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Subject: SEAM/SEAF Solder Joint Reliability under Thermal Cycling Conditions

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SUMMARY

The attachment reliability of SnPb and SAC SEAF/SEAM assemblies was estimated under mild to moderate field conditions: 25°C to 45°C and 25°C to 55°C thermal cycling at a frequency of 6 cycles/day. Reliability estimates were obtained by extrapolation of test failure cycles under Accelerated Thermal Cycling (ATC): 0°C to 100°C (10C/min ramp rates, 10 minute dwells) to field conditions, using strain-energy-based acceleration factors for both SnPb and SAC assemblies. Three groups of SEAF/SEAM connectors were evaluated with stack heights of 7 or 10 mm:

- Group A: SAC, 7 mm stack (SEAF 5.0 mm + SEAM 2.0 mm)
- Group C: SAC, 10 mm stack (SEAF 6.5 mm + SEAM 3.5 mm)
- Group D: SnPb, 10 mm stack (SEAF 6.5 mm + SEAM 3.5 mm)

Assuming: 1) good quality solder joints - i.e. assembly as per common workmanship requirements; and 2) creep-fatigue solder joint failures under ATC conditions, the SAC SEAF/SEAM 10 mm stack assemblies are predicted to have a longer life than the SnPb SEAF/SEAM 10 mm stack assemblies (Group C vs. Group D). The extrapolation of ATC failure times leads to the following predictions of cumulative fraction failed at 20 years (in ppm = parts per million):

Cumulative Fraction Failed for Group / Use Condition	**25/45C (6 cycles/day)**	**25/55C (6 cycles/day)**
Group A (SAC, 7 mm stack)	0.15 ppm	695 ppm (i.e. < 0.1%)
Group C (SAC, 10 mm stack)	<< 1 ppm	1.6 ppm
Group D (SnPb, 10 mm stack)	0.7 ppm	576 ppm (i.e. < 0.1%)

The main findings are:

- Under <u>25/45C conditions</u>, cumulative fractions of failed assemblies are predicted to be less than 1 ppm at 20 years for all three groups (A, C and D).

- Under <u>25/55C conditions,</u> cumulative fractions of failed assemblies are predicted to be less than 0.1% at 20 years for all three groups (A, C and D).

- The SAC SEAF/SEAM 10 mm stack assemblies are predicted to have lower failure rates, or a longer life than the SnPb SEAF/SEAM 10 mm stack assemblies (Group C vs. Group D).

The solder joint reliability projections are specific to 7 or 10 mm stack SEAF/SEAM assemblies on 92 mil thick FR-4 boards with similar properties as the test boards (with in-plane CTEs of about 13.5 and 15.1 ppm/C in x- and y- directions). In the absence of Failure Mode Analysis (FMA) results, one main assumption of the study is that the ATC failure times that were used for extrapolation purposes are for solder joint creep-fatigue failures. Fraction failed at 20 years will also change under other application-dependent thermal conditions and will increase under harsher use conditions than those used in this study.

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INTRODUCTION

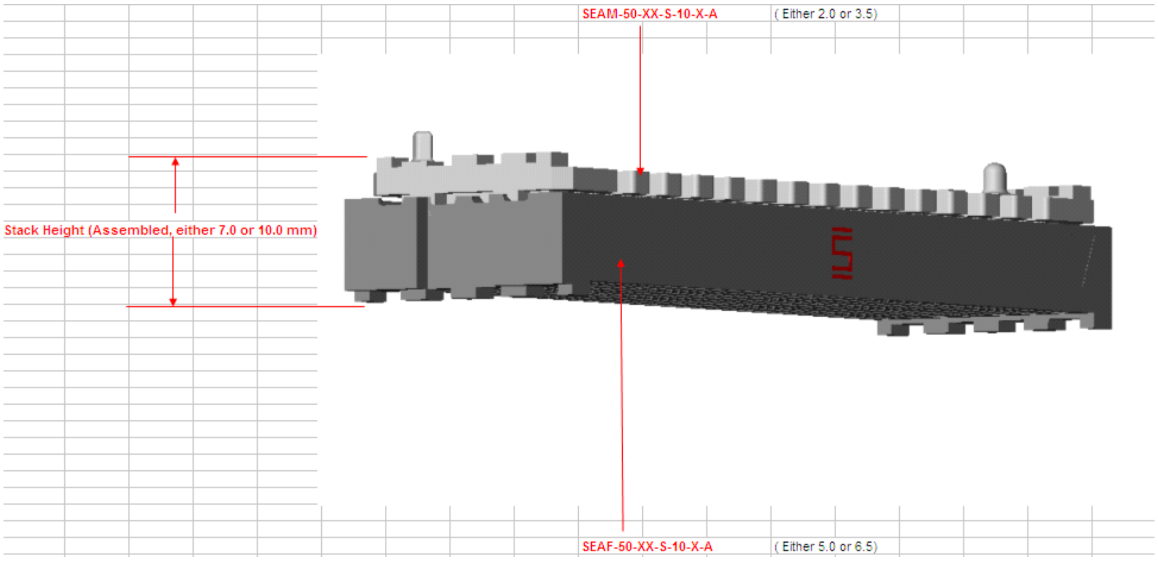


Figure 1: Schematic of SEAF/SEAM mated connectors.

Accelerated test results for SAMTEC's SEAF/SEAM assemblies (Figure 1) are extrapolated to mild and moderate use conditions using strain-energy based acceleration factors for SAC and SnPb solder joints under thermal cycling conditions. Three groups of SEAF/SEAM connectors were evaluated with stack heights of 7 or 10 mm:

- Group A: SAC, 7 mm stack (SEAF 5.0 mm + SEAM 2.0 mm)
- Group C: SAC, 10 mm stack (SEAF 6.5 mm + SEAM 3.5 mm)
- Group D: SnPb, 10 mm stack (SEAF 6.5 mm + SEAM 3.5 mm)

This report presents failure statistics from ATC testing, input data that was used to derive acceleration factors - including critical geometric parameters and material properties, and thermal cycling profiles – stress/strain analysis results (hysteresis loops) as well as predicted failure rates in the field. Acceleration factors for both SnPb and SAC assemblies are based on the ratio of cyclic strain energy (= area of stress/strain hysteresis loops) under test and use conditions.

FAILURE STATISTICS

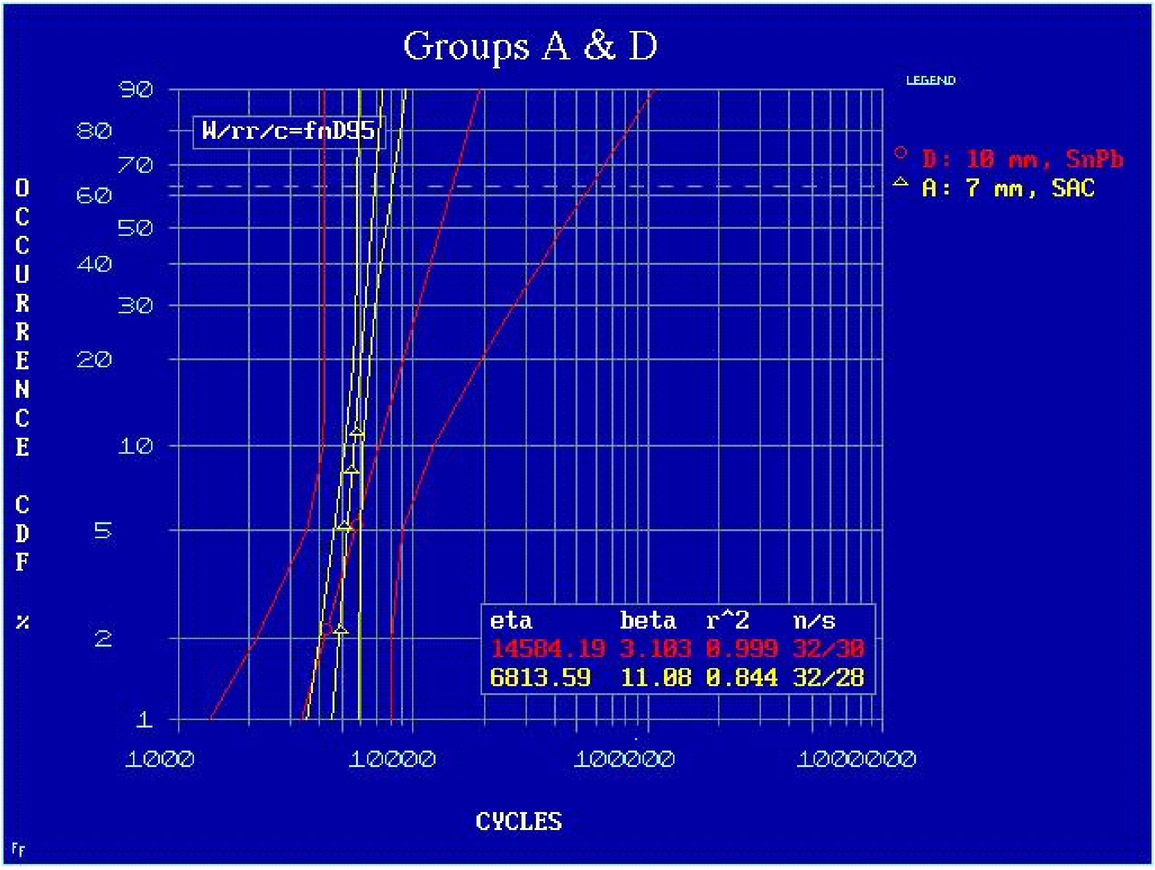


Figure 2: Two-parameter Weibull fit of ATC failure data for Groups A and D.

For each population of SAC and SnPb assemblies under test, sample size was n = 32 mated assemblies.

For Group A (SAC, 7 mm stack), 4 failures were recorded within a test period of 5838 cycles. Failure cycles are: 4919, 5027, 5470 and 5752 cycles. As seen in Figure 2, the two-parameter Weibull analysis of Group A failure cycles gives median values of the characteristic life: α = Cycles to 63.2% Failures = 6813 cycles and the shape parameter (slope of Weibull distribution): $\beta = 11.08$. Using 95% confidence bands, the corresponding lower bound values of Weibull parameters are: α (lower bound) = 5757 cycles, and β (lower bound) = 4.283. For comparison purposes, an “average” value of β for SnPb surface mount assemblies is about 6, and values of β are typically lower for SAC assemblies.

For Group C (SAC, 10mm stack assemblies), a single failure (i = 1) was recorded at 2666 cycles. For the shape parameter of the SAC failure distribution, assume a β of 4, somewhat less than an average β of 6 for SnPb assemblies. The characteristic life is then estimated by back-solving the two-parameter Weibull equation for α, as shown here after:

$$\% \text{ Fail at 1st failure} = (i - 0.3) / (n + 0.4) = (1-0.3)/(32 + 0.4) = 2.16\% = 1-\exp[-(2666 / \alpha)^4]$$

which gives α = 6,934 cycles.

For Group D (SnPb, 10 mm stack assemblies), only two failures were recorded at 4254 and 5691 cycles. From the Weibull plot of Group D data in Figure 2, median values of Weibull parameters are: α = N63.2% = 14584 cycles and $\beta = 3.103$. Lower bounds of Weibull parameters within the 95% confidence bands are: α = N63.2% = 3782 cycles, $\beta = 0.783$. The lower bound values of Weibull parameters cannot be used for the extrapolation of Group D failure times since the lower value of the slope β is less than 1. In the wear-out phase, failure rates increase with time and β is expected to be greater than 1.

The end goal of this analysis is to extrapolate the ATC test results to specific field conditions.

THERMAL CONDITIONS

Accelerated Thermal Cycling Conditions

Accelerated thermal cycling conditions are given as a temperature swing between 0°C and 100°C with ramp rates of 10ºC/minutes and dwell times of 10 minutes. The cycle duration is 40 minutes and the test frequency is 36 cycles per day.

Use Conditions

Two sets of use conditions were selected for field reliability projections

- Use condition # 1: 25/45ºC (ΔT = 20ºC), 10ºC/min. ramps, 6 cycles/day (1 cycle = 4 hours).
- Use condition # 2: 25/55ºC (ΔT = 30ºC), 10°C/min. ramps, 6 cycles/day (1 cycle = 4 hours).

Both cycles are at a frequency of 6 cycles/day. Reliability projections will differ for other field conditions.

SEAF / SEAM GEOMETRY AND MATERIAL PROPERTIES

Maximum Distance to Neutral Point

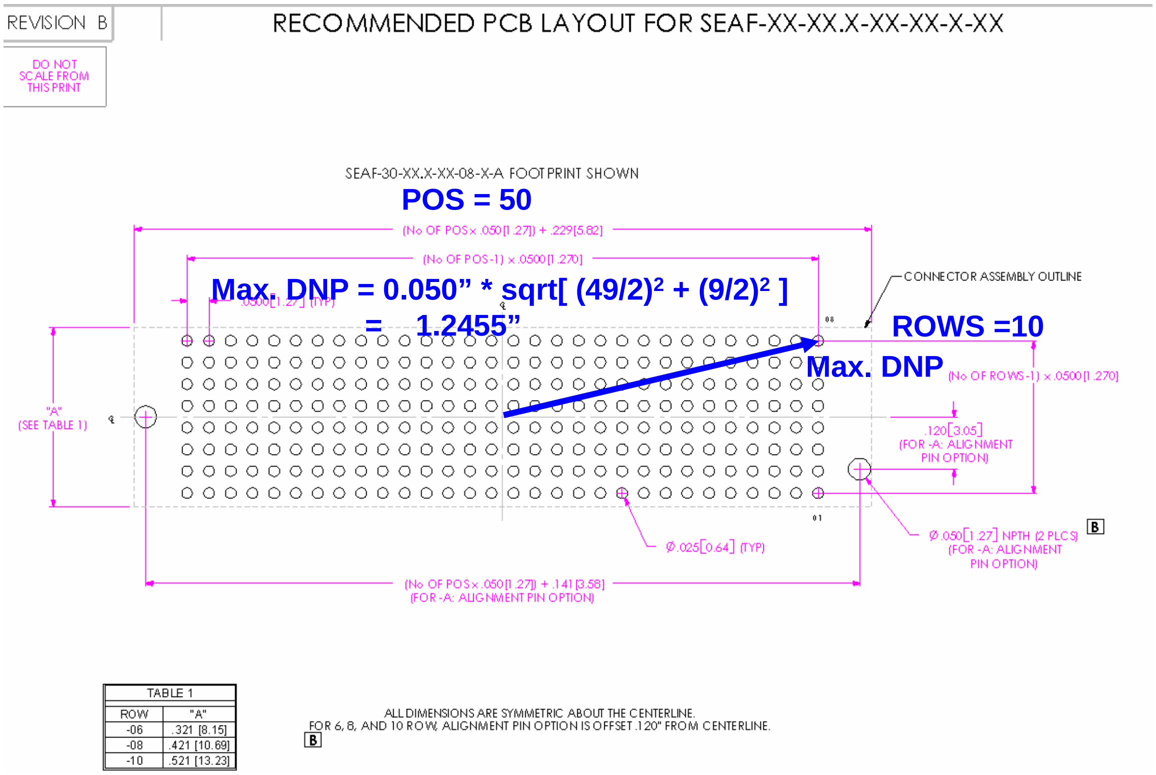


TABLE 1

ROW	"A"
-06	.321 [8.15]
-08	.421 [10.69]
-10	.521 [13.23]

Figure 3: Footprint layout and maximum Distance to Neutral Point (DNP_{max})

For all SEAF and SEAM parts under test, pins are in an area-array format with 10 rows and 50 positions per row (see Figure 3). Based on the footprint layout in Figure 3, the maximum Distance to Neutral Point

(DNP_{max}) at the outermost corner joints is 1.2455". The subsequent stress/strain, hysteresis loop analysis is done at the outermost corner joints.

Component Effective CTE in Diagonal Direction of SEAF / SEAM Parts

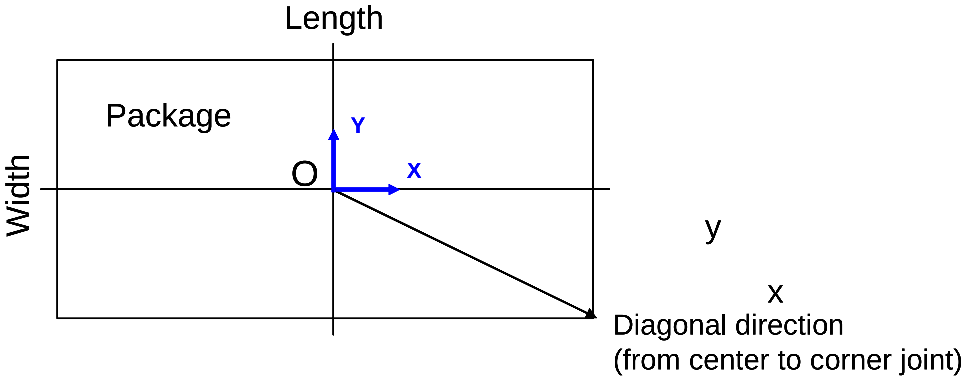


Figure 4: Component coordinate system for effective CTE calculation.

Since the maximum thermal expansion mismatch is at corner joints in the diagonal direction of the SEAF/SEAM assembly, and the components have different CTEs in the x- and y- directions we need to estimate the SEAF/SEAM effective CTE in the diagonal direction of the connectors (see Figure 4). The parts have measured, average Coefficients of Thermal Expansion (CTEs): CTE(in x-direction) = α_x = 10.7 ppm/°C and CTE(in y-direction) = α_y = 57.51 ppm/°C, where “x” is in the length direction of the connector parts (see Appendix A). Given CTEs were measured on parts that make up a 7 mm stack and are assumed to be the same for parts in a 10 mm stack. The “Package” or area array aspect ratio based on the footprint layout is: r = 49/9 for a 50 x 10 array, i.e., r = 5.444.

We thus get an effective CTE of the parts in their diagonal direction:

$$\alpha_{DIAG} = \frac{\alpha_Y + r^2 \alpha_X}{1 + r^2} = \frac{57.51 + 5.4444^2 \times 10.7}{1 + 5.4444^2} = 12.228\, ppm / C$$

Since x is the length direction of the connector parts, the calculated effective CTE of 12.228 ppm/°C in the diagonal direction is closer to the x-CTE of 10.7 ppm/°C for the SEAM/SEAF parts.

Board Effective CTEs and CTE Mismatches in Component Diagonal Direction

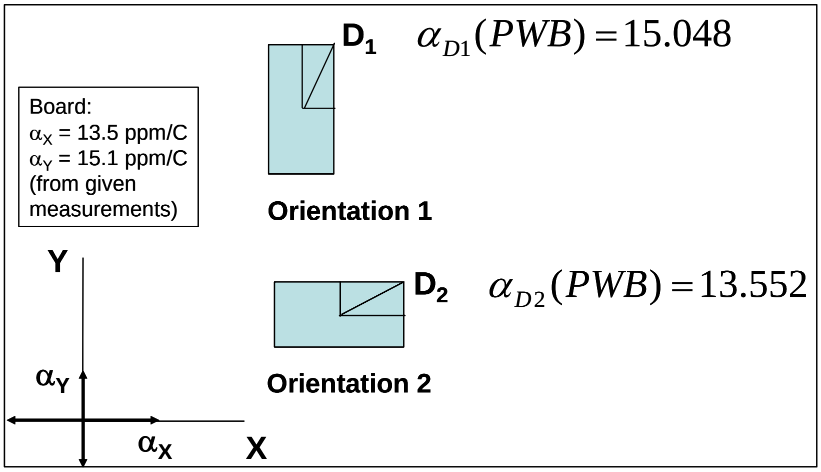


Figure 5: Board coordinate system and direction-dependent CTEs.

The board also has different in-plane CTEs in its own X- and Y-directions (see coordinate system in Figure 5): α_X = 13.5 ppm/ºC and α_Y = 15.1 ppm/ºC (average of given measured values; see Appendix A). The board to connector CTE mismatch will be different in the two diagonal directions D1 and D2 on the board when connectors are mounted with the length in the X or Y direction of the board (see Figure 6). The board effective CTEs in the D_1 and D_2 directions are calculated as:

$$\alpha_{D1} = \frac{\alpha_X + r^2 \alpha_Y}{1 + r^2} = \frac{13.5 + 5.4444^2 \times 15.1}{1 + 5.4444^2} = 15.048\, ppm / C$$

$$\alpha_{D2} = \frac{\alpha_Y + r^2 \alpha_X}{1 + r^2} = \frac{15.1 + 5.4444^2 \times 13.5}{1 + 5.4444^2} = 13.552\, ppm / C$$

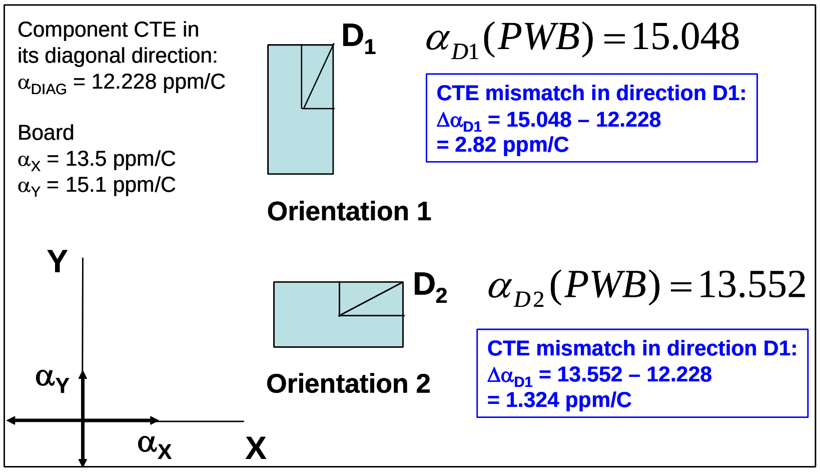


Figure 6: Maximum global CTE mismatch between board and connectors in diagonal directions D_1 & D_2.

Since the corner joints of the SEAF / SEAM assemblies are more prone to failure, we are interested in board-to-connector CTE mismatches in the diagonal directions D_1 and D_2. From the above calculated effective CTE of the connectors in their diagonal direction, and the effective CTEs of the board in the diagonal directions D_1 and D_2 (Figure 5), CTE mismatches are obtained as shown in Figure 6. The largest CTE mismatch is in the direction D_1. Although that CTE mismatch of 2.82 ppm/C is small, it can still lead to large shear strains in the outer most corner joints since the parts are rather large compared to common surface mount components.

In subsequent analysis, acceleration factors are computed for connectors mounted in Orientation 1 in Figure 6 (connector length parallel to board direction Y with a board CTE: α_Y = 15.1 ppm/ºC), i.e., in the worst case orientation with the largest CTE mismatch between the board and the connector parts.

Other Board Parameters

Board thickness is 92 mil.

For Young's modulus of FR-4 type boards, we use a standard value E = 2.50e6 psi.

Solder Joint / Assembly Parameters

The minimum solder joint thickness that is used in the analysis was given as h_S = 5 mil.

Another critical solder joint parameter is the solder joint crack area or minimum solder joint load bearing area in shear, A_S. Based on a footprint pad diameter of 25 mil, A_S is estimated as:

$$A_S = \pi * (25e\text{-}3 / 2)^2 = 4.9087E\text{-}04\ in^2$$

Other Connector Parameters

Connector parameters used in the connector / board assembly stiffness model are:

- Young's modulus of plastic insulator material (Polyplastics): E = 15,000 MPa = 2.175E6 psi

- Parts floor thickness = h_C = thickness of base or bottom of SEAF & SEAM parts (see Appendix A):
  - SEAF 5.0 mm: h_C = 0.059"; SEAF 6.5 mm: h_C = 0.118"
  - SEAM 2.0 mm: h_C = 0.053"; SEAM 3.5 mm: h_C = 0.112"

In addition, the board / connector assembly model includes a constraint for no bending of the assembly once the parts are mated together. For the definition of and details on assembly stiffness, see our SMI'96 paper (http://jpclech.com/clech_SRS_Model_smi96.pdf).

STRESS / STRAIN HYSTERESIS LOOPS AND ACCELERATION FACTORS

Methodology

All the input parameters that were given above are used to determine stiffness and CTE parameters that are then used to determine the slope and intercept of isothermal stress reduction lines and the solder joint stress/strain response under thermal cycling conditions, with separate analysis for stresses driven by global and local CTE mismatch. The previous parameters and analysis types are defined in our SMI'96 paper (http://jpclech.com/clech_SRS_Model_smi96.pdf). The basic algorithm that is used to generate stress/strain hysteresis loops with ramp rate effects is explained in an online report under NIST's Metallurgy Division web site, "Review and Analysis of Lead-Free Solder Material Properties" at: http://www.metallurgy.nist.gov/solder/clech/ . The application and validation of the strain energy approach to derive acceleration factors for SAC387/396 assemblies is discussed in details in our SMTAI'05 paper: http://jpclech.com/CLECH_SMTAI2005_PAPER.pdf, with further validation data for SAC387/396 assemblies presented at SMTAI'06 (ref.: Ron Zhang, Sun Microsystems, SMTAI Conference, September '06, Chicago).

Hysteresis loops for the SEAF/SEAM assemblies are presented next, and in Appendix C, followed by the derivation of acceleration factors that are obtained as the ratio of loop areas under test and field conditions.

Hysteresis Loops

All stress / strain hysteresis loops for SAC and SnPb corner joints under ATC and use conditions # 1 and 2 are shown in Appendix C. The global mismatch loops give the cyclic history of average shear stresses and shear strains in the solder joints due to global thermal expansion mismatch between the boards and connectors. Loops associated with stresses and strains arising from local CTE mismatches between solder and the boards or connectors are also shown in Appendix C since, as shown in tables of strain energy in the next subsection, the contribution from local CTE mismatches to the total cyclic strain energy is not negligible.

Strain Energy Results And Acceleration Factors

Cyclic strain energy results obtained from the area of hysteresis loops and acceleration factors for SAC and SnPb SEAF / SEAM assemblies are given in Appendix D for either SEAF or SEAM parts working against FR-4 boards. Acceleration factors, defined as the ratio of cyclic lives under use and test conditions are obtained as ratios of cyclic strain energies because of the inverse relationship between cyclic lives and strain energies, as shown empirically and as discussed in our SMTAI'05 paper (http://jpclech.com/CLECH_SMTAI2005_PAPER.pdf).

The strain energy results in Appendix D show that, in all cases (Groups A, C and D) global CTE mismatch is the dominant cyclic stress / strain driver under ATC conditions, with a small or negligible contribution of local CTE mismatches to the total strain energy (local + global strain energy). Under use conditions, strain energy from local CTE mismatch is a large and significant contributor in the case of SAC assemblies

(Groups A and C), whereas its contribution to total strain energy remains small (< 20%) in the case of SnPb assemblies (Group D).

As expected, comparing the AF results for Groups C (SAC, 10 mm stack) and D (SnPb, 10 mm stack), the SAC acceleration factors are greater than the SnPb acceleration factors. This trend has been observed in accelerated tests of SAC assemblies where SnPb assemblies were used as control boards

EXTRAPOLATION OF TEST RESULTS

Details of the extrapolation of test results to the two sets of field conditions (25/45C and 25/55C cycles) are tabulated for each group (A, C and D) in the following sub-sections. The main input of each sub-table is acceleration factors, test characteristic lives and shape parameters. Using two-parameter Weibull statistics, we then compute the cumulative fraction failed F at 20 years. The two-parameter Weibull equation is also back-solved for years in the field to a specified fraction failed (F = 0.1% or 0.01%). An overall summary of cumulative fraction failed at 20 years in the field is given in Table 1 below.

Cumulative Fraction Failed for Group / Use Condition	**25/45C (6 cycles/day)**	**25/55C (6 cycles/day)**
Group A (SAC, 7 mm stack)	0.15 ppm	695 ppm (i.e. < 0.1%)
Group C (SAC, 10 mm stack)	<< 1 ppm	1.6 ppm
Group D (SnPb, 10 mm stack)	0.7 ppm	576 ppm (i.e. < 0.1%)

Table 1: Summary of SEAF/SEAM SAC and SnPb reliability projections under field conditions: 25/45ºC and 25/55ºC at a use frequency of 6 cycles/day. Note: ppm = Parts Per Million.

The main findings are:

- Under <u>25/45°C conditions</u>, cumulative fractions of failed assemblies are predicted to be less than 1 ppm at 20 years for all three groups (A, C and D).
- Under <u>25/55°C conditions,</u> cumulative fractions of failed assemblies are predicted to be less than 0.1% at 20 years for all three groups (A, C and D).
- The SAC SEAF/SEAM 10 mm stack assemblies are predicted to have a longer life than the SnPb SEAF/SEAM 10 mm stack assemblies (Group C vs. Group D).

Group A (SAC, 7 mm stack) Reliability Projections

SAC 7 mm stack SEAM2.0 / SEAF5.0 assembly			
ANALYSIS FOR USE CONDITIONS: 25 to 45C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**6813**	**from 2P Weibull plot; slope β = 11.08**
Acceleration factor from ATC to 25/45C Use Conditions:	AF=	299.26	from stress/strain hysteresis loops
Characteristic life under 25/45C Use Conditions:	α_{field} (cycles) =	2.039E+06	$\alpha_{field} = AF * \alpha_{test}$
Target design life (Years):	**N_{Years} =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles} = N_{Years}$ * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =**	**0.0000E+00**	based on two-parameter Weibull distribution:
	F in ppm =	**0.0000**	F = 1 - exp[-$(N_{UseCycles} / \alpha_{field})^{\beta}$]
Years to 0.01% Cumulative Fraction Failed	**Years =**	**405.17**	
(i.e. F = 0.01% = 100 ppm)	**F =**	**0.0100%**	id.
	F(ppm) =	**100.000**	
Years to 0.1% Cumulative Fraction Failed	**Years =**	**498.78**	
(i.e. F = 0.1% = 1000 ppm)	**F =**	**0.1000%**	id.
	F(ppm) =	**1000.000**	
ANALYSIS FOR USE CONDITIONS: 25 to 55C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**6813**	**from 2P Weibull plot; slope β = 11.08**
Acceleration factor from ATC to 25/55C Use Conditions:	AF=	41.586	from stress/strain hysteresis loops
Characteristic life under 25/55C Use Conditions:	α_{field} (cycles) =	2.833E+05	$\alpha_{field} = AF * \alpha_{test}$
Target design life (Years):	**NYears =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles} = N_{Years}$ * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =**	**1.0459E-09**	based on two-parameter Weibull distribution:
	F in ppm =	**0.0010**	F = 1 - exp[-$(N_{UseCycles} / \alpha_{field})^{\beta}$]
	F in % =	**0.0000%**	
Years to 0.01% Cumulative Fraction Failed	**Years =**	**56.30**	
(i.e. F = 0.01% = 100 ppm)	**F =**	**0.0100%**	id.
	F(ppm) =	**100.000**	
Years to 0.1% Cumulative Fraction Failed	**Years =**	**69.31**	
(i.e. F = 0.1% = 1000 ppm)	**F =**	**0.1000%**	id.
	F(ppm) =	**1000.000**	

Table 2a: Extrapolation of Group A (SAC, 7 mm stack) test results to field conditions: 25/45ºC and 25/55ºC (6 cycles/day) based on median values of Weibull parameters in Figure 2 failure distribution.

From the previous table, and based on median values of Weibull parameters under ATC conditions, conclusions for Group A assemblies are:

- Under conditions 25/45°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed much less than 1 ppm at 20 years.

- Under conditions 25/55°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed of 0.001 ppm at 20 years.

- It would take about 56.3 years to reach a fraction failed of 100 ppm. With a “safety” factor of two on predicted life (56.3 years), a fraction failed of 100 ppm would be reached at about 28 years.

Extrapolations are based on the assumption that failures in test are solder joint creep/fatigue failures. First Group A failure in ATC was at 4919 cycles, and 4 out of 32 units had failed by 5838 cycles.

SAC 7 mm stack SEAM2.0 / SEAF5.0 assembly			
ANALYSIS FOR USE CONDITIONS: 25 to 45C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**5757**	**from lower 95% confidence bound of 2P Weibull plot with slope β = 4.283**
Acceleration factor from ATC to 25/45C Use Conditions:	AF=	299.26	from stress/strain hysteresis loops
Characteristic life under 25/45C Use Conditions:	α_{field} (cycles) =	1.723E+06	α_{field} = AF * α_{test}
Target design life (Years):	**N_{Years} =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =** **F in ppm =**	**1.4821E-07** **0.1482**	based on two-parameter Weibull distribution: F = 1 - exp[-($N_{UseCycles}$ / α_{field})$^{\beta}$]
Years to 0.01% Cumulative Fraction Failed (i.e. F = 0.01% = 100 ppm)	**Years =** **F =** **F(ppm) =**	**91.53** **0.0100%** **100.000**	id.
Years to 0.1% Cumulative Fraction Failed (i.e. F = 0.1% = 1000 ppm)	**Years =** **F =** **F(ppm) =**	**156.72** **0.1000%** **1000.00**	id.
ANALYSIS FOR USE CONDITIONS: 25 to 55C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**5757**	**from 2P Weibull plot; slope β = 11.08**
Acceleration factor from ATC to 25/55C Use Conditions:	AF=	41.586	from stress/strain hysteresis loops
Characteristic life under 25/55C Use Conditions:	α_{field} (cycles) =	2.394E+05	α_{field} = AF * α_{test}
Target design life (Years):	**NYears =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =** **F in ppm =** **F in % =**	**6.9452E-04** **694.5208** **0.0695%**	based on two-parameter Weibull distribution: F = 1 - exp[-($N_{UseCycles}$ / α_{field})$^{\beta}$]
Years to 0.01% Cumulative Fraction Failed (i.e. F = 0.01% = 100 ppm)	**Years =** **F =** **F(ppm) =**	**12.72** **0.0100%** **100.000**	id.
Years to 0.1% Cumulative Fraction Failed (i.e. F = 0.1% = 1000 ppm)	**Years =** **F =** **F(ppm) =**	**21.78** **0.1000%** **1000.00**	id.

Table 2b: Extrapolation of Group A (SAC, 7 mm stack) test results to field conditions: 25/45ºC and 25/55ºC (6 cycles/day) based on lower bound values of Weibull parameters in Figure 2 failure distribution.

From the previous table, and based on lower bound values of Weibull parameters under ATC conditions, conclusions for Group A assemblies are:

- Under conditions 25/45°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed of 0.1482 ppm, i.e. less than 1 ppm at 20 years.

- Under conditions 25/55°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed of 695 ppm at 20 years, i.e. less than 1000 ppm or 0.1%.
  - It takes 12.7 years to reach a fraction failed of 100 ppm (0.01%).
  - It takes 21.7 years to reach a fraction failed of 1000 ppm (0.1%).

Group C (SAC, 10 mm stack) Reliability Projections

SAC 10 mm stack SEAM3.5 / SEAF6.5 assembly			
ANALYSIS FOR USE CONDITIONS: 25 to 45C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**6934**	**based on 1st failure (1 of 32) at 2666 cycles, assuming Weibull shape parameter β = 4**
Acceleration factor from ATC to 25/45C Use Conditions:	AF=	1657	from stress/strain hysteresis loops
Characteristic life under 25/45C Use Conditions:	α_{field} (cycles) =	1.149E+07	α_{field} = AF * α_{test}
Target design life (Years):	**N_{Years} =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =**	**2.1177E-10**	based on two-parameter Weibull distribution:
	F in ppm =	**0.0002**	$F = 1 - \exp[-(N_{UseCycles} / \alpha_{field})^{\beta}]$
Years to 0.01% Cumulative Fraction Failed	**Years =**	**524.29**	
(i.e. F = 0.01% = 100 ppm)	**F =**	**0.0100%**	id.
	F(ppm) =	**100.000**	
Years to 0.1% Cumulative Fraction Failed	**Years =**	**932.44**	
(i.e. F = 0.1% = 1000 ppm)	**F =**	**0.1000%**	id.
	F(ppm) =	**1000.000**	
ANALYSIS FOR USE CONDITIONS: 25 to 55C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**6934**	**based on 1st failure (1 of 32) at 2666 cycles, assuming Weibull shape parameter β = 4**
Acceleration factor from ATC to 25/55C Use Conditions:	AF=	177	from stress/strain hysteresis loops
Characteristic life under 25/55C Use Conditions:	α_{field} (cycles) =	1.227E+06	α_{field} = AF * α_{test}
Target design life (Years):	**NYears =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =**	**1.6265E-06**	based on two-parameter Weibull distribution:
	F in ppm =	**1.6265**	$F = 1 - \exp[-(N_{UseCycles} / \alpha_{field})^{\beta}]$
	F in % =	**0.00016%**	
Years to 0.01% Cumulative Fraction Failed	**Years =**	**56.00**	
(i.e. F = 0.01% = 100 ppm)	**F =**	**0.0100%**	id.
	F(ppm) =	**100.000**	
Years to 0.1% Cumulative Fraction Failed	**Years =**	**99.60**	
(i.e. F = 0.1% = 1000 ppm)	**F =**	**0.1000%**	id.
	F(ppm) =	**1000.000**	

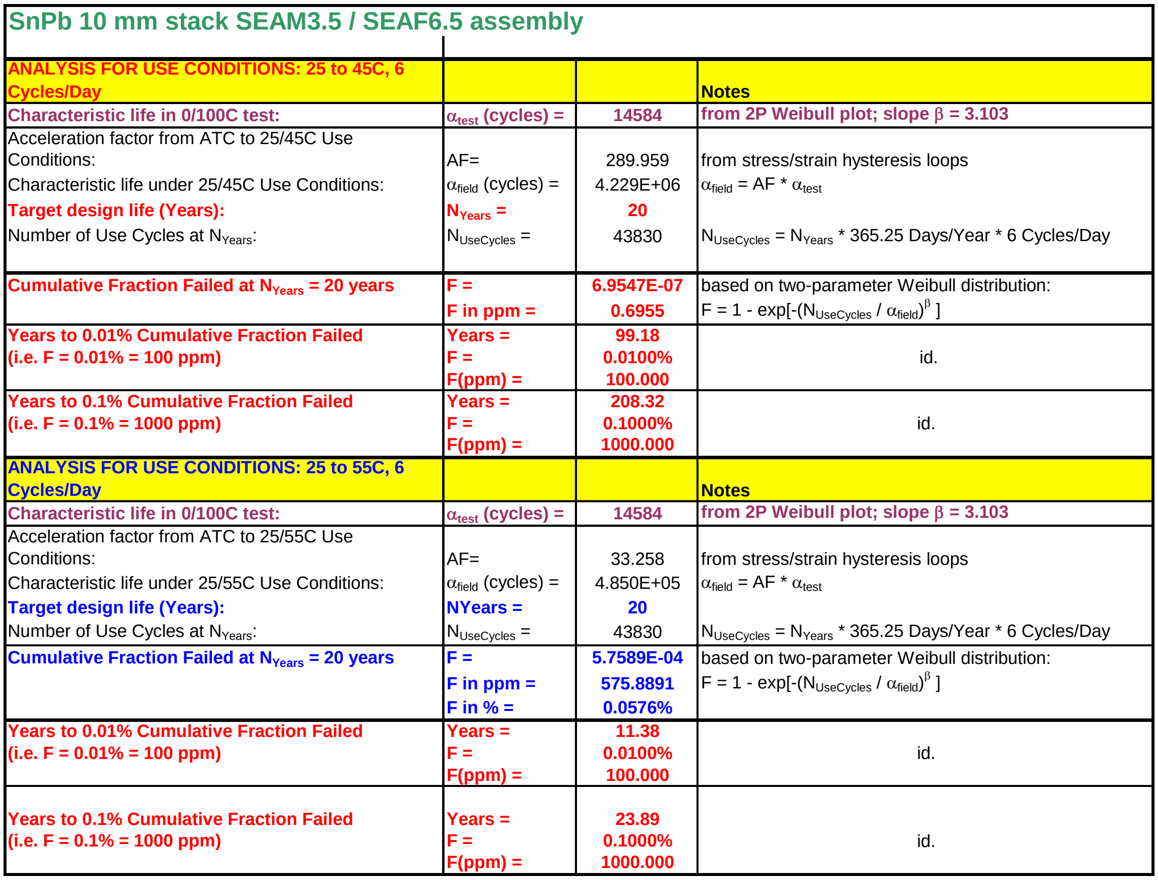
Table 3: Extrapolation of Group C (SAC, 10 mm stack) test results to field conditions: 25/45ºC and 25/55ºC (6 cycles/day).

From Table 3, and based on a single failure at 2666 cycles under ATC conditions, conclusions for Group C assemblies are:

- Under conditions 25/45°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed much less than 1 ppm at 20 years.
- Under conditions 25/55°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed of 1.6265 ppm at 20 years.
- It would take 56.0 years to reach a fraction failed of 100 ppm. With a "safety" factor of two on predicted life (56 years), a fraction failed of 100 ppm would be reached at 28 years. A similar conclusion was reached for the 7 mm stack which had a first failure that occurred later in test but had a lower acceleration factor.

The first and only failure in ATC within group C was at 2666 cycles. Since there was no other reported failures within this group until the end of test (5838 cycles), this only failure is possibly an "outlier", which is difficult to assess in the absence of failure mode analysis results.

Group D (SnPb, 10 mm stack) Reliability Projections



SnPb 10 mm stack SEAM3.5 / SEAF6.5 assembly			
ANALYSIS FOR USE CONDITIONS: 25 to 45C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**14584**	**from 2P Weibull plot; slope β = 3.103**
Acceleration factor from ATC to 25/45C Use Conditions:	AF=	289.959	from stress/strain hysteresis loops
Characteristic life under 25/45C Use Conditions:	α_{field} (cycles) =	4.229E+06	α_{field} = AF * α_{test}
Target design life (Years):	**N_{Years} =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =** **F in ppm =**	**6.9547E-07** **0.6955**	based on two-parameter Weibull distribution: F = 1 - exp[-($N_{UseCycles}$ / α_{field})$^{\beta}$]
Years to 0.01% Cumulative Fraction Failed (i.e. F = 0.01% = 100 ppm)	**Years =** **F =** **F(ppm) =**	**99.18** **0.0100%** **100.000**	id.
Years to 0.1% Cumulative Fraction Failed (i.e. F = 0.1% = 1000 ppm)	**Years =** **F =** **F(ppm) =**	**208.32** **0.1000%** **1000.000**	id.
ANALYSIS FOR USE CONDITIONS: 25 to 55C, 6 Cycles/Day			**Notes**
Characteristic life in 0/100C test:	**α_{test} (cycles) =**	**14584**	**from 2P Weibull plot; slope β = 3.103**
Acceleration factor from ATC to 25/55C Use Conditions:	AF=	33.258	from stress/strain hysteresis loops
Characteristic life under 25/55C Use Conditions:	α_{field} (cycles) =	4.850E+05	α_{field} = AF * α_{test}
Target design life (Years):	**NYears =**	**20**	
Number of Use Cycles at N_{Years}:	$N_{UseCycles}$ =	43830	$N_{UseCycles}$ = N_{Years} * 365.25 Days/Year * 6 Cycles/Day
Cumulative Fraction Failed at N_{Years} = 20 years	**F =** **F in ppm =** **F in % =**	**5.7589E-04** **575.8891** **0.0576%**	based on two-parameter Weibull distribution: F = 1 - exp[-($N_{UseCycles}$ / α_{field})$^{\beta}$]
Years to 0.01% Cumulative Fraction Failed (i.e. F = 0.01% = 100 ppm)	**Years =** **F =** **F(ppm) =**	**11.38** **0.0100%** **100.000**	id.
Years to 0.1% Cumulative Fraction Failed (i.e. F = 0.1% = 1000 ppm)	**Years =** **F =** **F(ppm) =**	**23.89** **0.1000%** **1000.000**	id.

Table 4: Extrapolation of Group D (SnPb, 10 mm stack) test results to field conditions: 25/45ºC and 25/55ºC (6 cycles/day).

From Table 4, conclusions for Group D assemblies are:

- Under conditions 25/45°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed slightly less than 1 ppm at 20 years.
- Under conditions 25/55°C, 6 cycles per day, extrapolation of ATC test results gives a fraction failed of 576 ppm at 20 years.
- A fraction failed of 100 ppm (= 0.01%) is reached at about 11 years. A fraction failed of 1000 ppm (= 0.1%) is reached at about 23 years.
- Compared to previous results (Groups A and C), SAC assemblies are predicted to be more reliable than SnPb assemblies.

CONCLUSIONS

- For field conditions: 25/45ºC, 6 cycles/day, the extrapolation of ATC (0/100ºC, 10°C/min ramps, 10 minute dwells) test results gives the following estimated of cumulative fraction failed, F, at 20 years of use:

    - For Group A (SAC, 7 mm stack): F is much less than 1 ppm.
    - For Group C (SAC, 10 mm stack): F is much less than 1 ppm.
    - For Group D (SnPb, 10 mm stack): F is about 0.7 ppm.

- For field conditions: 25/55ºC, 6 cycles/day, the extrapolation of ATC (0/100ºC, 10C/min ramps, 15 minute dwells) test results gives the following estimates of cumulative fraction failed, F, at 20 years of use:

    - For Group A (SAC, 7 mm stack): F = 0.001 ppm (median value) or F = 694 ppm (upper bound). The wide range of predicted F's is due to large variations in estimated values of Weibull parameters (median value of shape parameter, $\beta = 11.08$; 95% confidence lower bound value, $\beta = 4.28$).
    - For Group C (SAC, 10 mm stack): F = 1.6 ppm.
    - For Group D (SnPb, 10 mm stack): F = 576 ppm.

- Under field conditions considered in this study, the SAC, 10 mm stack SEAF/SEAM assemblies (Group C) have a longer life than SnPb assemblies (Group D) and SAC fraction failed at 20 years in the field are significantly lower than in the case of SnPb assemblies.

    - The estimated time to reach 0.1% failure is 23 years for Group D (SnPb, 10 mm stack), 99 years for Group C (SAC, 10 mm stack).

- All reliability projections assume that failures recorded in ATC testing are solder joint creep-fatigue failures. This main assumption is subject to verification based on the results of failure mode analysis of test boards.

- The extrapolation results are for SEAF / SEAM product boards with similar properties as the test board under ATC testing, and with a board to connector CTE mismatch of about 2.8 ppm/ºC in the diagonal direction of the connectors.

- The above reliability projections are application-dependent and will change for other board materials and use conditions.

- All needed geometric details and material properties that were used in this study are given in the first part of the report.

ACKNOWLEDGMENTS

The author is grateful to Samtec for their support of this study. Special thanks to Troy Cook and David Tiller for their help in providing the detailed input data that were required to conduct the analysis.

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APPENDIX A: Board and Parts CTEs

Specimen #	Specimen ID	Measurement Dir.	Avg.CTE(ppm/°C)
			(150° to -450°C)
#1	**SEAF-50-05.0-S-10-2**	X	10.0+/-0.2
		Y	62.0+/-0.2
#2	**SEAM-50-02.0-S-10-2**	X	11.4+/-0.2
		Y	53.02+/-0.2
#3	PCB-100504-TST-01	X	13.9+/-0.2
		Y	14.7+/-0.2
#4	PCB-100504-TST-02	X	13.1+/-0.2
		Y	15.5+/-0.2

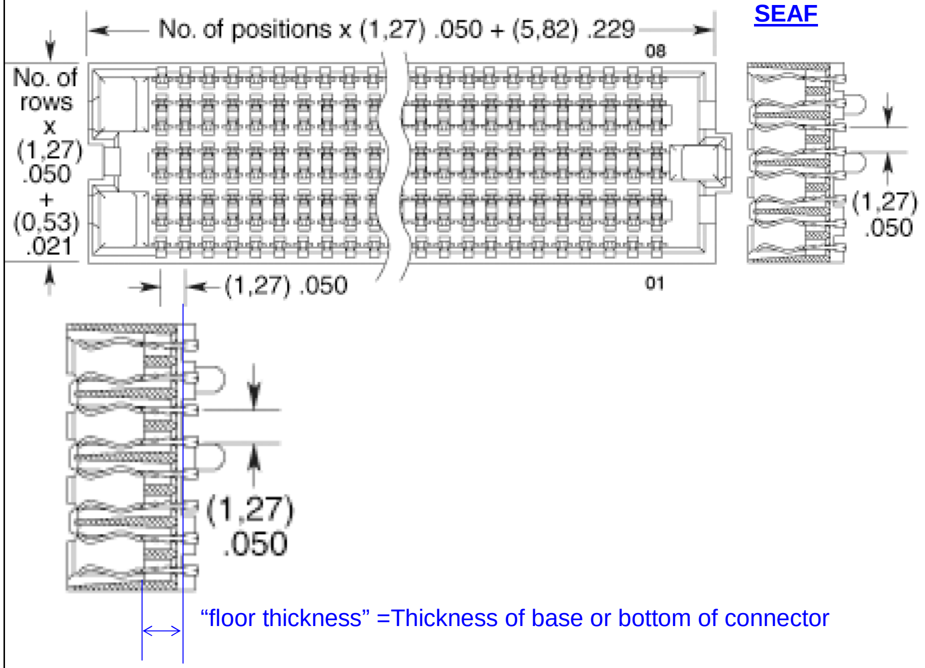
Average X- CTE = 10.7
Average Y- CTE = 57.51

BOARD CTEs:
13.5 = Average of # 3 and # 4 in X-direction
15.1 = Average of # 3 and # 4 in Y-direction

Table A1: Board and parts measured CTEs (provided by SAMTEC) and calculated average values of CTEs. For connector parts, X direction is the length direction, Y direction is the width.

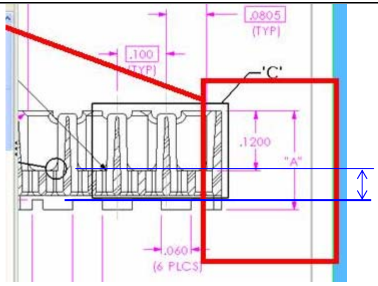
APPENDIX B: Floor Thickness of SEAM & SEAF Parts

SEAF



“floor thickness” =Thickness of base or bottom of connector

SEAF (cont’d)



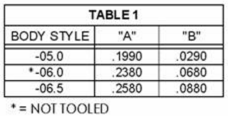
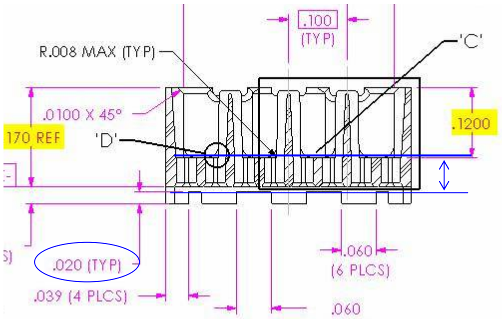


TABLE 1		
BODY STYLE	"A"	"B"
-05.0	.1990	.0290
*-06.0	.2380	.0680
-06.5	.2580	.0880

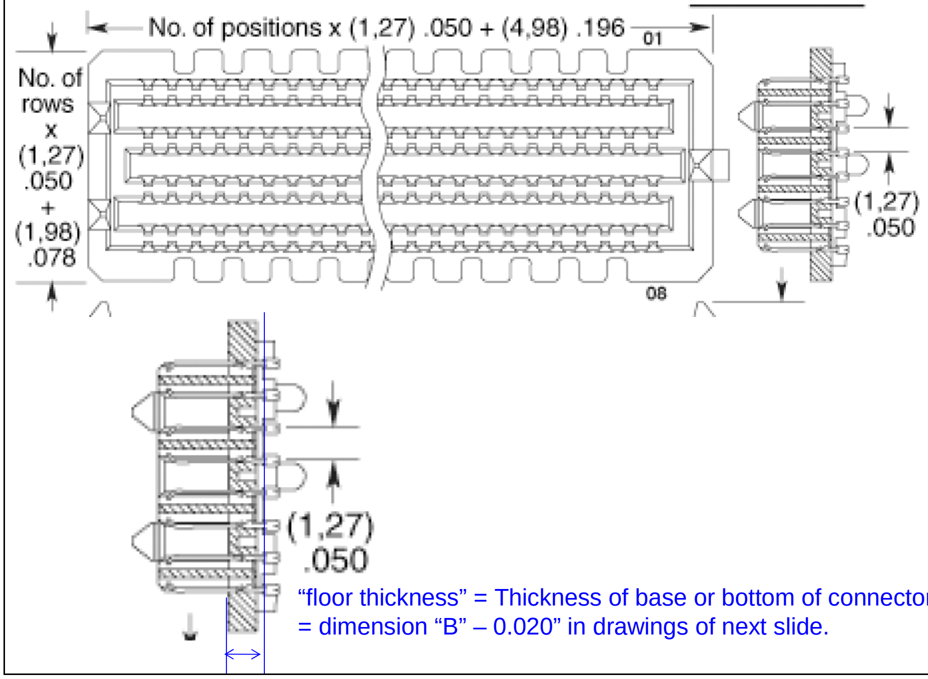
* = NOT TOOLED

“floor thickness” =Thickness of base or bottom of connector = “A” - 0.120 – 0.020



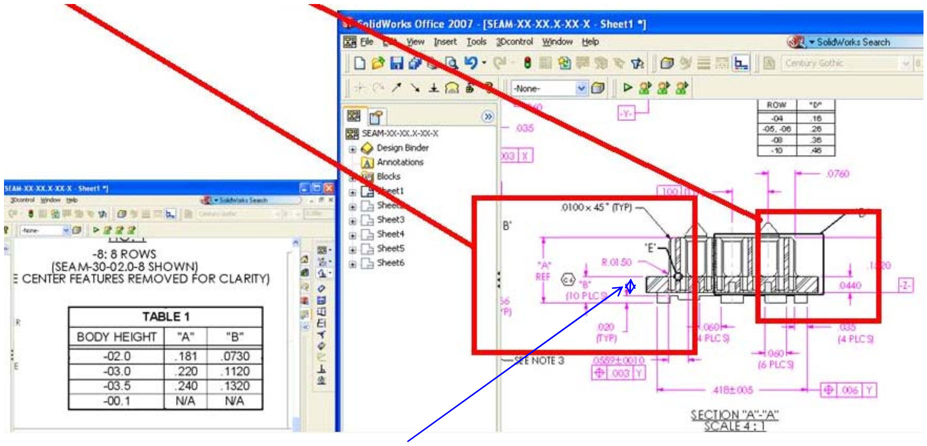
For SEAF 5.0 mm: floor thickness = 0.1990 – 0.120 - 0.020 = 0.059”
For SEAF 6.5 mm: floor thickness = 0.2580 – 0.120 - 0.020 = 0.118”

SEAM



"floor thickness" = Thickness of base or bottom of connector = dimension "B" – 0.020" in drawings of next slide.

SEAM (cont'd)



ROW	"D"
-04	.16
-05, -06	.26
-08	.36
-10	.46

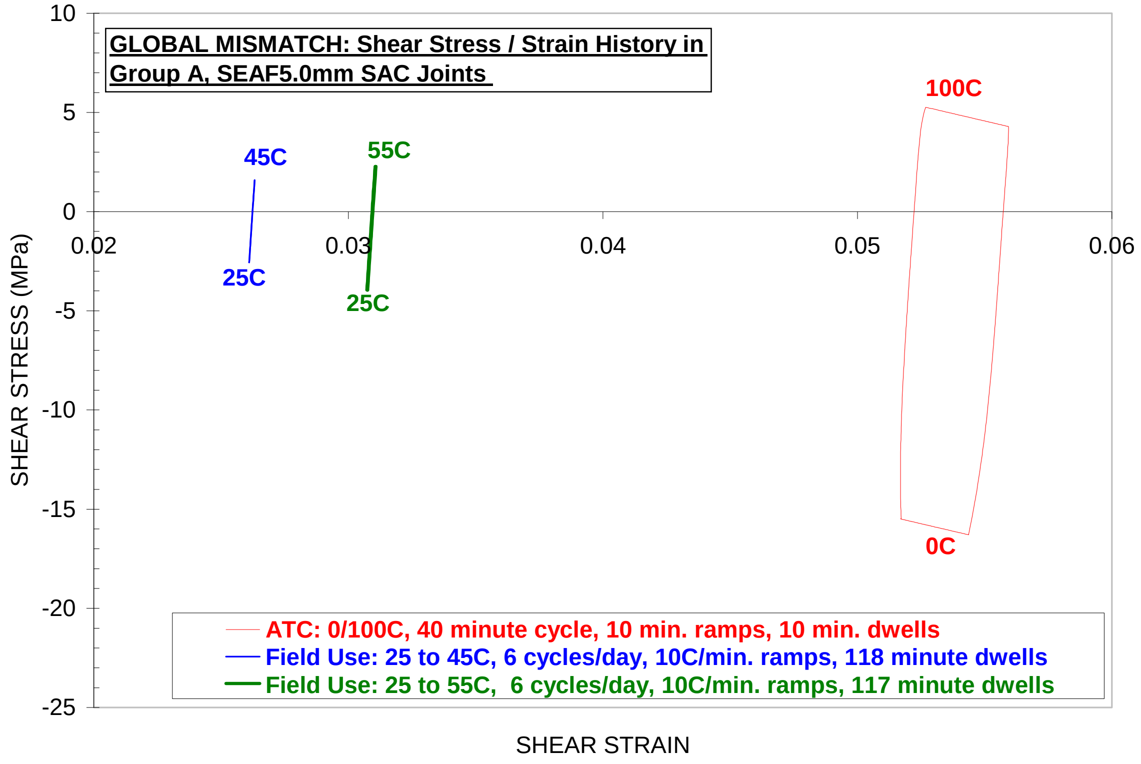
-8: 8 ROWS
(SEAM-30-02.0-8 SHOWN)
E CENTER FEATURES REMOVED FOR CLARITY)

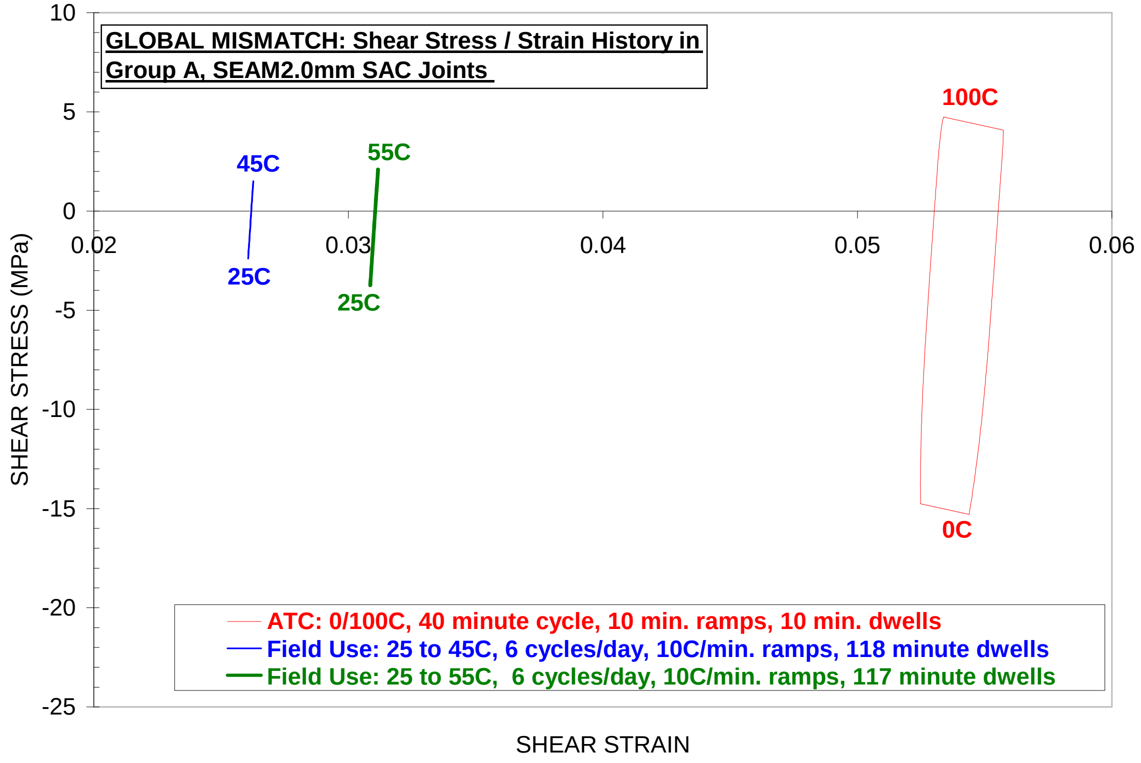
TABLE 1		
BODY HEIGHT	"A"	"B"
-02.0	.181	.0730
-03.0	.220	.1120
-03.5	.240	.1320
-00.1	N/A	N/A

"floor thickness" = Thickness of base or bottom of connector = "B" -0.020

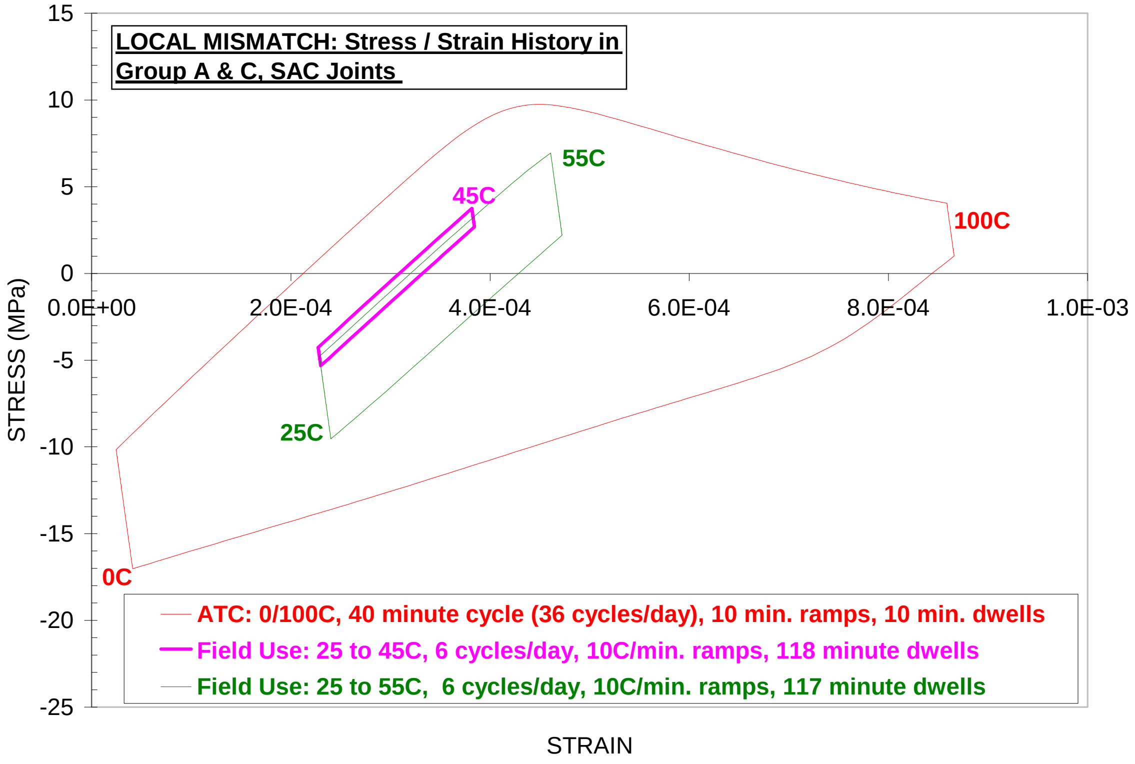
For SEAM 2.0 mm: floor thickness = 0.0730 - 0.020 = 0.053"
For SEAM 3.5 mm: floor thickness = 0.1320 -0.020 = 0.1120"

APPENDIX C: STRESS/STRAIN HYSTERESIS LOOPS

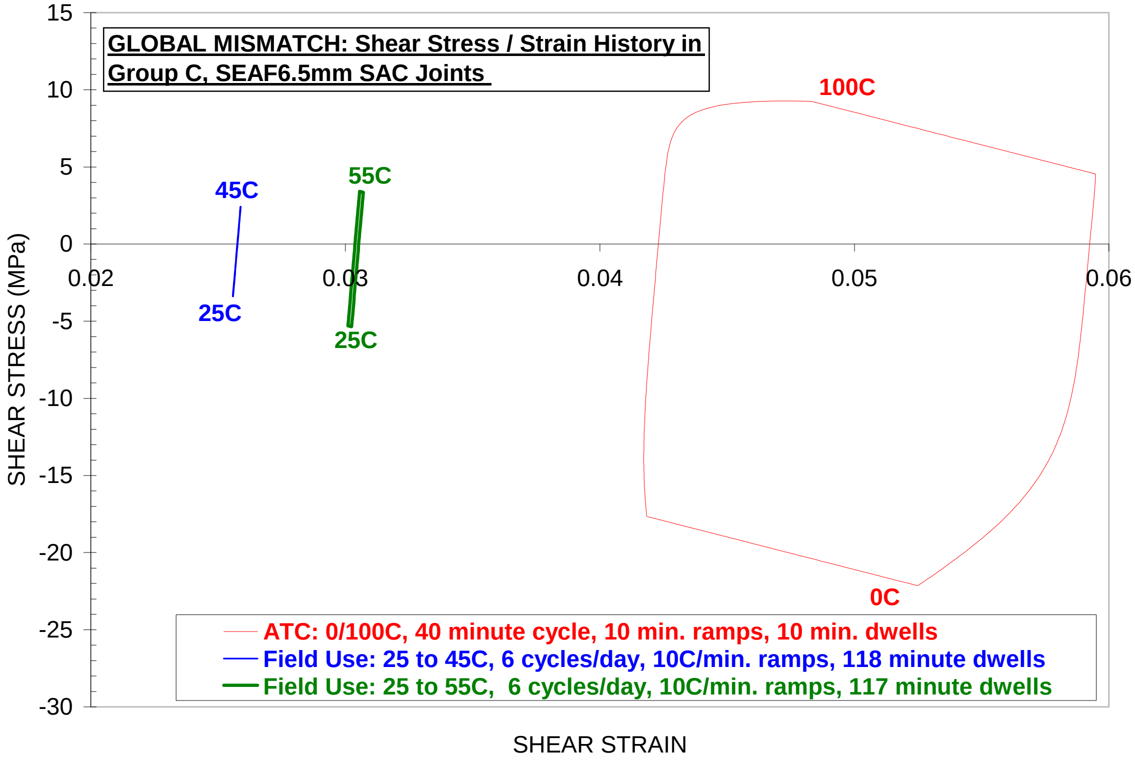


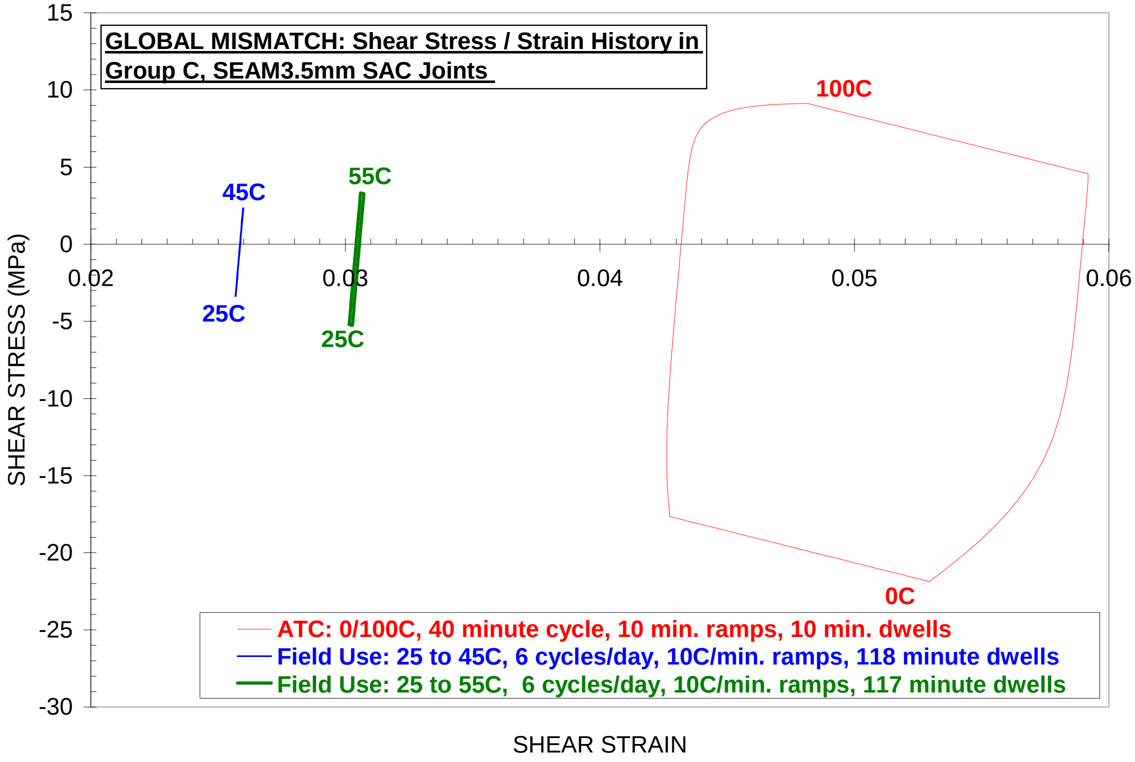


Group A (SAC, 7 mm stack) Assemblies: Global Mismatch Shear Stress/Strain Loops.

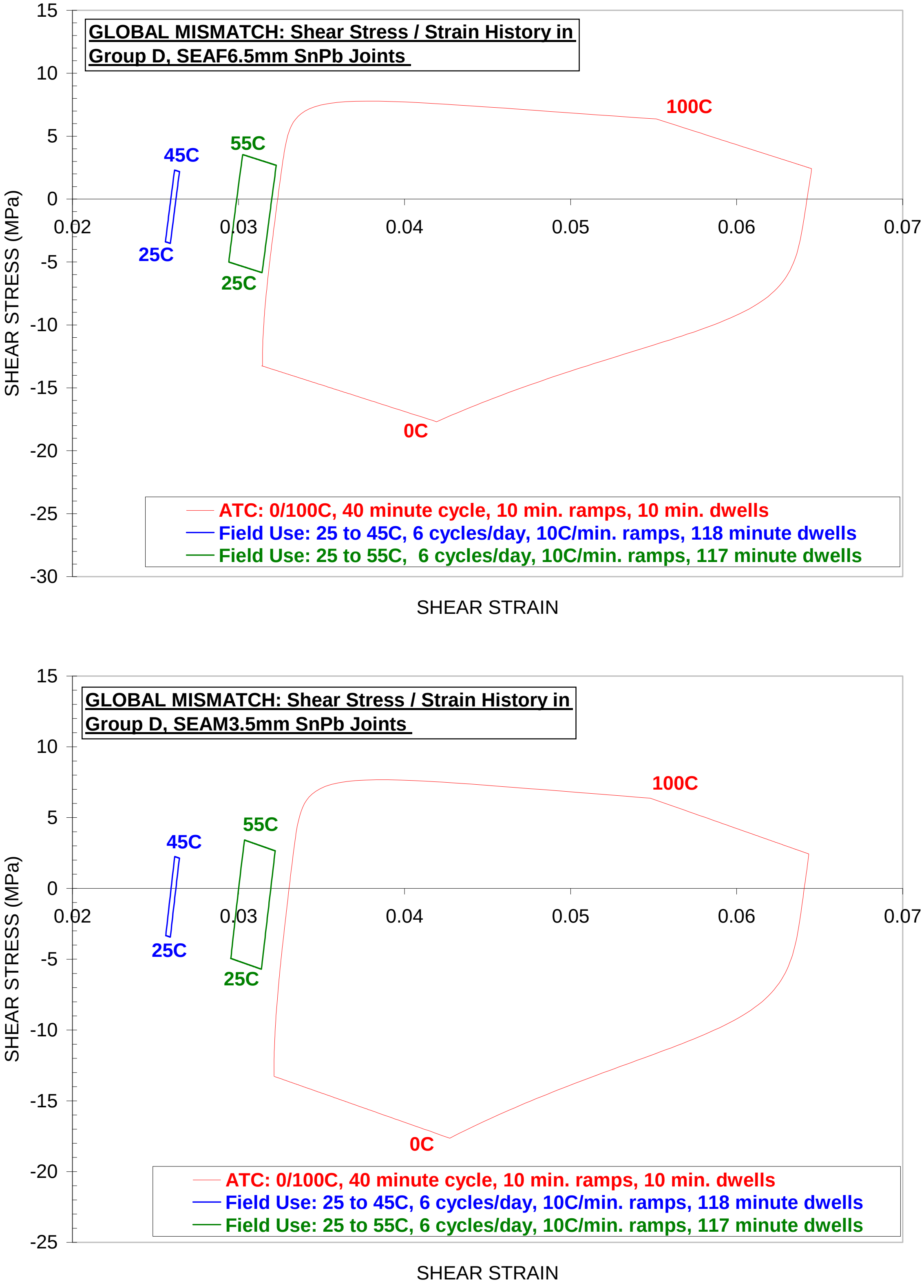


Group A (SAC, 7 mm) & C (SAC, 10 mm) Assemblies: Local Mismatch Stress/Strain Loops.

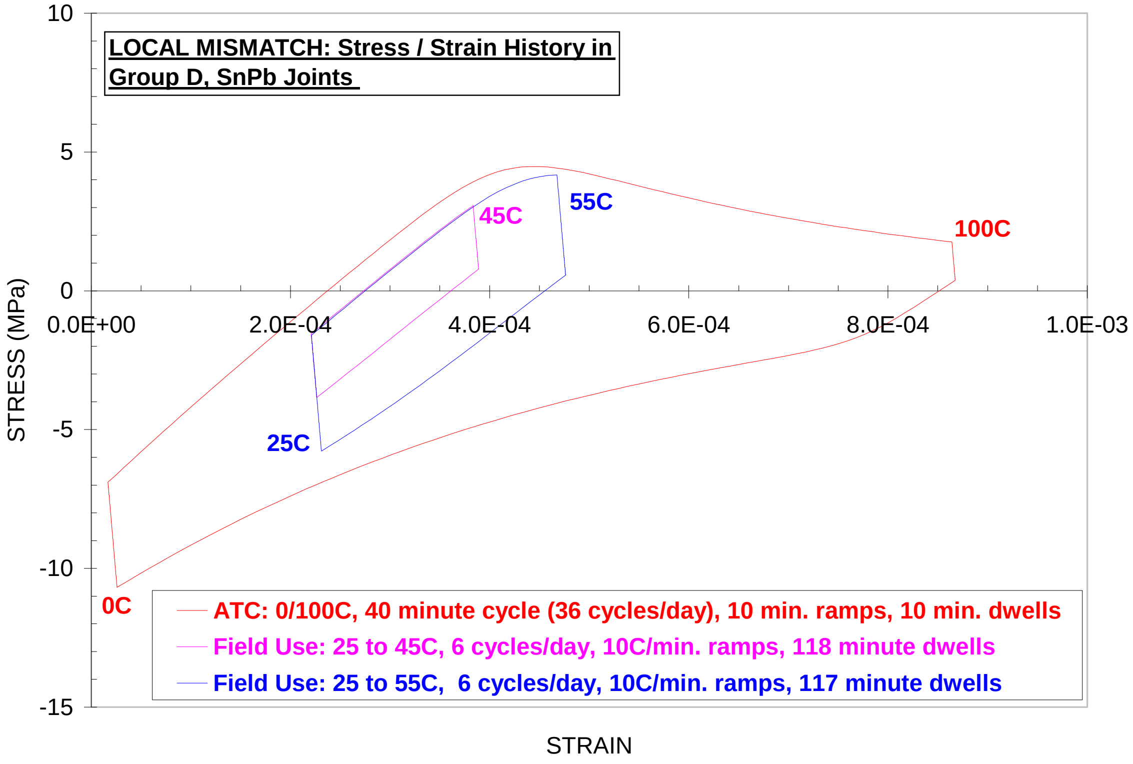




Group C (SAC, 10 mm stack) Assemblies: Global Mismatch Shear Stress/Strain Loops.



Group D (SnPb, 10 mm stack) Assemblies: **Global Mismatch Shear Stress/Strain Loops.**



Group D (SnPb, 10 mm) Assemblies: **Local Mismatch Stress/Strain Loops.**

APPENDIX D: STRAIN ENERGY RESULTS AND ACCELERATION FACTORS

Group A (7mm stack, SAC)Strain Energy Results and AFs

Group A: SAC, 7 mm stack, SEAF5.0

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 45C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**7.022E-02**	**1.274E-05**	
LOCAL MISMATCH	1.132E-02	1.855E-04	
TOTAL (LOCAL + GLOBAL)	**8.153E-02**	**1.982E-04**	**411.324**
% Local Strain Energy Over Total Strain Energy	13.881%	93.572%	

Table 1a: SAC results, 25/45C use conditions

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 55C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**7.022E-02**	**1.782E-04**	
LOCAL MISMATCH	1.132E-02	1.275E-03	
TOTAL (LOCAL + GLOBAL)	**8.153E-02**	**1.453E-03**	**56.118**
% Local Strain Energy Over Total Strain Energy	13.881%	87.736%	

Table 1b: SAC results, 25/55C use conditions.

Group A: SAC, 7 mm stack, SEAM2.0

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 45C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.690E-02**	**9.050E-06**	
LOCAL MISMATCH	1.132E-02	1.855E-04	
TOTAL (LOCAL + GLOBAL)	**5.822E-02**	**1.945E-04**	**299.260**
% Local Strain Energy Over Total Strain Energy	19.442%	95.348%	

Table 1c: SAC results, 25/45C use conditions

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 55C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.690E-02**	**1.252E-04**	
LOCAL MISMATCH	1.132E-02	1.275E-03	
TOTAL (LOCAL + GLOBAL)	**5.822E-02**	**1.400E-03**	**41.586**
% Local Strain Energy Over Total Strain Energy	19.442%	91.059%	

Table 1d: SAC results, 25/55C use conditions.

In 7mm stack SAC assemblies, solder joints on the SEAM side give the lowest acceleration factors (see AF results in Table 1c & d compared to results in Tables 1a & b above). We thus use AFs from Tables 1c & d for extrapolation of test results to use conditions. Note also that, under mild use conditions (25/45C and 25/55C), damage in solder joints is dominated by local mismatch strain energy, where as global mismatch strain energy is dominant under ATC conditions.

Group C (10 mm stack, SAC) Strain Energy Results and AFs

Group C: SAC, 10 mm stack, SEAF6.5

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 45C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.492E-01**	**7.938E-05**	
LOCAL MISMATCH	1.132E-02	1.855E-04	
TOTAL (LOCAL + GLOBAL)	**4.606E-01**	**2.649E-04**	**1738.867**
% Local Strain Energy Over Total Strain Energy	2.457%	70.029%	

Table 2a: SAC results, 25/45C use conditions

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 55C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.492E-01**	**1.260E-03**	
LOCAL MISMATCH	1.132E-02	1.275E-03	na
TOTAL (LOCAL + GLOBAL)	**4.606E-01**	**2.535E-03**	**181.680**
% Local Strain Energy Over Total Strain Energy	2.457%	50.284%	

Table 2b: SAC results, 25/55C use conditions.

Group C: SAC, 10 mm stack, SEAM3.5

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 45C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.132E-01**	**7.067E-05**	
LOCAL MISMATCH	1.132E-02	1.855E-04	
TOTAL (LOCAL + GLOBAL)	**4.246E-01**	**2.561E-04**	**1657.491**
% Local Strain Energy Over Total Strain Energy	2.666%	72.412%	

Table 2c: SAC results, 25/45C use conditions

JPC Compact Strain Energy Model for SAC3807/3906	**STRAIN ENERGY ΔW (MPa)**		**ACCELERATION FACTOR**
	ATC	**USE = 25C to 55C, 6 CYCLES/DAY**	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	**4.132E-01**	**1.112E-03**	
LOCAL MISMATCH	1.132E-02	1.275E-03	na
TOTAL (LOCAL + GLOBAL)	**4.246E-01**	**2.387E-03**	**177.885**
% Local Strain Energy Over Total Strain Energy	2.666%	53.408%	

Table 2d: SAC results, 25/55C use conditions.

In 10 mm stack SAC assemblies, solder joints on the SEAM side give the lowest acceleration factors: AF = 1657 for use conditions 25/45°C; and AF = 177 for use conditions 25/55°C (see AF results in above Tables 2a through 2d). We used those lowest values of AFs for extrapolation of test results to use conditions. Note also that, as in the case of Group A (7 mm stack, SAC) under mild use conditions (25/45°C and 25/55°C), damage in solder joints is dominated by local mismatch strain energy, where as global mismatch strain energy is dominant under ATC conditions.

Group D (10 mm stack, SnPb) Strain Energy Results and AFs

Group D: SnPb, 10 mm stack, SEAF6.5

JPC Compact Strain Energy Model for Sn37Pb	STRAIN ENERGY ΔW (MPa)		ACCELERATION FACTOR
	ATC	USE = 25C to 45C, 6 CYCLES/DAY	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	6.303E-01	1.786E-03	
LOCAL MISMATCH	5.167E-03	4.057E-04	
TOTAL (LOCAL + GLOBAL)	6.355E-01	2.192E-03	289.959
% Local Strain Energy Over Total Strain Energy	0.813%	18.511%	

Table 3a: SnPb results, 25/45C use conditions

JPC Compact Strain Energy Model for Sn37Pb	STRAIN ENERGY ΔW (MPa)		ACCELERATION FACTOR
	ATC	USE = 25C to 55C, 6 CYCLES/DAY	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	6.303E-01	1.794E-02	
LOCAL MISMATCH	5.167E-03	1.166E-03	
TOTAL (LOCAL + GLOBAL)	6.355E-01	1.911E-02	33.258
% Local Strain Energy Over Total Strain Energy	0.813%	6.100%	

Table 3b: SnPb results, 25/55C use conditions.

Group D: SnPb,10 mm stack, SEAM3.5

JPC Compact Strain Energy Model for Sn37Pb	STRAIN ENERGY ΔW (MPa)		ACCELERATION FACTOR
	ATC	USE = 25C to 45C, 6 CYCLES/DAY	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	6.112E-01	1.615E-03	
LOCAL MISMATCH	5.167E-03	4.057E-04	
TOTAL (LOCAL + GLOBAL)	6.164E-01	2.021E-03	305.070
% Local Strain Energy Over Total Strain Energy	0.838%	20.080%	

Table 3c: SnPb results, 25/45C use conditions

JPC Compact Strain Energy Model for Sn37Pb	STRAIN ENERGY ΔW (MPa)		ACCELERATION FACTOR
	ATC	USE = 25C to 55C, 6 CYCLES/DAY	AF= ΔW (ATC) / ΔW (USE)
GLOBAL MISMATCH	6.112E-01	1.616E-02	
LOCAL MISMATCH	5.167E-03	1.166E-03	na
TOTAL (LOCAL + GLOBAL)	6.164E-01	1.733E-02	35.573
% Local Strain Energy Over Total Strain Energy	0.838%	6.727%	

Table 3d: SnPb results, 25/55C use conditions.

In 10 mm stack SnPb assemblies, solder joints on the SEAF side give the lowest acceleration factors: AF = 289 for use conditions 25/45°C; and AF = 33 for use conditions 25/55°C (see AF results in above Tables 3a through 3d). We used those lowest values of AFs for extrapolation of test results to use conditions. As expected, the SnPb AFs are less than the SAC AFs in Group C (SAC, 10 mm stack). Note also that, in this case of SnPb assemblies, global mismatch strain energy is dominant under both ATC and use conditions.