Low-Silver BGA Assembly
Phase II – Reliability Assessment
Seventh Report: Mixed Metallurgy Solder Joint Thermal Cycling Results

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Abstract
Some ball grid array suppliers are migrating their sphere alloys from SAC305 (3% Ag) or SAC405 (4% Ag) to alloys with lower silver contents and often with "micro alloying" additions. There are numerous perceived reliability benefits to this change, but process compatibility and thermal fatigue reliability have yet to be fully demonstrated. The current study has been undertaken to characterize the influence of alloy type and reflow parameters on low-silver SAC spheres assembled with backward and forward compatible pastes and reflow profiles. This study combines low-silver sphere materials with eutectic tin-lead and lead-free SAC305 solder pastes.

This is the seventh report in a series being published as data become available, and presents the results of the thermal cycling of mixed metallurgy solder joints. Thermal cycling conditions include both 0 to 100°C and -40 to 125°C, with 10 minute dwell times. The accelerated thermal fatigue reliability of mixed Sn-Pb/Pb-free solder joints with varying Ag and "micro alloying" element concentrations are compared to those of 100% Sn-Pb and 100% Pb-free joints for four different package types. Further, the impact of thermal cycle conditions on the rank order of the reliability for the different solder joint compositions is presented. The implications of the data regarding the efficacy of using BGAs balled with low Ag alloys and soldered with Sn-Pb paste, and areas for future work are discussed.

Introduction

Since the original transition from Sn-Pb to Pb-free solders in the mid 2000s, the industry has continued to develop and deploy new Pb-free alloys. Low Ag alloys have received much of the attention due to their promising mechanical properties at moderate and high strain rates. However, as discussed in earlier papers of this series [1 – 6], these alloys raise process compatibility and thermal fatigue reliability concerns, specifically when used as solder spheres on area-array integrated circuit packages. The fatigue reliability concerns stem from early studies showing low Ag alloys may be less reliable than the Sn-Ag-Cu (SAC) compositions with 3 – 4% Ag [7]. More recent studies also suggest that low Ag SAC alloys may be less reliable that those with high Ag contents [8 – 10].

Another knowledge gap is that the reliability performance of mixed Sn-Pb/Pb-free joints using these low Ag BGA ball alloys has not been established. While most original equipment manufacturers (OEMs) try to avoid such "mixed metallurgy" situations, sometimes they become unavoidable. For example, low volume, "high reliability" product OEMs that are exempt from Pb-free regulations face the loss of supply of Sn-Pb-balled components as suppliers move to Pb-free solutions for their high volume customers. It is critical in such circumstances that the reliability of mixed metallurgy joints be established for all Pb-free alloys used on area-array components. Increasingly, these include low silver alloys.

This report is the third to present results from Phase II of our investigation, which addresses the thermal fatigue performance of several low-Ag alloys relative to eutectic Sn-Pb and SAC305. As discussed in the first report from Phase II [5], the experiment was designed to test both "mixed" joints (Pb-free balled packages assembled with eutectic Sn-Pb paste) and "unmixed" joints (either Sn-Pb balled packages assembled with Sn-Pb paste or Pb-free balled packages assembled with Pb-free paste). These unmixed assemblies give joints that are either 100% Sn-Pb or 100% Pb-free. This paper focuses on the results for mixed solder joints, and benchmarks their performance versus that of unmixed joints.

Our study on mixed joints was designed to answer several key questions about their thermal fatigue performance under accelerated conditions:

1. How does the performance of low-silver mixed joints compare to that of "unmixed" (100% Sn-Pb and 100% Pb-free) joints?
2. What is the quantitative impact of Ag concentration on the performance of mixed solder joints, and how does this compare to that for unmixed joints?
3. How does the variability in performance for mixed joints compare to that of unmixed joints?
4. How does the reliability at low failure rates (e.g., 1%) for mixed joints compare to that of unmixed joints?
5. How do the thermal fatigue conditions impact rank order of alloy performance and acceleration behavior for mixed joints?

The data presented in this paper provide, at least tentative, answers to the first four of these questions. The latter question is being examined in our ongoing work.

Experimental Materials and Procedures

Details of the experimental methods have been previously described [5,6], so only an overview is provided here.

Six sphere alloys were included in the investigation:

- SACX 0307 – Sn-0.3Ag-0.7Cu+ Bi+X,
- SAC 105 – Sn-1.0Ag-0.5Cu,
- LF35 – Sn-1.2Ag-0.5Cu + 0.05Ni,
- SAC 205 – Sn-2.0Ag-0.5Cu,
- SAC 305 – Sn-3.0Ag-0.5Cu (Pb-free baseline), and
- Sn-Pb – Sn-37Pb (Sn-Pb baseline).

Test assemblies included:

- Unmixed Joints
  - Components balled with Pb-free spheres and assembled with SAC305 paste (100% Pb-free joints),
  - Components balled with eutectic Sn-Pb spheres and assembled with eutectic Sn-Pb paste (100% Sn-Pb joints)
- Mixed Joints
  - Components balled with Pb-free spheres and assembled with eutectic Sn-Pb paste.

Four different BGA package types were studied:

- 1.27 mm pitch SuperBGA, 600 I/O; solder ball volume of 0.230 mm^3

- 1.0 mm pitch Plastic BGA, 324 I/O; solder ball volume of 0.131 mm^3
- 0.8 mm pitch ChipArray BGA, 288 I/O; solder ball volume of 0.051 mm^3
- 0.5 mm pitch ChipArray Thin Core BGA, 132 I/O; solder ball volume of 0.014 mm^3.

Note that solder ball volume varies by a factor of about 16 from the smallest to the largest components.

The test board used for this study has been shown in earlier papers [5,6] and has the characteristics given in Table 1. The pad finish on the area-array components was electrolytic Ni/Au.

Table 1. Test board characteristics.

Test Vehicle PCB Characteristics	
Thickness	0.093"
Finish	OSP
No. Cu Layers	2 Ground (1 oz.) layers 6 Signal (1/2 oz.) layers
Pad definition	Non-Solder Mask Defined
Laminate T_g	170°C
Laminate T_d	340°C

Typical microstructures for the mixed SnPb/Pb-free joints are given in Figure 1. As discussed in previous reports [1 - 4], the level of mixing between the Sn-Pb paste and the Pb-free ball is a function of ball size (which varies with pitch), reflow conditions, and alloy. For the Pb-free joints, any lack of mixing between the ball alloy and the SAC305 paste alloy is not discernable, either optically or with SEM, and "mixing" does not have meaning the way it does for mixed SnPb/Pb-free joints. Microstructures for these joints are typical of Pb-free joints for alloys of the type used in this study [1 – 4].

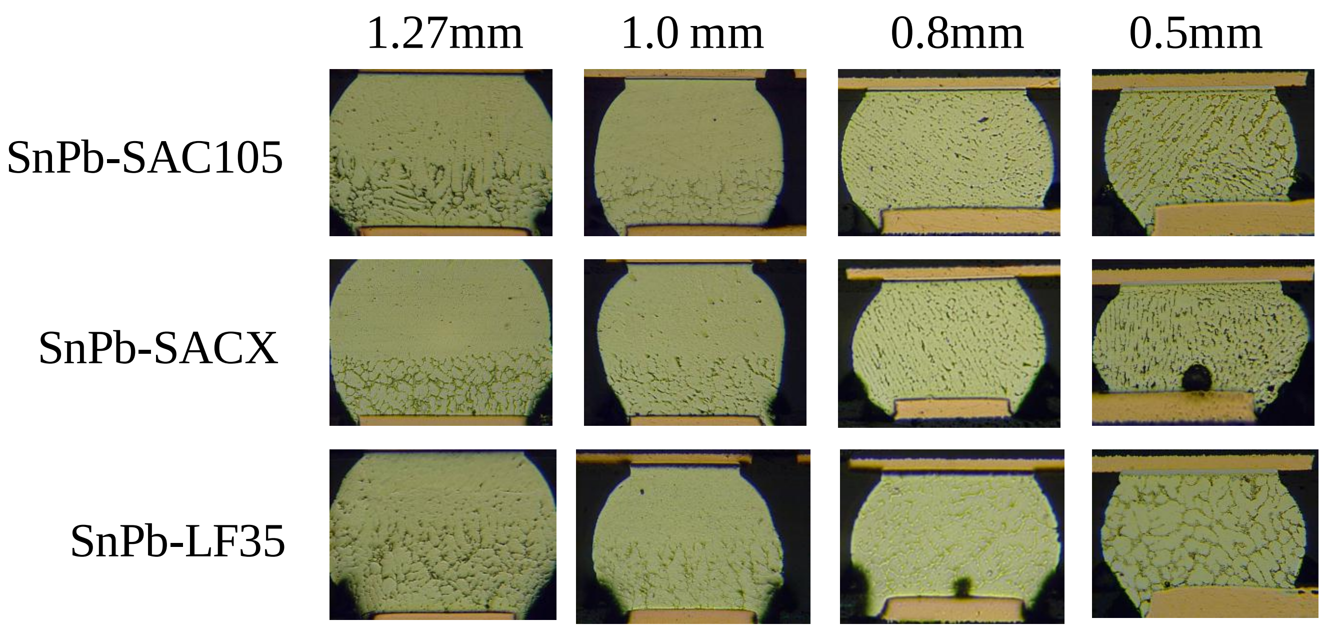


Figure 1 – Typical microstructures for mixed Sn-Pb/Pb-free solder joints tested in this study. Such joints were reflowed at peak temperatures of 215 °C to produce partial mixing on the larger packages (joints shown were formed in phase 1B [4]).

ATC Testing Procedure

Two target accelerated thermal cycle (ATC) profiles were selected for this study:

- IPC-9701A condition TC1: 0°C to 100°C with 10 minute ramps and dwells.
- IPC-9701A condition TC3: -40°C to 125°C with 16.5 minute ramps and 10 minute dwells.

The actual temperature profiles achieved experimentally were shown in our previous report [5] and are summarized in Table 2.

. **Table 2. Measured thermal cycle parameters.**

Nominal Profile	0/100°C	-40/+125°C
Range of Max. Temp. (°C)	101 to 104	126 to 129
Range of Min. Temp. (°C)	-4 to -1	-40.5 to -38.5
Range of High Temp. Dwell (min.)	10.5 to 12.0	10.5 to 13.5
Range of Low Temp. Dwell (min.)	8.5 to 10.5	9.0 to 11.5
Total Cycle Time (min.)	46.0 to 46.5	58

Solder joint integrity was monitored using one daisy-chain net for each package. Continuous in-situ monitoring of daisy-chain resistance was conducted throughout ATC testing, as described elsewhere [5]. The data acquisition software "flagged" a daisy-chain net as failed using the IPC-9701A standard criterion of a 20% resistance rise. For the data presented here, the tenth incidence of resistance reaching the failure criterion was used for plotting. This approach minimized the chance of plotting spurious signals rather than actual failures, and was intended to reduce "noise" in the Weibull curves.

The 0 to 100 °C test has been terminated after 10,068 cycles and the -40 to 125 °C test has been terminated after 3556 cycles. In both cases, the vast majority of components have failed, making further cycling unnecessary. Failure analysis (FA) currently is being performed, so in this paper it is assumed that all failures were due to thermal fatigue within the solder joint. Given this assumption, the results and conclusions cited here must be viewed as tentative until the failure modes are confirmed.

Results and Discussion

Table 3 summarizes the data collected in this study at test termination. The values given represent the number of failed packages for east test cell. Since 20 packages were placed under test for each "cell," a value less than 20 indicates that not all packages had failed prior to test termination. Note that for the 0.5 mm pitch Sn-Pb/Sn-Pb packages tested under the 0 to 100 °C condition, one early failure was discounted, so 19 failed packages represents completion of this test cell. If no value is provided in a cell then no packages were tested for the listed condition. Overall, 96.5% of packages were tested to failure.

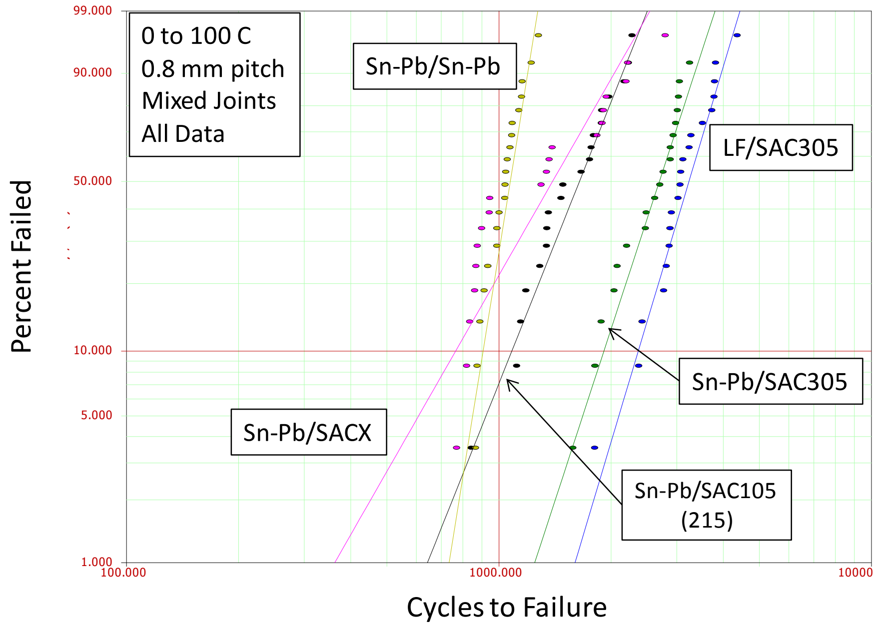
The anomalous late failures that commonly occurred for unmixed joints [6] were not so prevalent for mixed joints. Still, to address such cases and for consistency with the analysis for unmixed joints, the procedure to minimize the impact of "late" failures on the Weibull analyses was repeated for mixed joints. As described in our earlier paper [6], data for all test cells were truncated after 13 failures, corresponding to a failure rate of 65%, or just above the characteristic life, η. Figure 2 shows an example of how this procedure affects the Weibull data. All the joints represented in this figure were assembled using Sn-Pb paste except for those in the data set marked LF/SAC305, for which lead-free SAC305 paste was used to assemble components balled with SAC305.

A summary of all the Weibull data for mixed solder joints is given in the Appendix. Data are tabulated for analyses using all the available data and for the truncated data sets. The characteristic life (N63, or η), Weibull slope (beta, β), and correlation coefficient (rho, ρ) are given for each test cell. In some cases, the estimated number of cycles to 1% failure, N1, is also listed. Data for the unmixed cells were provided in the previous report [6]. Note that the 0/100 °C results given in the Appendix for the baseline Sn-Pb/Sn-Pb and SAC305/SAC305 test cells have been updated to include failures occurring since our last report.

Table 3. Thermal cycling progress at test termination.

			Failures 0 to 100 C (10,068 cycles)				Failures -40 to 125 C (3556 cycles)			
Paste Alloy	Ball Alloy	Peak Reflow T	0.5mm Part	0.8mm Part	1.0mm Part	1.27mm Part	0.5mm Part	0.8mm Part	1.0mm Part	1.27mm Part
Sn-Pb	Sn-Pb	215	19	20	20	20	20	20	20	20
Sn-Pb	SAC105	215	20	20	20	20	20	20	20	18
Sn-Pb	SAC105	220			20	17			20	20
Sn-Pb	SAC205	215								
Sn-Pb	SAC305	215	18	19	20	11	20	20	20	14
Sn-Pb	SACx	215	20	20	20	16	20	20	20	20
Sn-Pb	LF35	215	20				20			
SAC305	SAC105	235	20	20	19	15	20	20	20	18
SAC305	SAC205	235	20	20	20	19	20	20	19	20
SAC305	SAC305	235	20	20	19	10	20	20	20	19
SAC305	SACx	235	20	20	20	19	20	20	20	20
SAC305	LF35	235	20				20			

(a)



(b)

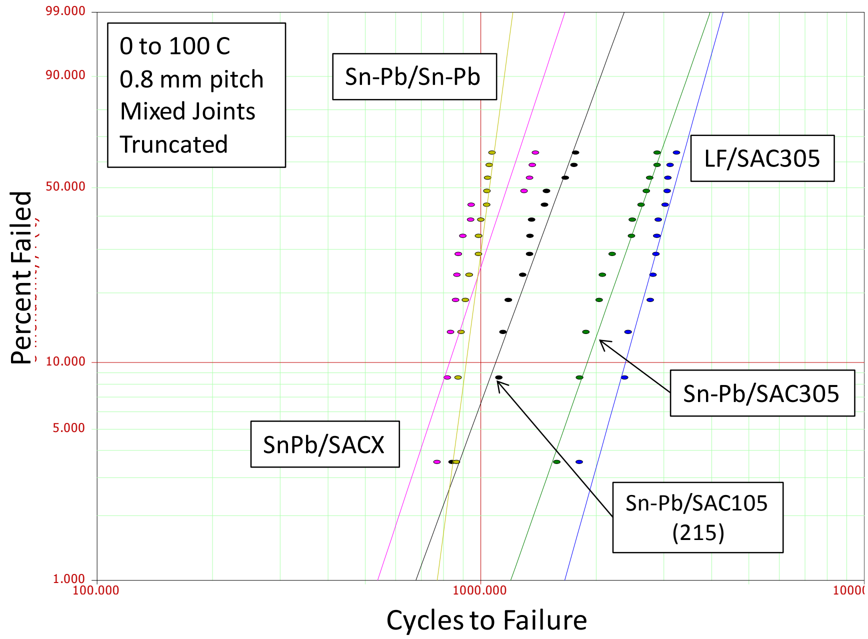


Figure 2 - Weibull failure plots for 0.8mm pitch components tested under the 0 to 100 °C profile. The plots show results for: (a) all data, and (b) data truncated at a failure percentage of 65%.

When the solder paste and solder sphere alloys are not the same the final solder joint composition is a combination of the two. The final composition depends on the amount of metal coming from these two sources, which in turn depends on the relative amounts of metal in the paste brick and the solder sphere. This ratio depends on ball size, paste brick volume, fraction of metal in the paste, and the alloy compositions. Assuming that full mixing of the two alloys takes place in the joint (which will depend on reflow conditions [1 – 4]) one can estimate the final composition of the solder joint. Professor John Pan of the California Polytechnic State University has published an on-line calculator to estimate mixed solder joint compositions [11]. Table 4 lists the estimated solder joint compositions for the alloys and packages used in this study. These estimates were made based on measured stencil aperture diameters and assuming a cylindrical paste brick. Transfer ratios were measured and were essentially 100%, except for the 0.5 mm pitch part for which the transfer ratio was about 82%. Both pastes were 50% metal by volume.

For the Pb-free joints, Table 4 demonstrates that the mixture of a low Ag ball alloy with SAC305 paste has the largest impact on overall joint composition for the small package (small ball volume) and lowest Ag ball alloys. For example, the nominal SACX Ag content of 0.3% changes to an overall joint Ag concentration of 0.83% (nearly triple) for the 0.5mm package, but only 0.52% (less than double) for the 1.27mm package. Similarly, for the SAC205 ball alloy, the Ag content increases from the nominal 2.0% to 2.2% for the 0.5 mm package and 2.08% for the 1.27 mm package; as a percentage increase, these are quite minimal. Also note that the results for the mixed Sn-Pb/Pb-free joints must be interpreted with caution since, as shown in Fig. 1, complete mixing may not occur for the larger packages. Finally, Table 4 also lists the estimated liquidus temperatures based on the calculated compositions. Keep in mind that mixed joints were reflowed at a peak temperature of 215 °C (except for one set of SAC105-balled parts reflowed at 220 °C). Thus, a liquidus temperature greater than 215 °C may suggest challenges in achieving full ball collapse and full mixing [1 – 4].

Table 4. Solder joint compositions estimated using Prof. Pan's on-line calculator [11].

		0.5mm CTBGA-132					0.8mm CABGA-288				
Paste Alloy	Ball Alloy	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)
Sn-Pb	Sn-Pb	37.00	0.00	0.00	63.00	183.00	37.00	0.00	0.00	63.00	183.00
Sn-Pb	SAC105	7.90	0.79	0.39	90.92	216.19	5.49	0.85	0.43	93.23	218.86
Sn-Pb	SAC305	7.86	2.36	0.39	89.39	211.35	5.46	2.56	0.43	91.55	213.61
Sn-Pb	SACX	7.91	0.24	0.55	91.30	216.64	5.49	0.26	0.60	93.65	219.36
Sn-Pb	LF35	7.90	0.94	0.39	90.77	215.70	---	---	---	---	---
SAC305	SAC105	0.00	1.39	0.50	98.11	223.73	0.00	1.27	0.50	98.23	224.11
SAC305	SAC205	0.00	2.20	0.50	97.30	221.24	0.00	2.14	0.50	97.36	221.43
SAC305	SAC305	0.00	3.00	0.50	96.50	218.75	0.00	3.00	0.50	96.50	218.75
SAC305	SACX	0.00	0.83	0.66	98.51	224.21	0.00	0.67	0.67	98.66	224.62
SAC305	LF35	0.00	1.55	0.50	97.95	223.24	---	---	---	---	---

		1.0mm PBGA-324					1.27mm SBGA-600				
Paste Alloy	Ball Alloy	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)
Sn-Pb	Sn-Pb	37.00	0.00	0.00	63.00	183.00	37.00	0.00	0.00	63.00	183.00
Sn-Pb	SAC105	3.65	0.90	0.45	95.00	220.90	3.35	0.91	0.45	95.29	221.23
Sn-Pb	SAC305	3.63	2.71	0.45	93.21	215.33	3.33	2.73	0.45	93.49	215.61
Sn-Pb	SACX	3.66	0.27	0.63	95.44	221.42	3.36	0.27	0.64	95.73	221.76
Sn-Pb	LF35	---	---	---	---	---	---	---	---	---	---
SAC305	SAC105	0.00	1.18	0.50	98.32	224.39	0.00	1.16	0.50	98.34	224.44
SAC305	SAC205	0.00	2.09	0.50	97.41	221.57	0.00	2.08	0.50	97.42	221.60
SAC305	SAC305	0.00	3.00	0.50	96.50	218.75	0.00	3.00	0.50	96.50	218.75
SAC305	SACX	0.00	0.54	0.68	98.78	224.93	0.00	0.52	0.68	98.80	224.98
SAC305	LF35	---	---	---	---	---	---	---	---	---	---

Using the truncated data, Figures 3 – 6 show the characteristic life as a function of estimated Ag concentration in the joint for all four package types. Figures 3 and 5 show the results for unmixed joints and can be compared to the plots provided in our previous paper [6], in which the silver content of the BGA ball alloy was plotted instead of the estimated overall composition of the joints. This comparison shows that differences in the two methods of plotting are minor. With the impact of the SAC305 paste on joint composition taken into account, the rise in η from the 100% Sn-Pb joints to the joints using SACX and SAC105 spheres is less steep, particularly for the smaller packages. Otherwise, no changes to the nature of the curves or the findings presented in the earlier report occur when plotting the estimated solder joint compositions.

The data in Fig. 4 show the general trends in performance for the mixed Sn-Pb/Pb-free joints as a function of estimated silver concentration for the 0 to 100 °C profile. Of course, caution is needed when interpreting these data since they assume a homogeneous distribution of elements in the joints. The micrographs in Figure 1 suggest, however, that this assumption likely is not valid for the larger packages. This fact could account for the unexpected drop in η when comparing the mixed Sn-Pb/SAC305 joints (estimated [Ag] $\cong$ 2.7%) to the baseline SAC305/SAC305 joints ([Ag] = 3.0%) for the 1.0 mm pitch components. Figure 4 also shows that for each package type all the mixed joints performed better than the baseline 100% Sn-Pb joints, at least using N63 as the metric (see discussion below). Overall, the curves for the mixed joints are fairly similar to those of the unmixed ones.

Mixed joint data for the -40 °C to 125 °C profile shown in Fig. 6 are reasonably similar to those given in Fig. 5 for unmixed joints, with a few notable exceptions. First, for each package type the mixed joints perform better than the baseline Sn-

Pb/Sn-Pb joints. This was not the case for unmixed joints of the two large packages; SACX joints were the lowest performers for the 1.0 mm and 1.27 mm packages (Fig. 5). Also, for the 0.5 mm package the peak in η for the SACX joints is more pronounced for the mixed than the unmixed joints. Finally, as for the 1.0 mm part exposed to the 0 to 100 °C profile, there is a drop in η from the mixed SAC305 joints to the fully lead-free SAC305 joints for the 1.0 mm and 1.27 mm packages. Partial mixing may explain this behavior but more investigation is needed before that conclusion can be made.

Finally, Figs. 4 and 6 show that the rank order of alloy performance, while varying by package type for mixed joints as for unmixed joints [6], is generally maintained for the two thermal cycle profiles. Within experimental error, these data show performance to scale in order of increasing Ag concentration, except for the 0.5mm pitch component which shows a plateau in performance across nearly the whole spectrum of Pb-free ball alloys. The only other exception to this rule is for the 1.27 mm component at the two highest Ag concentrations.

One concern about mixed Sn-Pb/Pb-Free solder joints is that manufacturing challenges or microstructural variability may lead an increase of early failures. In production, of course, even a small percentage of early failures are unacceptable, and OEMs typically design for 1% or fewer failures within the design or warranty life. Thus, even if the characteristic life (63% failures) for mixed joints is acceptable, one must also examine the breadth of variability (slope of the Weibull curve) and the projected life at low failure levels.

For this reason, the mixed solder joint data were compared with the corresponding unmixed (100% Pb-free and 100% Sn-Pb) baseline data to ascertain if the mixed joints exhibit greater variability (lower β) and/or lower values of life at the 1% failure level, N1. Since only 20 parts were tested for each cell, the N1 values were taken from the best-fit line of the Weibull plot extrapolated to 1% failures. Results for the truncated data sets are presented here, since they are less affected by possible anomalies at high failure levels.

Figure 7 gives results for the 0.5 mm pitch part exposed to the -40/+125 °C profile. This data set exemplifies the common finding in which the mixed solder joints have lower β and N1 values than the corresponding Pb-free alloys, despite having comparable values of N63. The exact reason for such behavior requires more study, but may be due to manufacturing challenges at the peak reflow temperature of 215 °C for mixed joints, which is lower than the liquidus temperature for some packages and alloys (Table 4). For unmixed joints, the peak reflow temperature (235 °C for lead free paste and 215 °C for Sn-Pb paste) always exceeded the liquidus temperature of the joint (221 °C for 100% SAC305 joints and 183 °C for 100% Sn-Pb joints). Further, for the mixed joints, even if the peak reflow temperature was high enough to create ball collapse, incomplete mixing could lead to microstructural variability that in turn could lead to high variability in thermal fatigue performance.

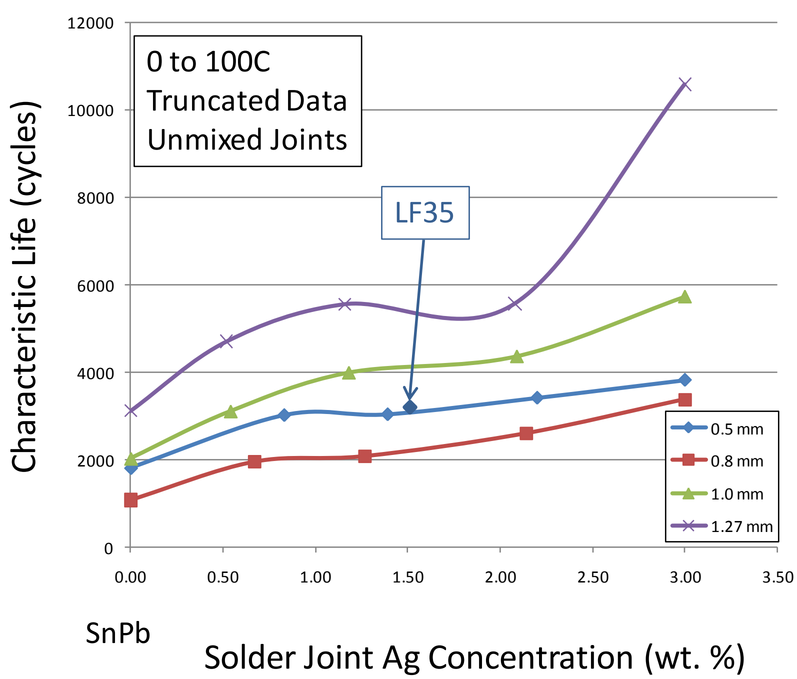


Figure 3 - Characteristic life of unmixed assemblies as a function of estimated Ag concentration in the solder joint for the 0 to 100 °C profile (truncated data).

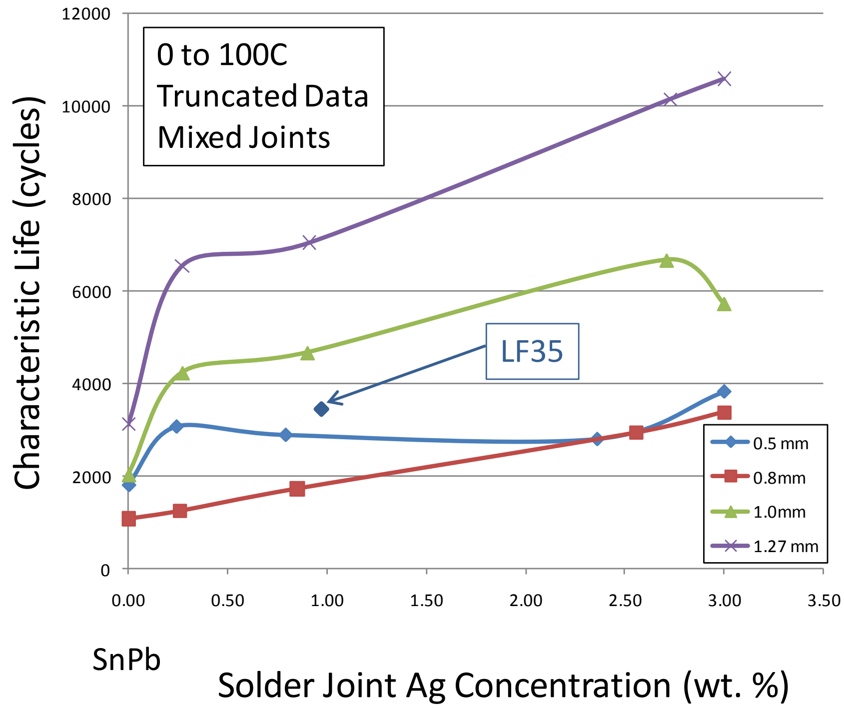


Figure 4 - Characteristic life of mixed assemblies as a function of estimated Ag concentration in the solder joint for the 0 to 100 °C profile (truncated data). Data points at a silver concentration of 3% are for the SAC305/SAC305 baseline.

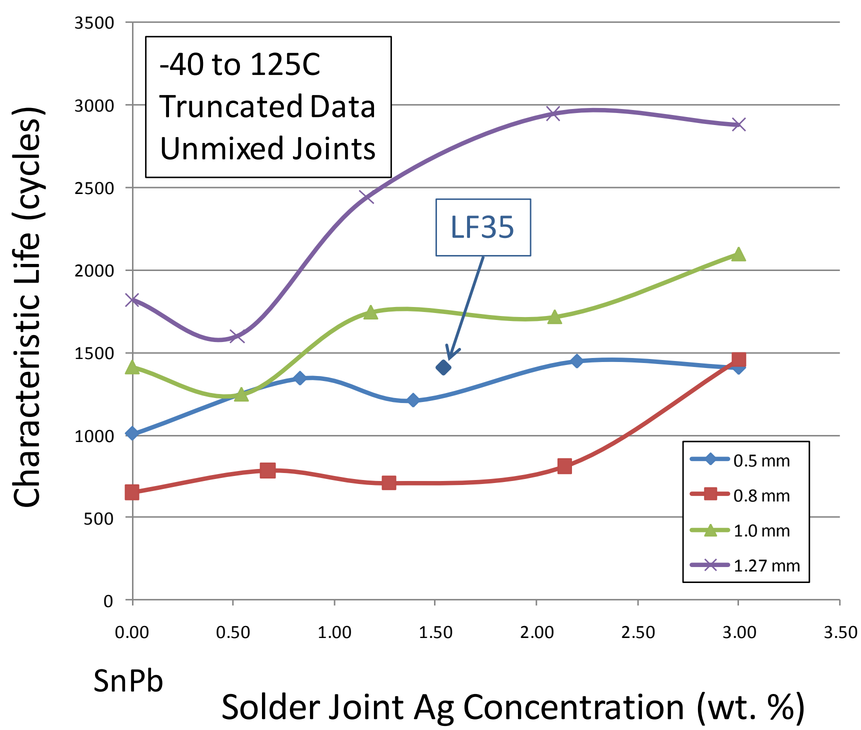


Figure 5 - Characteristic life of unmixed assemblies as a function of estimated Ag concentration in the solder joint for the -40 to 125 °C profile (truncated data).

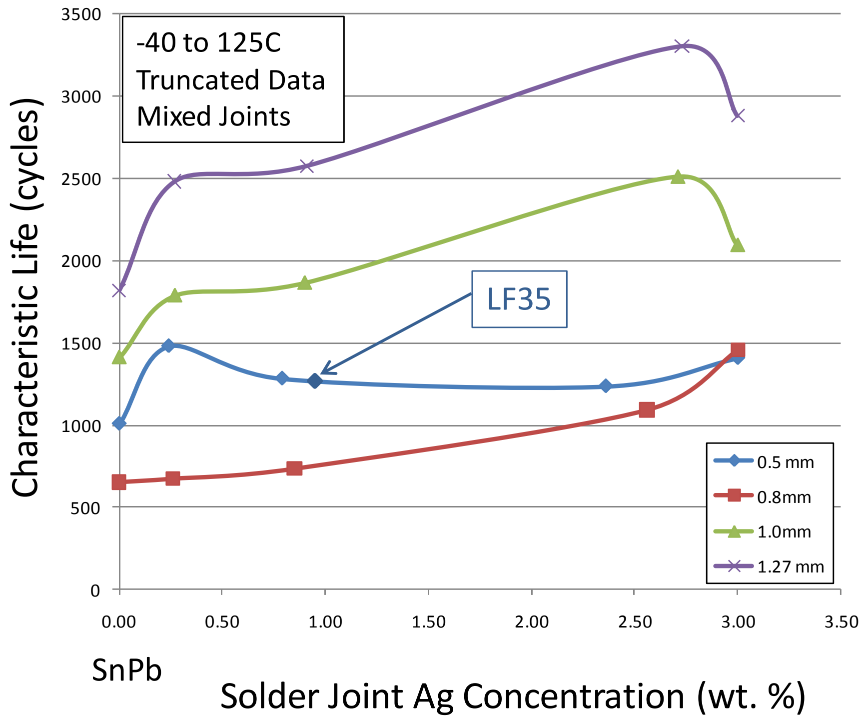


Figure 6 - Characteristic life of mixed assemblies as a function of estimated Ag concentration in the solder joint for the -40 to 125 °C profile (truncated data). Data points at a silver concentration of 3% are for the SAC305/SAC305 baseline.

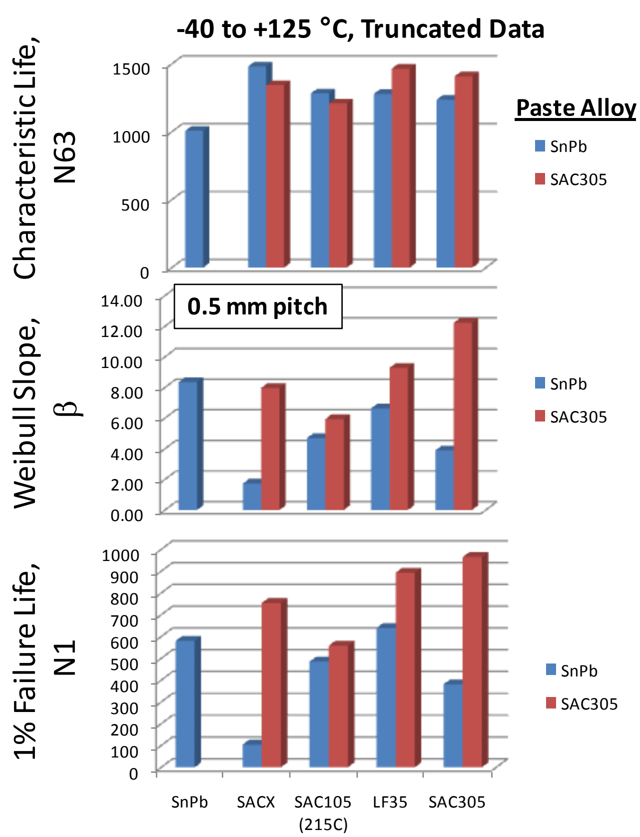


Figure 7 - Comparison of characteristic life, Weibull slope, and 1% failure life for mixed and unmixed solder joints. Data are for 0.5 mm pitch CTBGA-132 packages tested using the -40/125 °C profile (truncated data).

Full inspection of all the data, however, show that not every data set exhibited behavior such as that shown in Fig. 7. For example, Fig. 8 shows data for the 1.27 mm pitch component tested using the 0/100 °C profile. In this case, the N1 values for the SAC105 (215 °C peak reflow temperature) sphere alloy are the same within 10% for both paste alloys. Furthermore, the Pb-free SAC305 joints actually show lower β and N1 values than the mixed Sn-Pb/SAC305 joints.

Given these inconsistencies, an analysis was done to determine whether or not a clear trend is apparent when examining all the data. Table 5 shows the results of this analysis. While not overwhelming, it does appear that there is a tendency for the mixed solder joints to show greater variability (lower β) and lower reliability at low failure levels than their Pb-free counterparts. This general trend is apparent by the high percentages in the last two columns of Table 5 compared to those in the earlier columns. As stated, however, this trend is not followed for all data sets so care must be taken in making too firm a conclusion. Still, these results point to the need to be cautious when interpreting reliability data for mixed solder joints and to take into account possible tendencies for early failures.

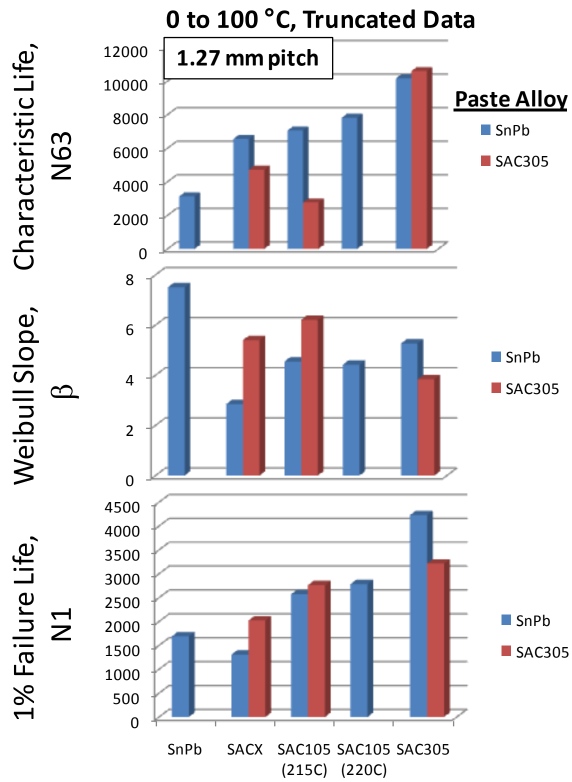


Figure 8 - Comparison of characteristic life, Weibull slope, and 1% failure life for mixed and unmixed solder joints. Data are for 1.27 mm pitch SBGA-600 packages tested using the 0/100 °C profile (truncated data).

Table 5. Summary of trends in the measured variability and reliability at low failure rates. Truncated data.

0 to 100 C	Mixed > Pb-Free (%)		Mixed ~ Pb-Free (%) *		Pb-Free > Mixed (%)	
Ball Alloy	Beta	N1	Beta	N1	Beta	N1
SACX	0	0	25	25	75	75
SAC105 (215 C)	0	25	50	50	50	25
LF35 **	0	0	0	0	100	100
SAC305	50	25	0	0	50	75
-40 to 125 C	Mixed > Pb-Free (%)		Mixed ~ Pb-Free (%) *		Pb-Free > Mixed (%)	
Ball Alloy	Beta	N1	Beta	N1	Beta	N1
SACX	50	50	0	0	50	50
SAC105 (215 C)	25	25	25	25	50	50
LF35 **	0	0	0	0	100	100
SAC305	25	25	25	25	50	50
* Values the same within 10%						
** Data available only for the 0.5 mm pitch package						

Summary and Preliminary Conclusions

Thermal cycle test data have been presented for eutectic Sn-Pb and five Pb-free solder ball alloys attached to four different package types. Assemblies were constructed to produce 100% Sn-Pb, 100% Pb-free and mixed Sn-Pb/Pb-free solder joints. These joints were tested under thermal cycling conditions of 0 to 100 °C and -40 to +125 °C. This report has focused on the behavior of mixed joints as compared to their fully Pb-free and Sn-Pb counterparts. Failure analyses and complete analysis of all test data have yet to be performed, but the findings as of the writing of this paper have been presented.

At this point, the answers to the questions posed in the Introduction appear to be as follows.

1. *How does the performance of low-silver mixed joints compare to that of "unmixed" (100% Sn-Pb and 100% Pb-free) joints?* Based on values of characteristic life, the mixed solder joints perform better than or equal to those of 100% Sn-Pb joints for all of the package types studied. Compared to Pb-free joints, the mixed joints may perform better, worse, or about the same. No clear pattern of relative performance has yet been established.
2. *What is the quantitative impact of Ag concentration on the performance of mixed solder joints, and how does this compare to that for unmixed joints?* Overall, the curves of characteristic life as a function of silver concentration for mixed joints tested using the 0/100 °C profile are similar to those of unmixed joints. Reliability increases with increasing [Ag], but not in a linear manner. For the -40/125 °C profile, mixed joint results are again similar to those for unmixed joints, with a few exceptions noted in the paper.
3. *How does the variability in performance for mixed joints compare to that of unmixed joints?* It appears that there is a tendency for the mixed solder joints to show greater variability (lower β) than their Pb-free counterparts. However, this trend is not followed for all data sets so care must be taken in making this conclusion too firmly.
4. *How does the reliability at low failure rates (e.g., 1%) for mixed joints compare to that of unmixed joints?* As with variability in performance, there is a tendency for the mixed solder joints to show worse reliability at low failure levels than their Pb-free counterparts. While this trend is not followed for all data sets, clearly one must be cautious when interpreting reliability data for mixed solder joints and to take into account possible tendencies for early failures.

Now that testing has been completed, future work is focused on failure analysis and further analysis of the data. Significant findings will be reported as they become available.

ACKNOWLEDGMENTS

The author wish to acknowledge Doug Lamond of HP for analyzing the substantial quantity of data so that Weibull plots could be constructed.

References

[1] C. Shea, et al., "Low-Silver BGA Assembly Phase 1 – Reflow Considerations and Joint Homogeneity Initial Report," Proceedings of APEX, 2008.
[2] C. Shea, et al., "Low-Silver BGA Assembly Phase 1 – Reflow Considerations and Joint Homogeneity Second Report: SAC105 Spheres with Tin-Lead Solder Paste," Proceedings of SMTA International, 2008.
[3] Chu, Q., et al., "Low-Silver BGA Assembly Phase 1 – Reflow Considerations and Joint Homogeneity Third Report: Comparison of Four Low-Silver Sphere Alloys and Assembly Process Sensitivities," Proceedings of APEX, 2009.
[4] C. Shea, et al., "Low-Silver BGA Assembly Phase II – Reflow Considerations and Joint Homogeneity Fourth Report: Sensitivity to Process Variations, Proceedings of SMTA International 2009.
[5] G. Henshall, et al., "Low-Silver BGA Assembly, Phase II – Reliability Assessment. Fifth Report: Preliminary Thermal Cycling Results," Proceedings APEX, S23_03, 2010.
[6] G. Henshall, et al., "Low-Silver BGA Assembly, Phase II – Reliability Assessment. Sixth Report: Thermal Cycling Results for Unmixed Joints," Proceedings SMTAi, p. 595, 2010.
[7] S. Terashima et al., "Effect of Silver Content on Thermal Fatigue Life of Sn-xAg-0.5Cu Flip-Chip Interconnects," **J. Electronic Materials, Vol. 32, no. 12**, 2003.
[8] R. Coyle, et al., "The Effect of Silver Content on the Solder Joint Reliability of a Pb-Free PBGA Package," Proceedings SMTAi, p. 613, 2010.
[9] Richard Coyle, et al., "The Influence of the Pb free Solder Alloy Composition and Processing Parameters on Thermal Fatigue Performance of a Ceramic Chip Resistor, Proceedings 59th ECTC, 423-430, May 26-29, 2009.
[10] G. Henshall et al., "Comparison of Thermal Fatigue Performance of SAC105 (Sn-1.0Ag-0.5Cu), Sn-3.5Ag, and SAC305 (Sn-3.0Ag-0.5Cu) BGA Components with SAC305 Solder Paste," Proceedings APEX, p. S05-03, 2009.
[11] J. Pan, "Lead-Free Liquidus Temperature Calculator," http://www.calpoly.edu/~pan/LTCalculator.html (2008).

Appendix – Tabulated Weibull Data

Table A.1. Mixed solder joint thermal cycling results: 0 to 100 °C profile. All data represented.

Paste	Ball Alloy	Peak Reflow T (C)	Pitch	N63	N1	Beta	Rho
SnPb	SnPb	215	0.5mm	1848	1138	9.41	0.9803
		215	0.8mm	1109	737	11.18	0.9688
		215	1.0mm	2206	1245	8.05	0.8843
		215	1.27mm	3660	1255	4.28	0.9153
SnPb	SACX	235	0.5mm	3146	1493	6.15	0.9806
		235	0.8mm	1565	364	3.15	0.9061
		235	1.0mm	3822	1417	4.63	0.9346
		235	1.27mm	7140	1132	2.50	0.9785
SnPb	LF35	235	0.5mm	3472	1380	4.99	0.9829
SnPb	SAC105	215	0.5mm	2927	1811	9.52	0.9916
		215	0.8mm	1784	642	4.51	0.9866
		215	1.0mm	4874	2527	6.97	0.9767
		215	1.27mm	7156	2482	4.34	0.9922
SnPb	SAC105	220	1.0mm	4638	2470	7.30	0.9679
		220	1.27mm	8013	2658	4.16	0.9735
SnPb	SAC305	235	0.5mm	3156	1415	5.70	0.7525
		235	0.8mm	2881	1249	5.50	0.9854
		235	1.0mm	6555	2528	4.82	0.9684
		235	1.27mm	10156	4229	5.27	0.9440
SAC305	SAC305	235	0.5mm	3775	2246	8.81	0.9870
		235	0.8mm	3440	1598	6.01	0.9803
		235	1.0mm	5777	2892	6.99	0.9922
		235	1.27mm	8211	3211	6.68	0.9069

Table A.2. Mixed solder joint thermal cycling results: -40 to 125 °C profile. All data represented.

Paste	Ball Alloy	Peak Reflow T (C)	Pitch	N63	N1	Beta	Rho
SnPb	SnPb	215	0.5mm	1016	565	7.86	0.9737
		215	0.8mm	664	425	10.27	0.9756
		215	1.0mm	1398	877	9.88	0.9826
		215	1.27mm	2022	767	4.75	0.9318
SnPb	SACX	235	0.5mm	1354	122	1.91	0.9833
		235	0.8mm	745	153	2.92	0.9743
		235	1.0mm	1852	1042	7.93	0.9653
		235	1.27mm	2525	1190	6.11	0.9736
SnPb	LF35	235	0.5mm	1365	565	5.19	0.9654
SnPb	SAC105	215	0.5mm	1272	479	4.74	0.9709
		215	0.8mm	711	161	3.09	0.9918
		215	1.0mm	1849	1000	7.50	0.9552
		215	1.27mm	2589	1069	5.19	0.9870
SnPb	SAC105	220	1.0mm	2054	1250	9.25	0.9670
		220	1.27mm	2129	878	5.18	0.9556
SnPb	SAC305	235	0.5mm	1232	375	3.89	0.9871
		235	0.8mm	1118	363	4.09	0.9914
		235	1.0mm	2442	1273	7.05	0.9645
		235	1.27mm	3319	1653	6.58	0.9693
SAC305	SAC305	235	0.5mm	1542	808	7.21	0.9271
		235	0.8mm	1446	510	4.39	0.9931
		235	1.0mm	2088	1320	10.02	0.9804
		235	1.27mm	2951	1116	4.71	0.9850

Table A.3. Mixed solder joint thermal cycling results: 0 to 100 °C profile. Truncated data.

Paste	Ball Alloy	Peak Reflow T (C)	Pitch	N63	N1	Beta	Rho
SnPb	SnPb	215	0.5mm	1816	1194	11.00	0.9818
		215	0.8mm	1084	772	13.49	0.9569
		215	1.0mm	2024	1475	14.04	0.9790
		215	1.27mm	3124	1690	7.51	0.9675
SnPb	SACX	235	0.5mm	3078	1541	6.64	0.9612
		235	0.8mm	1253	541	5.45	0.8186
		235	1.0mm	4232	1183	3.59	0.9507
		235	1.27mm	6546	1306	2.85	0.9917
SnPb	LF35	235	0.5mm	3391	1448	5.38	0.9672
SnPb	SAC105	215	0.5mm	2898	1847	10.19	0.9904
		215	0.8mm	1733	680	4.90	0.9746
		215	1.0mm	4667	2715	8.49	0.9704
		215	1.27mm	7051	2569	4.55	0.9878
SnPb	SAC105	220	1.0mm	4464	2677	9.02	0.9766
		220	1.27mm	7813	2783	4.42	0.9589
SnPb	SAC305	235	0.5mm	2808	1771	9.91	0.9510
		235	0.8mm	2942	1200	5.12	0.9823
		235	1.0mm	6672	2456	4.58	0.9413
		235	1.27mm	10156	4229	5.27	0.9440
SAC305	SAC305	235	0.5mm	3835	2190	8.17	0.9891
		235	0.8mm	3383	1654	6.44	0.9662
		235	1.0mm	5733	3036	7.21	0.9883
		235	1.27mm	10594	3212	3.84	0.9166

Table A.4. Mixed solder joint thermal cycling results: -40 to 125 °C profile. Truncated data.

Paste	Ball Alloy	Peak Reflow T (C)	Pitch	N63	N1	Beta	Rho
SnPb	SnPb	215	0.5mm	1007	580	8.35	0.9578
		215	0.8mm	653	438	11.53	0.9613
		215	1.0mm	1411	871	9.44	0.9734
		215	1.27mm	1819	954	7.16	0.9770
SnPb	SACX	235	0.5mm	1481	104	1.73	0.9777
		235	0.8mm	674	185	3.57	0.9636
		235	1.0mm	1788	1107	9.64	0.9384
		235	1.27mm	2483	1253	6.69	0.9964
SnPb	LF35	235	0.5mm	1279	639	6.64	0.9735
SnPb	SAC105	215	0.5mm	1283	485	4.70	0.9645
		215	0.8mm	735	151	2.89	0.9900
		215	1.0mm	1865	993	7.26	0.9154
		215	1.27mm	2576	1079	5.30	0.9832
SnPb	SAC105	220	1.0mm	1983	1345	11.83	0.9869
		220	1.27mm	1939	1045	7.39	0.9575
SnPb	SAC305	235	0.5mm	1236	381	3.89	0.9830
		235	0.8mm	1093	375	4.31	0.9849
		235	1.0mm	2511	1214	6.30	0.9480
		235	1.27mm	3307	1668	6.66	0.9654
SAC305	SAC305	235	0.5mm	1408	965	12.22	0.9326
		235	0.8mm	1457	499	4.28	0.9913
		235	1.0mm	2095	1323	9.91	0.9644
		235	1.27mm	2882	1156	5.01	0.9795

Low-Silver BGA Assembly
Phase II – Reliability Assessment
Seventh Report: Mixed Metallurgy Solder Joint Thermal Cycling Results

Greg Henshall and Michael Fehrenbach, Hewlett-Packard

Chrys Shea, Shea Engineering Services

Quyen Chu and Girish Wable, Jabil

Ranjit Pandher, Cookson Electronics

Ken Hubbard and Gnyaneshwar Ramakrishna, Cisco Systems

Ahmer Syed, Amkor

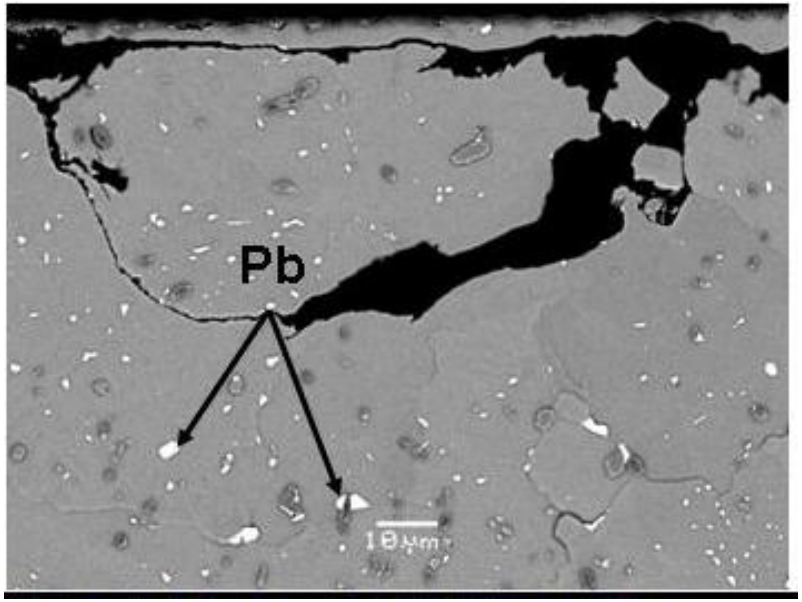
April 2011

Outline

- Introduction
- Experimental Materials and Procedures
  - Test Vehicles
  - ATC Testing
- Results for Mixed Solder Joints
- Preliminary Conclusions and Next Steps

Reduced Ag content may reduce thermal fatigue resistance but more work needed

- Growing number of studies recently and some knowledge gaps remain
- **Performance of low Ag BGAs when soldered using Sn-Pb paste (backward compatibility)**
- Impact of microalloy additions (e.g. Ni) unknown
- Impact of alloy composition on the acceleration factor unknown
  - Relates accelerated test life to life in the field

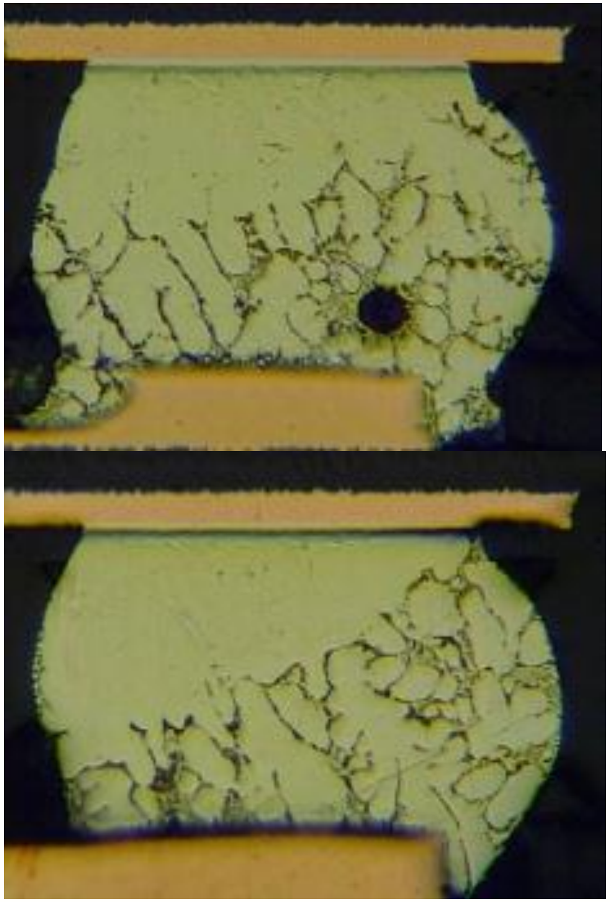


SAC105 component soldered with Sn-Pb paste; Thermal cycled to failure.
Coyle et al., SMTAI 2010

Impact of alloy composition on thermal fatigue life in the field difficult to judge

Reliability of Mixed Sn-Pb/Pb-Free Joints Must Be Established for Low Ag BGAs

- Most OEMs try to avoid mixing Sn-Pb and Pb-free soldering technologies
- Mixing sometimes unavoidable
    - Loss of supply of Sn-Pb BGAs for products out of scope for RoHS
- Little data on thermal fatigue reliability of mixed joints using low Ag BGAs
  (Coyle, et al., SMTAI 2010)



Mixed Sn-Pb/Pb-free solder joints
Shea, et al., APEX 2009

Mixed Joints: Questions to Answer about Thermal Fatigue Performance

1. How does the performance of low-silver mixed joints compare to that of “unmixed” (100% Sn-Pb and 100% Pb-free) joints?
2. What is the quantitative impact of Ag concentration on the performance of mixed joints and how does this compare to that for unmixed ones?
3. How does the variability in performance for mixed joints compare to that of unmixed joints?
4. How does the reliability at low failure rates (e.g. 1%) for mixed joints compare to that of unmixed joints?
5. How do the thermal fatigue conditions impact rank order of alloy performance and acceleration behavior for mixed joints?

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Solder Alloy Combinations

Solder Ball Alloys Studied:

- SnPb: Sn-37Pb ← Sn-Pb Baseline
- SAC 305: Sn-3.0Ag-0.5Cu ← Pb-free Baseline
- SACX 0307: Sn-0.3Ag-0.7Cu + Bi + X
- SAC 105: Sn-1.0Ag-0.5Cu
- LF35: Sn-1.2Ag-0.5Cu + 0.05Ni
- SAC 205: Sn-2.0Ag-0.5Cu

Low Ag

Mixed and Unmixed Solder Joints Manufactured:

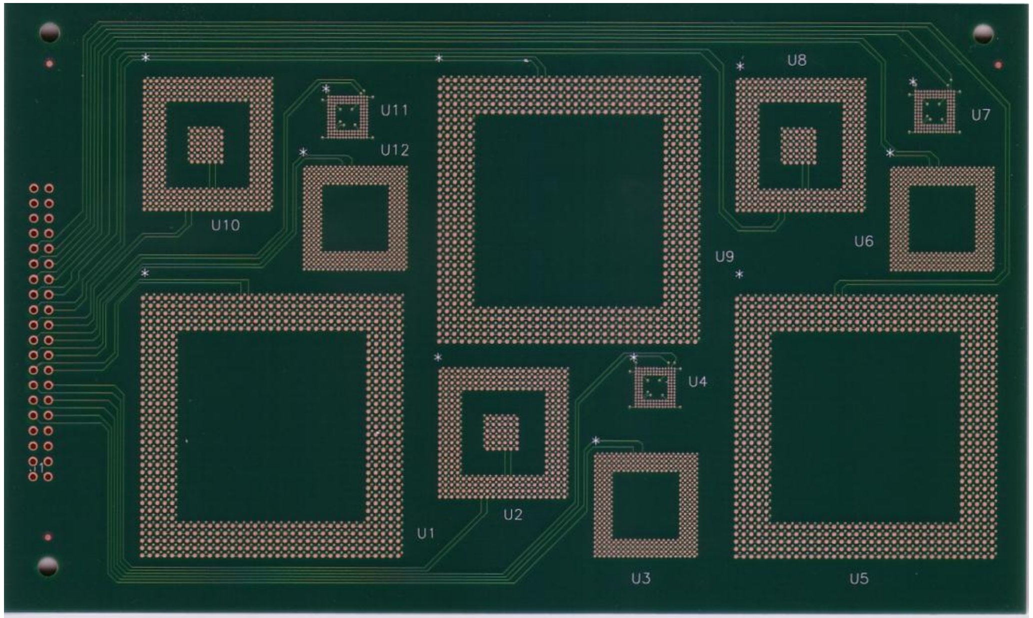
- Eutectic Sn-Pb paste with eutectic Sn-Pb components
- SAC305 paste with Pb-free components

Unmixed

- Eutectic Sn-Pb paste with Pb-free components ← Mixed

Test Vehicle – PCB Design

- PCB Dimensions:
  - 6.800” x 4.075” x **0.093**”
- Finish
  - Copper OSP
- Number of Layers
  - 2 Ground [1 oz.] Layers,
  - 6 Signal Layers
- Non-Solder Mask Defined Pads
- Tg = 170 ºC
- Td = 340 ºC

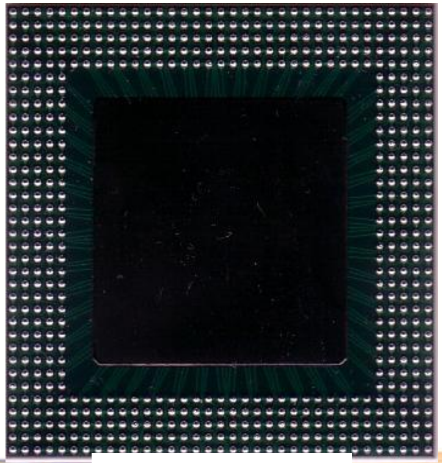


Bare Test Board
Designed by iNEMI Mixed Metals Project

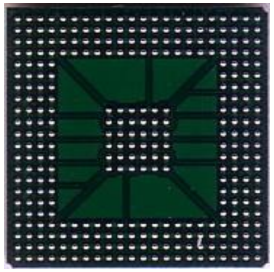
Test Vehicle – Components

Component Part #	I/O Count	Ball Pitch (mm)	Package Size (mm)	Ball Dia. - As Rec'd (mm)	Ball Diameter (mm)	Ball Height (mm)	Ball Volume (mm^3)	Qty Per Brd
A-SBGA600-1.27mm-45mm	600	1.27	45	0.76	0.62	0.52	0.2298	3
A-PBGA324-1.0mm-23mm	324	1	23	0.63	0.45	0.55	0.1309	3
A-CABGA288-.8mm-19mm	288	0.8	19	0.46	0.48	0.36	0.0510	3
A-CTBGA132-0.5mm-8mm	132	0.5	8	0.3	0.32	0.19	0.0141	3

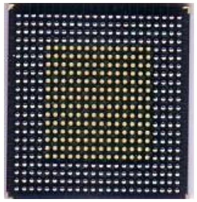
16x variation



1.27mm SBGA600



1.0mm PBGA324



0.8mm CABGA

0.5mm CTBGA132

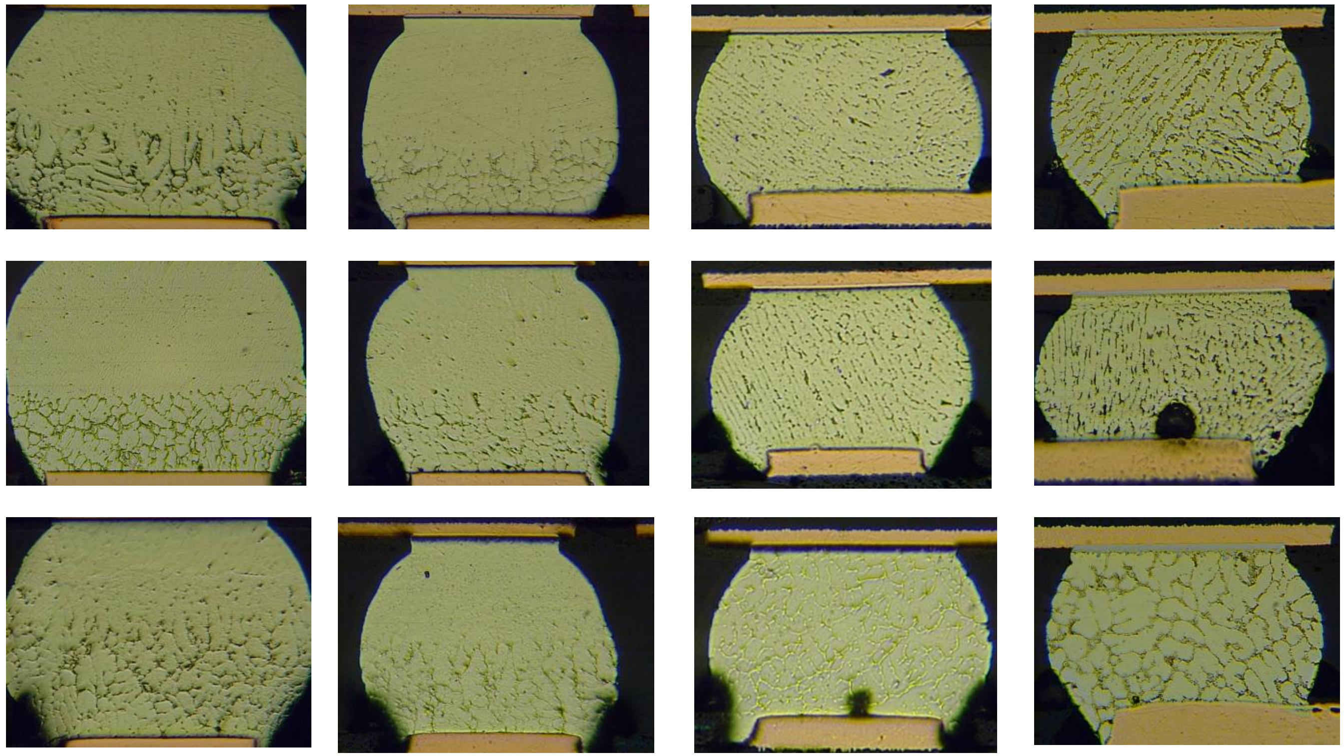
Mixed Sn-Pb/Pb-free microstructures

1.27mm 1.0 mm 0.8mm 0.5mm

SnPb-SAC105

SnPb-SACX

SnPb-LF35



Typical microstructures for mixed SnPb/Pb-free solder joints reflowed at peak temperatures of 215 ^{o}C to produce partial mixing on the larger packages (joints shown were formed in phase 1B).

Thermal Cycle Profiles & Failure Detection

Two target ATC profiles selected for this study:

- IPC-9701A condition TC1: 0 ^{o}C to 100 ^{o}C with 10 minute ramps and dwells (40 minute total cycle time)
- IPC-9701A condition TC3: -40 ^{o}C to 125 ^{o}C with 16.5 minute ramps and 10 minute dwells (53 minute total cycle time)

Nominal Profile	0/100^{o}C	-40/+125^{o}C
Range of Max. Temp. (^{o}C)	101 to 104	126 to 129
Range of Min. Temp. (^{o}C)	-4 to -1	-40.5 to -38.5
Range of High Temp. Dwell (min.)	10.5 to 12.0	10.5 to 13.5
Range of Low Temp. Dwell (min.)	8.5 to 10.5	9.0 to 11.5
Total Cycle Time (min.)	46.0 to 46.5	58

- **Continuous daisy-chain resistance monitoring** (1 net per component)
- **Electrical resistance failure criterion**
  - $R(T) > 1.20 \bullet R_o(T)$
  - Plots show 10th occurrence of failure (decrease noise)

Data Collected at Test Termination

			10,068 cycles				3556 cycles			
			Failures 0 to 100 C				Failures -40 to 125 C			
Paste Alloy	Ball Alloy	Peak Reflow T	0.5mm Part	0.8mm Part	1.0mm Part	1.27mm Part	0.5mm Part	0.8mm Part	1.0mm Part	1.27mm Part
Sn-Pb	Sn-Pb	215	19	20	20	20	20	20	20	20
Sn-Pb	SAC105	215	20	20	20	20	20	20	20	18
Sn-Pb	SAC105	220			20	17			20	20
Sn-Pb	SAC205	215								
Sn-Pb	SAC305	215	18	19	20	11	20	20	20	14
Sn-Pb	SACx	215	20	20	20	16	20	20	20	20
Sn-Pb	LF35	215	20				20			
SAC305	SAC105	235	20	20	19	15	20	20	20	18
SAC305	SAC205	235	20	20	20	19	20	20	19	20
SAC305	SAC305	235	20	20	19	10	20	20	20	19
SAC305	SACx	235	20	20	20	19	20	20	20	20
SAC305	LF35	235	20				20			

- 20 components under test for each ‘cell’
- Both chambers now halted; testing complete
- 96.5% of parts tested to failure
- Failure analysis pending; assume all failures due to thermal fatigue in solder

Outline

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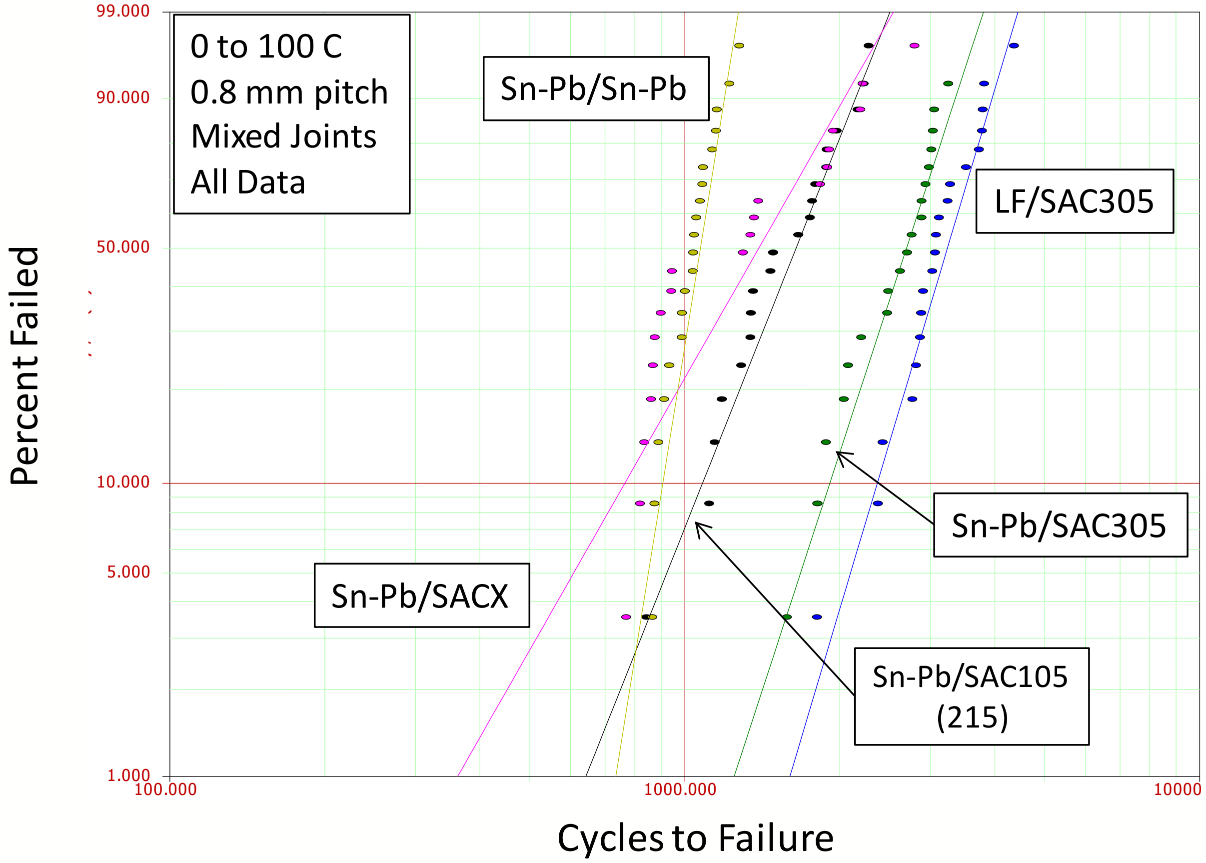
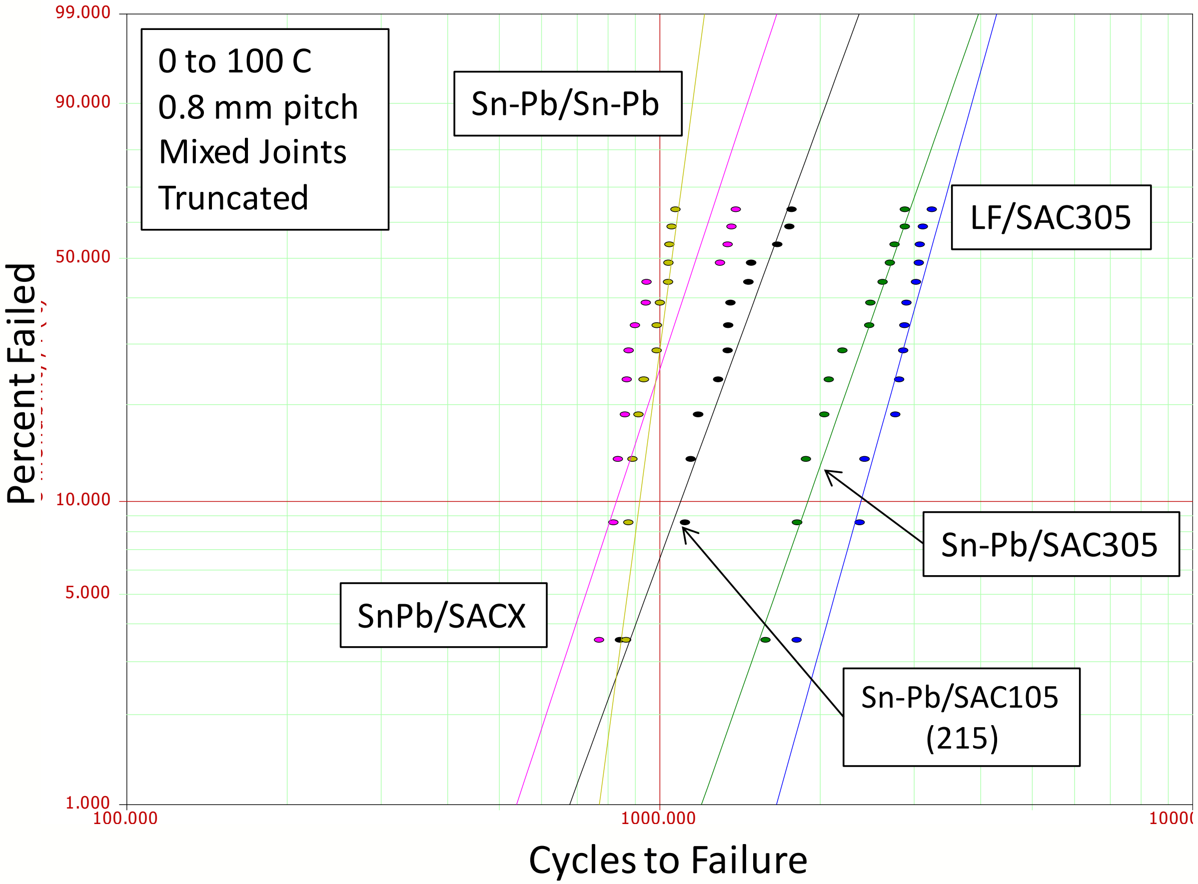
0/100 0.8mm Pitch – All Data Mixed Joints Compared to Controls



- Weibull plots of failure data compare results for:
  - Mixed joints (Pb-free ball with Sn-Pb paste)
  - Baseline Sn-Pb/Sn-Pb and SAC305/SAC305 joints (LF/SAC305)
- Few mixed joint data sets showed anomalous late failures like those observed for unmixed joints

0/100 0.8mm Pitch – Truncated Mixed Joints Compared to Controls



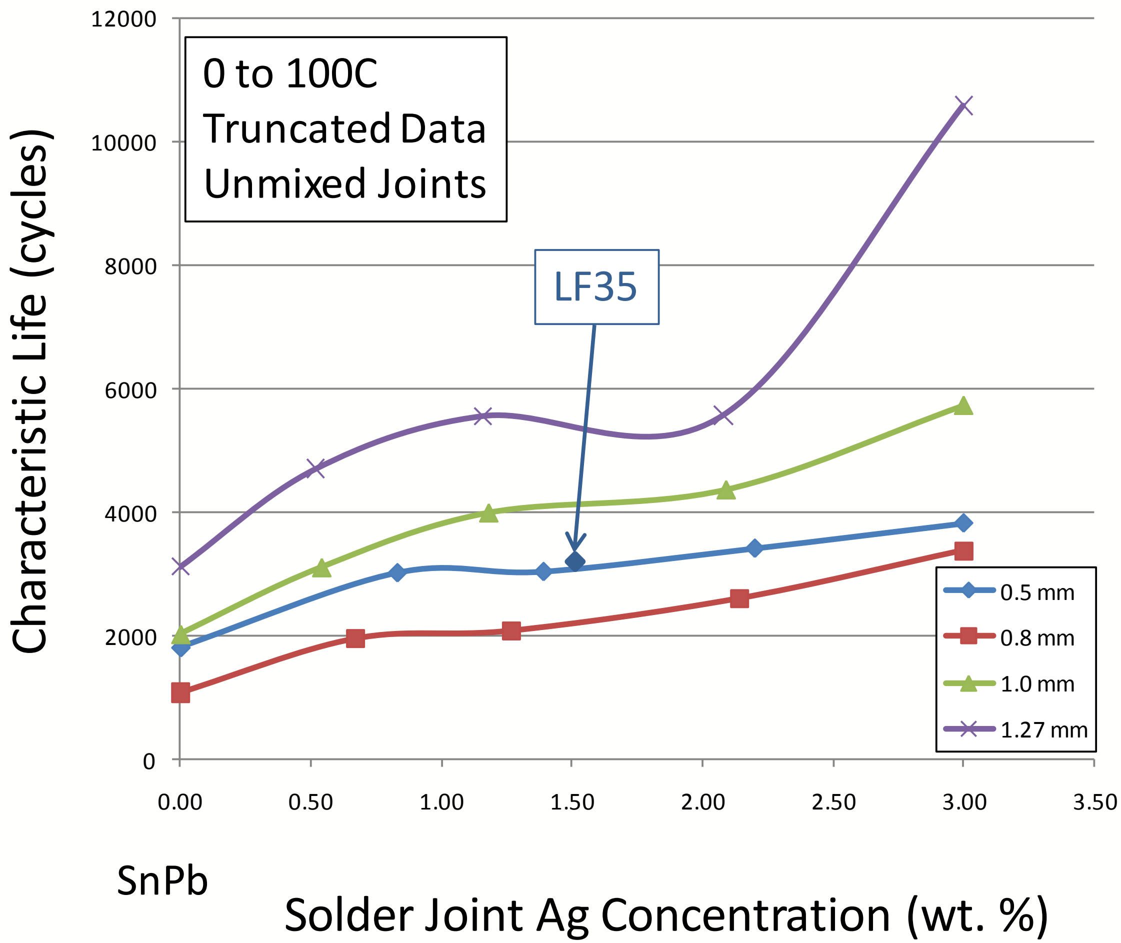
- Truncate data near N63 (13/20 parts → N65)
- Addresses the few mixed data sets with late failures
- Consistency of approach used for unmixed data
- Results using this approach labeled as "Truncated"
- Truncated and non-truncated data tabulated in paper for mixed and baseline test cells

Solder Joint Composition Estimates

- Estimates made using Prof. John Pan's on-line calculator
  http://www.calpoly.edu/~pan/LTCalculator.html
- Assumes full mixing
- Smallest and largest packages shown; paper gives all values

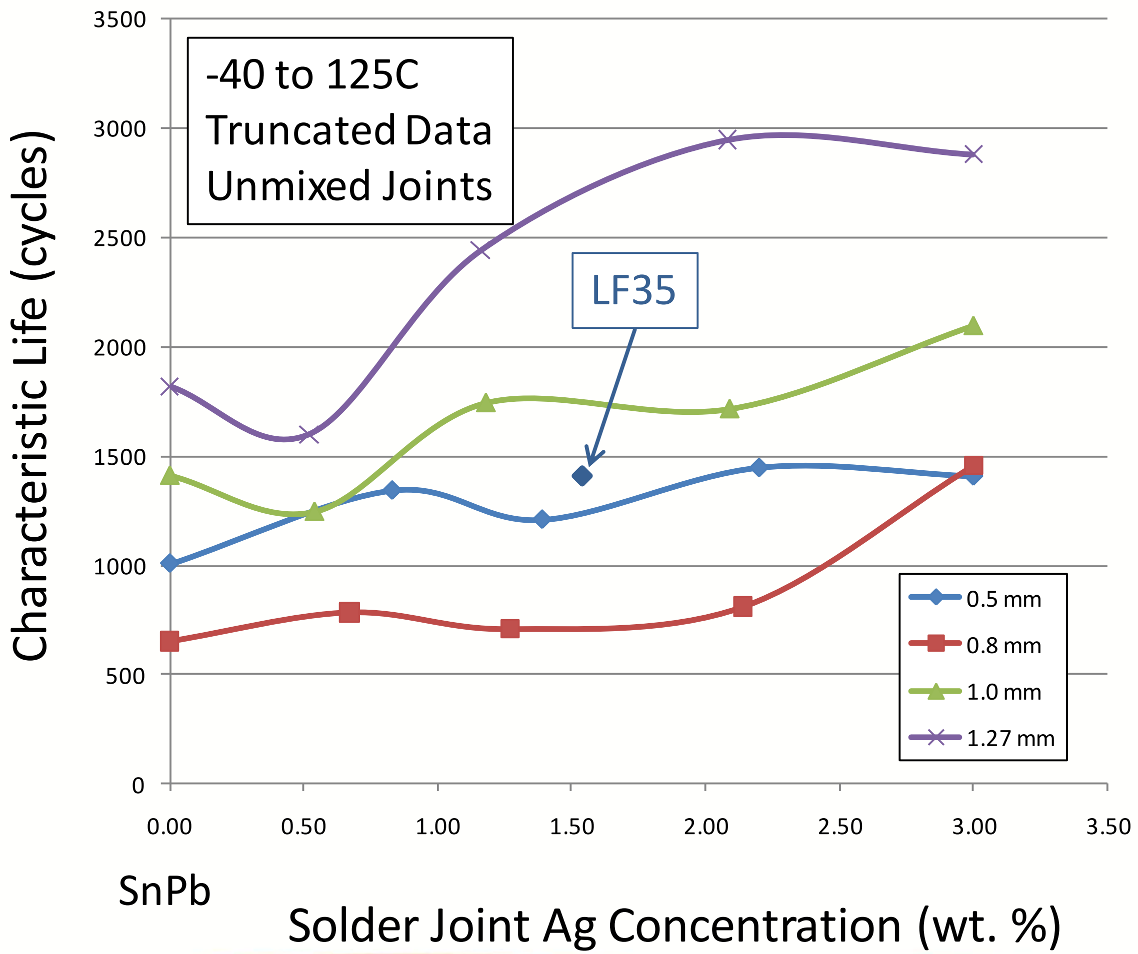
		0.5mm CTBGA-132					1.27mm SBGA-600				
Paste Alloy	Ball Alloy	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)	Pb (%)	Ag (%)	Cu (%)	Sn (%)	Liq. T (deg. C)
Sn-Pb	Sn-Pb	37.00	0.00	0.00	63.00	183.00	37.00	0.00	0.00	63.00	183.00
Sn-Pb	SAC105	7.90	0.79	0.39	90.92	216.19	3.35	0.91	0.45	95.29	221.23
Sn-Pb	SAC305	7.86	2.36	0.39	89.39	211.35	3.33	2.73	0.45	93.49	215.61
Sn-Pb	SACX	7.91	0.24	0.55	91.30	216.64	3.36	0.27	0.64	95.73	221.76
Sn-Pb	LF35	7.90	0.94	0.39	90.77	215.70	---	---	---	---	---
SAC305	SAC105	0.00	1.39	0.50	98.11	223.73	0.00	1.16	0.50	98.34	224.44
SAC305	SAC205	0.00	2.20	0.50	97.30	221.24	0.00	2.08	0.50	97.42	221.60
SAC305	SAC305	0.00	3.00	0.50	96.50	218.75	0.00	3.00	0.50	96.50	218.75
SAC305	SACX	0.00	0.83	0.66	98.51	224.21	0.00	0.52	0.68	98.80	224.98
SAC305	LF35	0.00	1.55	0.50	97.95	223.24	---	---	---	---	---

Effect of Silver Concentration on N63 for **Unmixed** Joints: 0/100C (Truncated)



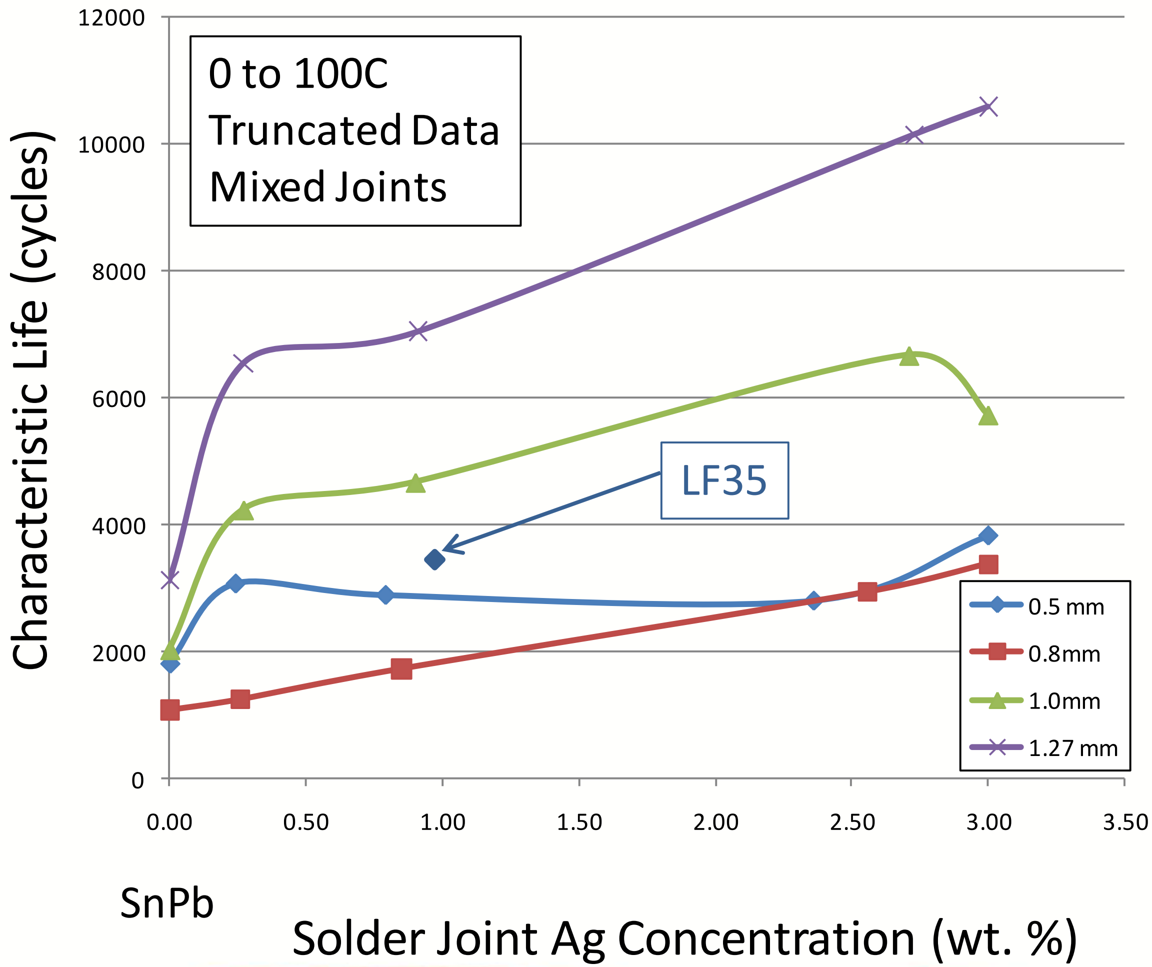
- No significant difference from plot of N63 vs. ball alloy Ag content presented previously
- N63 increases with [Ag] for all packages
  - Not linear
  - Plateaus in performance as a function of [Ag]

Effect of Silver Concentration on N63 for **Unmixed** Joints:-40/+125C (Truncated)



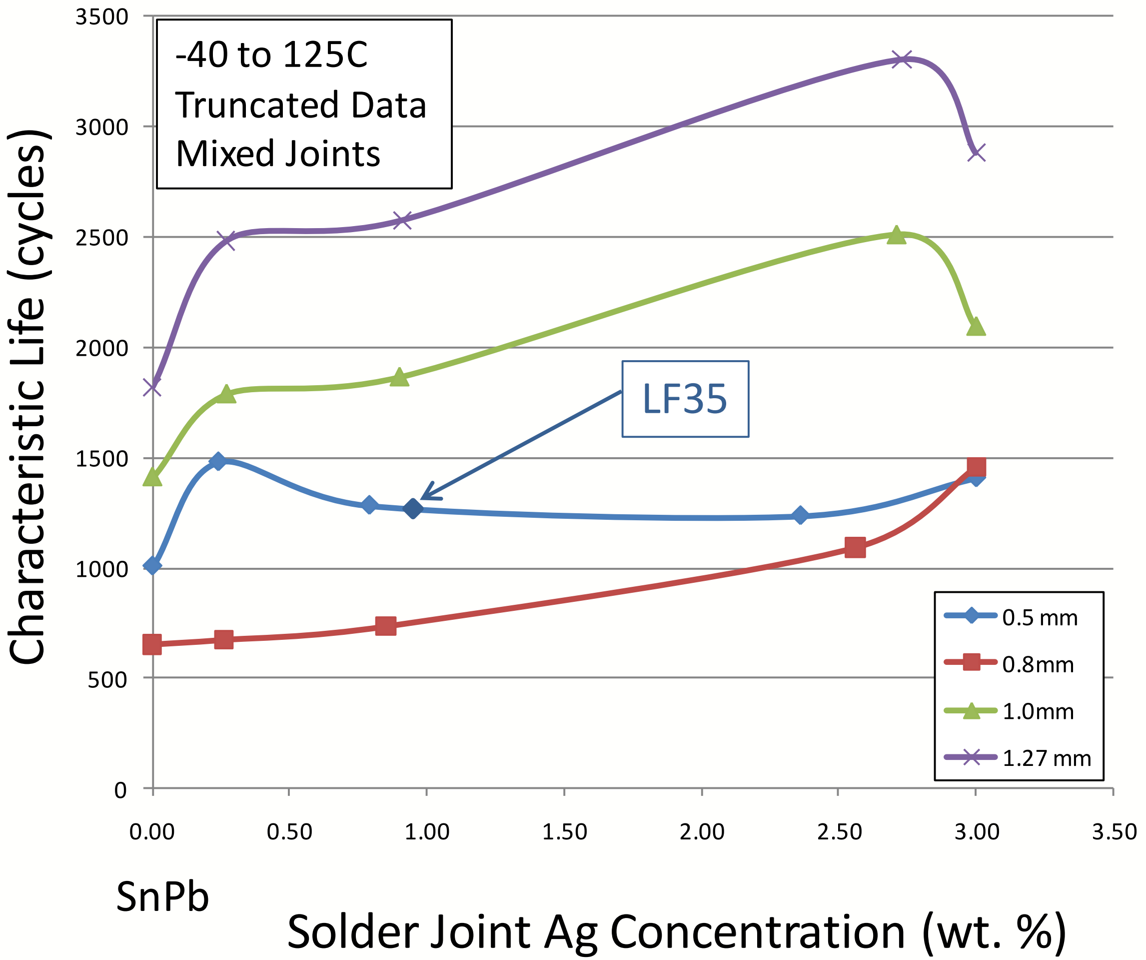
- No significant difference from plot of N63 vs. ball alloy Ag content presented previously
- Sn-Pb joints less reliable than Pb-free joints for:
  - Small pkgs. - All Pb-free alloys
  - Large pkgs. – All Pb-free alloys except SACX0307
- "Plateaus" in N63 with [Ag]; location depends on pkg.
- Impact of joint composition less dramatic that for 0/100 C profile

Effect of Silver Concentration on N63 for **Mixed** Joints: 0/100C (Truncated)



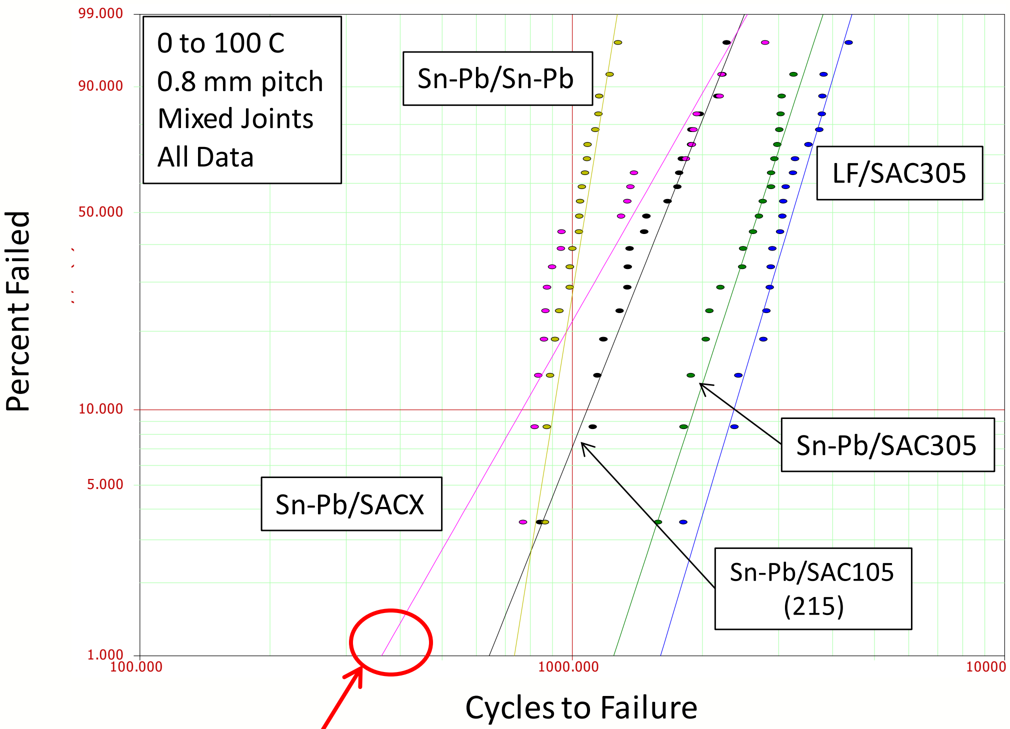
- Joint compositions based on assumption of full mixing
  - Likely a bad assumption for large packages (slide 10)
  - May explain drop in life for 1mm package at high [Ag]
- Mixed joints perform better than 100% Sn-Pb (using N63 as metric)
- Overall, curves not too different from those for unmixed joints

Effect of Silver Concentration on N63 for **Mixed** Joints: -40/+125C (Truncated)



- Curves similar to those for unmixed joints, except:
  - Mixed joints perform better than Sn-Pb for all packages (including 1.0 & 1.27 mm)
  - Peak in N63 for SACX balled 0.5 mm package more pronounced
  - Drop in N63 at highest [Ag] for 1.0 & 1.27 mm packages (maybe due to partial mixing?)

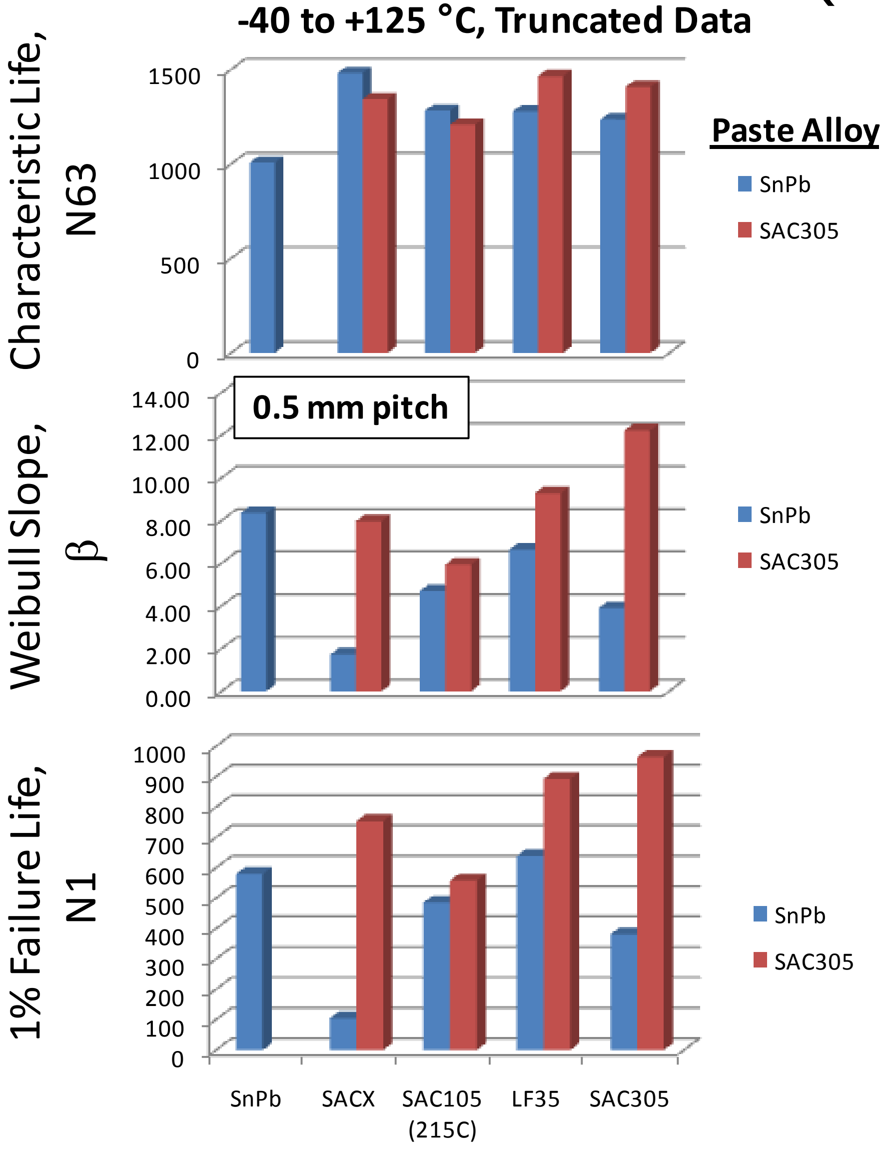
Mixed Joint Performance at Low Failure Levels



Projected 1% failure point, N1

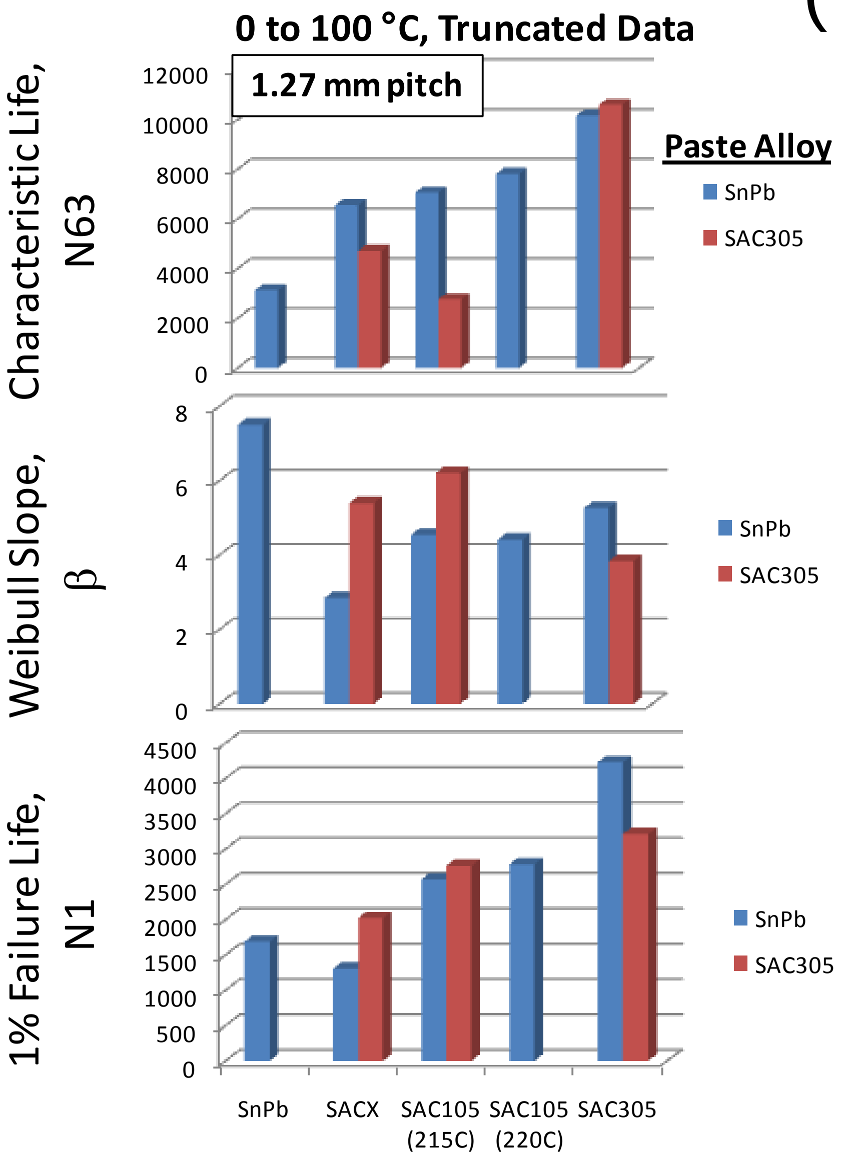
- Mixed joints raise concerns about early failures
  - Challenge of manufacturing sound joints at or above liquidus temperature
  - Variability in microstructure
- N63 is a good metric for comparing alloy performance of unmixed joints but OEMs design for life at much lower failure levels (e.g., 1%, 0.1%)
- Mixed joints may give broader variability in performance (low Weibull slope, β)
  - Poor performance at low failure percentage

Comparison of Mixed & Unmixed Joint Performance for 0.5 mm Parts: -40/+125C (Truncated)



- Mixed joints commonly had lower β, N1 even when N63 values were comparable to Pb-free values
- Possible causes:
  - Manufacturing challenges at peak reflow temperature of 215C when liquidus temperature is near or above this value
  - Microstructural variability (e.g. partial mixing)

Comparison of Mixed & Unmixed Joint Performance for 1.27 mm Parts: 0/100C (Truncated)



… however:

- Not all data showed poor performance of mixed joints
- In some cases N1 values for mixed joints were as good or better than their Pb-free counterparts

Trends in Variability and Reliability at Low Failure Rates (Truncated Data)

0 to 100 C	Mixed > Pb-Free (%)		Mixed ~ Pb-Free (%) *		Pb-Free > Mixed (%)	
Ball Alloy	Beta	N1	Beta	N1	Beta	N1
SACX	0	0	25	25	75	75
SAC105 (215 C)	0	25	50	50	50	25
LF35 **	0	0	0	0	100	100
SAC305	50	25	0	0	50	75
-40 to 125 C	Mixed > Pb-Free (%)		Mixed ~ Pb-Free (%) *		Pb-Free > Mixed (%)	
Ball Alloy	Beta	N1	Beta	N1	Beta	N1
SACX	50	50	0	0	50	50
SAC105 (215 C)	25	25	25	25	50	50
LF35 **	0	0	0	0	100	100
SAC305	25	25	25	25	50	50
* Values the same within 10%						
** Data available only for the 0.5 mm pitch package						

- Some tendency for mixed joints to have lower β, N1
- At a minimum, analysis shows need to assess performance of mixed joints at low failure levels

Outline

- Introduction
- Experimental Materials and Procedures
  - Test Vehicles
  - ATC Testing
- Results for Mixed Solder Joints
- Preliminary Conclusions and Next Steps

Summary & Preliminary Conclusions

Thermal cycle test data for unmixed solder joints have been presented

- Eutectic Sn-Pb and five Pb-free ball alloys
- Four different package types
- Thermal cycling conditions of 0 to 100C and -40 to +125C.
- Failure analyses and complete analysis of all test data pending

Findings for consideration at this time:

1. How does the performance of low-silver mixed joints compare to that of "unmixed" (100% Sn-Pb and 100% Pb-free) joints? Based on characteristic life, mixed solder joints perform better than or equal to those of 100% Sn-Pb joints for all of the package types studied. Compared to Pb-free joints, the mixed joints may perform better, worse, or about the same.
2. What is the quantitative impact of Ag concentration on the performance of mixed joints and how does this compare to that for unmixed ones? The curves of characteristic life vs. silver concentration for mixed joints tested using the 0/100C profile are similar to those of unmixed joints. Reliability increases with increasing [Ag], but not in a linear manner. For the -40/125C profile, mixed joint results are again similar to those for unmixed joints, with a few isolated exceptions.

Summary and Preliminary Conclusions

3. How does the variability in performance for mixed joints compare to that of unmixed joints? There is a tendency for the mixed solder joints to show greater variability (lower β) than their Pb-free counterparts. However, this trend is not followed for all data sets so care must be taken in making this conclusion too firmly.

4. How does the reliability at low failure rates (e.g. 1%) for mixed joints compare to that of unmixed joints? There is a tendency for the mixed solder joints to show worse reliability at low failure levels than their Pb-free counterparts. While this trend is not followed for all data sets, one must take into account possible tendencies for early failures of mixed joints.

Next Steps

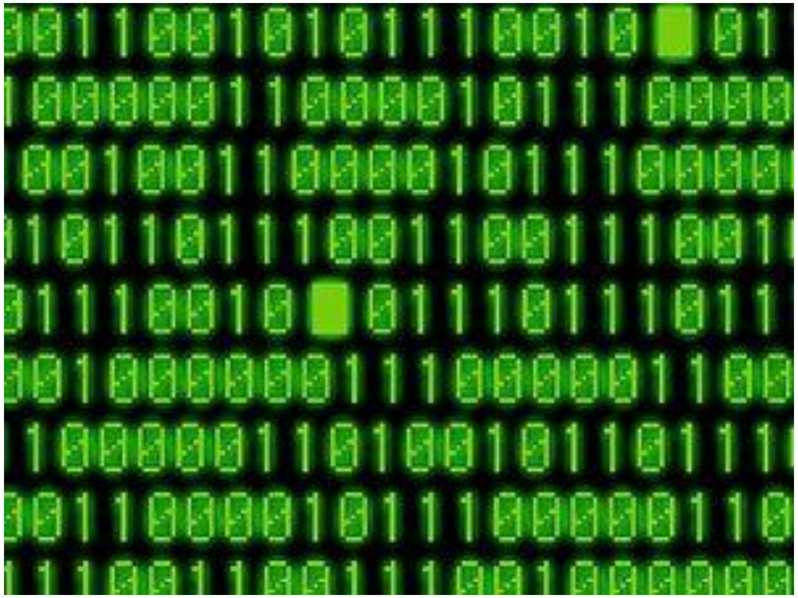
Project Team

- Perform failure analysis
- Perform further data analysis, as needed

Industry

- Quantitative assessment of acceleration behavior
- Further study on the impact of dopants
- Validation of findings

Acknowledgments



Thanks to Doug Lamond of HP for analyzing the substantial quantity of raw data so that Weibull plots could be constructed.

Thank You

- *Questions?*

Copies of presentation will be available next week at www.sheaengineering.com