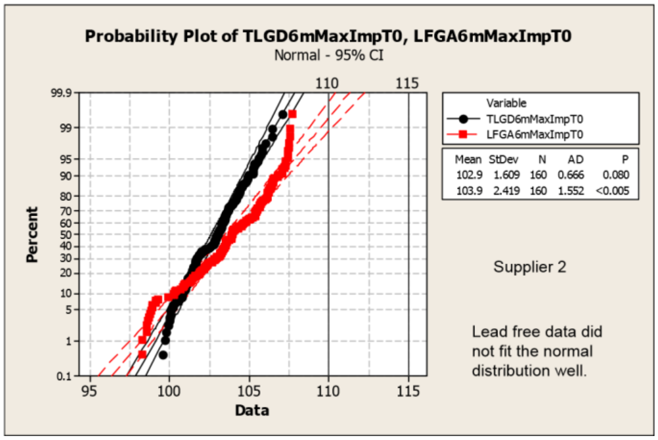


Figure 11: Supplier 2 time zero maximum impedance tin lead solder (black) and lead free solder (red).

Data from both supplier 1 and supplier 2 showed that using lead free solder does impact high performance characteristics but the effect is minor. The only significant and consistent observation was the maximum impedance. This may be related to the difference in the shape of the lead free solder fillets, see figures 12 and 13. Despite the slightly higher maximum transient impedance with lead free solder assemblies, the cable assemblies met all electrical performance requirements.

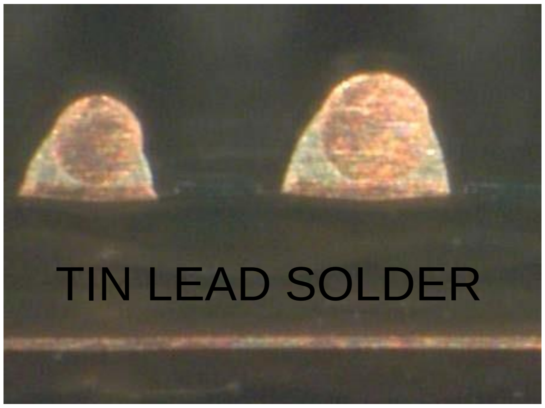


Figure 12: Solder cross section (Supplier 1)

Figure 13: Solder cross section (Supplier 1)

Environmental testing did impact the electrical performance of the cable assemblies. The effect was minor and similar regardless of the solder alloy.

Other Lessons Learned

All new high performance cable assembly families have been released with lead free solder beginning in 2010. At this point, all the qualification testing has been completed successfully. However, there have been mechanical issues identified on several high performance cables. These process issues can occur with any lead free cable assembly. As discussed previously, the lead free solder joints are stronger than tin lead but with less ductility and pad peeling can occur on properly manufactured cables. There are two issues that can occur. First, handling during manufacturing can result in side forces being applied during assembly into the backshell. A slight adjustment that was made with no problem on tin lead assemblies, can now lead to a fractured pad. Figure 14 shows a good cable where both pairs lined up in the center of the hot melt and a bad cable where one pair is not straight. When the wires are straightened to assemble into a backshell a fracture can result. Second, fracture pads can be caused by pistoning. High performance parallel pair bulk wire will piston. Pistoning can be defined as the relative motion between pairs within a jacketed bulk wire. Pistoning amounts can vary with bulk wire lot and supplier. A cable in which a large displacement results from pistoning can now result in popped pads due to the introduction of lead free solder.

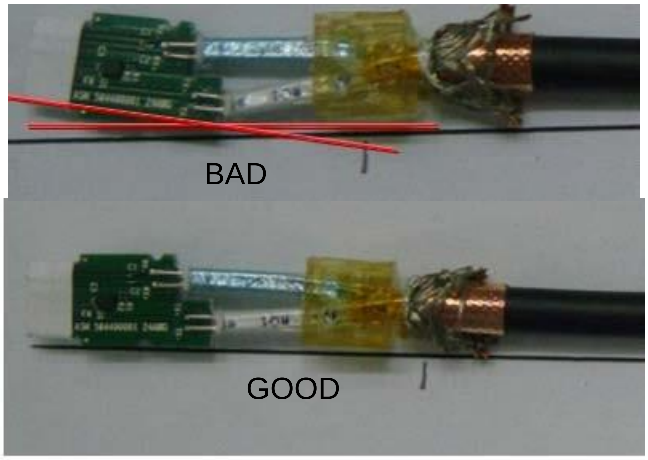


Figure 14: Good and bad cable assembly samples.

SUMMARY AND CONCLUSIONS:

Converting processes to lead free solder is not without challenge. The results support the conclusion that accelerated testing performance for lead free cables is not significantly different than those experienced using tin lead solder. This may, in part, be due to the small PCB used within cable assemblies. A larger thermal mass might significantly change the outcome.

It has also been learned that the key concern with lead free high performance cable assemblies is mechanical in nature. Handling and mechanical assembly design considerations are critical to success. It has also been shown that high performance electrical parameters need to be verified when moving an existing cable assembly from a tin lead to a lead free solder process. If adequate margins exist, the test results should be positive but data is needed to confirm. Consistency is the ultimate goal to minimize variability in cable performance.

If proper cable assembly designs, cable manufacturing process designs and process controls are established, a wide variety of cable assemblies can be built using lead free solder without impact to the end customer.

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REFERENCES:

[1] IBM Engineering Specification 0878235 “Cable Assembly Manufacturing” EC G42804, March 2007

[2] IBM Engineering Specification 0878235 “Cable Assembly Manufacturing” EC G36952, January 2010

[3] IBM Engineering Specification 0878235 “Cable Assembly Manufacturing” EC N44875, December 2012

[4] IBM Engineering Specification 41U0282 “InfiniBand® Solder Acceptance Criteria” EC J99529, July 2005

[5] IBM Engineering Specification 41U0282 “High Performance Cable Assemblies: Wires Soldered To Printed Circuit Board (PCB) Solder Acceptance Criteria” EC N44875, December 2012

[6] IPC Standard 610-A-610D “Acceptability of Electronic Assemblies”, April 2005

[7] IPC/WHMA-A-620 “Requirements and Acceptance for Cable and Wire Harness Assemblies”, March 2002

[8] IBM Engineering Specification 5528706 “Bare Wire Crimp Terminations” EC 231077, October 1991

[9] InfiniBand™ is a trademark of The InfiniBand Trade Association (IBTA)

[10] PCI Express® is a registered trademark of PCISIG