Joint Reliability by Different Combination of PCB Surface Finish and Solder Alloy Composition

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Introduction

Electronics assemblies for automotive applications are transitioning to the lead-free solder just like the ones for consumer electronics. However, they are exposed to more severe operation environment, such as vibration and high temperature. This increases concern over the strength of standard lead-free solder, Sn3.0Ag0.5Cu (hereinafter referred to as SAC305).

This concern increased demands for "high durability solder alloys" which is strengthened by solid solution by adding additive element, for instance, Indium (In), Bismus (Bi) and Antimony (Sb) in the base metal (Sn). However, it has been revealed that although In is effective on improving resistance on both static and dynamic stresses, it reacts with Ni in the PCB and component surface finish and deteriorates the durability. This article discusses findings from KOKI investigation.

1. Verification Methods

Table 1, table 2 and table 3 show investigated solder alloy compositions, investigated PCB surface finishes, and investigated components for this experiment, respectively. Fig. 1 shows the reflow profile used to solder the test samples.

Table 1 Investigated Solder Alloy Composition

	Sn	Ag	Cu	Bi	In
SAC305	Bal.	3.0	0.5	---	---
SB6N	Bal.	3.5	---	0.5	6.0
SB6NX	Bal.	3.5	0.8	0.5	6.0

Table 2 Investigated PCB Surface Finish

	Joint Reliability/ Structure observation		Drop Impact Test
Surface Finish	ENIG	OSP	ENIG
PCB Material	FR-4	FR-4	FR-4
PCB Thickness (mm)	1.6	1.6	1.0
Copper Pad Thickness (μm)	18	18	18
Ni-P Layer Thickness (μm)	5	-----	5
P content in Ni-P Layer (%)	7	-----	7

＊Stencil Thickness: 120μm

Table 3 Investigated Components

Type of Component	Specification, etc…
3216 Chip Resistor	Electrode: Sn electroplating
SAC305 BGA	Ball size: 500μm Ball pitch: 1.0mm Bump Composition: full grid # of bumps: 14*14 (196)

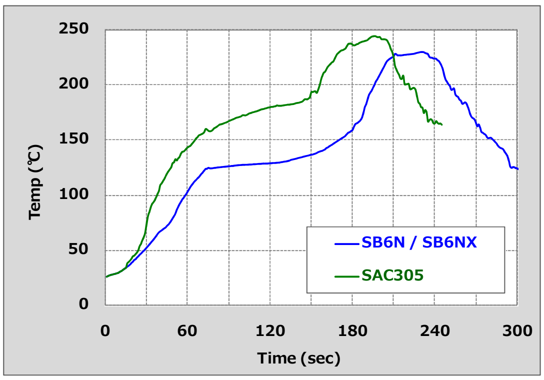


Fig. 1 Reflow Profile

1.1 Thermal Cycle Test

Test samples for thermal cycle test are prepared by mounting and reflowing 3216 chip resistors on PCBs with 2 different surface finish, Electroless Nickel/ Immersion Gold (ENIG) and heat resistant preflux (Organic Solderability Preservative: OSP).

Reflowed test samples were divided into 2 groups. One group is placed in the thermal cycle test chamber conditioned at -40/+125˚C. The other group is placed in the thermal cycle test chamber conditioned at -40/+150 ˚C. As for the thermal cycle profile, upper dwell time and lower dwell time are 30 minutes and ramp-up and ramp-down times are 5 minutes. Every 500 cycles, a few boards are taken out of the test chamber and joint strength test (shearing at 0.5mm/sec) and cross-section observation (for solder cracking and structure) were performed.

1.2 Board Level Drop Test

Test samples for board level drop test are prepared by mounting and reflowing BGA with SAC305 solder balls on PCBs with ENIG surface finish, and they were thermally aged in a hot air oven at 150 ˚C for 500 hours. The test was performed in accordance with JEDEC's JESD22-B1111. Board is dropped repeatedly until the voltage monitor detects intermittent discontinuity (when the voltage drops below 90%). Number of drops until the intermittent discontinuity were recorded and solder joint cross-section were observed for analysis.

2. Results

2.1 Joint Strength after Thermal Cycle

Fig. 2 shows solder joint strength after -40/+125 ˚C thermal cycles on 3216 chip resistors soldered on OSP and ENIG surface finish PCBs. SAC305 on ENIG finish PCB shows higher joint strength than SAC305 on OSP finish PCB. On the contrary, SB6N shows opposite result; ENIG finish PCB showed lower joint strength than OSP finish.

As for the SB6NX, no significant difference was observed between ENIG finish and OSP finish.

Similar trend but smaller difference was observed on the samples which underwent -40/+150 ˚C thermal cycles.

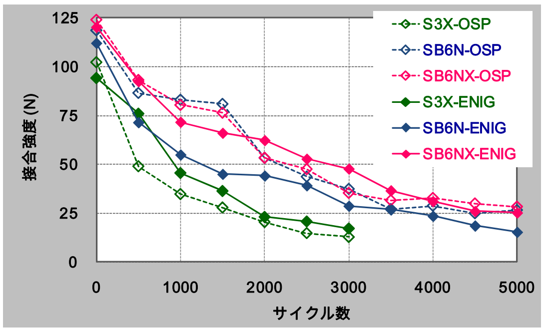


Fig. 2 Solder Joint Strength after -40/+125˚C thermal cycle

2.2 Crack Occurrence after Thermal Cycle

Fig. 3.1 and 3.2 are the cross-sectioned solder joints on OSP finished and ENIG finished PCBs after 3000 cycles at -40/+125 ˚C.

A crack which is propagating through entire SAC305 solder fillet on the side with stress concentration can be seen. For SB6N and SB6NX, crack initiation underneath the electrode can be seen but none of it propagates through the solder fillet.

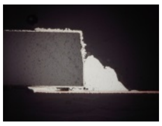
SAC305	SB6N	SB6NX
		

Fig. 3.1 Cracking on OSP finished PCBs after 3000 Thermal Cycling

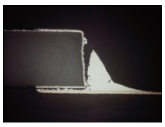
SAC305	SB6N	SB6NX
		

Fig. 3.2 Cracking on ENIG finished PCBs after 3000 Thermal Cycling

2.3 Changes in Joint Interface by Thermal Cycle

Fig. 4 show images of Inter-Metallic Compound (IMC) layer on OSP finish and ENIG finish PCBs at initial (as-reflowed) and after 3000 cycles in -40/+150 ˚C chamber.

OSP finish PCB soldered with SB6NX appears to show the least IMC growth; however, difference among the tested compositions is not significant. On the other hand, ENIG finish PCB soldered with SB6N shows significant IMC layer growth, thinner Ni-P layer and Kirkendall void occurrence.

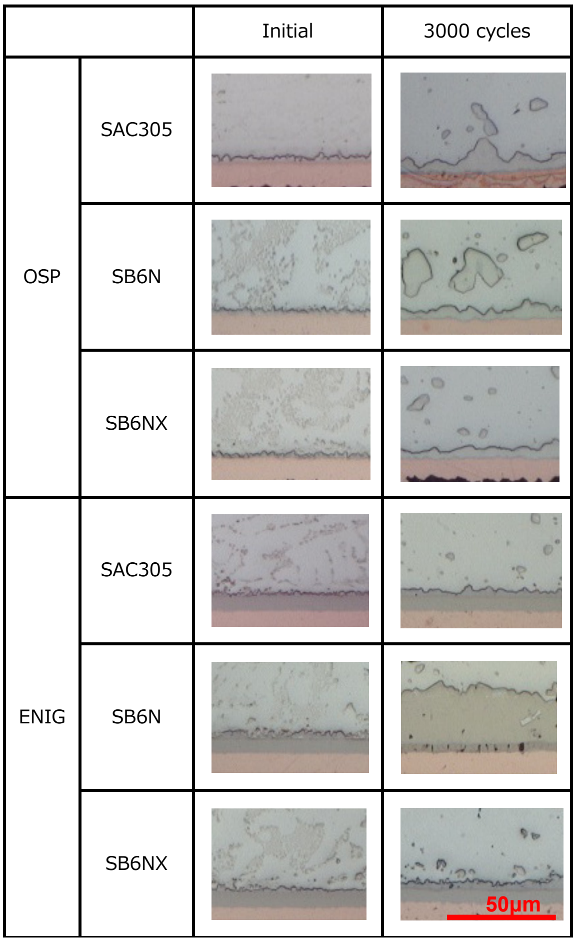


Fig. 4 Change in IMC Layer after 3000 cycles at -40/+150 ˚C

Fig. 5 show element mapping on IMC layer at solder joints of SB6N and SB6NX soldered on ENIG finish PCB.

After the thermal cycle, P in the SB6NX slightly concentrated within the upper Ni-P layer; however, in general, no significant difference between before and after the thermal cycles.

On the contrary, Ni in the SB6N broadly dispersed after the thermal cycle which conveys evident P concentration within the upper Ni-P layer.

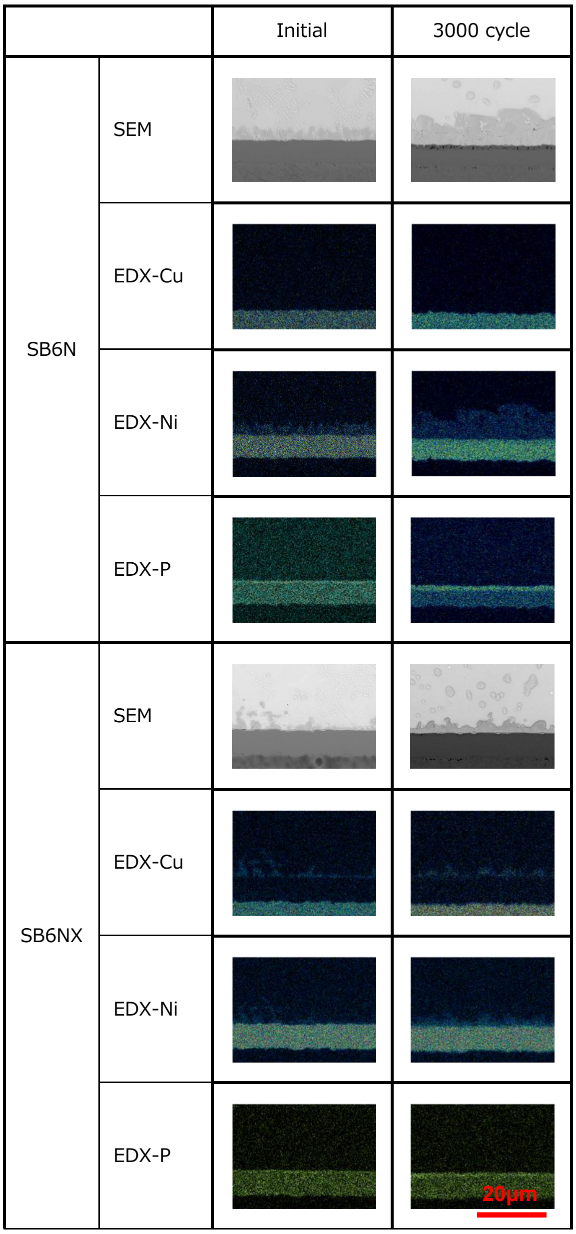


Fig. 5 IMC before and after -40/+150 ˚C thermal cycles

2.4 Board Level Drop Test

Fig.6 shows the result of board level drop tests in accordance with JEDEC JESD22-B111 test method.

SB6NX withstand more drops until the intermittent discontinuity than SB6N. Fig. 7.1 shows the cross-sectioned images of BGA solder joints after drop tests. SB6N's fracture occurred at the solder joint, while SB6NX's solder joint fractured at the package side. This result suggests that SB6NX soldered on ENIG finish PCB obtained more sufficient impact resistance than that of SB6N.

In addition, Fig. 7.2 shows that SB6N's P concentration within upper Ni-P layer can be observed even when the majority of solder joint is consisted of SAC305 from BGA solder ball.

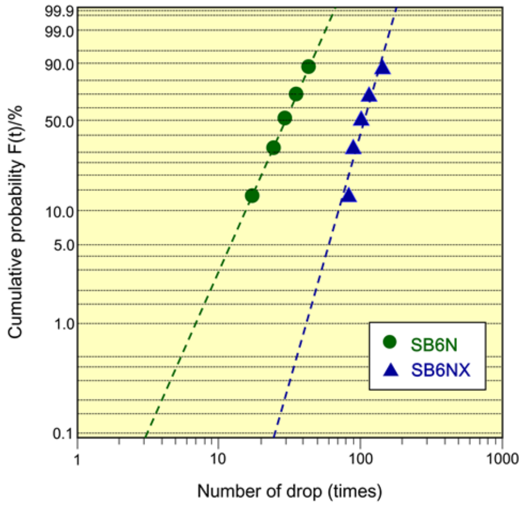


Fig. 6 Board Level Drop Test Result after Aging at 150 °C (ENIG Finish PCB)

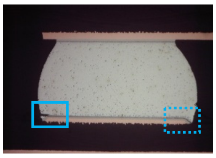
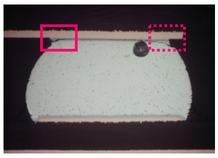
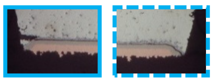
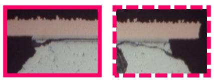
	SB6N	SB6NX
Whole Bump		
Magni-fied		

Fig. 7.1 Fracture Location from Board Level Drop Test

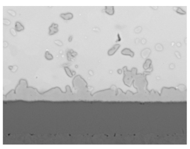
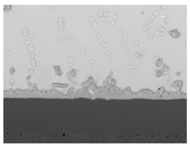
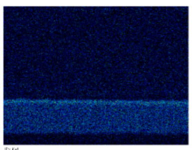
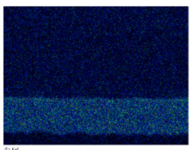
	SB6N	SB6NX
SEM		
EDX-P		

Fig. 7.2 Solder Joint Element Mapping from ENIG Finish PCB after Aging at 150 °C (SEM-EDX)

3. Discussion

Poorly manufactured ENIG finish PCB has been associated with Ni-P layer delamination and black pads which may deteriorate the joint reliability and durability. However, properly manufactured ENIG finish board and standard SAC305 solder alloy can form solder joint which can perform joint strength equivalent to OSP finish and standard SAC305 solder alloy solder joints.

On the other hand, joint strength of the high durability alloy containing In degrades after thermal cycle to be equivalent to the SAC305 solder alloy. Long time exposure to high temperature causes Ni in Ni-P layer to disperse into the bulk solder generating kirkendall voids in the process, and forms considerably thick IMC layer and P concentration in upper Ni-P layer.

These phenomena are derived from In's high reactivity toward Ni. Thus, to prevent above phenomena and improve thermal fatigue resistance, another additive element which reacts with In better than Ni is necessary.

SB6NX on ENIG finish PCB exhibits improved joint strength after thermal cycles, about the same strength as SB6NX on OSP finish PCB, owing to the Cu additive. Cu additive captures dispersed Ni and forms IMC at joint interface. As a result, substantial IMC layer growth and P concentration are inhibited.

Benefit of Cu additive can be found in both board level drop test and joint strength test after thermal cycles.

In this study, composition ratio at the bulk solder may have been diluted as BGA balls are standard SAC305 alloy; however, impact resistance at the solder joint made of SB6NX and ENIG finish PCB was drastically improved, compared to SB6N solder joint. These superior impact resistance and durability make SB6NX an optimal candidate for application on automotive electronic assemblies which requires thermal stress and vibration resistance.

This study revealed that there are no significant differences between SB6N and SB6NX in terms of crack occurrence after thermal cycling, which may have further ensured the effectiveness of additive elements. This suggests that the enlarged IMC layer and P concentrated area are less affected by the static stress, such as thermal fatigue. Furthermore, it also indicates that SB6N, without Cu additive, could perform as same reliability as solder joints made of OSP finish PCB on assembled products as long as they are not subject to the dynamic stress such as shock or vibration.

4. Conclusion

(1) Between the OSP finish PCB and ENIG finish PCB, joint strength after thermal stress depends on the alloy composition of the solder. Solder joints made of solder alloy with In additive (e.g. SB6N: Sn/3.5Ag/0.5Bi6.0In) and ENIG finish board could perform worse than OSP finish board.

(2) Solder joints made of In added solder alloy and ENIG finish PCB shows significant IMC layer growth and Kirkendall voids and P concentration can be seen within Ni-P layer.

(3) Joint reliability of the ENIG finish PCB and solder alloy with In addition can be as good as OSP finish PCB if the solder alloy also contains Cu, which captures dispersed Ni.