MECHANICAL PROPERTIES OF Sn3.5Ag AND Sn3.8Ag0.7Cu SOLDER BALLS FOR BGA PACKAGE

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ABSTRACT

The use of Sn3.5Ag and Sn3.8Ag0.7Cu solder ball alloys on Ball Grid Array (BGA) components with Cu/Ni/Au pad finishing were characterised in order to identify the most suitable in respect of reliability of BGA package. The melting point of the solder ball alloys were studied using Differential Scanning Calorimetry (DSC). The Solder ball shear and cold pull strength tests were carried out after ball attach, high temperature storage (HTS) and multiple reflow to obtain the mechanical properties. Drop Tests also carried out to evaluate joints robustness againt vibration and impact shock. Melting properties and mechanical strength suggest that SnAg posses better overall performance. Thus, SnAg eutectic solder may be considered as a potential candidate for lead-free solder joint improvement, at least in term of mechanical strength and package robustness.

***Keywords**: Intermetallics; Sn3.5Ag, Sn3.8Ag0.7Cu, shear and pull strength, drop test.*

INTRODUCTION

Environmental and health concerns have resulted in significant activities to find substitutes for lead-contained solders for microelectronics. The potential candidates such as Sn-Ag and Sn-Ag-Cu [1] eutectic solders with melting temperatures of 221ºC and 217ºC, respectively are the most prominent solders because of their excellent mechanical properties as compared with that of eutectic Sn-Pb solder [2]. Other candidates as drop in replacements for eutectic Pb-Sn solder, such as Sn-In-Zn alloys, may have melting point close to 185ºC, though not eutectic, and an acceptable solidification range but have received only limited attention due to various reasons and concerns [3]. During soldering, various interfacial reactions can occur between liquid solders and metallic substrates forming intermetallic compounds. Such interface formation can bring wetting as well as joint strength to secure joint ability, however excessive growth of intermetallic layers cause brittleness which adversely affects joint strength [4].

This happens after lengthy aging and multiple reflows, resulting in the excessive growth of compounds, such as Cu_6Sn_5 or the formation of another compound in the edge of the solder such as Cu_3Sn. In lead free soldering, the interfacial reactions become complex due to multicomponent systems to improve their chemical and mechanical properties [5]. Thus, to understand the microstructure and mechanical effect of alloying elements in solder on the interface formation becomes the key objective in this paper. Many reports claimed that SAC alloy is the most suitable candidate, however this study shows that Sn3.5Ag solder system performs better than Sn3.8Ag0.7Cu in terms of joint strength and brittle mode failure. A detailed experimental work was carried out to study both the alloy systems in terms of melting behavior, microstructure, and mechanical strength. This was carried out with the effect of high temperature storage aging and multiple reflow conditions.

EXPERIMENTAL APPROACH

Two solder systems Sn3.5Ag and Sn3.8Ag0.7Cu were used on BGA components with Cu/Ni/Au pad finishing. Table 1 shows the solder composition and test vehicle of the experiment.

Table 1: Solder Composition and Test Vehicle

Solder Composition	(SnAg) 96.5wt%Sn3.5wt%Ag (SnAgCu) 95.5%Sn3.8wt%Ag0.7wt%Cu
Test vehicle	480 TBGA
Package size	37.5 x 37.5mm
Ball Pitch	1.27mm
Ball diameter	30 mils (0.76 mm)
Solder Pad Solder Mask Opening	25 mils (0.64 mm)
Pad-to-ball Ratio	0.84
Solder Pad finishing	Electrolytic Ni-Au Plating

Similar lead free flux (water soluble) and ball attach reflow profile were used in this study. The ball attach profile is ramp-to-peak with 240^0C peak temperature and 35 second time above 230^0C.

Melting properties of each solder type was characterize using differential scanning calorimeter (DSC) model *Metler Toledo* 822e with heating rate of 5ºC/min for the range of 180-260ºC. Microstructure of the samples underwent standard metallurgical cross sectioning to reveal the IMC. Sample size for cross-sectioning is 3 units per read point, 2 balls per unit, and 3 maximum IMC peaks per ball. To investigate the strength between solder ball and substrate, the shear test and cold pull test were carried out using *Dage* 4000. For ball shear test, the shearing height is 30µm with test speed is 300µm/s and 5mm/s for cold ball pull test. Samples for ball shear test, cold ball pull test and cross-sectioning were prepared from two different tests conditions; high temperature storage (HTS) and multiple reflow. Samples of HTS were dry baked in oven at 150ºC. In this study, storage time tested were 0, 48, 96 and 168 hours. Besides observing the aging time, samples were multiple reflowed for 1x, 2x, 3x and 6x at peak temperature 240ºC using the 7-zone BTU production reflow furnace. In this study, zero storage time (T0) is referred as fresh samples after assembly and T168 is referred as 168 hours of 150ºC thermal aging. The drop test was carried out according to Advanced Semiconductor Engineering (ASE) and Freescale methods to obtain drop fail data. This is important to evaluate the solder joint's ability to absorb vibration and impact shock.

RESULTS AND DISCUSSION

Melting properties

Table 2 shows the summary results of DSC for both solder alloys. It shows that the ition Sn3.5Ag has melting peak ~ 4ºC higher than SAC 387. Average melting range is 2.3 ºC for Sn3.5Ag and 1.8 ºC for SAC 387, which is insignificantly different in terms of statistical t-test of the melting range, assuming normal distribution of the melting range data.

Table 2: Summary results of the melting behaviour

Solder	Onset (ºC)	Peak (ºC)	Endset (ºC)	Average Melting Range (ºC)
Sn3.5Ag	221.02	222.05	222.82	2.3
SAC 387	217.29	218.21	219.14	1.8

The DSC indicates both Sn3.5Ag & SAC 387 solder alloys have considerably small melting range due to Sn3.5Ag is the eutectic composition with melting point of 221 ºC, whereas SAC387 solder is located near the ternary eutectic composition [4] with melting temperature of 217ºC. It is believe that the melting range influences intermetallic growth as the onset melting indicates the start of the molten solder reaction and endset indicates the end. Hence, the larger melting range indicates a longer temperature range of intermetallic formation which lead a thicker intermetallic formation. General perception is that larger melting range is associated with higher IMC growth.

IMC cross-sectioning result

IMC thickness is one of the major concerns to predict the solder joint reliability. It is widely accepted that higher IMC thickness will cause the joint to be more prone to brittle failure. The thicker the IMC layer at the interface is correspond to the lower shear strength of the joint [6].

Figure 1 and 2 shows that Sn3.5Ag has lower intermetallic thickness for all the conditions of HTS and multiple reflow, compared to SAC 387. IMC thickness for Sn3.5Ag does not show significant growth following thermal aging and multiple reflow compared to SAC 387. Therefore correlation between melting range and IMC thickness may not be established. On the other hand, Ho et. al. Reported that SAC alloy with Cu-rich IMC has bigger grain size which resulted in thicker IMC than Ni-Sn IMC of Sn3.5Ag alloy. This is in good agreement of this work which implies better joint reliability for Sn3.5Ag.

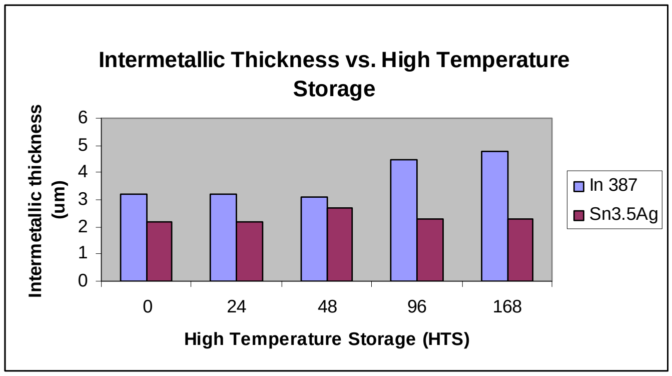

Figure 1: Intermetallic thickness for HTS samples

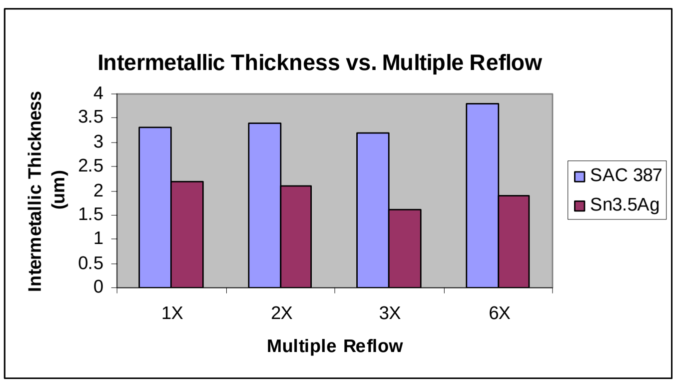

Figure 2: Intermetallic thickness for multiple reflow samples

Ball shear result

Ball shear test is used to estimate the joint strength of each solder composition with the pad metallurgy. Result of Figure 3 shows the average of shear strength result for both the solder system at different multiple reflow conditions. In all cases, the shear strength is indicate by shear load in gram. Both alloys show ductile failure mode in all the stress conditions with Sn3.5Ag solder has relatively lower shear strength but still much higher above the lower spec limit of the shear strength (1000g). It is believe that the lower shear value is due to the nature of the solder that is softer (with Vickers hardness at 17.4 Hv) and less rigid compared to SAC 387 (with Vickers hardness at 18.2 Hv). However, shear result for the high temperature storage units shown in Figure 4 shows a slightly different behavior as compared to multiple reflow. Sn3.5Ag is found to have higher shear strength at T48, T96 & T168. This could be explained by the growth of Ag-Sn microstructure following HTS condition that creates a dispersion hardening effect.

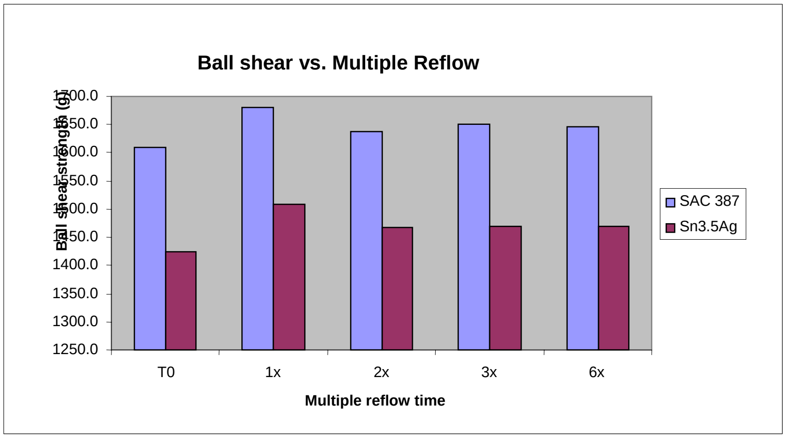

Figure 3: Ball shear strength with multiple reflow time of 1x, 2x, 3x and 6x

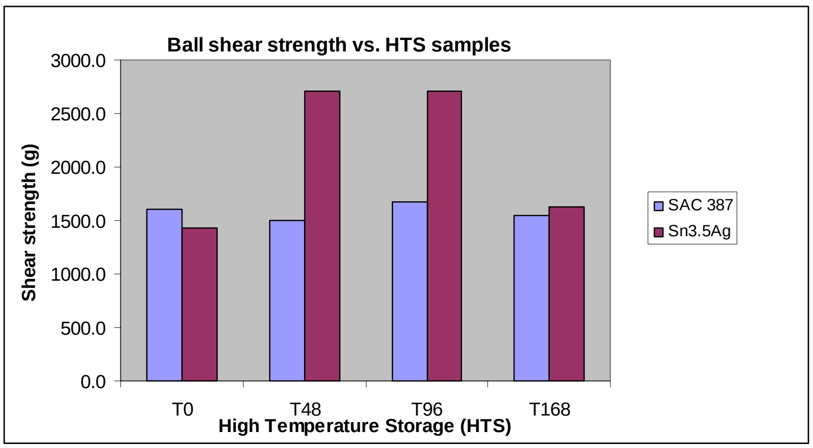

Figure 4: Ball shear strength with HTS time of T0, T48, T96 and T168 hours

Cold ball pull result

Cold ball pull method is widely acknowledged by the industry in the recent years to fully determined the weak interface and the joint strength. Ball pull is found to be more stringent than ball shear because of the pulling mechanicism that minimizes ball deformation above the bond site, as well as causes the bond not to be supported by the solder pad cavity wall, thus exposes the true bond strength. In the case of ball shear, higher ball deformation above the bond site is found at the peak of shear force which will result in smaller test area, and support from solder pad cavity wall could substantially shield a bad bond from failing[7]. Figure 5 and Figure 6 shows the pull strength of both the alloy system after multiple reflow and high temperature storage, respectively. Sn3.5Ag alloy system shows better solder joint performance even at prolonged aging of reflow and HTS conditions. It has 0% of brittle failure and capable to maintain or occasionally increase its joint strength throughout the aging conditions. SAC 387 however shows a very high percentage of brittle failure (~100%) for both multiple reflow and HTS conditions. Both the conditions shows that joint strength decrease from T0 condition to 6x reflow and T168@150ºC storage. From the ball pull result, it can be conclude that Sn3.5Ag provides better solder joint strength as compared to SAC 387.

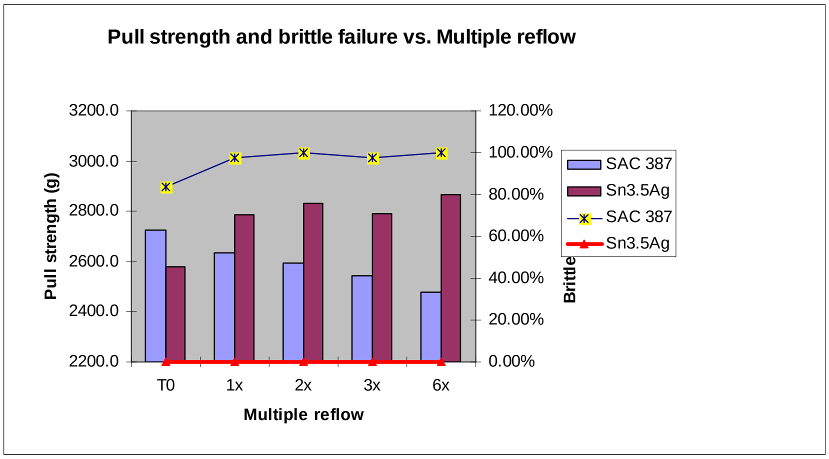

Figure 5: Pull strength at 5000 um/s and percentage of brittle failure at multiple reflow of 1x, 2x, 3x and 6x

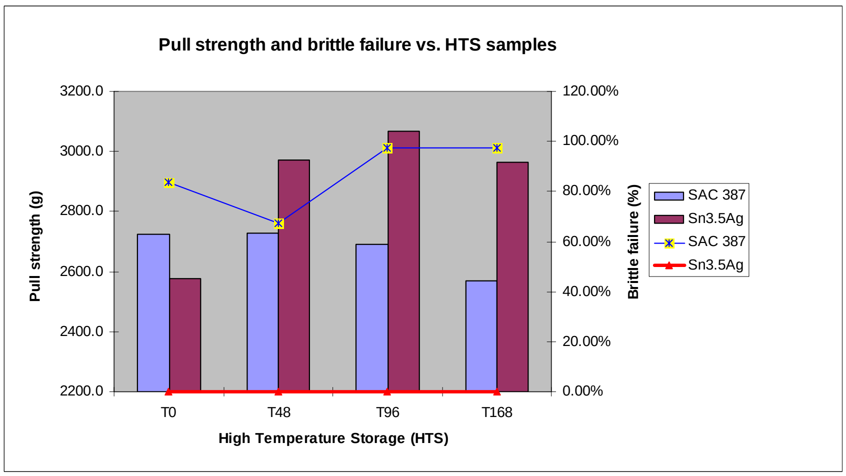

Figure 6: Pull strength at 5000 um/s and percentage of brittle failure at HTS of T0, T48, T96 and T168

Drop Tests

Two drop tests were carried out to assess the solder joints robustness againt vibration and impact shock. They were Advenced Semiconductor Engineering (ASE) drop test (6 units sample size) and Freescale packing drop test (60 units sample size) as illustrated in Figure 7 & Figure 8, respectively. The most stringent package chosen for this test was 740TBGA (37.5x37.5mm) with 1mm ball pitch and 0.68 pad-to-ball ratio. The samples were dropped through many cycles until dropped ball was found, with maximum 20 cycles tested. Following every cycle, the samples were then inspected for dropped balls, and any broken trays were replaced to prevent dropped balls caused by chips from the trays. The number of cycles was recorded and shown in Table 3 for ASE drop test and Table 4 for Freescale Packing Drop Test.

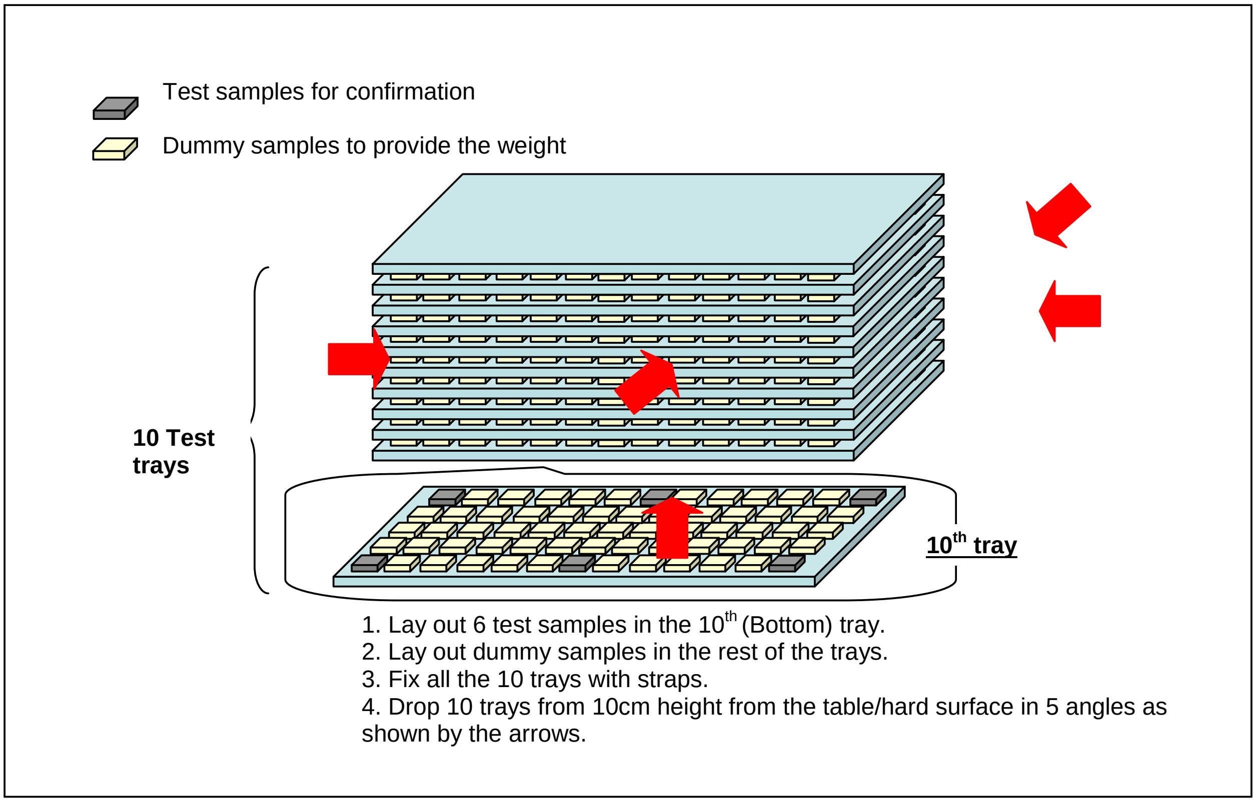

Figure 7: ASE Drop Test

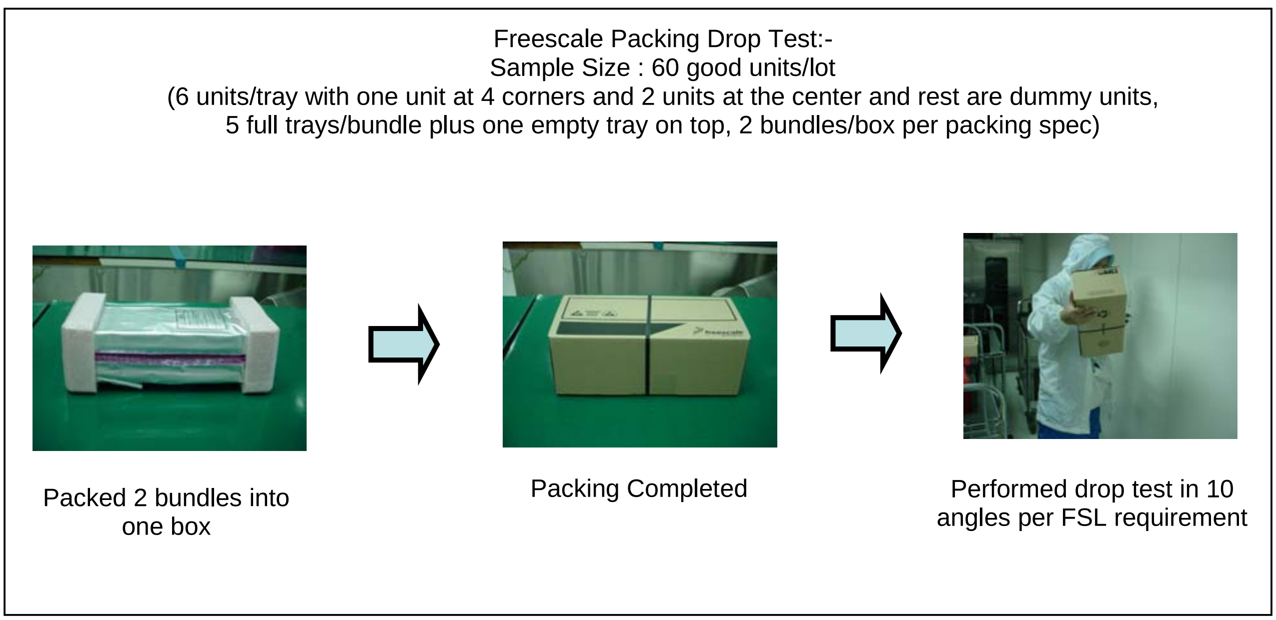

Figure 8: Freescale Packing Drop Test

Table 3: ASE Drop Test Result

Solder Composition	No of Cycle tested	No of Cycle when ball drop happened	No of units with ball drop	No of balls drop
Sn3.5Ag	17	17	2	2
SAC 387	2	2	1	4

Table 4: Freescale Packing Drop Test Result

Solder Composition	No of Cycle tested	No of Cycle when ball drop happened	No of units with ball drop	No of balls drop
Sn3.5Ag	20	No ball drop seen	0	0
SAC 387	3	3	3	5

From the drop test result, it can be concluded that Sn3.5Ag solder system is more robust than SAC 387 against vibration and impact shock. Sn3.5Ag encountered ball drop after 17 cycles of ASE drop test but SAC 387 failed for ball drop after just 2 cycles. No failure for Sn3.5Ag after 20 cycles of Freescale Packing Drop Test but SAC 387 failed at the 3rd cycle of drop test. This shows that Sn3.5Ag solder system is more robust than SAC 387 against vibration and impact shock.

CONCLUSION

Melting properties study and metallurgical cross-section suggest that the correlation between melting range and IMC thickness may not be established. Thermal aging and multiple reflow also does not support significant growth IMC for Sn3.5Ag compared to SAC 387. Sn3.5Ag is found to have higher shear strength at T48, T96 & T168. Ball pull result suggested that Sn3.5Ag provides better solder joint strength as compared to SAC 387. Sn3.5Ag solder system is also more robust than SAC 387 against vibration and impact shock according to drop test.

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