HIGH I/O BGA CONNECTOR SOLDER JOINT INTEGRITY INVESTIGATION

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ABSTRACT
The innovations that have enabled smaller physical size and increased functionality of today's electronic products have transformed how we integrate them into our everyday routines. These achievements have resulted in higher component densities on printed circuit assemblies, which have the obvious effect of requiring product design teams to implement high I/O connector component styles. A non-obvious effect is how these high density connectors impact assembly producibility and solder joint integrity. An investigation was conducted to characterize the solder joint integrity of high I/O BGA connector technologies under IPC Class 3 thermal cycle conditioning. Thermal cycle testing was conducted per IPC-9701 using a -55°C to +125°C temperature range. The testing identified a number of high I/O BGA connector configurations that exhibited robust solder joint integrity.

Key words: BGA connector, solder joint integrity, thermal cycling

INTRODUCTION
As electronic products have become progressively smaller and have increased in component density, there has been a greater demand for high I/O connectors by product design teams. Traditional surface mount and plated through hole connectors are beginning to approach their limits on the number of signals that can be effectively used for small form factor, high I/O product applications. The commercial electronics industry is increasingly using BGA style connectors as a solution to this design constraint and industry publications [1, 2] report good solder joint integrity for commercial use applications. However, no data have been published on the reliability of BGA connector solder joints when subjected to the rigors of avionics and defense equipment product use environments (i.e. IPC Class 3). Historically, BGA and high I/O type connectors have had poor solder joint reliability in these applications. However, over the past ~5 years, the connector industry has responded with creative connector design solutions to improve this reliability issue. This investigation was conducted to assess the solder joint integrity of BGA style connectors and high I/O "hockey stick lead" style connectors.

OBJECTIVE
The objective of the investigation was to examine the producibility and reliability of six different styles of high density board-to-board connectors - three BGA connectors and three Hockey Stick Lead connectors.

PROCEDURES
Design of Experiment Variables
The variables for this Design of Experiment (DOE) were:

- 2 Solder Alloys: Tin Lead (SnPb) and Lead Free (Pb Free)
- 2 Adhesive Conditions: With and Without Zymet Edgebond UA-2605 material
- 2 Stencil Thickness:
  - BGA Style Connectors: 0.004"and 0.006"
  - Hockey Stick Connectors: 0.004" and 0.005"

Test Components
Two types of high density connectors were tested in this study: (1) Ball Grid Array Connectors and (2) Hockey Stick Lead Connectors. The tin/lead (SnPb) and lead-free (Pb Free) compatible connectors used in this testing are shown in Table 1 and Table 2, respectively.

Table 1: Tin/Lead Connector Test Components

Vendor	Name	Vendor Part Number
Amphenol	NexLev	470-3075-101
		471-3025-101
TE Connectivity	Mezalok	2102061-1
		2102060-1
Samtec	SEARAY	SEAM-30-07.0-L-08-1-A-K-TR
		SEAF-30-06.0-L-08-1-A-K-TR
	Ultrafine pitch hockey stick	SS4-30-3.00-L-D-K-TR
		ST4-30-1.00-L-D-P-TR
	ROLC / MOLC	ROLC-145-02-S-Q-P-TR
		MOLC-145-02-S-Q-TR
	SOLC / TOLC	SOLC-130-02-S-Q-A-K-TR
		TOLC-130-12-S-Q-A-K-TR

Table 2: Lead Free Connector Test Components

Vendor	Name	Vendor Part Number
Amphenol	NexLev	470-3075-601
		471-3025-601
Tyco Electronics	Mezalok	2102061-2
		2102060-2
Samtec	SEARAY	SEAM-30-07.0-L-08-2-A-K-TR
		SEAF-30-06.0-L-08-2-A-K-TR
	Ultrafine pitch hockey stick	SS4-30-3.00-L-D-K-TR
		ST4-30-1.00-L-D-P-TR
	SOLC / TOLC	SOLC-130-02-S-Q-A-K-TR
		TOLC-130-12-S-Q-A-K-TR

Amphenol "NexLev" Connector:
The Amphenol "NexLev" connector utilizes a 'solderball on a spring' for its solder joint interconnect (Figure 1). The rationale for the design is that the compliant lead will act like a spring and reduce solder joint stress.

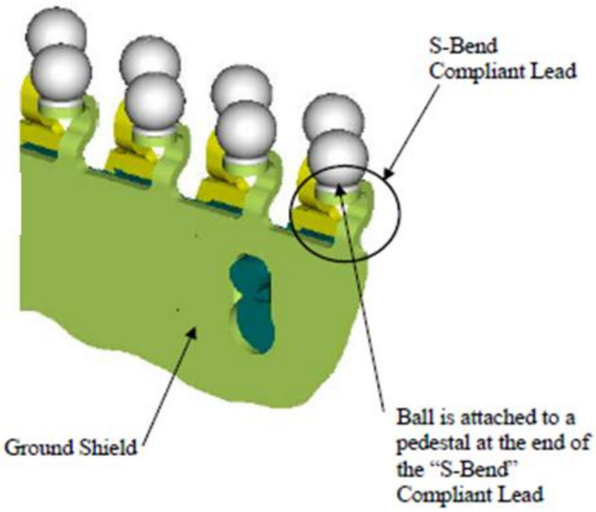

Figure 1: Amphenol "NexLev" Connector [3]

TE Connectivity (Tyco) Mezalok Stacking Connector:
The Mezalok Stacking Connectors are designed to meet or exceed the requirements of XMC2.0 per the VITA 61 standard. The VITA 61 standard defines performance requirements for a rugged, high-speed stacking connector system. These requirements include mating durability of 500 cycles minimum and signal transmission speeds of 5+GHz. The connectors are available in a plug assembly and receptacle assembly that provide a connection between two parallel printed circuit boards. The connectors are available in 60, 114, and 320 positions. The plug has a nominal height of 4 mm and the receptacles are available with nominal heights of 6, 8, 11 and 14 mm (Figure 2).

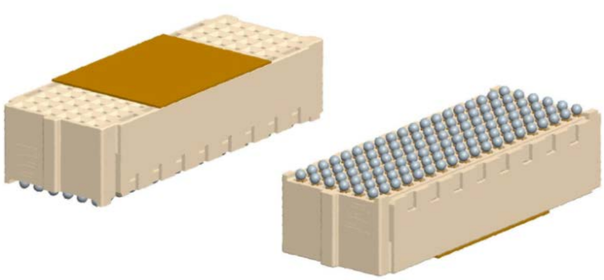

Figure 2: Tyco Mezalok Stacking Connector [4]

Samtec SEARAY Connector:
The Samtec SEARAY connector is a departure from the traditional connector configuration due to the inclusion of a solder preform on a blade lead geometry (Figure 3). The purpose of the solder preform is to increase the overall solder joint volume and final solder joint geometry. This high density connector allows for maximum routing and grounding flexibility and allows for speeds up to 18 GHz/pair.

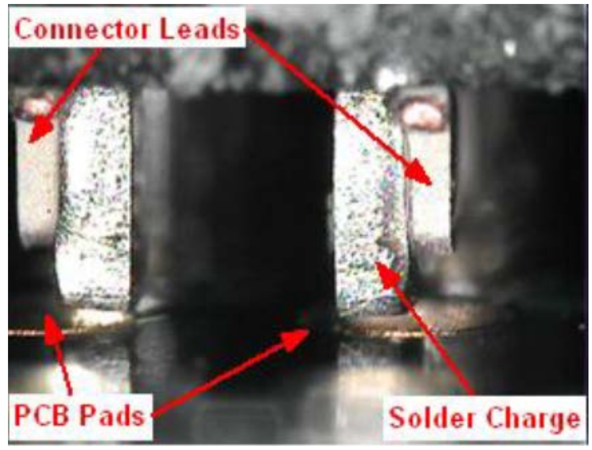

Figure 3: SAMTEC SEARAY Connector [5]

Samtec ST4/SS4 Ultrafine Pitch Hockey Stick Connector:
The Samtec ST4 / SS4 series connectors are designed for speeds up to 7.0 GHz / 14 Gbps. The stack heights range from 4.00 mm – 6.00 mm. The connector is illustrated in Figure 4.

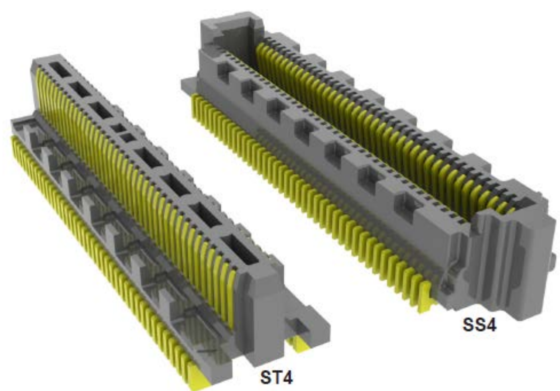

Figure 4: SAMTEC ST4 / SS4 Ultra-Fine Pitch Hockey Stick Lead Connector [6]

Samtec TOLC / SOLC Connector:
This is a quad row surface mount connector with hockey stick type leads. The connector is illustrated in Figure 5.

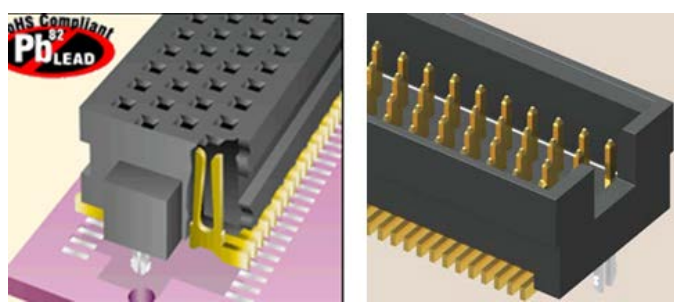

Figure 5: Samtec SOLC (left), Samtec TOLC (right) [7]

Samtec MOLC / ROLC Connector:
The Samtec MOLC connector is a more traditional configuration with leads in the shape of flat gull wing. The ROLC mating connector has leads resembling the shape of a hockey stick. Figure 6 illustrates the connector.

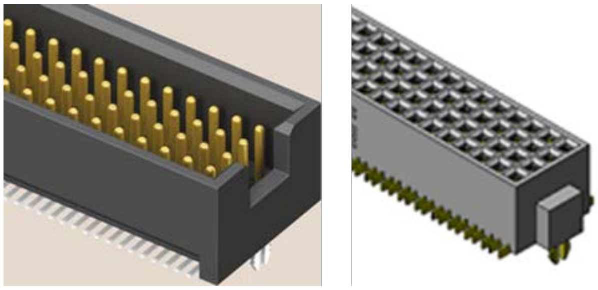

Figure 6: Samtec MOLC (left), Samtec ROLC (right) [7]

Test Vehicle
The test vehicle was 0.079 ± 0.008 inches thick with 12 layers. The vehicle was constructed using FR-4 material in accordance with IPC-4101/126 with electroless nickel/immersion gold (ENIG) surface finish. The test vehicle had the mating half of each test connector routed in a break-off coupon to facilitate removal and connector assembly. The pad sizes and stencil apertures used in the DOE, which can significantly impact producibility and reliability, are shown in Table 3. Figure 7 illustrates the assembled test vehicle.

Table 3: Test Vehicle Pad Size, Soldermask (SM) Opening, and Stencil Design

Name	Vendor Part Number	Pad Size	SM Opening	Stencil Aperture	SM Web	Stencil Thickness
NexLev	470-3075-101	25	31	25	15	4 & 6
	471-3025-101					
Mezalok	2102061-1					
	2102060-1					
SEARAY	SEAM-30-07.0-L-08-1-A-K-TR	25	41	35	9	4 & 6
	SEAF-30-06.0-L-08-1-A-K-TR					
Ultrafine pitch hockey stick	SS4-30-3.00-L-D-K-TR	9x37	12x40	9x37	4	4 & 5
	ST4-30-1.00-L-D-P-TR					
ROLC / MOLC	ROLC-145-02-S-Q-P-TR	11x92	15x96	11x92	7	4 & 5
		11x118	15x146	11x118		
	MOLC-145-02-S-Q-TR	16x118	20x122	16x118	5	4 & 5
		16x118	20x172	16x118		
SOLC / TOLC	SOLC-130-02-S-Q-A-K-TR	16x192	20x96	16x192	5	4 & 5
		16x148	20x152	16x148		
	TOLC-130-12-S-Q-A-K-TR	16x118	20x122	16x118	5	4 & 5
		16x118	20x172	16x118		

Note: All dimension in English units (mils)

Figure 7: As-Assembled Test Vehicle

Test Vehicle Assembly
The soldered test vehicles were assembled at a Rockwell Collins production facility. An MPM UltraPrint 2000 automated stencil printer was used to apply the solder paste. The two stencil thicknesses used for the BGA connectors were 0.004 inch and 0.006 inch. The Hockey Stick connectors also were assembled with two different stencil thicknesses: 0.004 inch and 0.005 inch. The tin/lead, i.e. SnPb solder paste, was Indium solder alloy SMQ92J solder paste while the lead free, i.e. Pb Free solder paste, was Indium 8.9 SAC305 lead-free solder alloy. The components were placed on the test vehicles using a Universal Advantis machine for large component placement.

The test vehicles were reflowed with a Heller 1912EXL Convection Reflow Oven. This oven has 14 temperature zones. The oven used the high convection setting and the test vehicles were placed on the rails. The conveyor speed for the SnPb reflow was 37 inches per minute while the conveyer speed for the Pb Free reflow was 28 inches per minute. The reflow oven settings for both reflow processes are shown in Table 4.

Table 4 Heller 1912EXL Reflow Oven Profiles (°C)

Zone	1	2	3	4	5	6	7
SnPb	175	125	126	145	150	170	175
Pb Free	175	140	150	175	180	195	200
Zone	8	9	10	11	12	13	14
SnPb	182	190	238	246	200	123	115
Pb Free	215	220	264	287	207	126	120

The test vehicles were allowed to cool after reflow and then placed in the Electrovert Aquastorm 200 in-line cleaning system for removal of solder flux residues and other contaminants from the assembly. The in-line cleaner used Kyzen Aquanox 4625 saponifier in deionized water. After cleaning, the mating halves of the connectors were routed out of the test vehicle panel.

Edgebond
After the test vehicles were assembled, half of the connectors were processed with Zymet UA-2605-B edgebond material. The edgebond variable was included in the DOE to determine whether applying an adhesive to the

connectors would extend the thermal fatigue life of the solder joints. Traditional underfill materials could not be used with these connectors due to potential wicking of material into the connector contacts. The edgebond material was applied with a 0.023 inch needle for the hockey stick connectors and a 0.047 inch needle for all other connectors. After application, the edgebond material was cured for 30 minutes in a 130°C oven. Figure 8 illustrates the adhesive coverage, which extended 20% - 30% from any corner of part and left an opening of 40% - 60% along the side of the part.

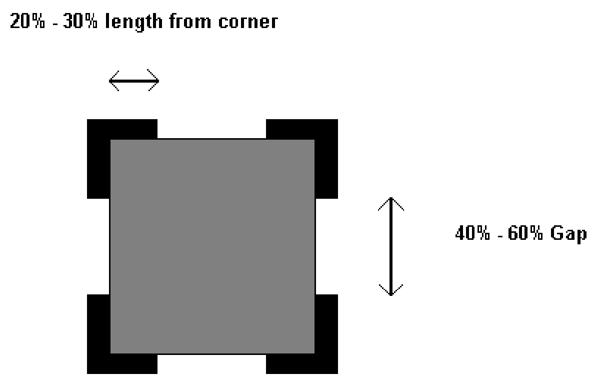

Figure 8: Edgebond Material Perimeter Coverage

Figure 9 illustrates an example of the UA2605-B material after edgebond material processing.

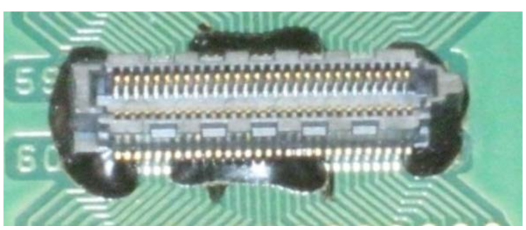

Figure 9: Example of Edgebond Applied to a Connector

Thermal Cycle Testing

Test vehicles were arranged into a custom test fixture inside the thermal chamber and the cables were fed through a port in the chamber wall to the GDS-1024T Glitch Detector System (Figure 10). The GDS-1024T is a Rockwell Collins custom-designed and built fault detection system.

Figure 10: Thermal Cycling Test Vehicles with Cables and Thermocouples Attached

Thermocouples were attached to the test vehicles to monitor the temperatures of each vehicle within the thermal chamber. As the chamber cycled for one and a half cycles, the data from the thermocouples were collected and plotted to establish a thermal profile. By adjusting ramp rates, temperatures, hold times and the airflow, the thermal profile was modified until the individual test vehicle temperatures were closely grouped and consistent.

The parameters of the thermal profile are as follows:

- +125°C High temperature
- -55°C Low temperature
- 10°C/minute transition ramp rate
- All vehicles ±5°C of each other at temperature extremes for at least 10 minutes

One thermal cycle lasted approximately 134 minutes. All test assemblies were subjected to 2007 thermal cycles.

Solder Joint Failure Detection Methodology

The practical definition of a solder joint failure is an electrical interruption lasting greater than 1μsec and having continuity greater than 300Ω. Electrical failure during the thermal cycling test as monitored by the GDS is defined below:

1. Electrical interruption lasting greater than 0.2 μsec
2. Interface resistance greater than 300 Ω
3. 12 volt compliance limited to 1.3 mA
4. Failure pattern recognition (can be two events but always occurring while transitioning hot)
5. Record electrical events every 30 seconds
6. Record room temperature resistance and monitor trends approximately every 250 cycles
7. Record visual observations

TEST RESULTS

Statistical Analysis Approach

The solder joint thermal cycle integrity was statistically analyzed using regression analysis to determine the Weibull shape factor (β) and characteristic lives (θ) for the failure data. The Weibull function relates the cumulative failure distribution, F(n), to the number of thermal cycles at which a failure occurred, n, as $F(n) = 1\text{-}exp(-m/\theta)^{\beta}$. The characteristic life in a Weibull distribution, θ, corresponds to the number of cycles at which 63.2% of the population is expected to have failed. This parameter is often referred to as "N63" and may be thought of as an indication of the approximate average life of the population. The shape factor (β) is often referred to as the Weibull slope and is a measure of how tightly grouped the failures are. The lower the shape factor, the wider the range of failure data (i.e. a wider range of thermal cycles where failures are seen). The higher the shape factor, the more uniform the reliability across the population is; if all components fail at exactly the same point the shape factor would be infinity. A shape factor of less than 1.0 is generally considered to be indicative of infant mortality. Electronic components in thermal cycling that are undergoing 'post infant mortality' failures have typically exhibited shape factors in the range of 4-8, depending on the particular packaging style. The following sections report the failure statistics for each connector style and show metallurgical cross-sections obtained as part of the physical failure analysis.

Amphenol "NexLev" Connector:

The Amphenol "NexLev" connector demonstrated good performance in the thermal cycle testing for both the SnPb and Pb Free solder processes (see Figure 11 and Table 5). The connectors without edgebond were actually more reliable than those with edgebond. The Pb Free connectors without edgebond had no failures recorded while the SnPb connectors had only 2 failures, for an overall failure rate after 2000 cycles of less than 5%. The Pb Free connectors with edgebond had only one early failure that appears to be an outlier while the SnPb connectors with edgebond did exhibit a number of failures starting at 512 cycles with an N63 of more than 3000 thermal cycles.

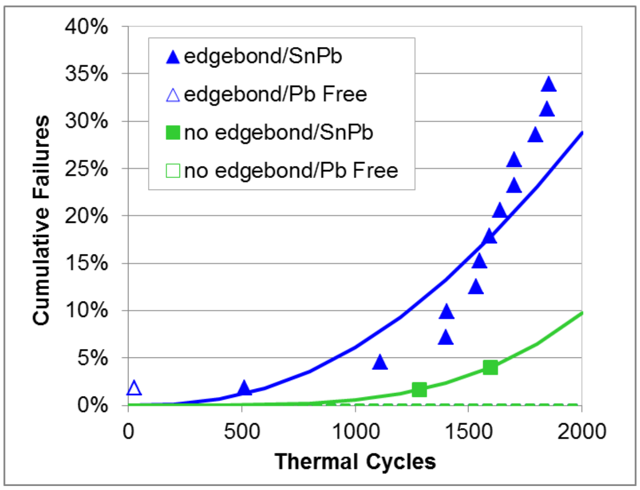

Figure 11: Amphenol "NexLev" Connector Failure Plots

Table 5: Failure Statistics for Amphenol "NexLev" Connector

Solder	SnPb	Pb Free	SnPb	Pb Free
Edgebond	Yes	Yes	No	No
# of samples	37	38	42	38
# of failures	13	1	2	0
failure rate	35%	3%	5%	0%
1st failure	512	26	1282	n/a
N63	3112	n/a	3486	n/a
beta	2.44	n/a	4.09	n/a

Previous testing [8] had documented conflicting statistical analysis and physical failure results for the Amphenol "NexLev" connector. Root cause analysis demonstrated that this was likely due to the connector contact interface "chattering" during thermal cycle testing, which causes the computer monitoring system to register a "false open" for solder joint cracking/failure. Figure 12 illustrates a cross-sectional view of the connector and the interface locations in which chatter led to problems in earlier testing. This failure root cause was avoiding during this investigation by instituting a seating/reseating of the connector interfaces on a specific interval schedule. Figure 13 shows cross-sectional views of the connector solder joints from the current testing that demonstrated acceptable solder joint integrity. Solder joint microstructure coarsening and some solder joint cracks due to the impact of the thermal cycling were observed, especially in the SnPb joints.

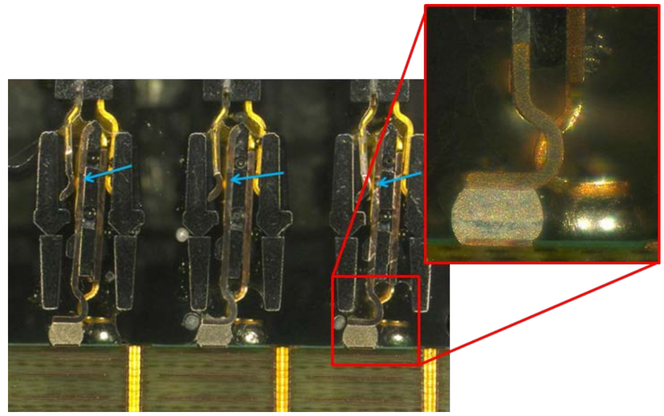

Figure 12: NexLev Connector Contact Interface (Arrows Indicates Interface "Chatter" Location) [8]

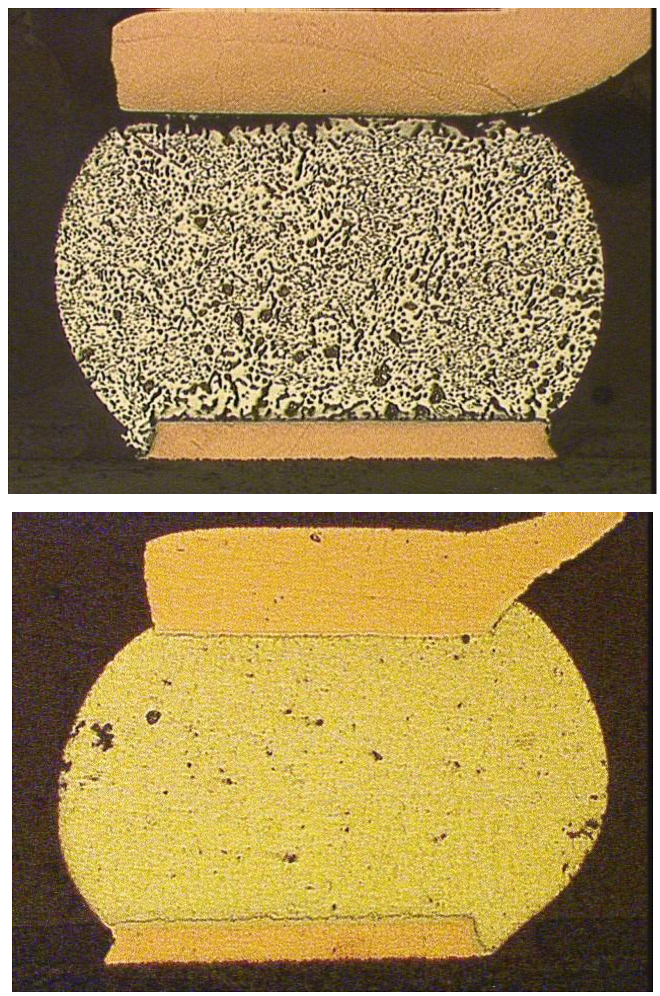

Figure 13: NexLev Connector, Typical Solder Joints, SnPb (top), Pb Free (bottom)

Tyco Mezalok Stacking Connector

The Mezalok Stacking connector had a nearly perfect thermal cycle testing performance. As shown in Table 6, only 3 failures were observed in a population of 160 connectors, and none of these failures occurred prior to 1500 thermal cycles. No valid Weibull graphs or values are reported due to the lack of sufficient failures to determine fits to the Weibull curve.

Table 6: Failure Statistics for Mezalok Stacking Connector

Solder	*SnPb*	*Pb Free*	*SnPb*	*Pb Free*
Edgebond	*Yes*	*Yes*	*No*	*No*
# of samples	38	40	42	40
# of failures	1	0	1	1
failure rate	3%	0%	2%	3%
1st failure	1593	n/a	1789	1714

An independent confirmation of the performance of the Mezalok connectors was completed during the investigation. Tyco representatives, following Rockwell Collins recommendations of solder joint integrity testing per the IPC-9701 specification, completed 2000 thermal cycles from -55°C to +125°C with no failures [9]. Tyco's testing also confirmed that the Rockwell Collins "chattering" test issue was a result of the connector contact interface motion and not a solder joint integrity issue. Figure 14 illustrates how Tyco was able to eliminate suspected solder joint integrity issues after 2000 thermal cycles by cleaning the contact interfaces.

Figure 15 through Figure 17 illustrate the cross-sectional views of the Mezalok Stacking connectors after 2007 thermal cycles. Some regions of solder joint microstructure coarsening is apparent after completing the thermal cycle testing in the SnPb solder joint.

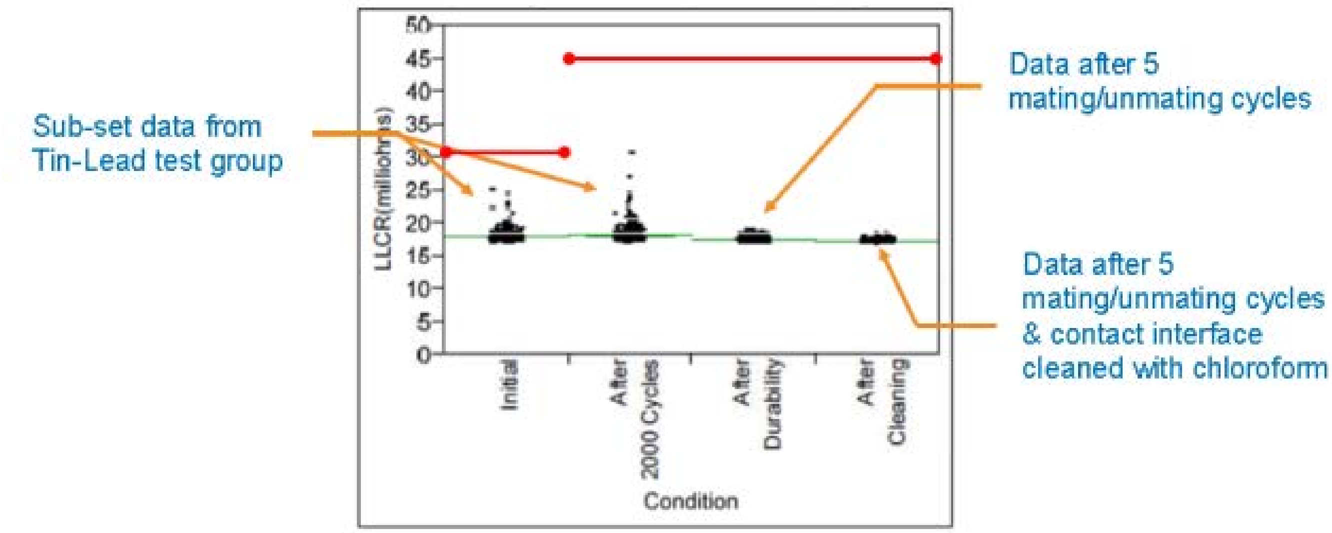

Figure 14: Mezalok BGA Connector Data Demonstrating Impact of Connector Interface on Solder Joint Integrity Measurements [9]

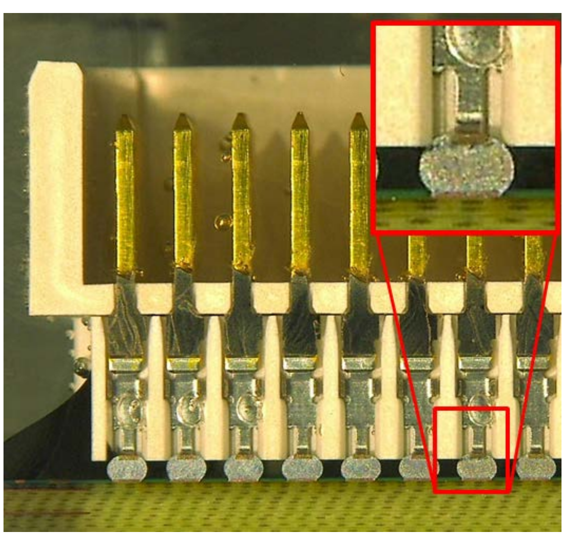

Figure 15: Mezalok Stacking Connector

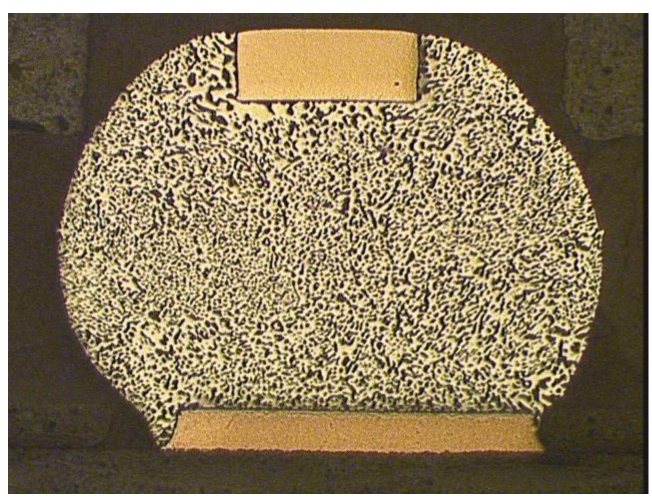

Figure 16: Mezalok Stacking Connector, Typical Solder Joints, SnPb Alloy

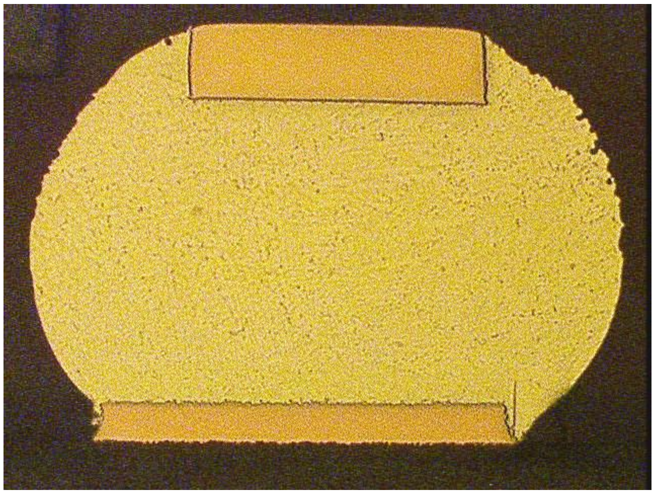

Figure 17: Mezalok Stacking Connector, Typical Solder Joints, Pbfree Alloy

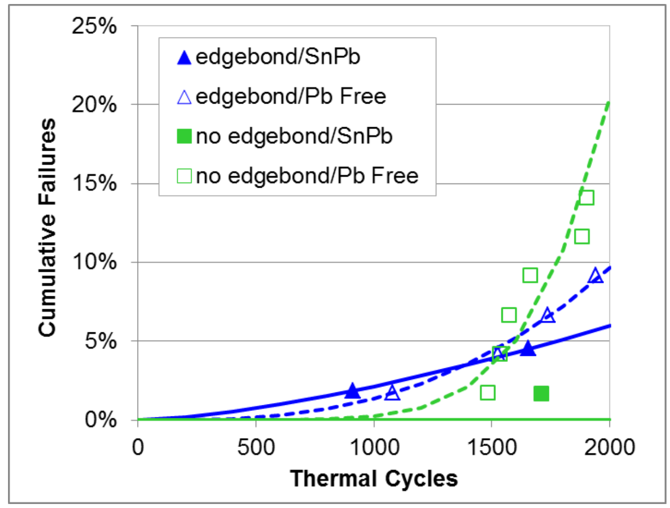

Figure 18: SEARAY Connector Failure Plots

SAMTEC SEARAY Connector:

The SAMTEC SEARAY connector exhibited excellent SnPb and Pb Free thermal cycle performance (Table 7 and Figure 18). Only 3 failures out of a population of 79 connectors were observed for the SnPb configurations while the Pb Free configurations had 10 failures out of a population of 80 components with only two failures before 1500 thermal cycles. Edgebonding of the connectors did improve the average life of the connectors, however this improvement does not appear to be significant and the edgebonded connectors did suffer earlier first failures than the connectors with no edgebond. Therefore, the use of edgebond on these connectors does not appear to be an effective method for ruggedization. As with the "NexLev" connector, previous testing [8] had documented conflicting statistical analysis and physical failure results for the SEARAY connector due to the connector contact interface "chatter" phenomenon. Again, the procedure of seating/reseating of the connector interfaces eliminated the issue during this testing sequence. Figure 19 - Figure 21 illustrate the solder joint cross-section observations. Some minor solder joint microstructure coarsening is apparent and there is some cracking around the Pb Free solder joint "eye of the needle" resulting from thermal cycling.

Table 7: Failure Statistics SEARAY Connector

Solder	*SnPb*	*Pb Free*	*SnPb*	*Pb Free*
Edgebond	*Yes*	*Yes*	*No*	*No*
# of samples	37	40	42	40
# of failures	2	4	1	6
failure rate	5%	10%	2%	15%
1st failure	911	1079	1708	1482
N63	n/a	4393	n/a	2493
beta	n/a	2.9	n/a	6.67

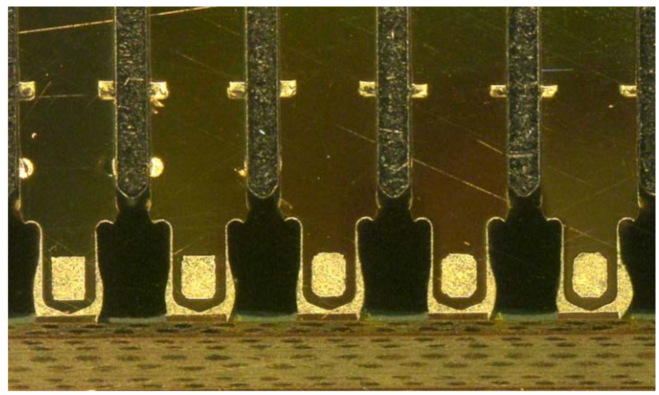

Figure 19: Macro View of SEARAY Connector, Sn/Pb Solder Process

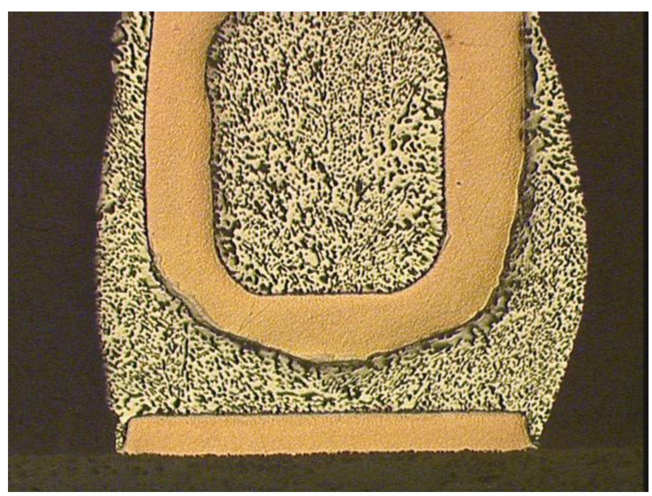

Figure 20: SEARAY, Typical Solder Joints, SnPb Alloy

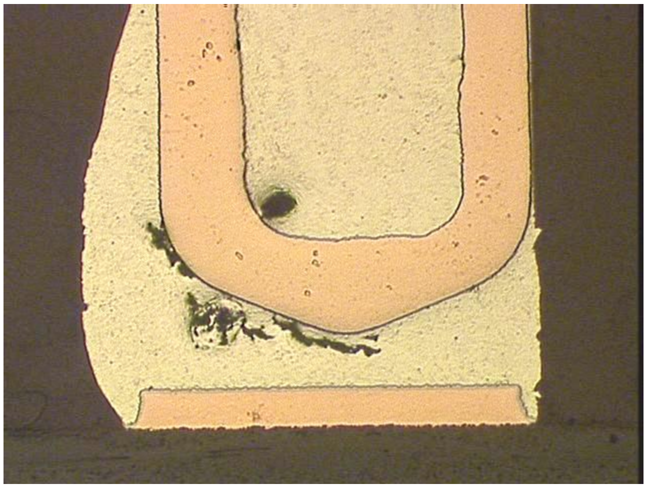

Figure 21: SEARAY, Typical Solder Joints, Pb Free Alloy

SAMTEC ST4 / SS4 Ultrafine Pitch Hockey Stick Lead Connector:
The ST4/SS4 Ultrafine Pitch connectors had acceptable thermal cycle solder joint integrity performance (Figure 22 and Table 8). With only one exception, the SnPb and Pb Free connectors without edgebond did not register any failures until 1500 thermal cycles, which demonstrates good solder joint integrity. An examination of the connector configurations that had edgebonding after testing found that the edgebond material had caused physical interference that prevented many of the connectors from properly mating. The small dimensions and tight tolerances of the Ultrafine Pitch connectors make them poor candidates for utilizing edgebonding as a reliability enhancement. In addition, a large number of the Ultrafine Pitch connectors were eliminated from the testing due to manufacturing defects that resulted from the extremely small dimensions and correspondingly tight tolerances that led to lower yields and reduced manufacturability.

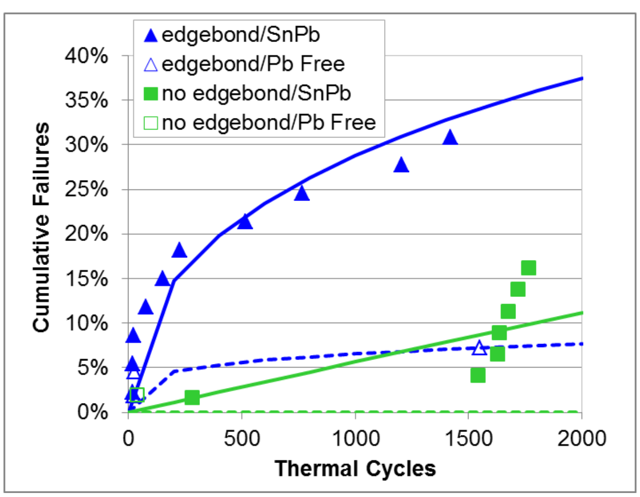

Figure 22: ST4/SS4 Ultrafine Pitch Hockey Stick Connector Failure Plots

Table 8: Failure Statistics ST4/SS4 Ultrafine Pitch Hockey Stick Connector

Solder	*SnPb*	*Pb Free*	*SnPb*	*Pb Free*
Edgebond	***Yes***	***Yes***	***No***	***No***
# of samples	31	37	41	35
# of failures	10	3	7	1
failure rate	32%	8%	17%	3%
1st failure	20	22	280	39
N63	9958	n/a	16.2k	n/a
beta	0.47	n/a	1.02	n/a

Figure 23 and Figure 24 illustrate the SST/SS4 solder joint microstructures observed. Significant microstructure coarsening is present and the connector lead-to-pad alignment is poor, particularly with the SnPb solder. Additionally, the solder joint volumes are minimal as some of the solder volume is distributed up the connector lead rather than being located at the connector lead/pad interface.

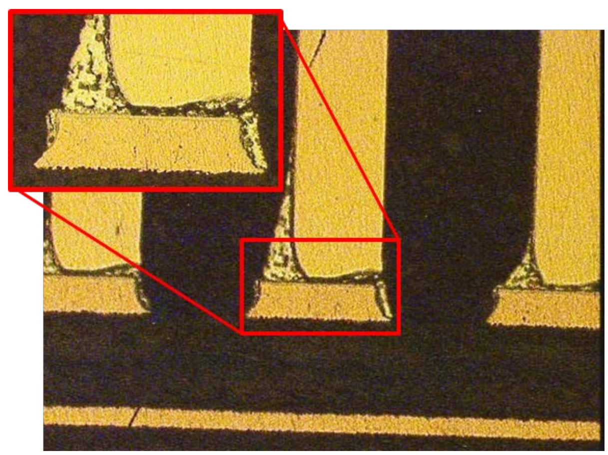

Figure 23: ST4/SS4 Connector, SnPb, Failed @ 227 Cycles

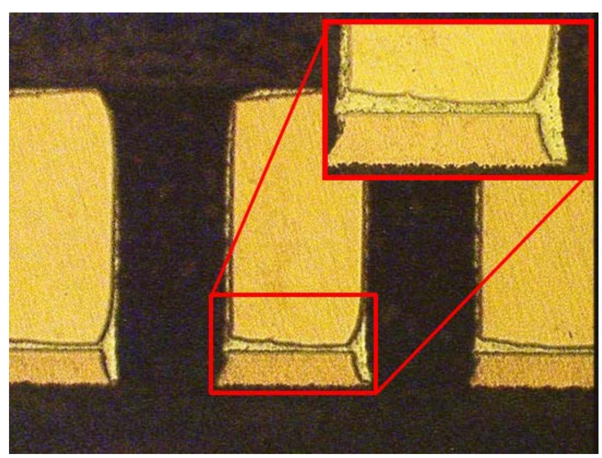

Figure 24: ST4/SS4 Connector, Pb Free, Typical Solder Joint

SAMTEC TOLC / SOLC Connector:

The TOLC/SOLC connectors exhibited good thermal cycle solder joint integrity results (Figure 25 and Table 9). Only the SnPb connectors with no edgebond had sufficient failures to determine Weibull parameters and none of these failures occurred before 1500 thermal cycles. The investigation used a new pad geometry for the TOLC/SOLC connectors relative to earlier Rockwell Collins studies; this change is presumably responsible for the highly reliable performance observed with these results.

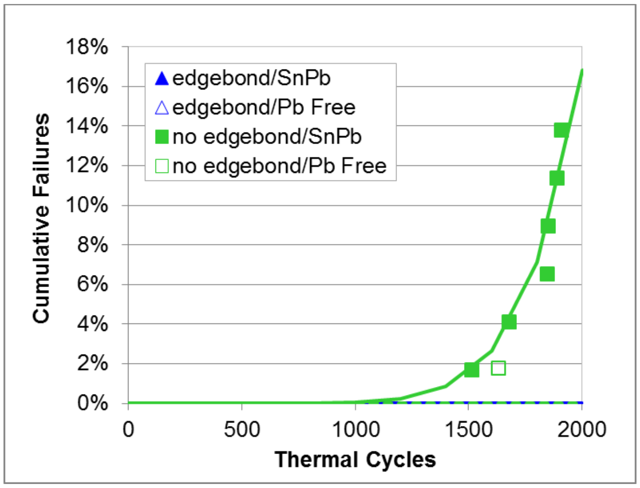

Figure 25: TOLC / SOLC Connector Failure Plots

Table 9: Failure Statistics for TOLC / SOLC Connector

Solder	*SnPb*	*Pb Free*	*SnPb*	*Pb Free*
Edgebond	*Yes*	*Yes*	*No*	*No*
# of samples	34	39	41	39
# of failures	0	0	6	1
failure rate	0%	0%	15%	3%
1st failure	n/a	n/a	1515	1631
N63	n/a	n/a	2425	n/a
beta	n/a	n/a	8.66	n/a

Figure 26 shows solder joint microstructures of a failed component with a crack within the solder joint. Figure 27 shows a Pb free connector solder joint, that was not damaged by the thermal cycling. In both of these cross-section views, it is evident that the solder joint volume is distributed up the connector negatively impacting the solder joint integrity.

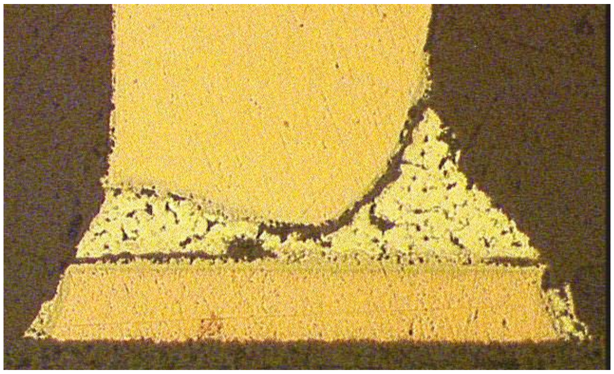

Figure 26: TOLC/SOLC Connector, SnPb, Failed @ 1515 Cycles

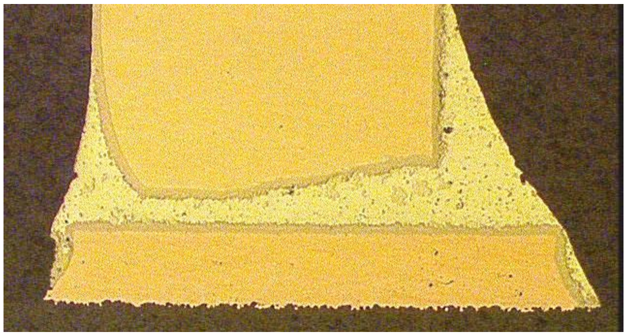

Figure 27: TOLC/SOLC Connector, Pb Free, Typical Solder Joint

SAMTEC MOLC / ROLC Connector

Figure 28 illustrates the failure results for the MOLC / ROLC connector (note that no Pb Free configurations were included in the investigation for this connector). This connector by far showed the poorest solder joint integrity during testing with more than half of the components failing by 500 cycles. The use of edgebond slightly improved the overall reliability of the population, but also appeared to introduce a number of early infant mortality failures that occurred before 100 thermal cycles. The Weibull coefficients, which are shown in Table 10, exhibit low beta values that correspond to inconsistent assembly that leads to infant mortality failure.

This inconsistent build is at least in part due to the extremely poor manufacturing yield of the MOLC / ROLC connector that led to the need to rework multiple solder joints on each connector. This extensive rework confounded the test results since it was not clear whether the subsequent poor reliability during thermal cycling should be attributed to the connectors or to the rework processes. The producibility challenges encountered in assembling the investigation test vehicle build are reflective of the same issues that occur when these connectors are used on production assemblies. Regardless of whether the poor solder joint integrity was due to the connectors or the rework process, these test results indicate that this connector style is not generally suitable for Rockwell Collins avionics applications.

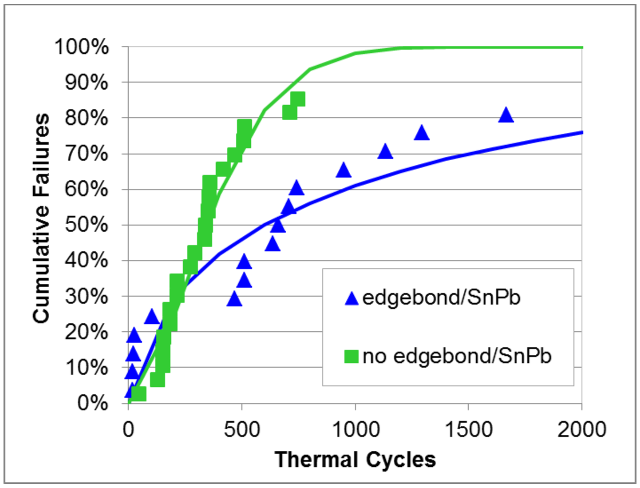

Figure 28: MOLC / ROLC Connector Failure Plots

Table 10: Failure Statistics for MOLC / ROLC Connector (SnPb Solder)

Edgebond	*Yes*	*No*
# of samples	19	25
# of failures	16	22
failure rate	84%	88%
1st failure	20	44
N63	1103	446
beta	0.6	1.64

Figure 29 shows cross sections of a typical failure of a MOLC/ROLC connector. The solder exhibits significant coarsening and cracking despite the comparatively early failure (638 cycles) relative to the life of other connector families evaluated in this study. This indicates the existence of severe local stresses at the solder joints with minimal stress relief provided by the hockey stick lead.

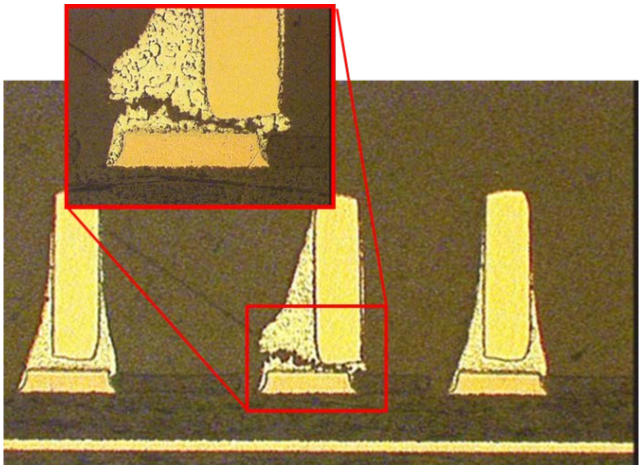

Figure 29: MOLC/ROLC Connector, SnPb, Failed @ 638 Cycles

Impact of Stencil Thickness on Solder Joint Integrity (No Edgebond Material Configuration)

The investigation included two different stencil thicknesses so that the impact of solder volume on the BGA and Hockey Stick connector solder joint integrity could be assessed. Industry literature and internal Rockwell Collins opinions varied greatly on the degree to which solder joint integrity could be improved with the use of a thicker stencil to increase the overall solder volume. Test results from this study showed that the solder stencil thickness had minimal effect on the solder joint integrity for either the BGA or the Hockey Stick style connectors used in the testing. Figure 30/Figure 31 and Table 11 illustrate the investigation results for stencil thickness impact on solder joint integrity.

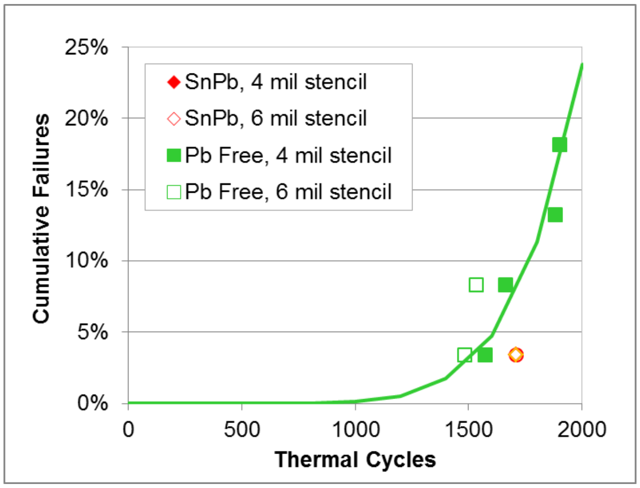

Figure 30: SEARAY Connector - Impact of Stencil Thickness Results

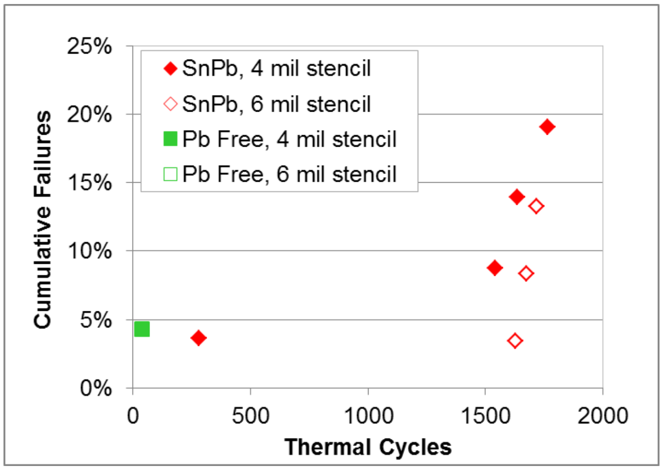

Figure 31: Hockey Stick Style Connectors (all groups) - Impact of Stencil Thickness Results

Table 11: Impact of Stencil Thickness on Hockey Stick Style Connectors Weibull Statistics

Connector	Solder	Stencil	# samples	# failed	% fails	1st fail	N63	beta
Amphenol NexLev	Pb Free	4 mil	20	0	0%	0	n/a	n/a
Amphenol NexLev	Pb Free	6 mil	18	0	0%	0	n/a	n/a
Amphenol NexLev	SnPb	4 mil	20	0	0%	0	n/a	n/a
Amphenol NexLev	SnPb	6 mil	20	0	0%	0	n/a	n/a
Tyco Mezalok	Pb Free	4 mil	20	1	5%	1714	n/a	n/a
Tyco Mezalok	Pb Free	6 mil	20	0	0%	0	n/a	n/a
Tyco Mezalok	SnPb	4 mil	20	0	0%	0	n/a	n/a
Tyco Mezalok	SnPb	6 mil	20	0	0%	0	n/a	n/a
Samtec SEARAY	Pb Free	4 mil	20	4	20%	1573	2368	7.7
Samtec SEARAY	Pb Free	6 mil	20	2	10%	1482	1686	26
Samtec SEARAY	SnPb	4 mil	20	0	0%	0	n/a	n/a
Samtec SEARAY	SnPb	6 mil	20	1	5%	1708	n/a	n/a
Samtec Ultrafine pitch hockey stick	Pb Free	4 mil	16	1	6%	39	n/a	n/a
Samtec Ultrafine pitch hockey stick	Pb Free	5 mil	19	0	0%	0	n/a	n/a
Samtec Ultrafine pitch hockey stick	SnPb	4 mil	19	4	21%	280	19316	0.79
Samtec Ultrafine pitch hockey stick	SnPb	5 mil	20	3	15%	1628	1849	25.9
Samtec MOLC / ROLC	SnPb	4 mil	13	11	85%	44	434	1.42
Samtec MOLC / ROLC	SnPb	5 mil	11	10	91%	130	472	1.7
Samtec TOLC / SOLC	Pb Free	4 mil	20	1	5%	1631	n/a	n/a
Samtec TOLC / SOLC	Pb Free	5 mil	19	0	0%	0	n/a	n/a
Samtec TOLC / SOLC	SnPb	4 mil	19	5	26%	1515	2361	7.61
Samtec TOLC / SOLC	SnPb	5 mil	19	1	5%	1679	n/a	n/a

DISCUSSION/CONCLUSISONS

The overall investigation results were very positive with all three of the BGA style connectors, the SAMTEC TOLC/SOLC connectors and the SAMTEC ST4/SS4 connectors demonstrating acceptable thermal cycle solder joint integrity. It is anticipated that these five connectors will meet product design team demands for small form factor, high I/O product applications.

The test results revealed that using edgebond material did not improve solder joint integrity under thermal cycle conditions. Edgebonding may provide a reliability enhancement for vibration, drop shock or handling situations, but product design teams will need to further investigate those design attributes.

The solder joint integrity of the ROLC/MOLC connectors did not meet the IPC Class 3 criteria in this testing. Additional investigation will be required to understand what applications, and in which product use environments, these connectors can be successfully used.

It should be noted that this investigation was focused on solder joint integrity. Connector performance requirements can be very specific to particular product designs and product use environments, therefore programs considering the use of these connectors must still conduct 'due diligence' assessments to verify the suitability of a particular connector for a specific design.

RECOMMENDATIONS

The following recommends are made based on the investigation test results:

- The Amphenol "NexLev", the Samtec SEARAY, and the Tyco Mezalok BGA connectors and the two hockey stick type connectors, SOLC/TOLC or ST4/SS, would be acceptable for IPC Class 3 product applications. They are highly reliable and very manufacturing friendly.
- The ROLC-MOLC connector series requires additional investigation. This connector series was not producible and performed poorly in this investigation.
- Edgebonding may be used to protect against shock, vibration, and/or handling, however it has not been shown to protect against stresses from thermal cycling. Care must be taken to apply the edgebond material such that it does not interfere with proper mating of connectors. Edgebond is not recommended for use with the ultrafine pitch hockey stick (ST4/SS4) connectors since it can wick into the leads during application such that once it cures, the material can introduce failures by preventing proper connector mating.
- The objective of this investigation was to investigate the connector solder joints only. Individual programs will need to assess the following connector features for their specific application and environment:
  - The connector contact design and reliability.
  - Whether or not to use mounting hardware. Mounting hardware was not used in this experiment and is not considered a requirement for solder joint reliability.
  - Whether to use edgebond for vibration, shock, or handling. Edgebond is not required for solder joint reliability.

ACKNOWLEDGEMENTS

The authors would like to thank Ken Blazek/Ryan Walker/Tyler Schlueter for cross-sectioning assistance and Lauren Waste for edgebonding assistance.

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