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A Near-Eutectic Sn-Bi Low-Temperature Alloy with High Thermal Fatigue Resistance

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ABSTRACT

This study reports a new near-eutectic Sn-Bi-based low-temperature solder alloy (Bi+) which can reflow between 165°C and 190°C. The Bi+ alloy showed improved thermal fatigue resistance under a thermo-cycling test (TCT) profile of -40/125°C and 10 min dwell time as compared to SnBi1Ag and SAC305 in a ball-grid array (BGA) assembly (SAC305 ball). The alloy is strengthened by the addition of elements like Ag and Ni, the choices of which target properties that include particle strengthening, grain boundary strengthening, intermetallic compound (IMC) toughening, solidification behavior changes, and microstructural changes. For example, Ni is known to reduce the undercooling of Sn-based alloys. This influences the formation of a near-eutectic microstructure, refining of the Sn grain size, and toughening of IMC at the interface. These properties jointly contribute to improved thermal fatigue resistance.

SAC305/Bi+ hybrid solder joints also showed significantly reduced solder joint shifting compared to SAC305/SnBi1Ag and other SAC305/low-temperature solder (LTS) solder joints when cycled at -40/125°C profile. Hybrid solder joints shifting is increased by an in-balance in the SAC/LTS regions that cause intra-joint phase CTE mismatch. The intra-joint phase CTE mismatch complicates the CTE mismatch between the board and the component, stretching the hybrid solder joints. The Bi+ alloy is designed to withstand this effect in a hybrid BGA/LTS assembly to maintain upright stable solder joints after thermal cycling for more than 6,900 cycles. The SAC305/Bi+ hybrid solder joints have shown a higher percentage of Bismuth mixing at time zero (T0) and during thermal cycling as compared to SAC305/SnBi1Ag and other low-temperature solder alloys. The Bi+ alloy was designed so that the as-reflowed hybrid CABGA192 solder joints built with SAC305/Bi+ achieved an average Bi mixing of approximately 50%. After thermal cycling for about 6,900 cycles, the hybrid solder joints attained an average Bi mixing of more than 90%. An FR4 board of 1.54mm thickness with a glass transition temperature (Tg) of 130°C was used as the test vehicle (board) in this study. Similarly, 0805 chip resistors that were reflowed on homogeneous Bi+ paste returned higher resistance to cracking as compared to SnBi1Ag and SAC305 after thermal cycling. When thermal cycled with -40/105°C for up to 5000 cycles, Bi+ solder joints had smaller percentage crack sizes and no cracks under the die as compared to both SnBi1Ag and SAC305.

The overall performance of the alloy is a combination of alloy design, process optimization, solidification behavior studies, and paste parameters tuning such as powder size, metal load and paste-to-ball volume ratio.

Key words: Near-eutectic Sn-Bi solder, Hybrid solder joint, Thermal fatigue resistance, Solder joint shifting, Bismuth mixing, Paste to ball volume ratio, and Percentage crack size.

INTRODUCTION

The electronics industry has made a deliberate effort to replace high melting SAC solders with low temperature melting solders owing to the many benefits that accrue as a result of low temperature assembly [4]. There are several drivers toward this end that include reduction of warpage defects and improvement of the thermomechanical performance, enabling step soldering for different package technologies, reduction in the cost of assembly, and reduction in the carbon emissions among others. The leading candidates for LTS alloy systems are the Sn-Bi based alloys. However, these Sn-Bi based LTS alloys exhibit some drawbacks. They are harder and brittle as compared to the SAC solder regimes and are poor in managing drop and thermal shock. Secondly, phasing out the SAC solders from components in the supply chain and replacing them with the new LTS solders is costly, risky, and takes a long time. Therefore, the SAC/LTS hybrid solder joints must serve as a stop gap solution as the industry moves toward full LTS transition.

However, if the Sn-Bi based solder alloy is carefully designed, and the whole production process optimized accordingly, the SAC/LTS system can revolutionize thermomechanical fatigue performance with benefits spanning from low temperature reflow, to increased melting temperature, better drop and thermal shock resistance, to high temperature applications. Several studies have been conducted to improve on the thermomechanical performance of these Sn-Bi hybrid solder joints in BGA assemblies. Data from various hybrid solder tests have shown that in certain cases, the hybrid system is a viable system that can be a stand-alone solder system but not merely as a transition solder system [3].

It is not easy to improve the thermomechanical properties of a near eutectic Sn-Bi based solder system by elemental strengthening mechanisms, such as particle and solid solution strengthening mechanisms, because the resultant alloys become more brittle and are subject to severe cracking under thermomechanical stress [7]. However, with the SAC/LTS solder system configuration, the desired properties for good thermal fatigue performance can be achieved. First, the design of the LTS alloys has to consider the compositional complications brought about by the inclusion of SAC in the system. The in-balance in the composition of the elemental species of the near-eutectic Sn-Bi sets up concentration gradients within the solder joints. It is also known that Tin (Sn) diffusion in Bismuth (Bi) matrix is not as welcome as Bismuth (Bi) diffusion into the Tin (Sn) matrix. Although there is likelihood of Tin (Sn) undergoing self-diffusion in order to achieve equilibrium, the activation energy for self-diffusion is higher, and hence this mechanism may not happen or might be short lived [1, 2]. On the other hand, given that the amount of Bismuth in the LTS region is near eutectic, and the amount of Bismuth in the SAC region is about 0 wt.% at the time of solder joint formation, there will exist a Bismuth concentration gradient. Solid state diffusion will take place if the temperature is enough to activate it, and then provide a diffusion force. In other words, dissolution of Bismuth (Bi) in beta Tin (Sn) and diffusion of Bismuth (Bi) in the beta (Sn) matrix are the two limiting factors and are thermal and concentration dependent. It is anticipated that the two elemental species diffuse in opposite directions until homogenization of the solder joint is achieved. The diffusion process and the compositional changes have a bearing in the thermal, mechanical, and reliability properties of the solder system [1].

However, with the SAC/LTS hybrid system, compositional changes can be achieved alongside other benefits such as low temperature reflow and higher temperature applications. This is because the offspring alloy from such combinations is an alloy whose composition lies in between that of the parent alloys. Such is the alloy obtained from reflowing SAC on LTS paste. Although this combination can be reflowed at lower temperatures, the hybrid has a higher melting point than the LTS and can be used in applications whose application temperatures are higher than that of the LTS melting point.

EXPERIMENTAL METHODS

Thermal cycling performance was investigated using three test vehicles. The first test vehicle is an all CABGA192 daisy-chained board designed according to JEDEC and IPC standards. The board is made of FR4 material with a Tg of 130°C and has a size of 139x132mm. This test vehicle has twelve CABGA192 parts as shown in Figure 2. The surface finish is OSP whose pads are NSMD. The package size is 14x14mm with a ball pitch of 0.8mm and a die size of 12x12mm. The SAC305 solder ball has a diameter of 0.46mm reflowed on an electrolytic Nickel-Gold surface with a gold coat thickness of about 0.6µm. The stencil has a thickness of 4mil and designed such that the paste to ball volume ratio is 0.5. This board was used for -40/125°C thermal cycling.

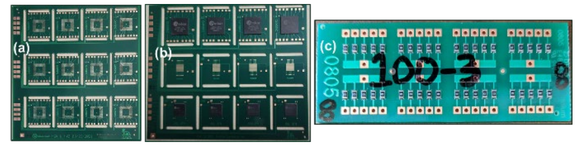


Figure 1. Two CABGA192 boards (a), (b), and (c) a 0805 chip resistor board used for thermal cycling and shear strength testing.

The second board used is a three-component daisy-chained board made of FR4 material of Tg 130°C, and whose dimensions are 135x110mm. It has four CABGA192 parts, four WLP parts and four QFN(MLF68) parts. Of greater interest in this board was the CABGA192 parts whose properties are described above. The surface finish on the pads was OSP and the board was used for the -40/105°C thermal cycling. The board is shown in Figure 2.

The third board is a daisy-chained one-component board made of FR4 material of Tg 130°C and whose dimensions are 69x27.2mm. The surface finish on the pads was OSP. The component is an 0805-chip resistor with a total of forty chip resistors per board. This board was used with the -40/105°C thermal cycling profile. The board was used to test the shear strength of homogenous pastes at different thermal cycles as well as microstructural analysis of the crack ratio at those cycle intervals. The board is shown in Figure 2.

For the first and second boards and tests, two sets of boards were used. One set of boards was for in-situ monitoring and their data was used for Weibull analysis. The other set of boards was for microstructural analysis at various cycle intervals where several parameters such as percent Bismuth mixing, solder joint height, and crack ratio were measured. The two thermal cycling profiles used had 10-minute dwell times at both extremes. All the samples were reflowed with the same profile whose peak temperature was 185°C. The reflow profile was a primarily straight ramp profile with a time above liquidus of about 100 seconds. All the samples were examined via X-ray and images taken to assist in quantifying the BGA solder joint shifting. Samples taken for microstructural analysis were examined by cross-sectioning, and others by dye and pry analysis. Both optical and Scanning Electron Microscopy were used to take images that were used for failure and other types of analysis.

RESULTS AND DISCUSSIONS

Evolution of the Microstructure of the hybrid CABGA192 SAC/LTS with Thermal Cycling

The SAC/LTS hybrid solder joints were built by printing LTS paste with a 0.5 paste to ball volume ratio and were reflowed at a peak reflow temperature of 185°C.

Immediately after reflow, the hybrid solder joints were observed to consist of a SAC region on the component side and an LTS region on the board side as shown in Figure 2.

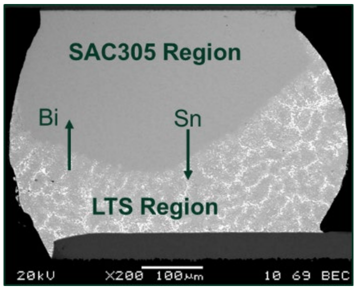


Figure 2. A T0 (as reflowed) back scattered SEM image of a CABGA192 hybrid solder joint of CABGA192 SAC305/Bi+ solder joint at T0 illustrating the two regions of SAC and LTS.

The ratio of the area of the solder joint covered by the Bismuth phase to the total area of the solder joint is a measurable quantity usually referred to as the "percent Bismuth mixing." This quantity was calculated for T0 CABGA192 hybrid solder joints of SAC305/Bi+ and SAC305/SnBi1Ag. The values were found to be 48% and 46% respectively. In total, every data point presented is an average of at least 16 values. Examples of T0 SEM images of the solder joints are shown in Figure 3.

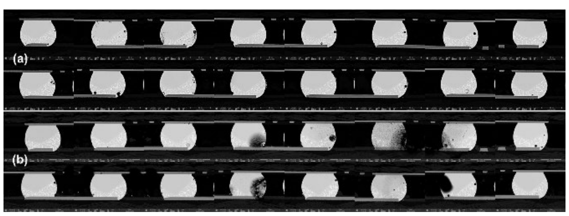


Figure 3. SEM images of as reflowed CABGA192 hybrid solder joints of (a) Bi+ and (b) SnBi1Ag.

These set of samples were thermal cycled with -40/125°C thermal profile.

Another set of samples was thermal cycled at -40/105°C. For this set of samples, the powder size was changed. All other processing parameters were the same as for the samples that were thermal cycled at -40/125°C. When the percentage Bismuth mixing were measured immediately after reflow, the values obtained were significantly lower than for the previous samples. The percentage Bismuth mixing for CABGA192 solder joints of SAC305/Bi+ and SAC305/SnBi1Ag were found to be 38% and 35% respectively. See T0 SEM images shown in Figure 4 and the plots of Figure 5b.

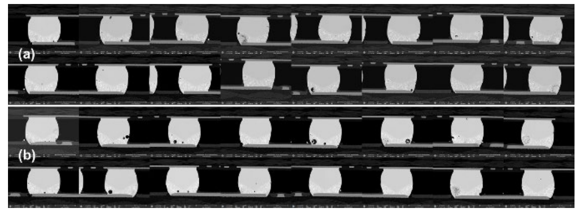


Figure 4. T0 CABGA192 hybrid solder joints of (a) SAC305/Bi+ and (b) SAC305/SnBi1Ag for samples that were thermal cycled at -40/105°C.

The measured values of the percent Bismuth mixing over thermal cycling time is shown by the plots in Figure 5a for the samples which were thermal cycled at -40/125°C and Figure 5b for the samples which were thermal cycled at -40/105°C.

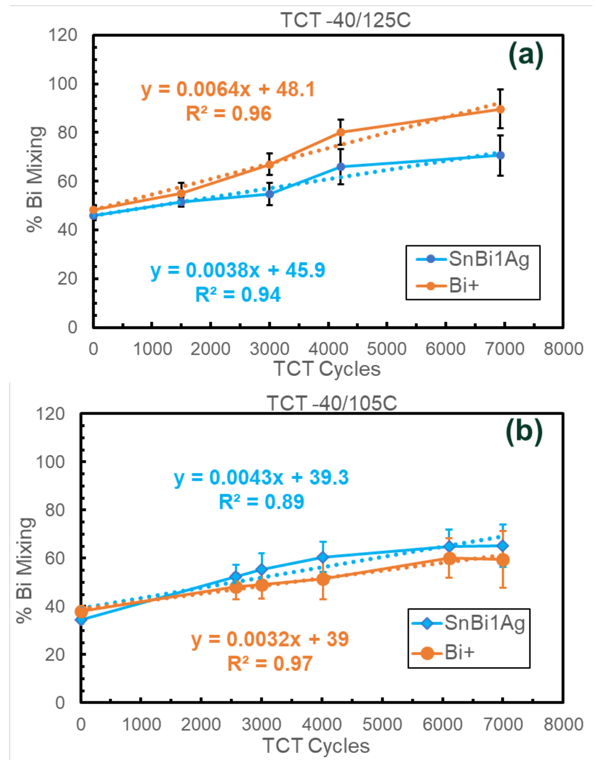


Figure 5. Percent Bismuth mixing for samples of SAC305/SnBi1Ag and SAC305/Bi+ which were thermal cycled at (a) -40/125°C and (b) thermal cycled at -40/105°C.

For both thermal cycling profiles, the percentage Bismuth mixing was observed to increase with the increase in the thermal cycling time. The rate of Bi mixing for SAC305/Bi+ (slope) was calculated to be 1.7 times higher than for SAC305/SnBi1Ag when both alloys were thermal cycled at -40/125°C, but it was 0.7 times when the samples were thermal cycled at -40/105°C. The rate of Bismuth mixing for SAC305/Bi+ was two times higher when thermal cycled at -40/125°C than when thermal cycled at -40/105°C. On the other hand, the rate of Bi mixing for SAC305/SnBi1Ag at -40/125°C was 0.9 times that of same alloy at -40/105°C. Clearly, there is a significant change in these quantities for the two pastes at different thermal cycling profiles. That difference is by the change in the powder particle size. This is a clear show that the hybrid solder joints are sensitive to small changes in the process or composition. A summary of the relationship between the rate of percent Bismuth mixing with cycle number, T0 percent Bismuth mixing, and thermal cycling profile is given in Table 1.

	$\frac{\Delta(\%Bi)}{\Delta(Cycles)}$ x 10^{-3}		% Bi mixing at T0 Cycles	
Paste	-40/105C	-40/125C	-40/105C	-40/125C
Bi+	3.2	6.4	39	48.2
SnBi1Ag	4.3	3.8	39.3	46

Table 1. A SAC/Bi+ marry of the relationship between the paste, the rate of percent Bismuth mixing with cycle number, T0 percent Bismuth mixing, and thermal cycling profile.

Figure 6 shows the SEM cross section images of CABGA192 Bi+ and SnBi1Ag thermal cycled at -40/105°C for 6,998 cycles.

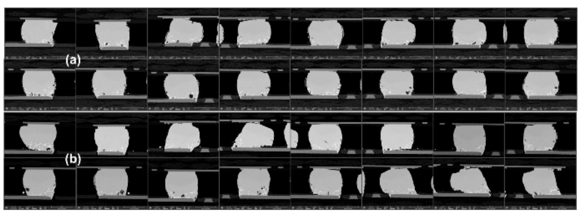


Figure 6. Shows SEM images of (a) SAC305/Bi+ at 6,998 cycles thermal cycled at -40/105°C and (b) samples of SAC305/SnBi1Ag thermal cycled for 6,998 cycles at -40/105°C.

Both alloys multiple solder joints that had completely failed. A significant number of solder joints also showed shifting. In some cases, the shifted solder joints have full cracks.

A similar sample set of CABGA192 SAC305/Bi+ and SAC305/SnBi1Ag thermal cycled for 6,927 cycles at -40/125°C are shown in Figure 7.

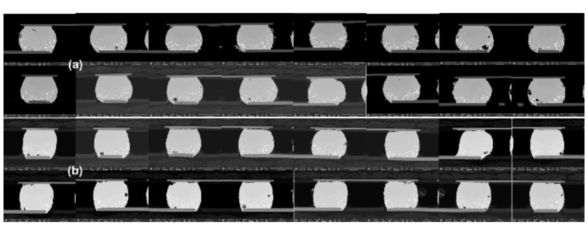


Figure 7. SEM images of (a) SAC305/Bi+ at 6,927 cycles thermal cycled at -40/125°C and (b) samples of SAC305/SnBi1Ag thermal cycled for 6,927 cycles at -40/125°C.

For this set of samples that were thermal cycled at -40/125°C, SnBi1Ag has six joints with full cracks on the component side while Bi+ does not have any solder joint with full cracks. In fact, Bi+ did not record any crack size greater than 40%. Solder joint shifting is also seen with SnBi1Ag but not with Bi+.

Figures 8, 9, 10, and 11 show the progression of the Bi particle size with thermal cycling time for both thermal profiles and for both Bi+ and SnBi1Ag alloys.

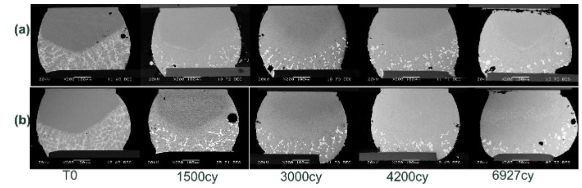


Figure 8. Representative SEM images of (a)SAC305/SnBi1Ag (b) SAC305/Bi+ hybrid CABGA192 solder joints starting from T0 to 6,927 cycles at -40/125°C thermal cycle profile.

The eutectic Bismuth network is seen to break into smaller Bismuth particles surrounding some coarsened Bi particles in the LTS region as early as 1,500 cycles for both the Bi+ and SnBi1Ag alloys thermal cycled at -40/125°C and as early as 2,000 cycles for both the SnBi1Ag and Bi+ solder joints thermal cycled at -40/105°C.

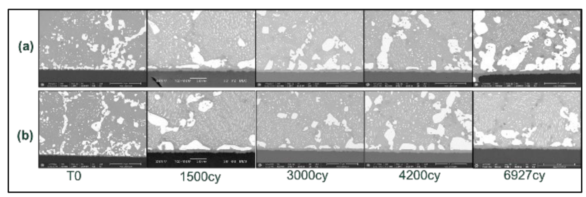


Figure 9. Representative SEM images of the board side of (a) SAC305/SnBi1Ag and (b) SAC305/Bi+ hybrid CABGA192 solder joints starting from T0 to 6,927 cycles at -40/125°C thermal cycle profile.

Away from the LTS region and toward the SAC region, only small particles are seen. The large particles remain mostly around the original LTS region. It is also observable that the percent Bismuth mixing increases with the cycle number.

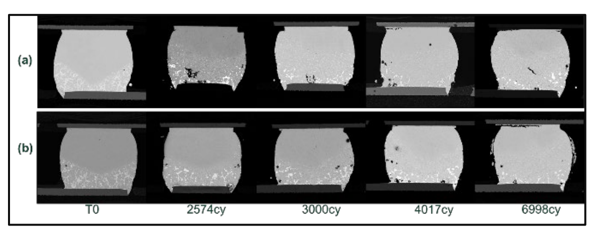


Figure 10. Representative SEM images of (a) SAC305/SnBi1Ag and (b) SAC305/Bi+ hybrid CABGA192 solder joints starting from T0 to 6,998 cycles at -40/105°C thermal cycle profile.

In terms of the changes in the Bismuth phase morphology, samples thermal cycled at -40/105°C thermal profile exhibits similar behavior to those thermal cycled at -40/125°C. See Figure 10 and Figure 11.

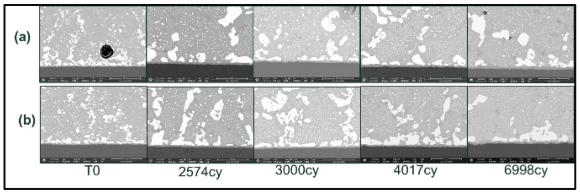


Figure 11. Representative SEM images of the board side of (a) SAC305/SnBi1Ag and (b) SAC305/Bi+ hybrid CABGA192 solder joints starting from T0 to 6,998 cycles at -40/105°C thermal cycle profile.

FAILURE ANALYSIS

Thermal Fatigue Crack Growth and the Shift in the Stress Concentration

Failure analysis from CABGA192 x-sections of hybrid SAC305/Bi+ and SAC305/SnBi1Ag, show that small cracks start to appear as early as 1,500 cycles for thermal cycling at -40/125°C on the board side and component side. Comparatively, at these early cycles, larger cracks are seen on the board side than on the component side. However, for late cycles, larger cracks are seen on the component side than the board side, and some of these cracks are catastrophic. As can be seen from the box plots in Figure 12 and the Weibull analysis of Figure 13, SAC305/SnBi1Ag starts to show failures as early as 3,000 cycles. However, SAC305/Bi+ does not show any catastrophic failures up to 6,927 cycles when the test was stopped. At 6,927 cycles, the largest crack measured was about 36% in size.

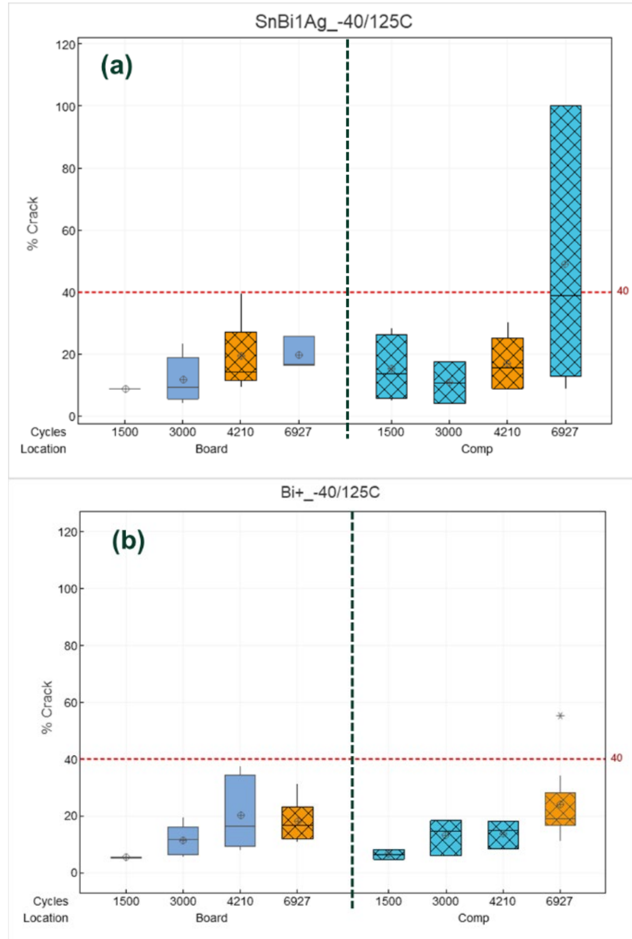


Figure 12. (a) Percent crack ratio for CABGA192 built with SnBi1Ag and thermal cycled with -40/125°C. The failure locations are divided into board side on the left and component side on the right. (b) Percent crack ratio for CABGA192 built with Bi+ and thermal cycled with -40/125°C.

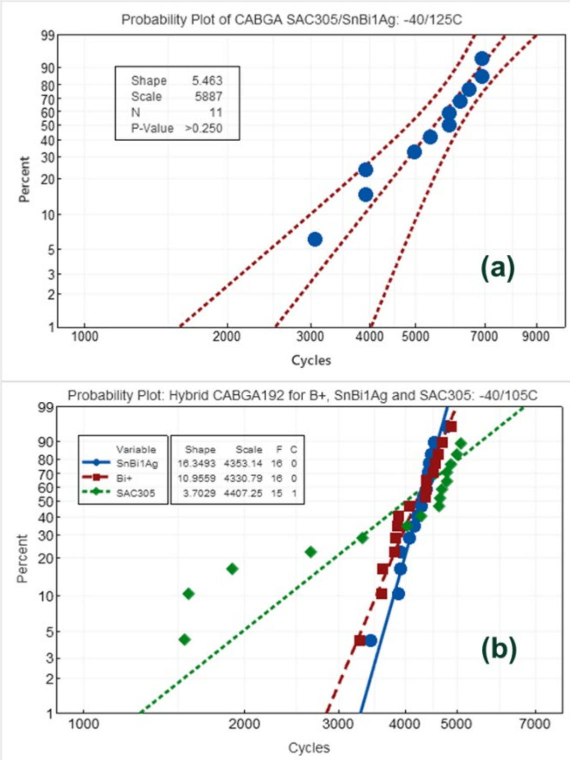


Figure 13. The Weibull plots of (a) hybrid CABGA192 SAC305/SnBi1Ag cycled at -40/125°C. (b) Hybrid CABGA192 Bi+, SnBi1Ag and SAC305 cycled at -40/105°C.

The Weibull plots in Figure 13 show that for the -40/105°C thermal profile, SAC305/Bi+, SAC305/SnBi1Ag, and SAC305/SAC305 have similar lives of slightly above 4,300 cycles. For the -40/125°C, only SAC305/SnBi1Ag had failures to generate a Weibull plot by the time the test was stopped. This performance is surprising and opposite from expectation. Previously, it has been observed that alloys perform poorer when harsher profiles are applied [3].

For the -40/105°C thermal cycling, a similar trend to that observed with -40/125°C is seen for the SAC305/Bi+ and SAC305/SnBi1Ag solder joints. Larger cracks are seen on the board side at the early cycles while at later cycles, larger cracks are seen on the component side than on the board side, including catastrophic cracks.

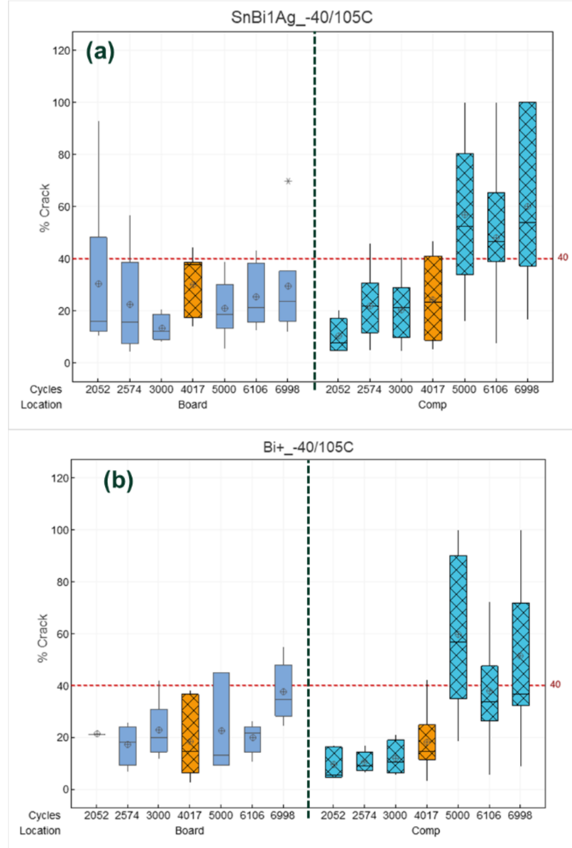


Figure 14. (a) Percent crack ratio for CABGA192 built with SnBi1Ag and thermal cycled with -40/105°C. The failure locations are divided into board side on the left and component side on the right. (b) Percent crack ratio for CABGA192 built with Bi+ and thermal cycled with -40/105°C.

For the CABGA192 SAC305 solder joints thermal cycled at -40/105°C, a mixture of board and component failures are seen. Figure 15 illustrates this fact.

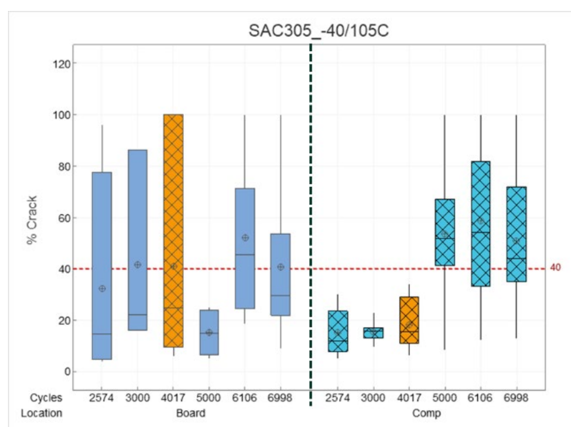


Figure 15. Percent crack ratio for CABGA192 built with SAC305 and thermal cycled with -40/105°C. The failure locations are divided into board side on the left and component side on the right.

0805 CHIP RESISTORS

Microstructure and Percent crack size during Thermal cycling at -40/105°C.

Figure 17 shows the optical images of 0805 chip resistors from T0, 4,017 cycles and 6,106 cycles for (a) SnBi1Ag, (b) Bi+, and (c) SAC305. The chip resistors were thermal cycled at -40/105°C.

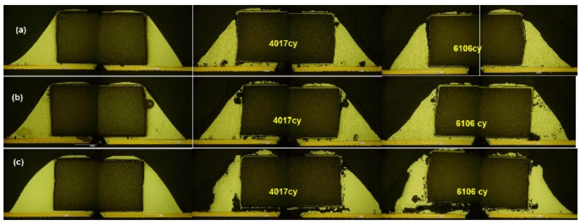
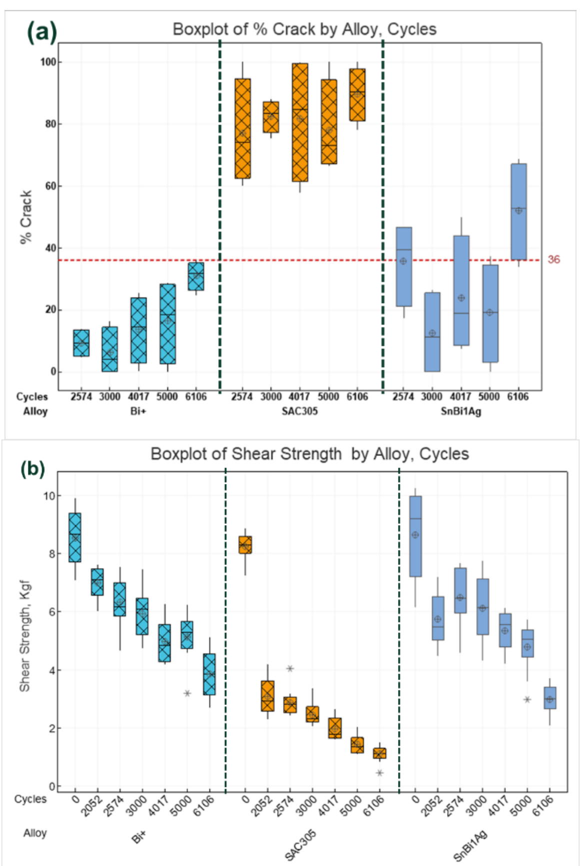


Figure 17. (a) SnBi1Ag, (b) Bi+, and (c) SAC305 optical images of 0805 chip resistor for T0, 4,017 cycles and 6,106 cycles thermal cycled at -40/105°C.

The percentage crack size was measured from 2,574 cycles to 6,106 cycles and the data shown in box plots of Figure 18.



Figures 18. Box plots for 0805 chip resistor samples of homogeneous Bi+, SAC305, and SnBi1Ag thermal cycled at -40/105°C (a) showing the variation of the percent crack size with cycle number and alloy (b) showing the shear strength variation with the cycle number.

Full cracks for 0805 chip resistors made with SAC305 paste were seen as early as 2,000 cycles. For 0805 chip resistors made with Bi+ paste, the largest cracks measured cycles ranging from 2,574 cycles to 6,106 cycles were less than 40% in size. On the other hand, SnBi1Ag had cracks measuring up to 69% within the same range of cycles. No cracking under the die was seen for both Bi+ and SnBi1Ag up to 5,000 cycles. However, SAC305 had joints with 100% cracks under the die as early as 2,000 cycles.

DISCUSSION

The microstructure of the as-reflowed hybrid SAC/LTS solder joint system consists of two distinct regions: the SAC region and the LTS region as shown in Figure 2. The solder system is not stable due to the composition difference between the two regions that are joined together. When enough energy is applied to the solder system either through thermal cycling or aging, the solder system strives to gain stability or homogenization by dissolution and diffusion of Bismuth from the LTS region toward the SAC region and self-diffusion of Sn toward the LTS region, Figure 2. The spread of Bismuth from the LTS region towards the SAC region is usually referred to as the Bismuth mixing and it's a measurable quantity expressed as a percentage. The Bismuth mixing is a thermally activated process that happens in solid state. It is temperature dependent and can be derived from the diffusion equation described by the Arrhenius relationship. The energy required for diffusion to occur can be thought as an activation energy whose diffusion coefficient is given by $D=D_o e^{-E_a/K_B T}$ where D_o is the maximum value of diffusivity, E_a is the activation energy, K_B is the Boltzmann constant, and T is the temperature. Thus, Bismuth mixing is higher for higher peak thermal cycling and/or aging temperature.

The percentage Bismuth mixing is observed to increase with the increase in the cycle number, and the thermal cycling profile. Other factors include the initial percent Bismuth mixing, the alloy, and the peak thermal cycling temperature. As Bismuth moves away from the LTS region, its particle size decreases and some of the Bismuth particles within the LTS region were observed to coarsen, as seen from Figures 5 to 11 [1]. The LTS region starts to lose the eutectic Bi phase structure as the Bismuth starts to precipitate into smaller and smaller Bi particles on the primary β-Sn matrix as thermal cycling progresses and the solder joint composition changes. The change in the composition of the solder joints affects the melting temperature of the original alloy accordingly. For example, if the composition shifts from the eutectic to about 68 wt.% Sn and 29 wt.% Bi, the melting temperature of the new Sn-Bi-based alloy increases significantly to almost 200°C. At this resultant composition, the primary phase is β-Sn and Bismuth precipitates on the β-Sn matrix. Figure 16 illustrates this example in the Sn-Bi binary phase diagram.

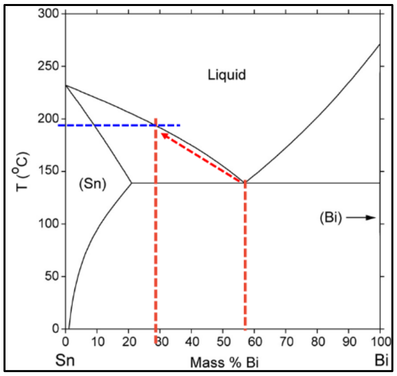


Figure 16. Sn-Bi binary phase diagram [ref NIST] showing the changes in the melting properties with composition change from the eutectic.

It is postulated that if the initial percent Bismuth mixing is low (e.g., solder joints in -40/105°C), it may require a higher thermal peak temperature to achieve good percent Bismuth mixing to stabilize the solder joints and reduce thermal fatigue damage. Higher percent Bismuth mixing coupled with changes in the solder joints composition and other alloy properties, the SAC305/Bi+ has outperformed SAC305/SnBi1Ag in the -40/125°C.

The crack location is usually consistent with the maximum stress-strain concentration area of the solder joints while the crack size is an indicator of the material's ability to withstand thermal stress and the extent of the cumulative stress damage [2]. The shift in the location of the larger cracks from the board side at early thermal cycles to the component side at late cycles indicates a shift in the stress concentration from the board side at early cycles to the component side on the late cycles. This unique behavior is characteristic of the hybrid solder joints and not present in homogeneous solder joints as seen with SAC305/SAC305 solder joints.

SUMMARY AND CONCLUSIONS

This study reports a new near-eutectic Sn-Bi-based low-temperature solder alloy (Bi+) which can reflow between 165°C and 190°C. Although reflowed at lower temperatures, this alloy in the hybrid SAC305/Bi+ BGA assembly configuration can be used in applications whose service temperature is higher than that of typical low temperature alloys. In a BGA assembly with SAC305, the Bi+ alloy showed improved thermal fatigue resistance under a TCT profile of -40/125°C and 10-minute dwell time as compared to SnBi1Ag and SAC305 in a BGA assembly (SAC305 ball). The performance of the SAC305/Bi+ BGA solder joints and indeed other LTS alloys is sensitive changes in composition and process parameters such as powder size, peak reflow temperature, paste to ball volume ratio, and thermal cycling profile. When the design of the LTS alloy is right, the processing is right, the initial percent Bismuth mixing is optimized, percent Bismuth mixing is good, then thermal fatigue failure is delayed during thermal cycling as observed with hybrid SAC305/Bi+ BGA solder joints and not SAC305/SnBi1Ag BGA solder joints. It is observed that SAC305/Bi+ CABGA192 solder joints outperform SAC305/SnBi1Ag and the SAC305/SAC305 solder joints in thermal fatigue resistance. The BGA SAC305/LTS thermal fatigue failure is almost entirely caused by cracking on the component side. At early cycles, larger and non-catastrophic cracks on the board side dominate, but as thermal cycling continues, larger cracks are seen on the component side, which includes catastrophic cracks as well. This behavior is evident regardless of the thermal cycling profile and points to a shift in the stress concentration with thermal cycling.

Similarly, homogeneous Bi+ paste built with 0805 chip resistors returned higher shear strength and higher thermal fatigue resistance to cracking as compared to SnBi1Ag and SAC305 after thermal cycling.

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