Reliability Testing and Data Analysis of an 1657CCGA (Ceramic Column Grid Array) Package with Lead-Free Solder Paste on Lead-Free PCBs (Printed Circuit Boards)

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Study Objectives

- **To perform temperature cycling test and statistical analysis of an 1657CCGA package on PCBs with HASL(Hot-Air Solder Leveling)-SnCu, NiAu (Electroless Ni and Immersion Au), and OSP (Organic Solderability Preservative) finishes.**

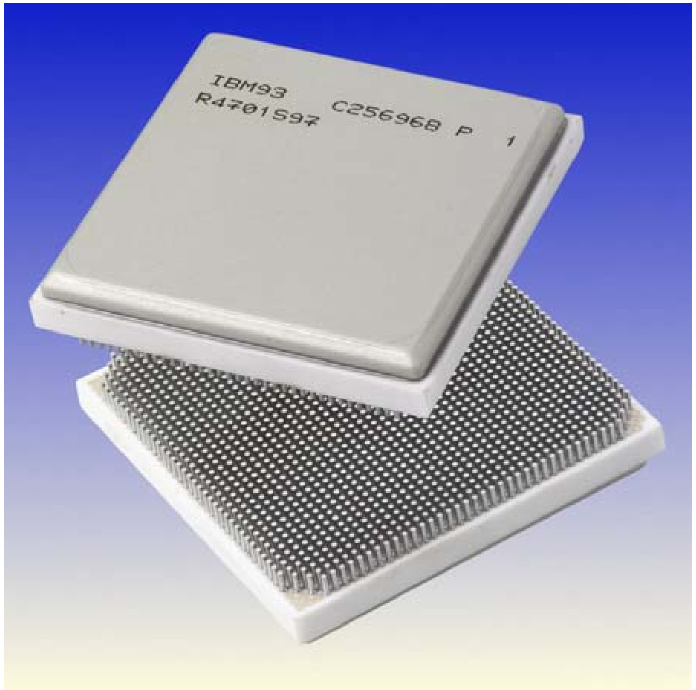
- ***<u>For a given confidence level</u>*, determine the population mean, true characteristic life, and true Weibull slope of the 1657CCGA solder joints.**

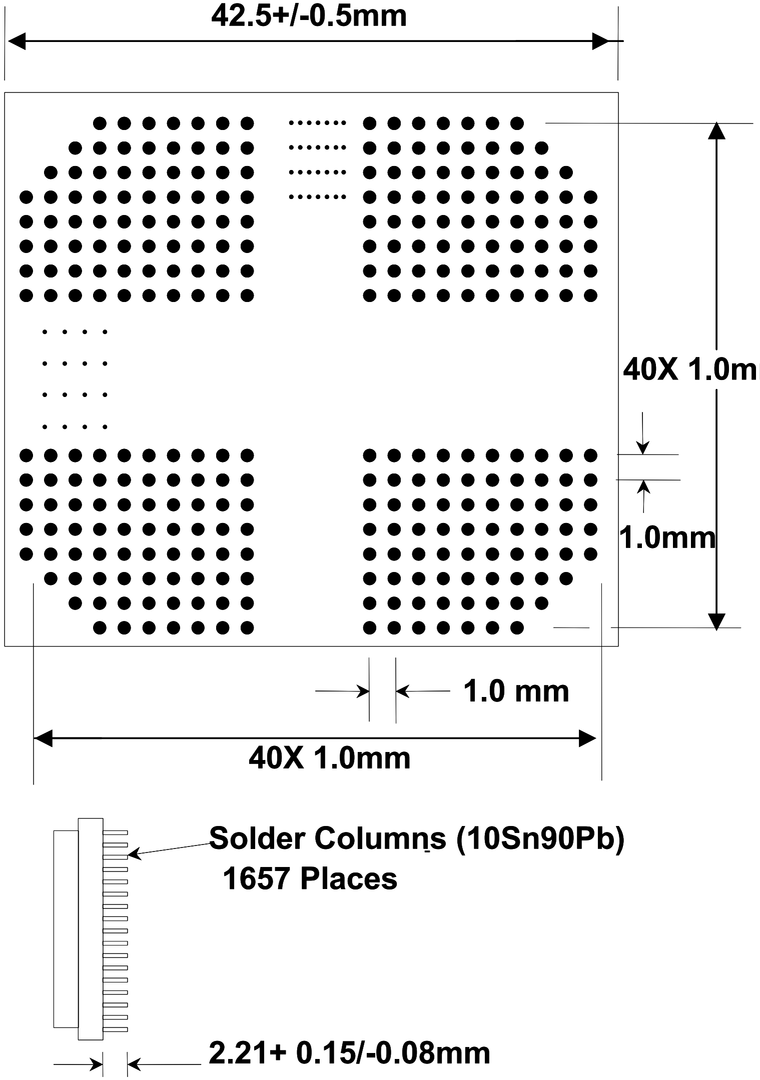
- ***<u>To determine the confidence</u>* for comparing the quality (mean life) of the 1657CCGA solder joints on PCBs with different surface finishes.**

Contents

- Introduction
- 1657CCGA Components
- Test Board
- Test Chamber and Temperature Cycling
- Data Acquisition System and Failure Criterion
- Reliability of 1657CCGA Solder Joints
  (A) Simple Statistics
  (B) Statistical Analysis of 1657CCGA Solder Joints
  (C) Failure Modes
- Summary and Recommendation

IBM's High-Density High-Performance 1657CCGA Package





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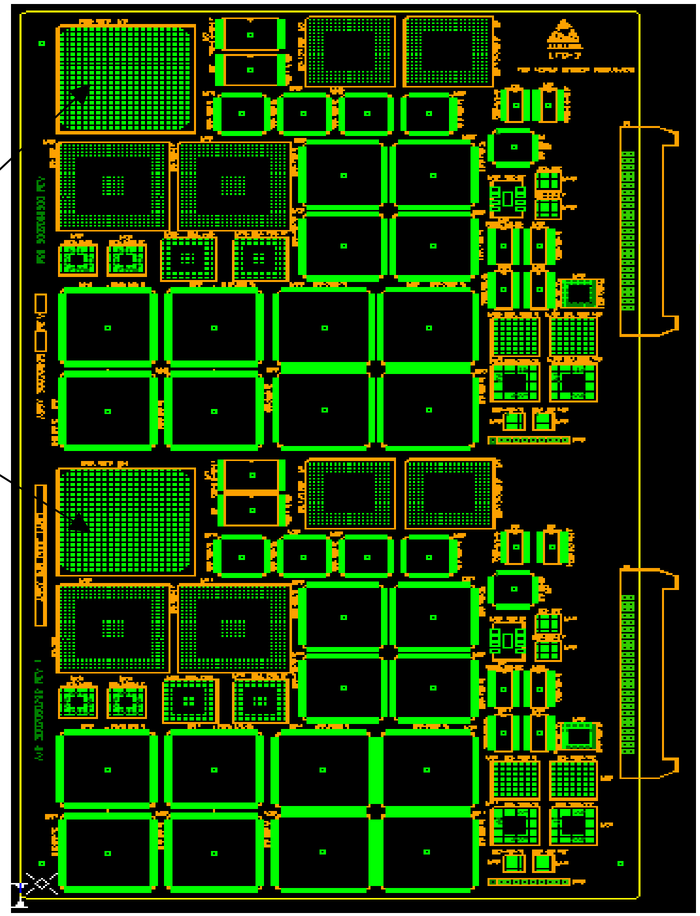
Test Board with 1657-Pin Ceramic Column Grid Array (CCGA) Packages

CCGA



Solder Pastes:

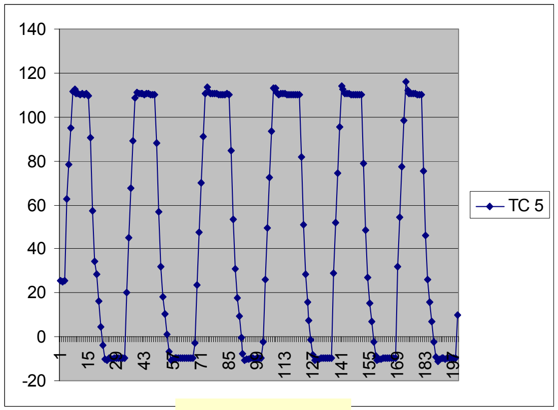
Sn37Pb

Sn3.9Ag0.6Cu

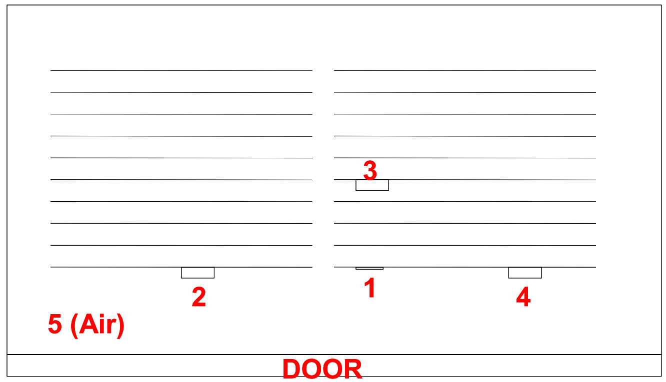
PCB and 1657CCGA Sample Size

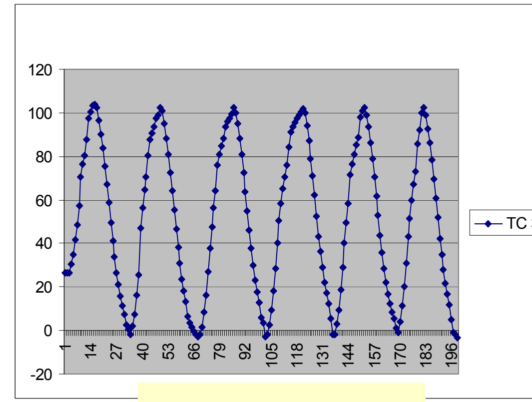
Number of Boards	Board Finishes	Solder Paste	Number of Components
5	OSP	SnPb	2
5	OSP	SnAgCu	2
5	ENIG	SnAgCu	2
5	SnCu HASL	SnAgCu	2

Test Boards in Thermal Cycling Chamber (top-view) and Thermal Couples' Locations

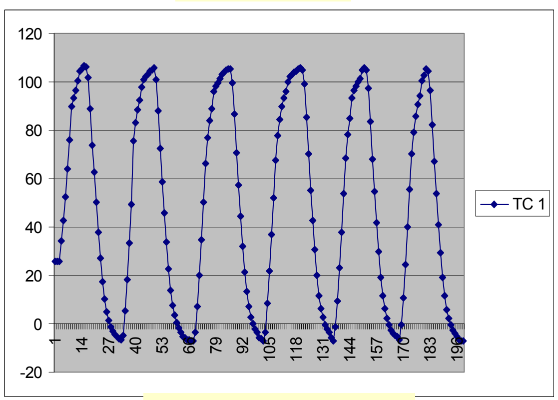


In Air

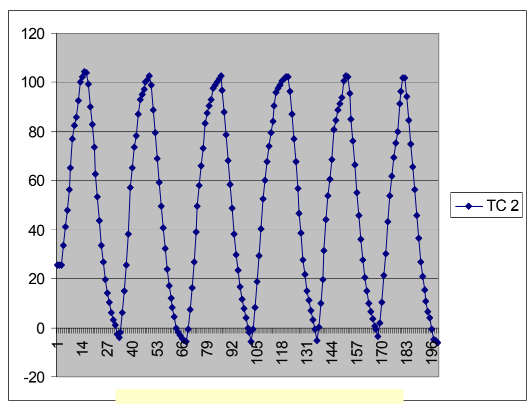




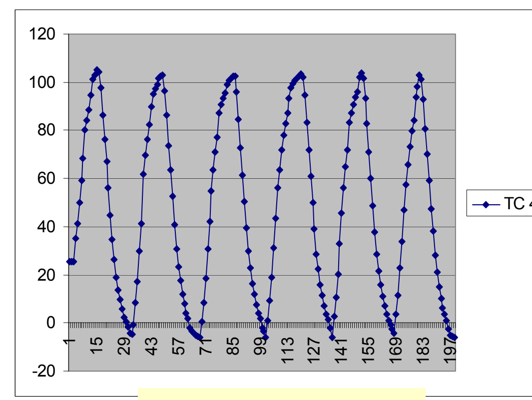
Location 3



On Board



Location 2



Location 4

1657CCGA Test Results (0 to 100^{o}C, 40 min.)

Solder Paste	SnCu HASL PCB	ENIG (NiAu) PCB	OSP (Entek) PCB
	1771	2423	2128
	1945	2521	2480
	2111	2568	2620
	2276	2682	2722
SnAgCu	2394	3009	2826
	2581	3513	2899
	2611		2972
	2652		3045
	2688		3118
	3009		3200
			2303
			3451
			3537
			3555
SnPb	NA	NA	3684
			3694
			3851
			4404
			4507
			4595

Reliability

The reliability of solder joints of a particular package on a PCB is defined as the *probability* that the solder joints will perform their intended function for a specified period of time, under a given operating condition, without failure.

Numerically, reliability is the percent of survivors,

$$R(t)=1-F(t)$$

$R(t)$ is the reliability (survival) function $F(t)$ is the cumulative distribution function (CDF), representing the percentage of failures.

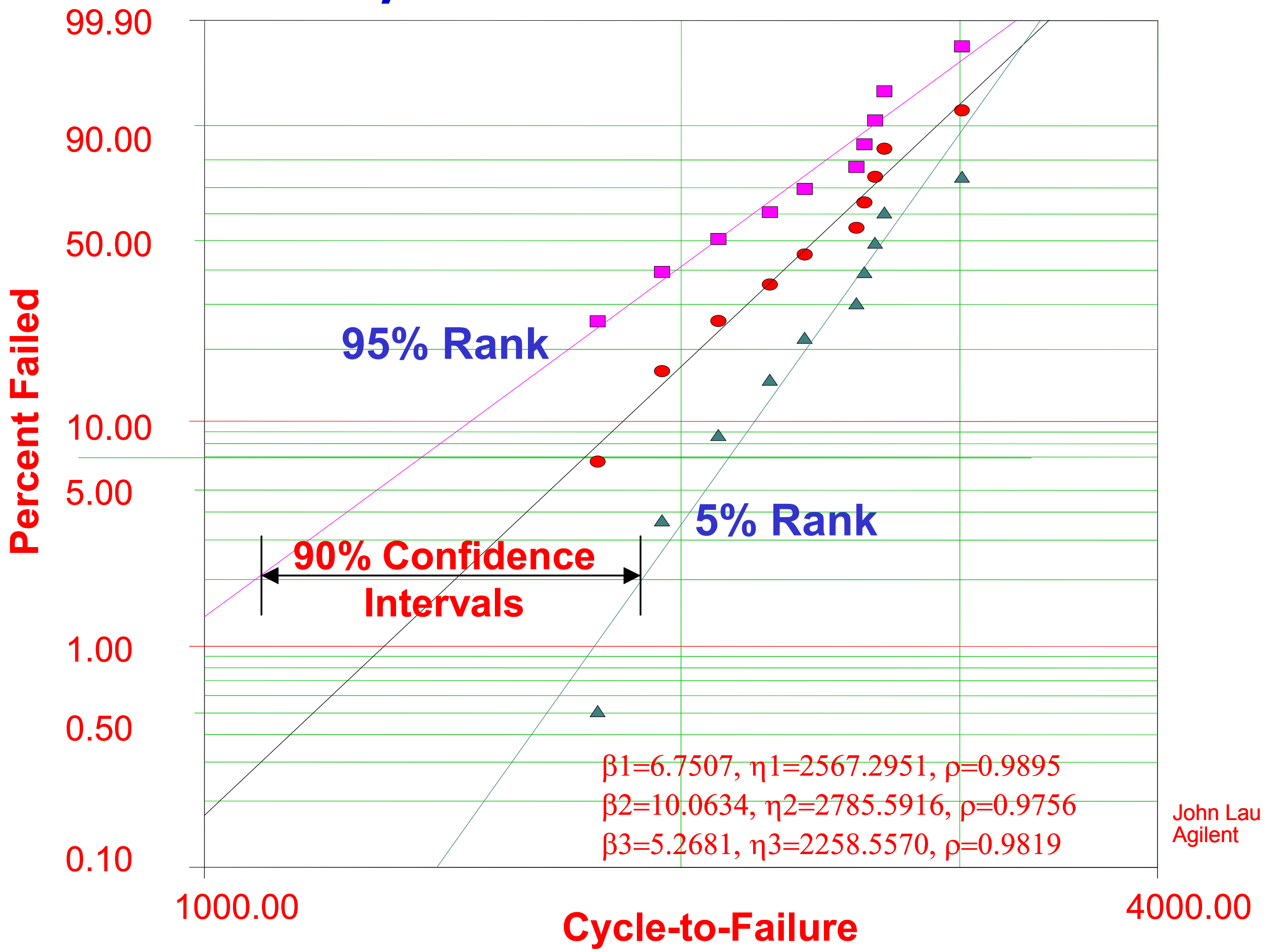
Order Statistics (Ranking)

$$1-(1-z)^{n}-nz(1-z)^{n-1}-\frac{n(n-1)}{2!}z^{2}(1-z)^{n-2}-\cdots$$
$$-\frac{n(n-1)\cdots(n-j+1)}{(j-1)!}z^{j-1}(1-z)^{n-j+1}=G$$

j **= the failure order number**
n **= number of samples**
G = required ranking
z **= the percent rank of the *j*th value in *n***

Median rank ~ (*j* - 0.3)/(*n* + 0.4)

1657CCGA with SnAgCu Paste on HASL-SnCu PCB (90% Confidence)



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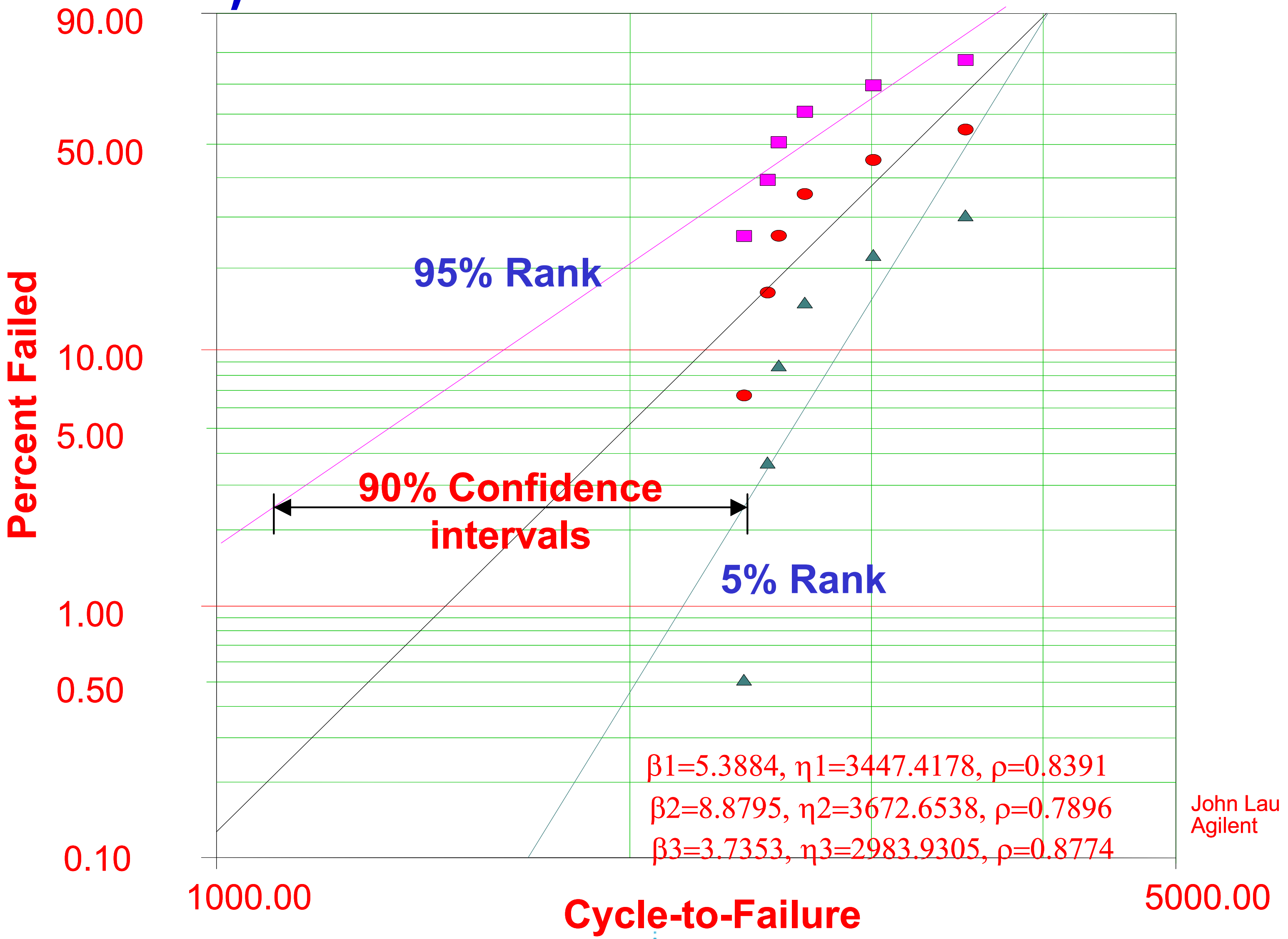
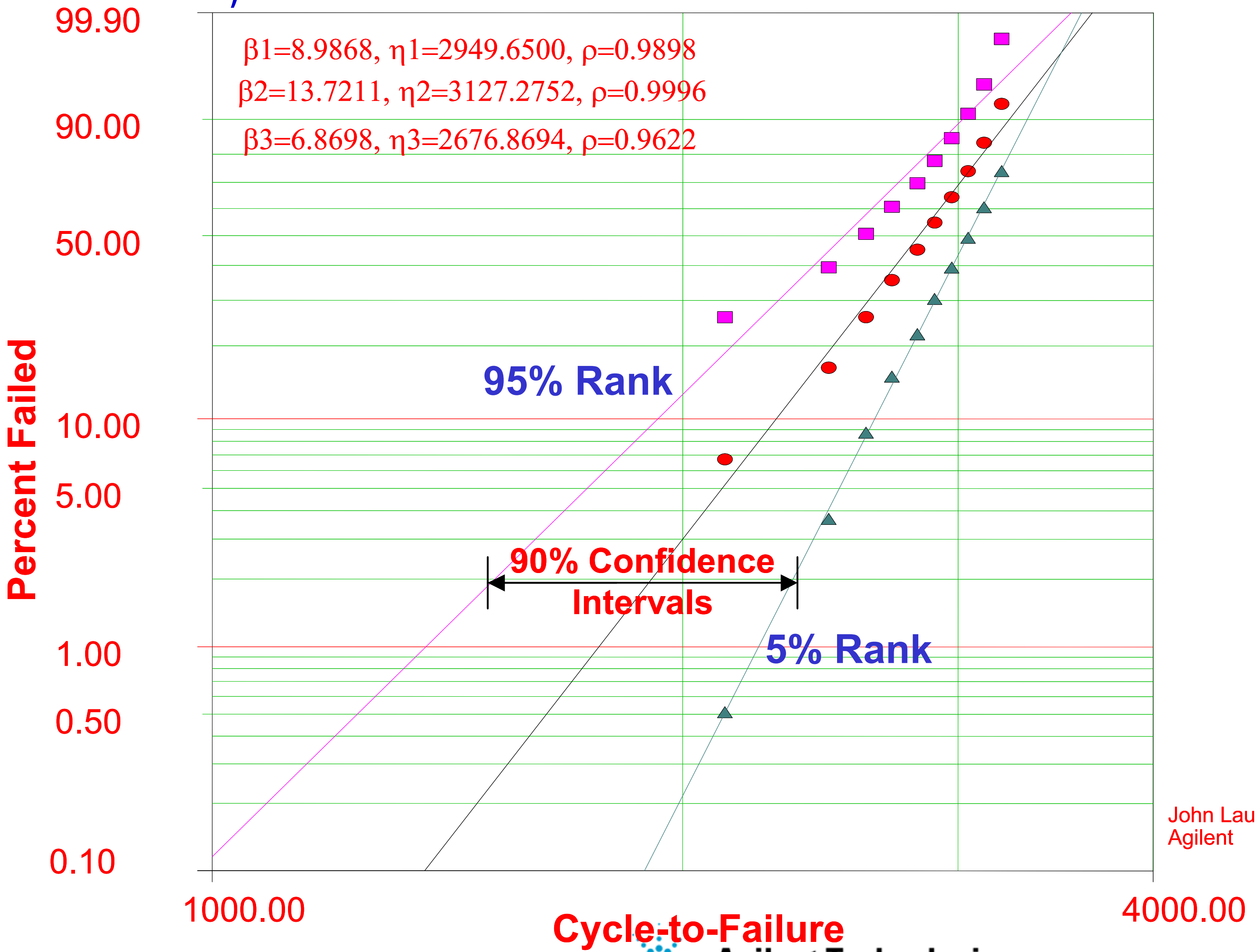
Mean Life, Characteristic Life, and Weibull Slope of the 1657CCGA Solder Columns with SnAgCu and SnPb Solder Pastes on Various PCBs (90% Confidence Intervals)

		SnAgCu paste on HASL PCB	SnAgCu paste on NiAu PCB	SnAgCu paste on OSP PCB	SnPb paste on OSP PCB
	Sample	**2397**	**3179**	**2793**	**3760**
Mean Life (μ), cycle	***Percent failed at mean***	**46.72**	**47.61**	**45.75**	**47.66**
	Population μ* at *90% confidence	**2069≤μ≤2552**	**2655≤μ≤3497**	**2492≤μ≤3017**	**3107≤μ≤4267**
Character-istic Life (θ),	***Sample***	**2567**	**3447**	**2950**	**4082**
cycle	***True θ (cycle) at 90% confidence***	**2259≤μ≤2786**	**2984≤μ≤3673**	**2677≤μ≤3127**	**3461≤μ≤4500**
	Sample	**6.75**	**5.39**	**8.99**	**5.29**
Weibull Slope (β)	***β error (%) at 90% confidence***	**37**	**47**	**37**	**37**
	True β at 90% confidence	**4.25≤β≤9.25**	**2.86≤β≤7.92**	**5.66≤β≤12.32**	**3.33≤β≤7.25**

1657CCGA with SnAgCu Paste on NiAu PCB (90% Confidence)



1657CCGA with SnAgCu Paste on OSP PCB (90% Confidence)



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Mean Life, Characteristic Life, and Weibull Slope of the 1657CCGA Solder Columns with SnAgCu and SnPb Solder Pastes on Various PCBs (90% Confidence Intervals)

		SnAgCu paste on HASL PCB	SnAgCu paste on NiAu PCB	SnAgCu paste on OSP PCB	SnPb paste on OSP PCB
	Sample	**2397**	**3179**	**2793**	**3760**
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	True β at 90% confidence	**4.25≤β≤9.25**	**2.86≤β≤7.92**	**5.66≤β≤12.32**	**3.33≤β≤7.25**

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Weibull Slope Error (*E*)

$$\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{E\sqrt{2N}} e^{-\frac{t^2}{2}}\,dt = \frac{(1+C)}{2}$$

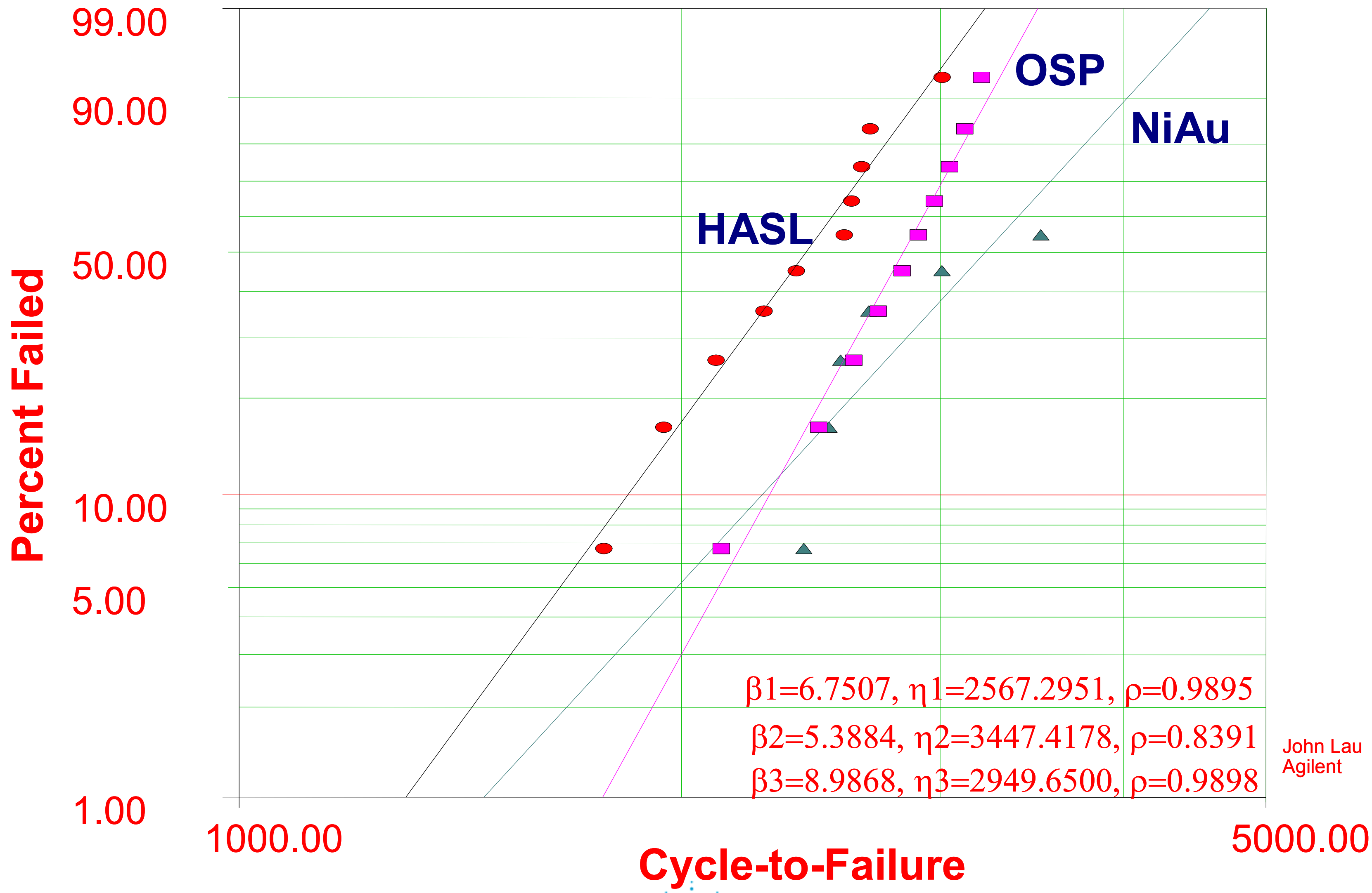
$$\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{E\sqrt{2N}} e^{-\frac{t^2}{2}}\,dt = 1 - Z(x)(b_1 t + b_2 t^2 + b_3 t^3 + b_4 t^4 + b_5 t^5) + \varepsilon(x)$$

$$Z(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \qquad t = \frac{1}{1+px}$$

$p = .2316419$
$b_1 = .31938153$
$b_2 = -.356563782$
$b_3 = 1.781477937$
$b_4 = -1.821255978$
$b_5 = 1.330274429$
$|\varepsilon(x)| < 7.5\text{x}10^{-8}$

***N* = number of failures** **_C_ = the required confidence level**

1657CCGA with SnAgCu Paste on HASL, NiAu, and OSP PCBs (Median Rank)



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Confidence Level (*P*) for Comparing the Quality (Mean Life) of Two Sets of Solder Joints

$$P = \frac{1}{1 + \frac{\log 1/q}{\log 1/1-q}}$$

$$q = 1 - \frac{1}{\left[1 + \left(\frac{t + 4.05}{6.12}\right)^5\right]^{40/7}}$$

$$t = \frac{\sqrt{1+\sqrt{T}}\,[\rho - 1]}{\rho\Omega_2 + \Omega_1}$$

$$T = (r_1 - 1)(r_2 - 1)$$

$$\rho = \frac{\mu_2}{\mu_1}$$

$$\Omega_1 = \sqrt{\frac{\Gamma(1 + 2/\beta_1)}{\Gamma^2(1 + 1/\beta_1)} - 1}$$

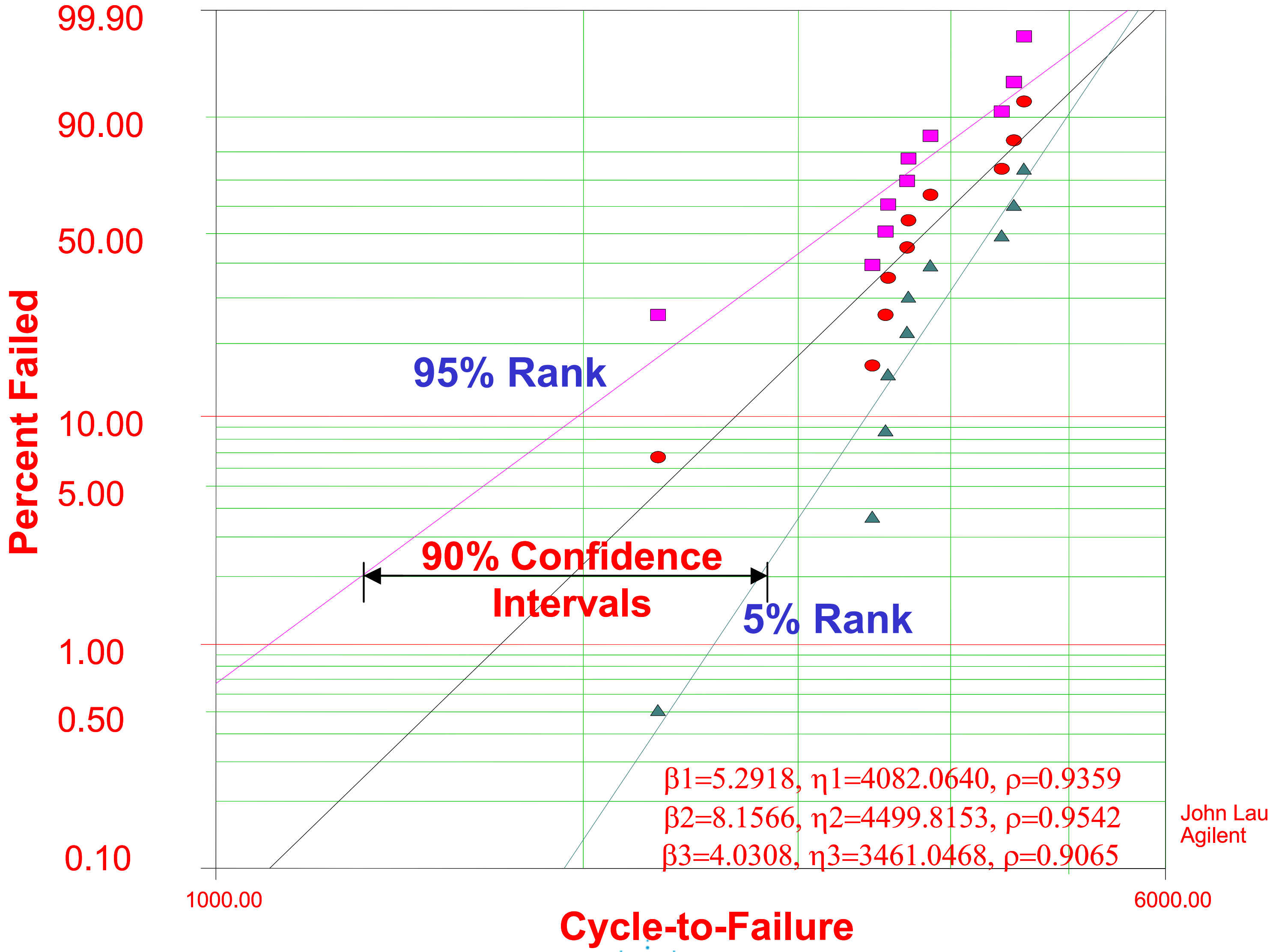
$$\Omega_2 = \sqrt{\frac{\Gamma(1 + 2/\beta_2)}{\Gamma^2(1 + 1/\beta_2)} - 1}$$

μ_1 and μ_2 are the sample mean lives, β_1 and β_2 are the sample Weibull slopes, r_1 and r_2 are the number of failures, respectively, of sample 1 and sample 2. T is called the total degrees of freedom.

Mean Life Ratio of the 1657CCGA Columns with SnAgCu and SnPb Pastes on Various PCBs

Different Assembly	Assigned Symbol	Mean Life, cycles	Mean Life Ratio (Comparison)	Determined Confidence
SnAgCu paste on HASL PCB	A	2397	*B/A = 1.33*	*99%*
SnAgCu paste on NiAu PCB	B	3179	*B/C = 1.14*	*89%*
SnAgCu paste on OSP PCB	C	2793	*C/A = 1.17*	*94%*
SnPb paste on OSP PCB	D	3760	*D/C = 1.35*	*99%*

1657CCGA with SnPb Paste on OSP PCB (90%Confidence)



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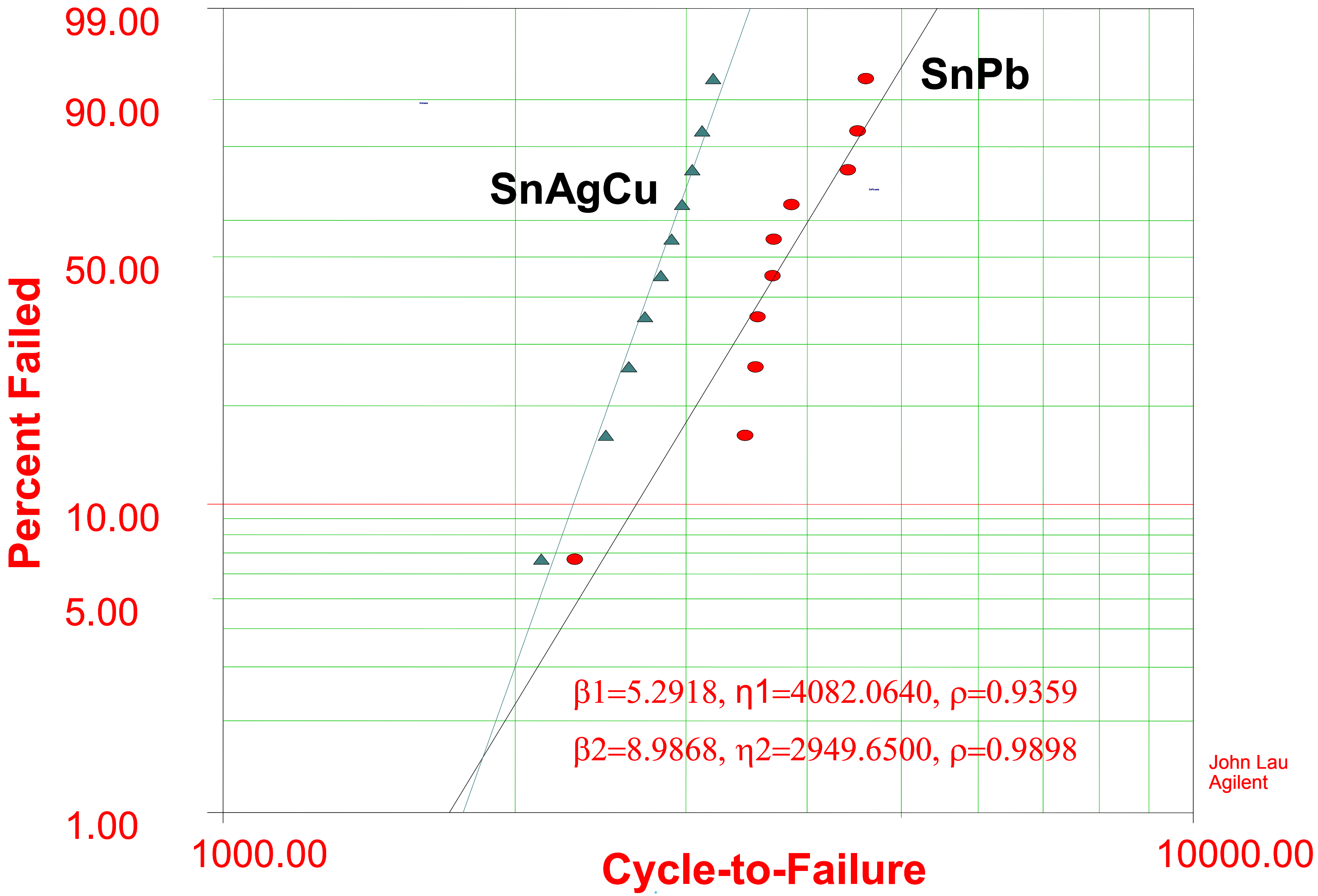
1657CCGA with SnAgCu and SnPb Pastes on OSP PCB (Median Rank)



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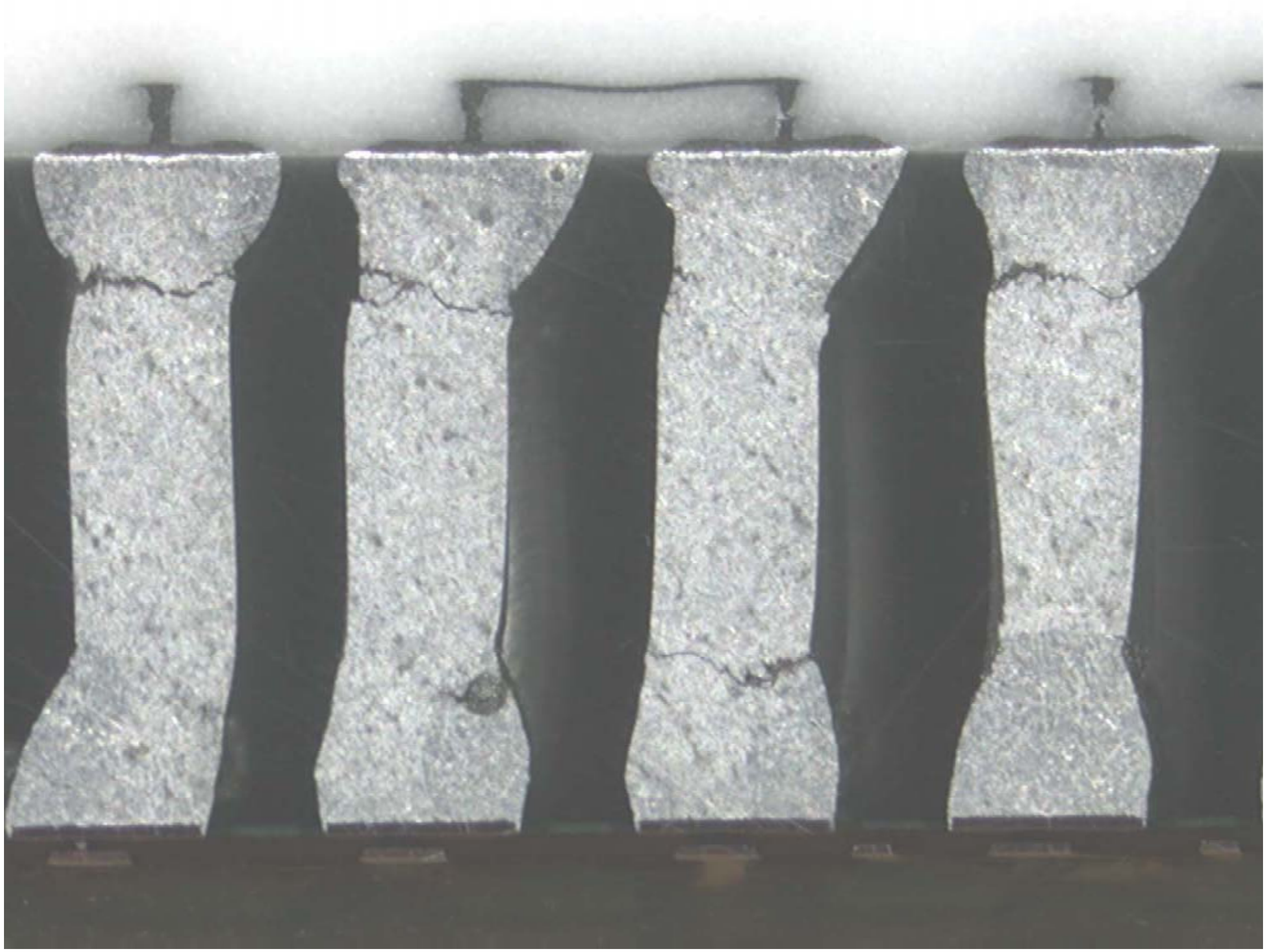
SnPb paste on OSP PCB	D	3760	*D/C = 1.35*	*99%*

Cross Section of the Failed Columns



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CONCLUSIONS and RECOMMENDATIONS

•At 90% confidence (i.e., in 9 out of 10 cases), the true characteristic life of the CCGA solder columns with SnAgCu solder paste on HASL (SnCu) PCB is larger than 2259 cycles and less than 2786 cycles. The true mean life can be as low as 2069 cycles and as high as 2552 cycles. The true Weibull slope is larger than 4.25 and less than 9.25.

•Similarly, at 90% confidence, the true characteristic life of the CCGA solder columns with SnAgCu solder paste on NiAu PCB can be as low as 2984 cycles and as high as 3673 cycles. The true mean life can be no less than 2655 cycles and no more than 3497 cycles. The true Weibull slope is larger than 2.86 and less than 7.92.

At 90% confidence, the true characteristic life of the CCGA solder columns with SnAgCu solder paste on OSP (Entek) PCB is larger than 2677 cycles and less than 3127 cycles. The true mean life can be as low as 2492 cycles and as high as 3017 cycles. The true Weibull slope is larger than 5.66 and less than 12.32.

CONCLUSIONS and RECOMMENDATIONS

•At 90% confidence, the true characteristic life of the CCGA solder columns with SnPb solder paste on OSP (Entek) PCB is larger than 3461 cycles and less than 4500 cycles. The true mean life can be as low as 3107 cycles and as high as 4267 cycles. The true Weibull slope is larger than 3.33 and less than 7.25.

•The quality (mean life) of the CCGA solder columns (with SnAgCu solder paste) on the NiAu PCB is better than that on the OSP with 89% confidence and that on the SnCu HASL with 99% confidence.

•In 94 out of 100 cases, the quality of the CCGA solder columns (with SnAgCu solder paste) on the OSP PCB is better than that on the SnCu HASL PCB.

•The quality of the CCGA solder columns with SnPb solder paste on OSP PCB is better than those with SnAgCu solder paste. This agreed very well with finite element simulation results reported elsewhere.

•More thermal cycling tests and finite element simulations should be done on lead-free assemblies with different dwell times.