Sn3.2Ag0.7Cu5.5Sb Solder Alloy with High Reliability Performance up to 175°C

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ABSTRACT
A novel lead-free solder alloy 90.6Sn3.2Ag0.7Cu5.5Sb (SACSb), was developed targeted for high reliability with a wide service temperature capability. The alloy exhibited a melting temperature range of 223 to 232°C, reflowable at profile with peak temperature 245°C and 255°C, with ambient temperature Yield Stress 60MPa, UTS 77 MPa, and ductility 28%, and a higher stress than both SAC305 and 90.9Sn3.8Ag0.7Cu3Bi1.45Sb0.15Ni (SACBSbN), the latter two alloys were used as controls. When tested at 140°C and 165°C, the die shear stress of SACSb was comparable with SACBSbN but higher than SAC305, and the ductility was higher than both SACBSbN and SAC305, with SACBSbN exhibiting distinct brittle behavior. When aged at 125°C and 175°C, the die shear strength of SACSb was comparable or higher than both controls. When pretreated with a harsh condition, a temperature-shock test (-55°C/155°C) for 3000 cycles, the die shear strength of SACSb was 8 times of that of SACBSbN and SAC305. When pre-conditioned using a temperature-cycling test (-40°C/175°C) for 3000 cycles, the die shear strength of SACSb was 11 to 20 times higher than that of SACBSbN and SAC305, depending on the flux type used. Both SACSb and SACBSbN are alloys based on SnAgCu, but reinforced with precipitate hardening and solution hardening, with the use of additives including Sb, Ni, and Bi. SACSb exhibited a finer microstructure with less particles dispersed, while SACBSbN exhibited more particles with some blocky Ag_3Sn plates or rods. SACSb is rigid and ductile, while SACBSbN is rigid but brittle. Under the harsh test condition where ΔT was high, the dimension mismatch between parts and substrate became very significant due to CTE mismatch. This significant dimension mismatch would cause a brittle joint to crack quickly, as seen on SACBSbN. The challenge was more tolerable for a ductile joint, as shown by SACSb. Accordingly SACSb showed a much better reliability than SACBSbN under harsh conditions, including high testing temperature and large ΔT. Overall, to achieve high reliability under a wide service temperature environment, a balanced ductility and rigidity for solder alloy is critical for success.

KEY WORDS: reliability, automotive, 90.6Sn3.2Ag0.7Cu5.5Sb, SACSb, ductility, SAC, die attach, thermal aging, thermal cycling test, TCT, thermal shock test, TST

INTRODUCTION

While SnAgCu has been the prevailing choice for SMT assembly and some packaging solder alloy at electronic industry, the adaptability toward next generation automotive applications, including automotive LED applications, is challenged due to questionable service temperature range capability [1-10]. For automotive applications, high reliability is a must not only under moderate temperature, but also under high service temperature conditions. A number of new solder alloys have been attempted by the industry, with major emphasis on enhancing the high temperature capability. However, only limited success has been achieved up to this point, except for the developed novel solder alloy, with high reliability demonstrated on both moderate and high service temperature conditions. In this work, this new alloy was characterized on its physical properties, mechanical properties, and its soldering performance including wetting and voiding. The reliability performance in TCT, TS, and thermal aging tests will be discussed.

Sn3.2Ag0.7Cu5.5Sb

For high reliability with a wide service temperature, one alloy 90.6Sn3.2Ag0.7Cu5.5Sb (SACSb) was developed, as shown in Table 1. Also included in this Table are 96.5Sn3Ag0.5Cu (SAC305), and 90.9Sn3.8Ag0.7Cu3Bi1.45Sb0.15Ni, denoted as SACBSbN.

Table 1 Composition of solder alloys evaluated for high reliability applications

Alloy	Sn	Ag	Cu	Bi	Sb	Ni	Solidus (°C)	Liquidus (°C)
SAC305	96.5	3	0.5	--	--	--	217	218
SACBSbN	90.9	3.8	0.7	3	1.45	0.15	212.6	221.7
SACSb	90.6	3.2	0.7	--	5.5	--	222.9	231.9

The melting behavior of SACSb measured by Differential Scanning Calorimetry (DSC) was shown in Figure 1.

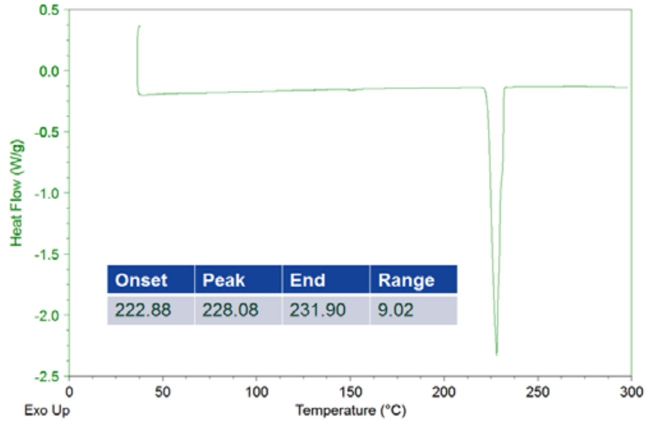


Figure 1 DSC thermograph of solder alloy SACSb

The melting temperature of SACSb is about 11°C higher than SACBSbN, as shown in Table 1.

In this work, the reliability of solder joints for a Si die attached onto Alloy42 leadframe was of primary interest, and the solder joint die shear strength with increasing number of thermal cycling or thermal shock treatment, or with increasing time of high temperature aging, was used to characterize the alloy reliability. Here the CTE mismatch is 13.7 ppm/K, as shown in Table 2. However, during the trial test, the silicon die often cracked before the solder joints failed, thus hindering assessment of joint strength degradation. In order to be able to monitor the solder joint strength degradation, Cu die on Alloy42 was used, with a CTE mismatch of 12.2 ppm/K. Here the CTE mismatch is comparable with that of Si on Alloy42, and a Cu die does not crack during shear testing.

Table 2 Coefficient of thermal expansion (CTE) of several materials

Material	CTE 10^{-6} m/(mK)	ΔCTE 10^{-6} m/(mK)
Silicon	3	13.7 (Si on Cu)
Cu	16.7	12.2 (Cu on Alloy42)
Alloy42 (Fe58/Ni41/Mn0.8)	4.5	

The ambient-temperature mechanical properties of the alloys listed in Table 1 are shown in Table 3. The shear test curves for solder joints of Cu die (3mm x 3mm) attached onto Alloy42 substrate measured at 140°C and 165°C are shown in Figure 2 and Figure 3, respectively. The solder materials used were solder pastes using Flux B (FB).

Table 3 Ambient temperature mechanical properties of several solder alloys

Alloy	Yield stress, MPa	UTS, Mpa	Ductility, %
SAC305	39.0±3.1	50.8±4.8	37.1±2.4
SACBSbN	44.0±4.0	81.2±10.1	16.6±1.3
SACSb	59.5±2.9	77.3±1.7	27.6±3.2

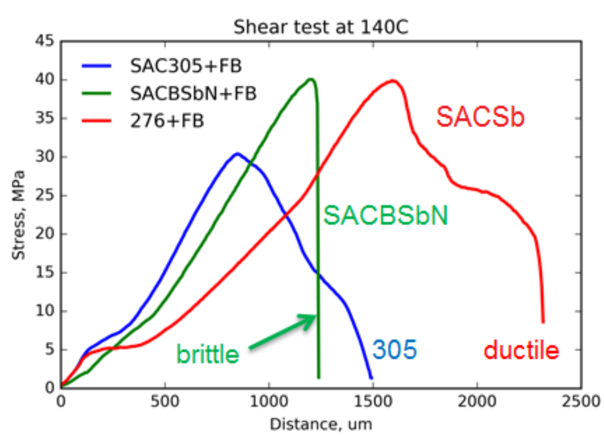


Figure 2 Shear test curves for solder joints of Cu die (3mm x 3mm) attached onto Alloy42 substrate measured at 140°C

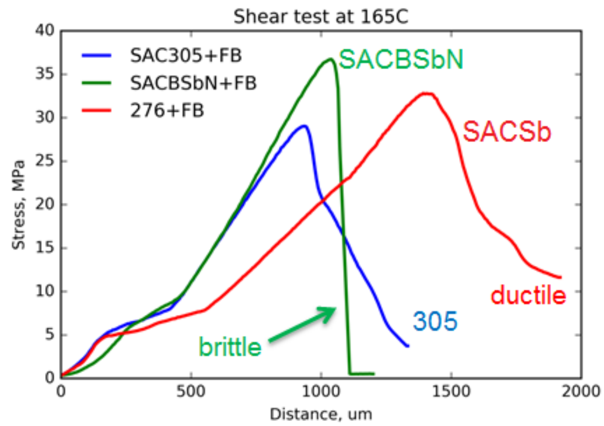


Figure 3 Shear test curves for solder joints of Cu die (3mm x 3mm) attached onto Alloy42 substrate measured at 165°C

As shown in Table 3 and Figure 2 and Figure 3, both SACBSbN and SACSb exhibit higher yield stress and UTS (Ultimate tensile stress) than SAC305. SACBSbN has the lowest ductility, and the rapid drop in stress failure pattern shown in Figure 2 and Figure 3 indicated brittle failure. SAC305 exhibited higher ductility than SACSb at ambient temperature. But, the relative ranking reversed at elevated temperature, 140°C and 165°C, with SACSb being more ductile than SAC305, as shown in Figure 2 and Figure 3.

REFLOW PROFILE

Two reflow profiles under air atmosphere were used in this study, as shown in Figure 4 with a peak temperature of 245°C and Figure 5 with a peak temperature of 255°C. Unless otherwise specified, the 255°C peak temperature profile was used.

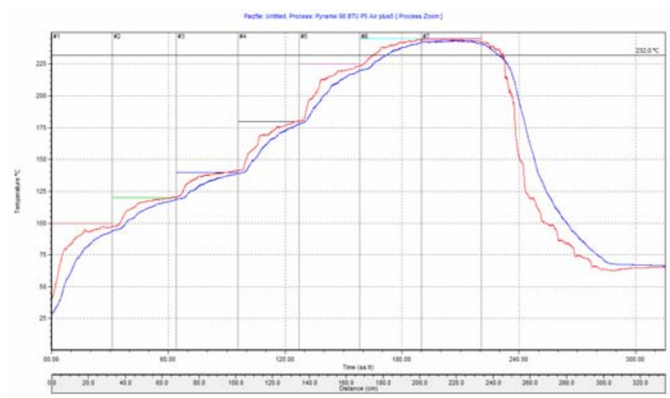


Figure 4 Reflow profile with a peak temperature of 245°C.

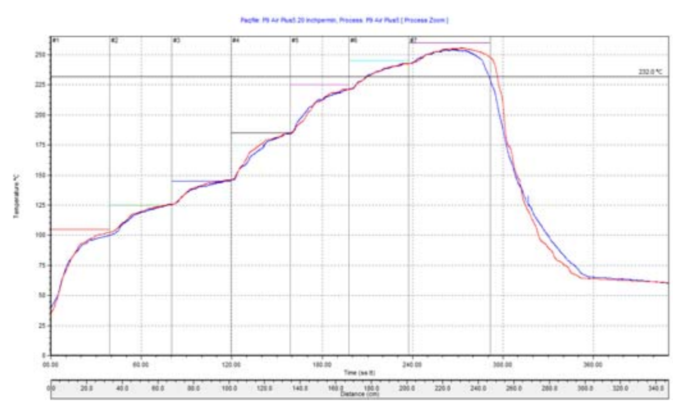


Figure 5 Reflow profile with a peak temperature of 255°C.

VOIDING

The voiding was monitored by X-ray imaging. For samples processed with 255°C peak temperature profile, the voiding results are shown in Figure 6. Flux B (FB) showed less voiding than Flux A (FA). SAC305 showed the lowest voiding, with SACSb and SACBSbN being comparable in voiding amount. Cu die on OSP showed lower voiding than Cu die on Alloy42.

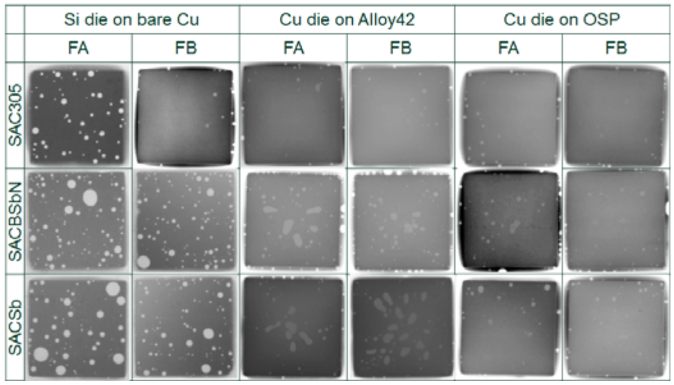


Figure 6 X-ray showing voids in as-reflowed assembly, reflowed with peak 255°C, die size 3x3 mm

SHEAR STRENGTH AS-REFLOWED

The shear strength of as-reflowed solder joints measured at room temperature for various combinations of materials and solder alloys are shown in Figure 7. All solder pastes were reflowed with a 255C Peak profile.

Several trends were observed. First, Cu-Cu resulted in higher shear strength than Cu-Alloy42, presumably due to better wetting on Cu than on Alloy42. Secondly, SACSb showed a higher shear strength than both SAC305 and SACBSbN. Thirdly, Flux A (FA) showed a higher strength than Flux B (FB). However, the relative ranking of flux on shear strength could not be observed in Figure 8 to be discussed next, suggesting a possible data scattering effect.

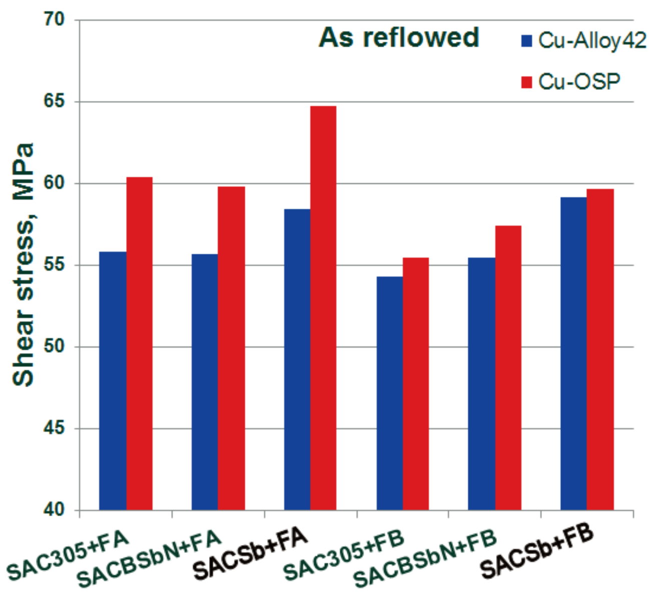


Figure 7 The shear strength measured at room temperature for various combination of materials and solder alloys reflowed with Peak255 profile

The shear strength of as-reflowed solder joints measured at 25°C, 65°C, 105°C, 140°C, and 170°C were shown in Figure 8.

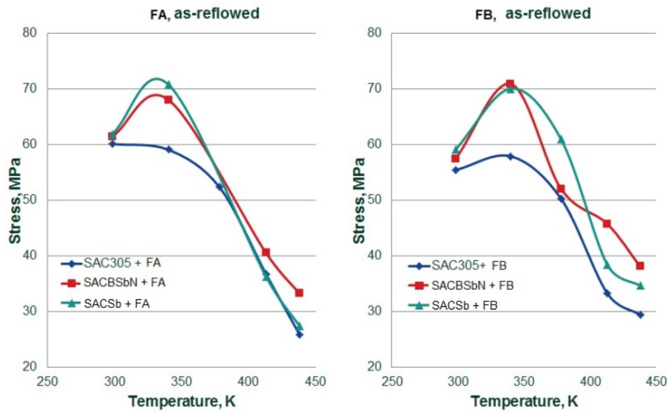


Figure 8 The shear strength of as-reflowed solder joints measured at various temperatures

In general, the shear strength decreased with increasing temperature, except for the initial increase in shear strength at 65°C. The latter could be attributed to annealing or stress relaxation effect. The shear strength of SACSb and SACBSbN were comparable, and both were higher than SAC305. The effect of flux type was unclear, suggesting an insignificant effect on shear strength.

DIE ATTACH RELIABILITY

The reliability of solder joints was assessed by pre-conditioning the solder joints with various TA (thermal aging) or TCT (thermal cycling test) or TST (thermal shock test) treatment, followed by measuring the shear strength.

Figure 9 showed solder joint shear strength measured at room temperature after the mild TA (thermal aging) at 125°C up to 2016 hours.

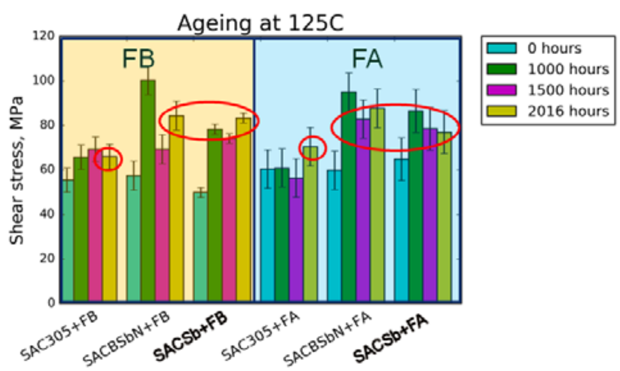


Figure 9 Solder joint shear strength measured at room temperature after TA at 125°C up to 2016 hours.

For automotive applications, 125°C aging condition is considered a mild condition. Under this condition, SACSb is comparable with SACBSbN in shear strength, and the two alloys are equivalent or superior to SAC305. Here the flux factor also is insignificant.

For the more stressed TA treatment at 175°C, after 2088 hours SACBSbN showed a shear strength about 40% of SACSb for FA system, and about 75% of SACSb for FB system, as shown in Figure 10.

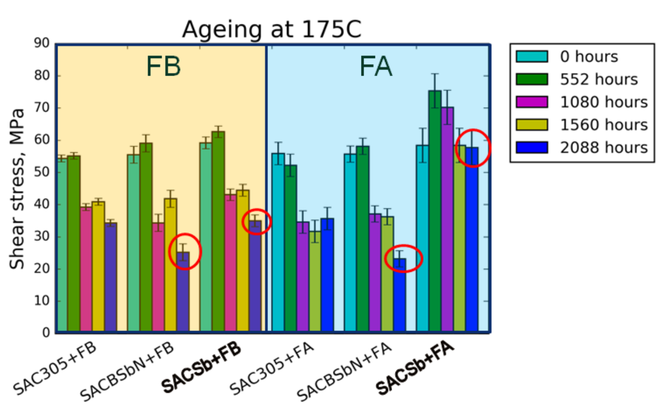


Figure 10 Solder joint shear strength measured at room temperature after 175°C TA up to 2088 hours.

For the mild TCT (-40/125°C) condition, the shear strength against cycling number is shown in Figure 11. After 2238 cycles, the shear strength of SACSb is comparable with SACBSbN, and both of them are higher than SAC305.

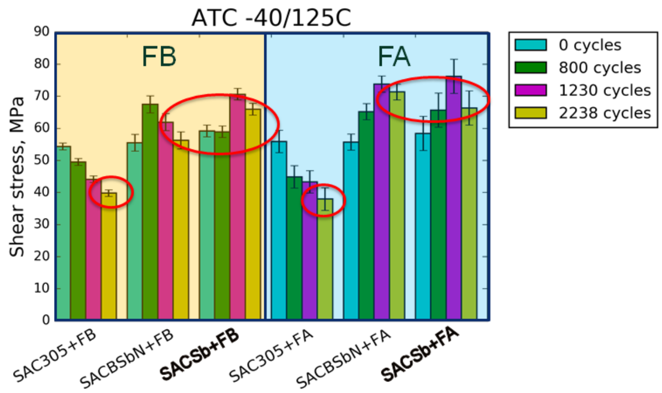


Figure 11 Solder joint shear strength measured at room temperature after TCT (-40°C/125°C) up to 2238 cycles.

For harsh TCT (-40°C/175°C) condition, SAC305 dropped to less than 50% of initial strength after 1000 cycles. SACBSbN and SAC305 exhibited a shear strength about 1/20-1/11 of SACSb, as shown in Figure 12. Flux-wise, FA is comparable with FB.

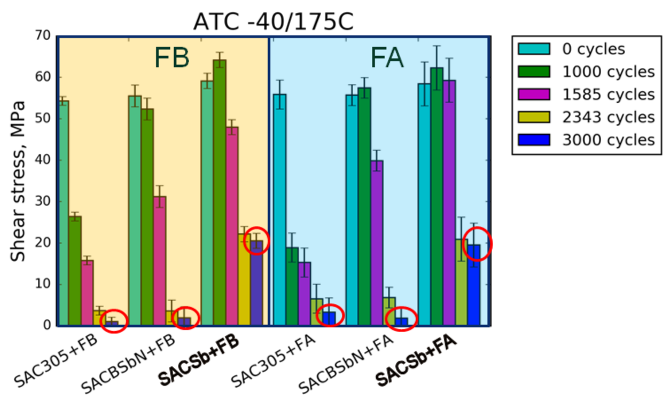


Figure 12 Solder joint shear strength measured at room temperature after TCT (-40°C/175°C) up to 3000 cycles.

For the harsh TST conducted at -55°C/155°C, the results are shown in Figure 13. The cycling detail was 10 min dwell time, ~24 min per cycle.

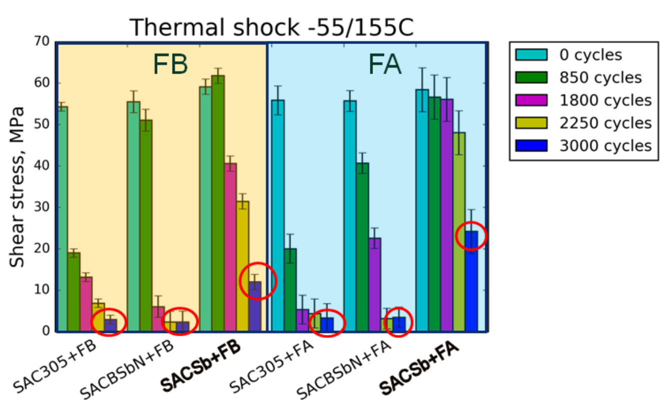


Figure 13 Solder joint shear strength measured at room temperature after TST (-55°C/155°C) up to 3000 cycles.

With increasing TST cycling number, SACSb retained strength very well, followed by SACBSbN, with SAC305 declining most rapidly. After 3000 cycles, the shear strength of SACSb is about 8 times of SACBSbN and SAC305. Joints with FA showed slightly higher shear strength than those of FB.

FAILURE PATTERN

The cross-sectional view of samples using FB after TST (-55/155°C) and TCT (-40/175°C) treatment is shown in Figure 14. The dark arrow signs showed the cracks in the joints. In most incidences, the crack appeared to initiate from the edge of the joints. In the TCT treated samples, both SAC305 and SACBSbN showed obvious cracks after 1000 cycles, SACSb showed signs of cracks after 1500 cycles, and minor cracks after 2343 cycles.

Figure 15 shows some close-up views of joints after TCT treatment. The crack in SAC305 is very obvious.

For TST treated samples, SAC305 showed cracks after 850 cycles, while SACSb and SACBSbN still remained intact.

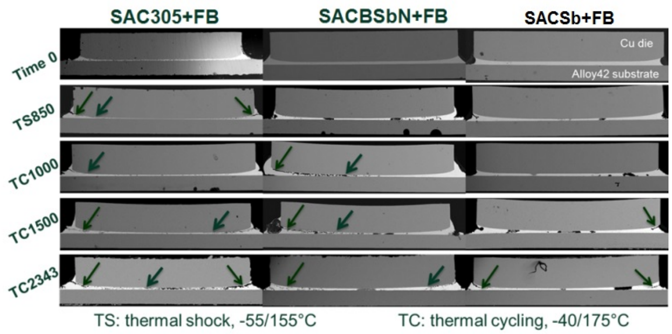


Figure 14 Cross-sectional view of samples using FB after TST (-55/155°C) and TCT (-40/175°C) treatment

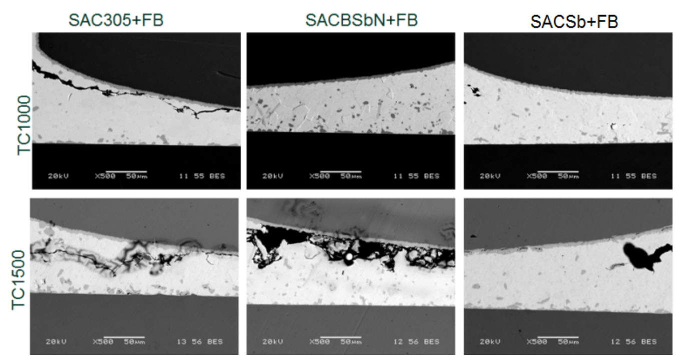


Figure 15 Close-up look of cross-sectioned samples using FB after TCT (-40/175°C) treatment

For samples using FA, Figure 16 shows the cross-sectional view of samples after 2343 TCT cycles (-40/175°C). Clear delamination was observed for SAC305 and SACBSbN, while that of SACSb still remained intact.

Figure 17 shows cross-sectional views of samples using FA after TST (-55/155°C) up to 2250 cycles. Both SAC305 and SACBSbN showed severe cracks after 850 cycles, while SACSb remained intact at 850 cycles, and showed initial cracks after 2250 cycles.

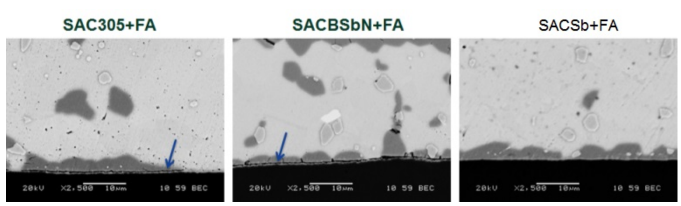


Figure 16 Cross-sectional view of samples using FA after TCT (-40/175°C) 2343 cycles.

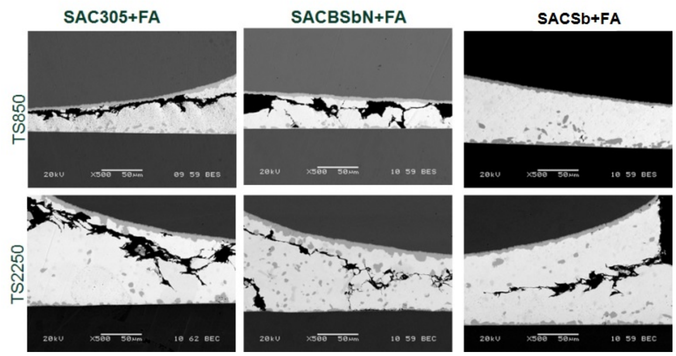


Figure 17 Cross-sectional view of samples using FA after TST (-55/155°C) up to 2250 cycles.

DYE & PRY & X-RAY ANALYSIS

The samples after TCT (-40/175°C) or TST (-55/155°C) treatment were examined by X-ray for delamination and voiding, followed by Dye-and-Pry treatment for crack or delamination analysis.

Figure 18 shows samples using FB after TCT 2343 cycles. The light-colored regions on the substrate marked with red arrows were the surviving joined area. SAC305 and SACBSbN were barely connected, while joints of SACSb largely remained intact. For SACBSbN, the peripheral dark region of the X-ray picture was attributed to the warped Cu die.

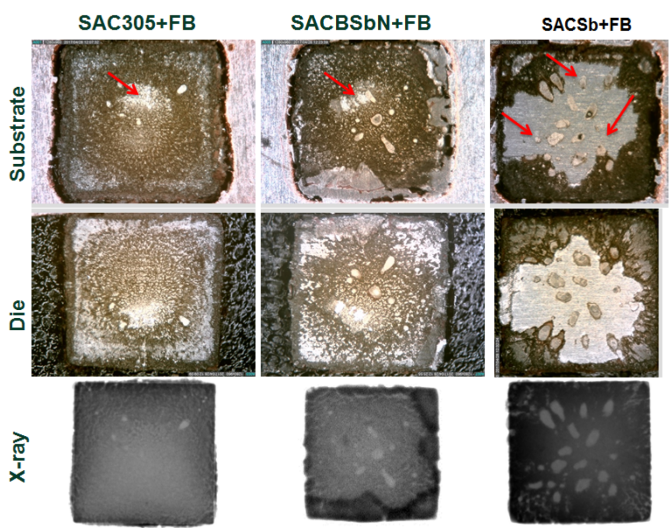


Figure 18 Samples using FB after TCT (-40/175°C) 2343 cycles.

Figure 19 shows samples using FB after TST 3000 cycles. SACBSbN virtually fully separated. SAC305 barely remained connected, while joints of SACSb generally remained intact.

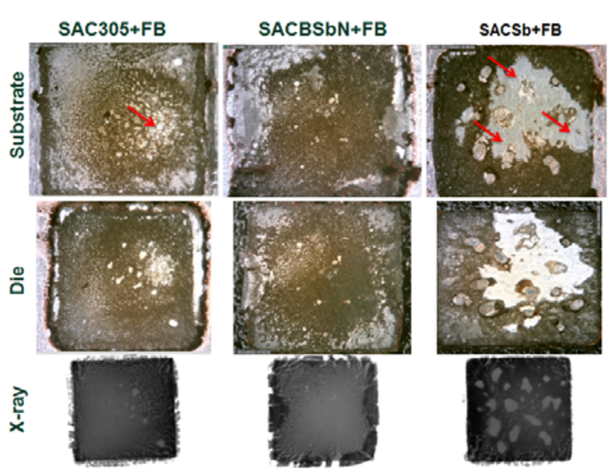


Figure 19 Samples using FB after TST (-55/155°C) 3000 cycles.

The performance of samples using FA and FB was fairly similar. Figure 20 shows samples using FA after TST 3000 cycles. SAC305 virtually was fully separated. SACBSbN barely remained connected, while joints of SACSb largely remained intact.

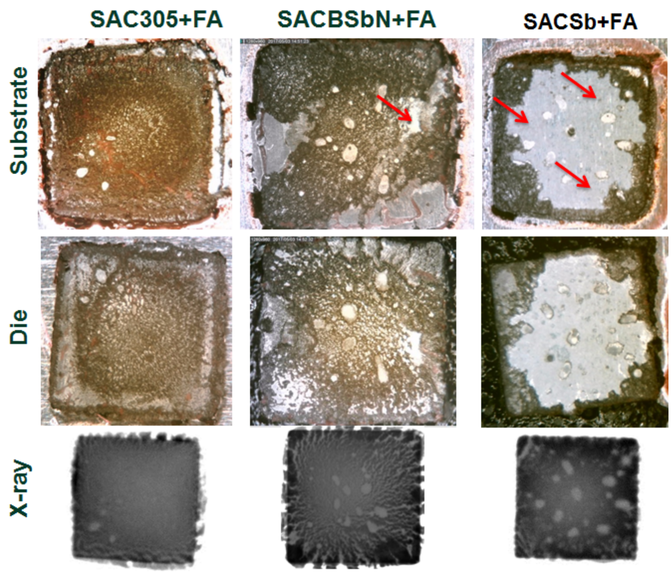


Figure 20 Samples using FA after TST (-55/155°C) 3000 cycles.

RELIABILITY DATA SUMMARY

The reliability data is summarized and listed in Table 4.

Table 4 showed that under mild test condition, SACSb was comparable with SACBSbN, and both performed better than SAC305.

However, under harsh condition, SACSb was much better than SACBSbN, which was equal or better than SAC305.

RELIABILITY VERSUS MECHANICAL PROPERTIES

The reliability summarized in Table 4 can be correlated with the mechanical properties.

Both SACSb and SACBSbN are alloys based on SnAgCu, but reinforced with precipitate hardening and solution hardening, with the use of additives including Sb, Ni, and Bi. The high rigidity resulting from reinforcement should result in higher creep resistance, which promised a better thermal fatigue life than SAC305 under stressed conditions [11, 12], as reflected in Figure 9 to Figure 13.

As shown in Figure 2 and 3, both SACSb and SACBSbN showed a higher maximum stress than SAC305. This suggests that both alloys may deform to a less extent than SAC305 under a typical stressed condition, hence may promise a better joint integrity under mild conditions.

However, there is a significant difference between SACSb and SACBSbN. SACSb is rigid and ductile, while SACBSbN is rigid but brittle, as shown in Figure 2 and Figure 3. Under the harsh test condition where ΔT was high, the dimension mismatch between parts and substrate became very significant due to CTE mismatch. This significant dimension mismatch would cause a brittle joint to crack quickly, as seen on SACBSbN. The challenge was more tolerable for a more ductile joint, as shown by SACSb. Accordingly SACSb showed a much better reliability than SACBSbN under harsh conditions, including high testing temperature and large ΔT.

DUCTILITY

The nature of solder ductility or brittleness were exemplified by the joint fracture pattern as shown in Figures 21, 22, and 23 for as-reflowed SAC305, SACBSbN, and SACSb, respectively.

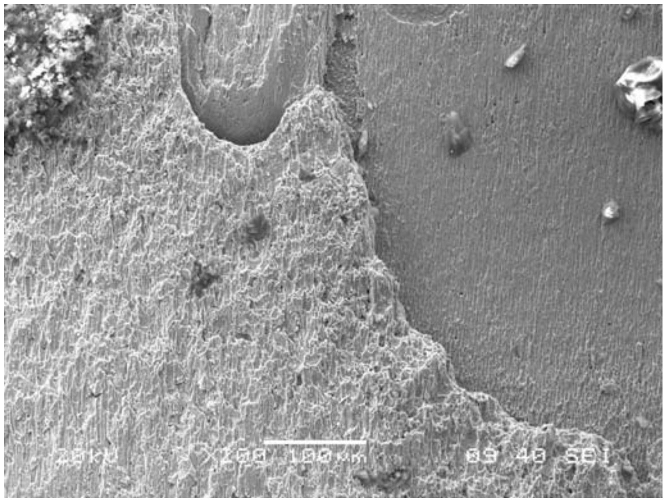
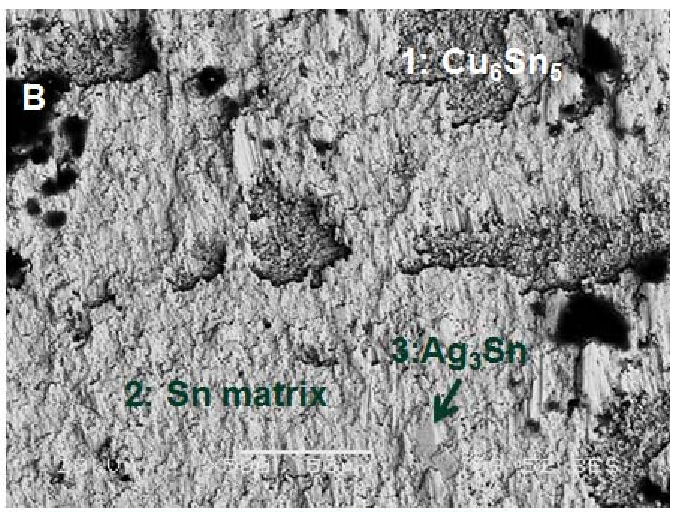


Figure 21 Fractured die back surface of as-reflowed SAC305 joints (200X), with ductile texture shown clearly.

Table 4 Reliability data summary

Note: 305 – SAC305

Test	Condition	Level	Category		
			Shear Strength	Crack	Dye & Pry
TA	125°C	Mild	SACSb ~ SACBSbN > 305	-	-
	175°C	Harsh	SACSb > SACBSbN ~ 305	-	-
TCT	-40/125°C	Mild	SACSb ~ SACBSbN > 305	-	-
	-40/175°C	Harsh	SACSb >> SACBSbN ~ 305	SACSb > SACBSbN > 305	SACSb > SACBSbN ~ 305
TST	-55/155°C	Harsh	SACSb >> SACBSbN ~ 305	SACSb > SACBSbN > 305	SACSb > SACBSbN ~ 305



	Ni-K	Cu-K	Ag-L	Sn-L	Bi-M
1	2.25	55.38		42.37	
2		8.51	1.22	88.68	1.60
3			63.65	36.35	

Figure 22 Fractured die back surface of as-reflowed SACBSbN joints (500X), without sign of ductile texture.

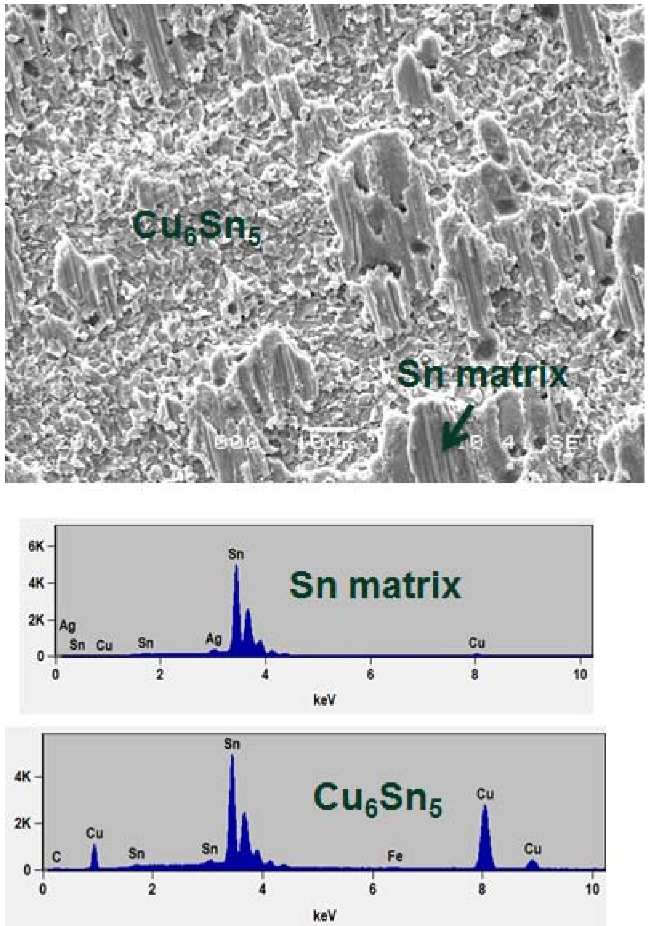


Figure 23 Fractured die back surface of as-reflowed SACSb joints (1000X), with ductile texture shown clearly

MICROSTRUCTURE VERSUS DUCTILITY

The ductility can be closely related to the microstructure of solder joints.

In SACBSbN, the presence of blocky Ag_3Sn plates or rods noted by the arrows can be observed easily, as shown in Figure 24. On the contrary, SACSb showed a much finer and homogeneous microstructure. This non-homogeneity microstructure of SACBSbN strongly suggested that it will have a greater difficulty to exhibit a ductile behavior than other joints with a more homogeneous structure.

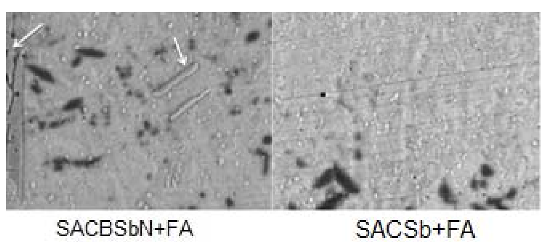
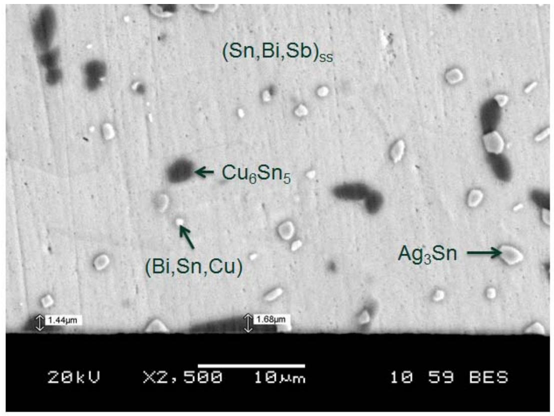


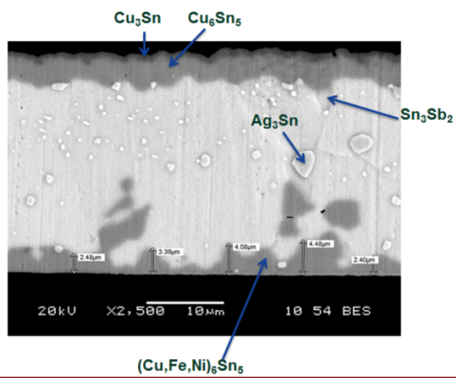
Figure 24 SEM microstructure of cross-sectioned solder joints after reflowed with peak255 profile, with blocky Ag3Sn plates or rods indicated by arrow sign

The effect of homogeneity of microstructure on reliability can also be exemplified by examining the solder joints after 850 cycles of -55/155°C thermal shock treatment, as shown in Figures 25 and Figure 26 for SACBSbN and SACSb, respectively. Figure 25 shows presence of a higher concentration of a variety of IMC particles for SACBSbN, compared with the lower concentration of IMC particles for SACSb joint shown in Figure 26.



	Fe-K	Ni-K	Cu-K	Ag-L	Sn-L	Bi-M
818-4-2 CENTER(1)_pt1	1.30		8.38	57.19	33.14	
818-4-2 CENTER(1)_pt2			5.45		24.84	69.70
818-4-2 CENTER(1)_pt3	0.80	1.74	16.76	37.19	43.50	

Figure 25 SEM of cross-sectioned SACBSbN solder joint after 850 cycles of -55/155°C thermal shock treatment.



Atom %

	Fe-K	Ni-K	Cu-K	Ag-L	Sn-L	Sb-L
TS 850 818-2-5 CENTER(1)_pt1			3.62		56.04	40.34
TS 850 818-2-5 CENTER(1)_pt2					56.38	43.62
TS 850 818-2-5 CENTER(1)_pt3				65.62	34.38	
TS 850 818-2-5 CENTER(1)_pt4			1.85	70.21	27.93	
TS 850 818-2-5 CENTER(1)_pt5	2.54	2.43	48.60	0.27	46.15	

Figure 26 SEM of cross-sectioned SACSb solder joint after 850 cycles of TST (-55°C/155°C) treatment.

A similar impact of non-homogeneity can also be observed in the TCT test (-40/175°C). Figure 16 shows the joints after 2343 cycles. SACBSbN exhibited a greater number of IMC particles than SACSb, and cracks can be seen easily in the SACBSbN joint.

Apparently, to achieve high reliability under a wide service temperature environment, a balanced ductility and rigidity of the solder alloy is critical for success.

CONCLUSIONS

A novel lead-free solder alloy 90.6Sn3.2Ag0.7Cu5.5Sb (SACSb), was developed targeted for high reliability with a wide service temperature capability. The alloy exhibited a melting temperature range of 223 to 232°C, reflowable at profiles with peak temperature 245°C and 255°C, with ambient temperature Yield Stress 60MPa, UTS 77 MPa, and ductility 28%, and a higher stress than both SAC305 and SACBSbN, the latter two alloys being used as controls. When tested at 140°C and 165°C, the die shear stress of SACSb was comparable with SACBSbN but higher than SAC305, and the ductility was higher than both SACBSbN and SAC305, with SACBSbN exhibiting distinct brittle behavior. When aged at 125°C and 175°C, the die shear strength of SACSb was comparable or higher than both controls. When pretreated with a harsh condition, TST (-55°C/155°C) for 3000 cycles, the die shear strength of SACSb was 8 times of that of SACBSbN and SAC305. When pre-conditioned at TCT (-40°C/175°C) for 3000 cycles, the die shear strength of SACSb was 11 to 20 times of SACBSbN and SAC305, depending on the flux type used. Both SACSb and SACBSbN are alloys based on SnAgCu, but reinforced with precipitate hardening and solution hardening, with the use of additives including Sb, Ni, and Bi. SACSb exhibited a finer microstructure with less particles dispersed, while SACBSbN exhibited more particles with some blocky Ag_3Sn plates or rods. SACSb is rigid and ductile, while SACBSbN is rigid but brittle. Under the harsh test condition where ΔT was high, the dimension mismatch between parts and substrate became very significant due to CTE mismatch. This significant dimension mismatch would cause a brittle joint to crack quickly, as seen on SACBSbN. The challenge was more tolerable for a ductile joint, as shown by SACSb. Accordingly SACSb showed a much better reliability than SACBSbN under harsh conditions, including high testing temperature and large ΔT. Overall, to achieve high reliability under a wide service temperature environment, a balanced ductility and rigidity of solder alloys is critical for success.

ACKNOWLEDGEMENTS
The authors would like to acknowledge the significant support of Christine LaBarbera on the microstructure characterization of the solder joints.

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Sn3.2Ag0.7Cu5.5Sb Solder Alloy with High Reliability Performance up to 175°C

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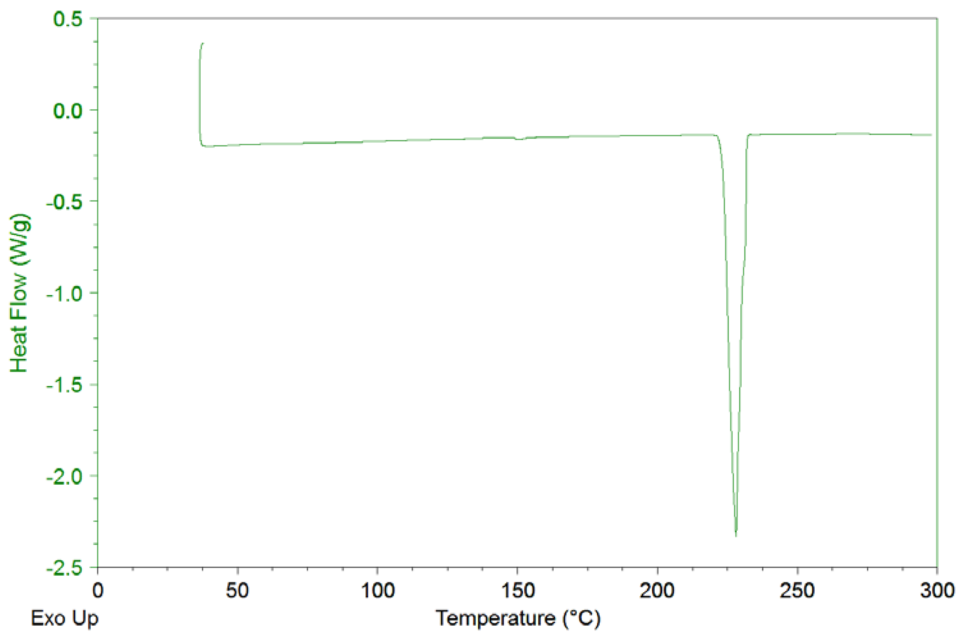
Indium Corporation

Introduction

- For automotive applications, with wide service temperature range, Pb-free solder alloys promising reliability considerably better than SAC are highly desired.
- A novel alloy 90.6Sn3.2Ag0.7Cu5.5Sb (SACSb) was developed, the performance against SAC305 & SACBSbN will be presented.

Composition of solder alloys evaluated for high reliability applications

Alloy	Sn	Ag	Cu	Bi	Sb	Ni	Solidus (°C)	Liquidus (°C)
SAC305	96.5	3	0.5	--	--	--	217	218
SACBSbN	90.9	3.8	0.7	3	1.45	0.15	212.6	221.7
SACSb	90.6	3.2	0.7	--	5.5	--	222.9	231.9



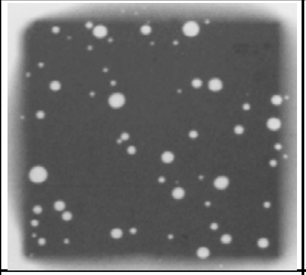
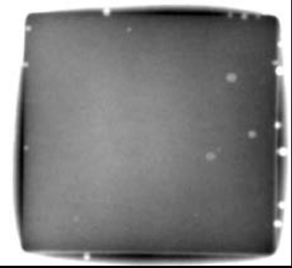
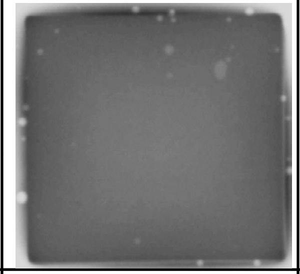
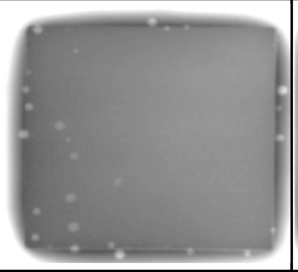
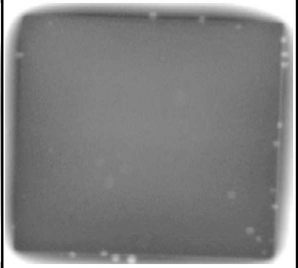
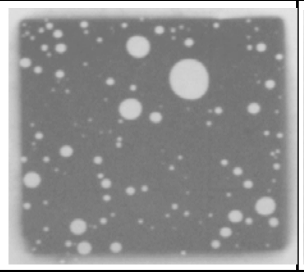
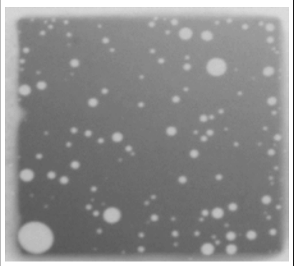
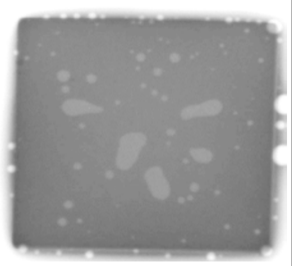
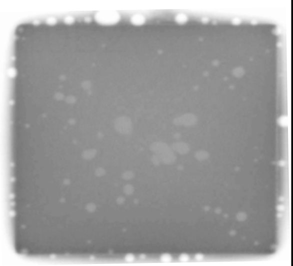
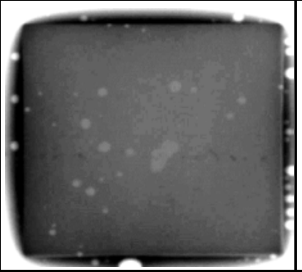
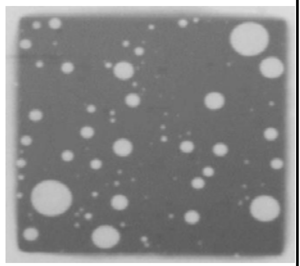
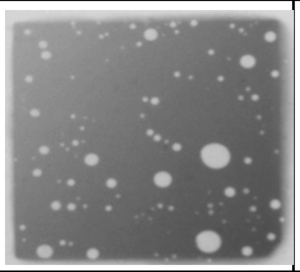
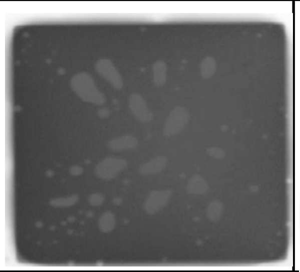
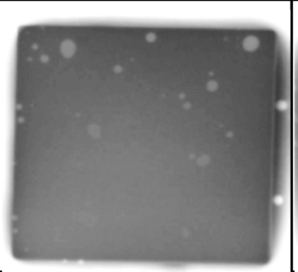
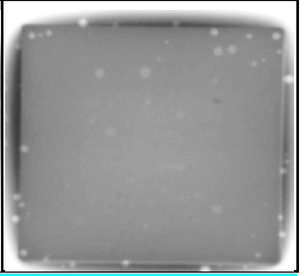
CTE of several materials

Material	CTE 10^{-6} m/(mK)	ΔCTE 10^{-6} m/(mK)
Silicon	3	13.7 (Si on Cu)
Cu	16.7	12.2 (Cu on Alloy42)
Alloy42 (Fe58/Ni41/Mn0.8)	4.5	

Si die on Cu leadframe often failed at Si die at shear test.

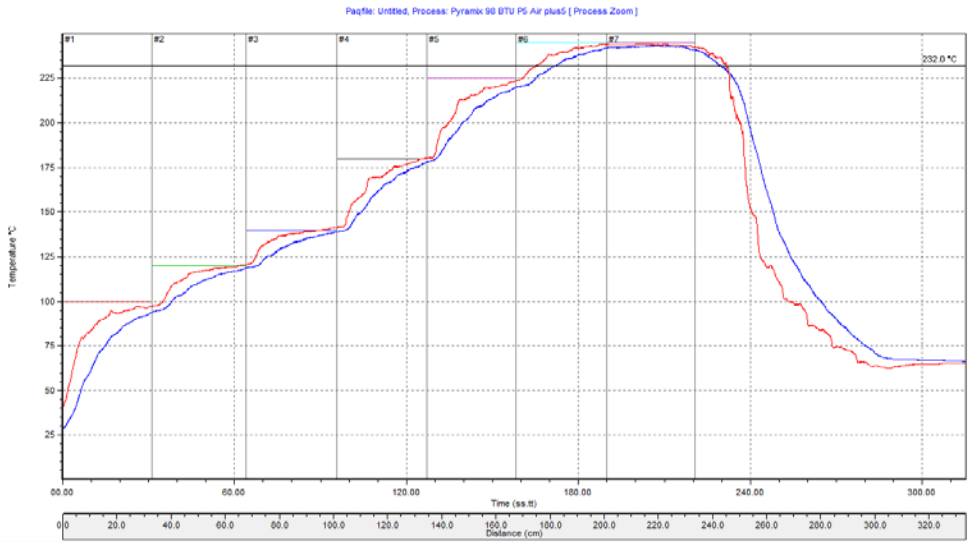
To monitor solder joint deterioration on shear strength, combination of Cu/Alloy42 was selected, with comparable CTE mismatch & tough die.

X-ray showing voids in as-reflowed assembly, reflowed with peak255, die size 3x3 mm

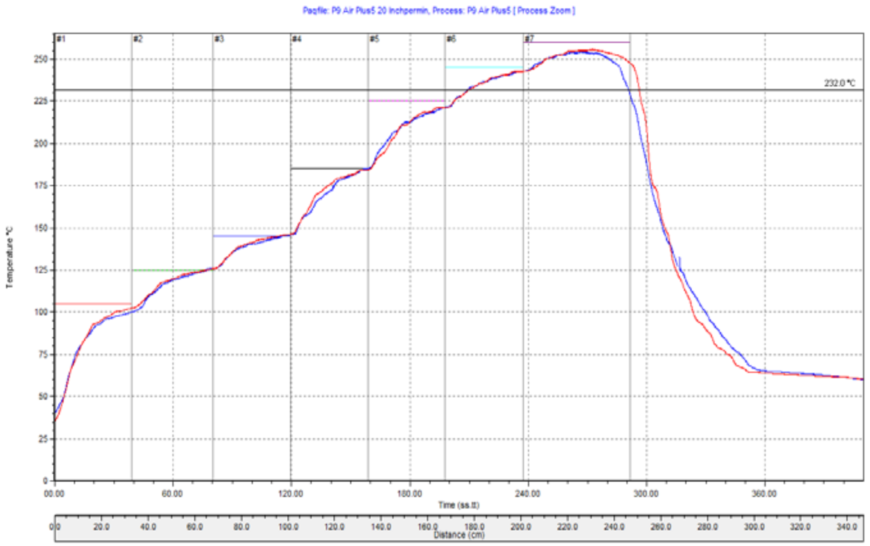
	Si die on bare Cu		Cu die on Alloy42		Cu die on OSP	
	FA	FB	FA	FB	FA	FB
SAC305						
SACBSbN						
SACSb						

SACSb ~ SACBXbN, poorer than 305

Reflow Profiles



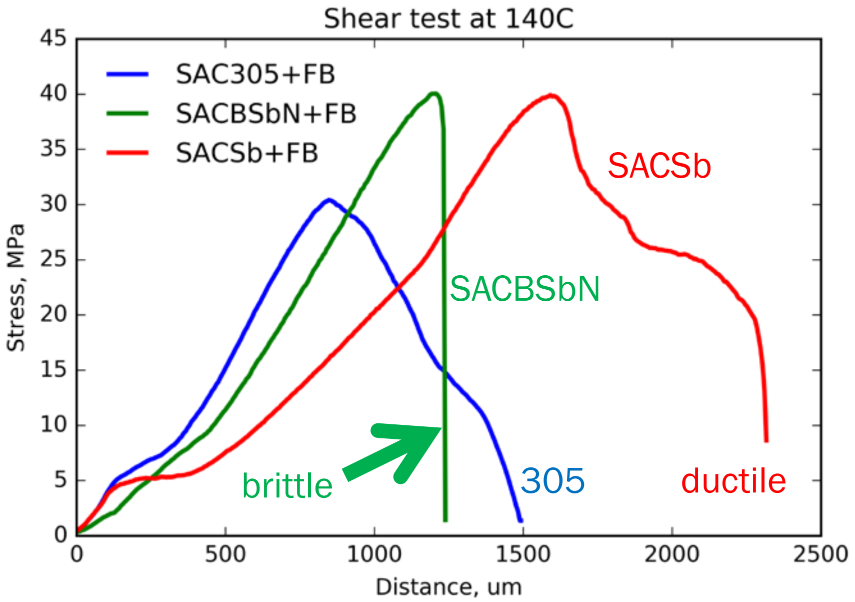
245°C

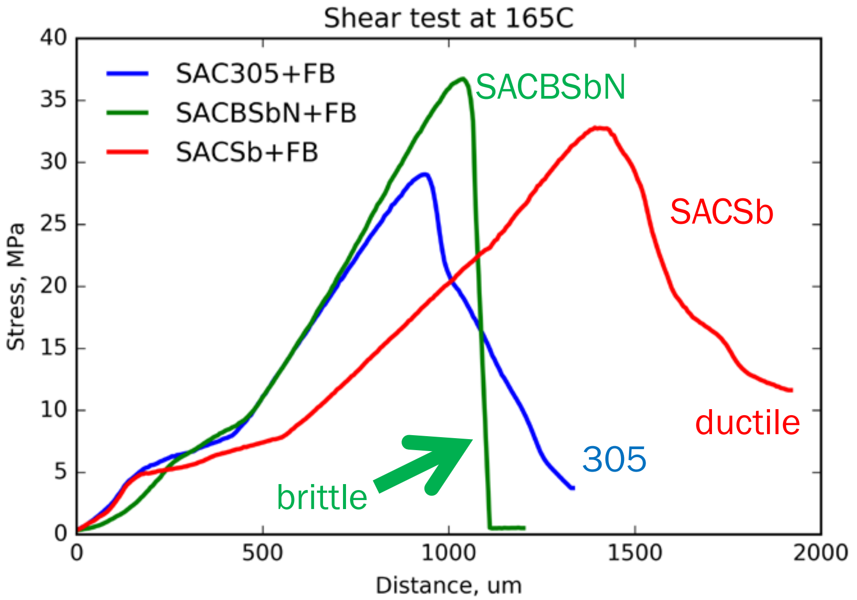


255°C

Both profiles acceptable for SACSb. Major data based on 255C profile.

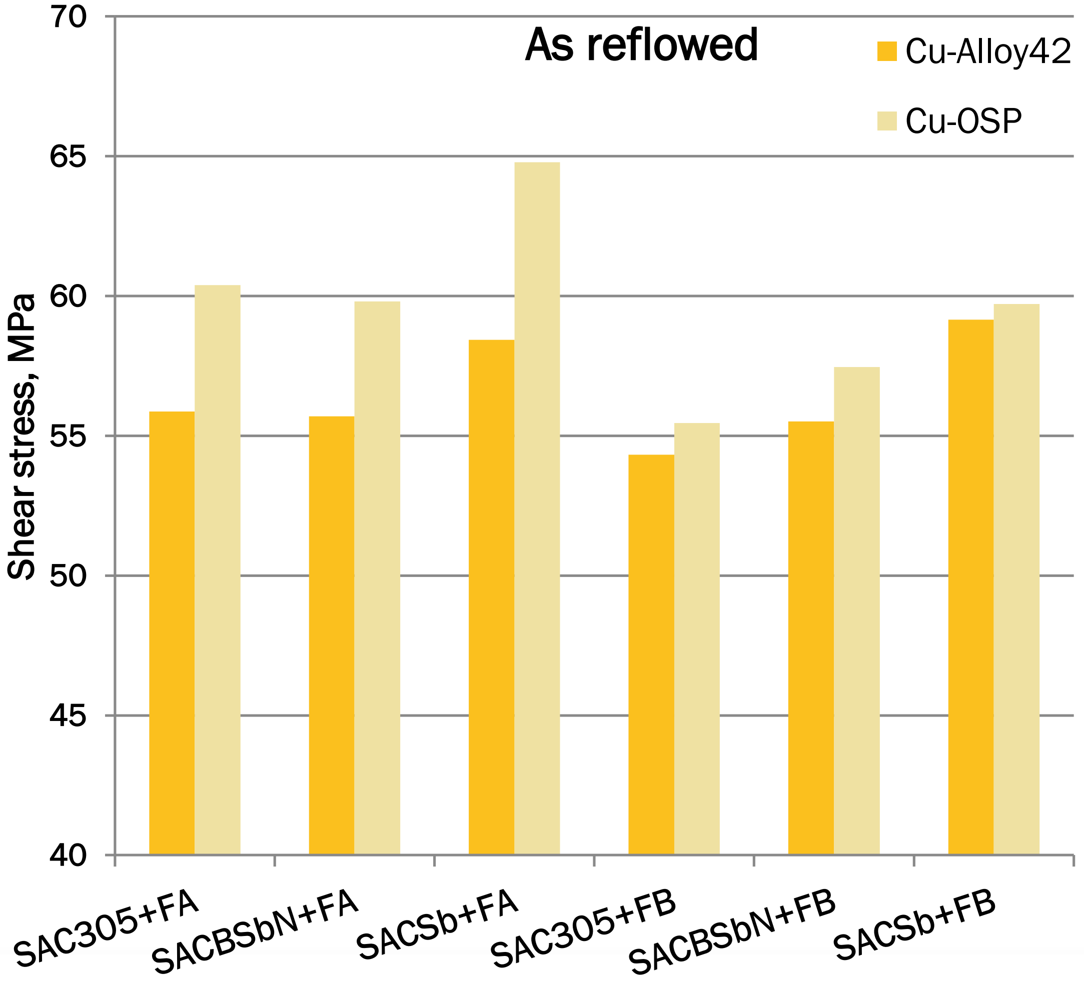
Shear test curves for solder joints of Cu die (3mm x 3mm) on Alloy42 substrate





At high temperature, SACSb more ductile than both SAC305 & SACBSbN
SACBSbN very brittle.

Shear stress at RT, as-reflowed



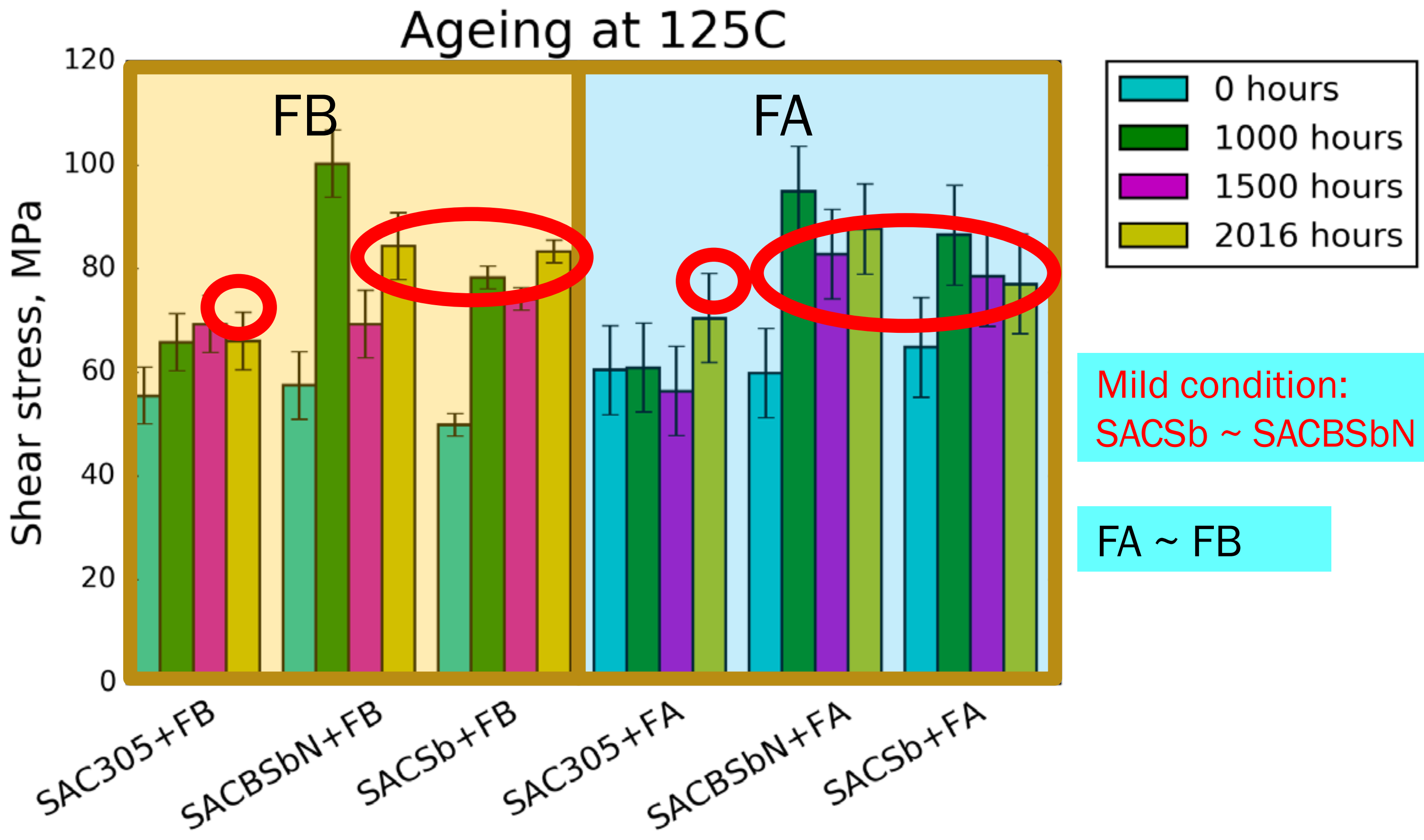
RT Shear Strength

SACSb
> SACBSbN & 305

Reliability testing completed

1. Isothermal ageing at 125°C: 2016 hours
2. Isothermal ageing at 175°C: 2088 hours
3. TCT -40/125°C: 2238 cycles
4. TCT -40/175°C: 3000 cycles
5. TST -55/155°C: 3000 cycles

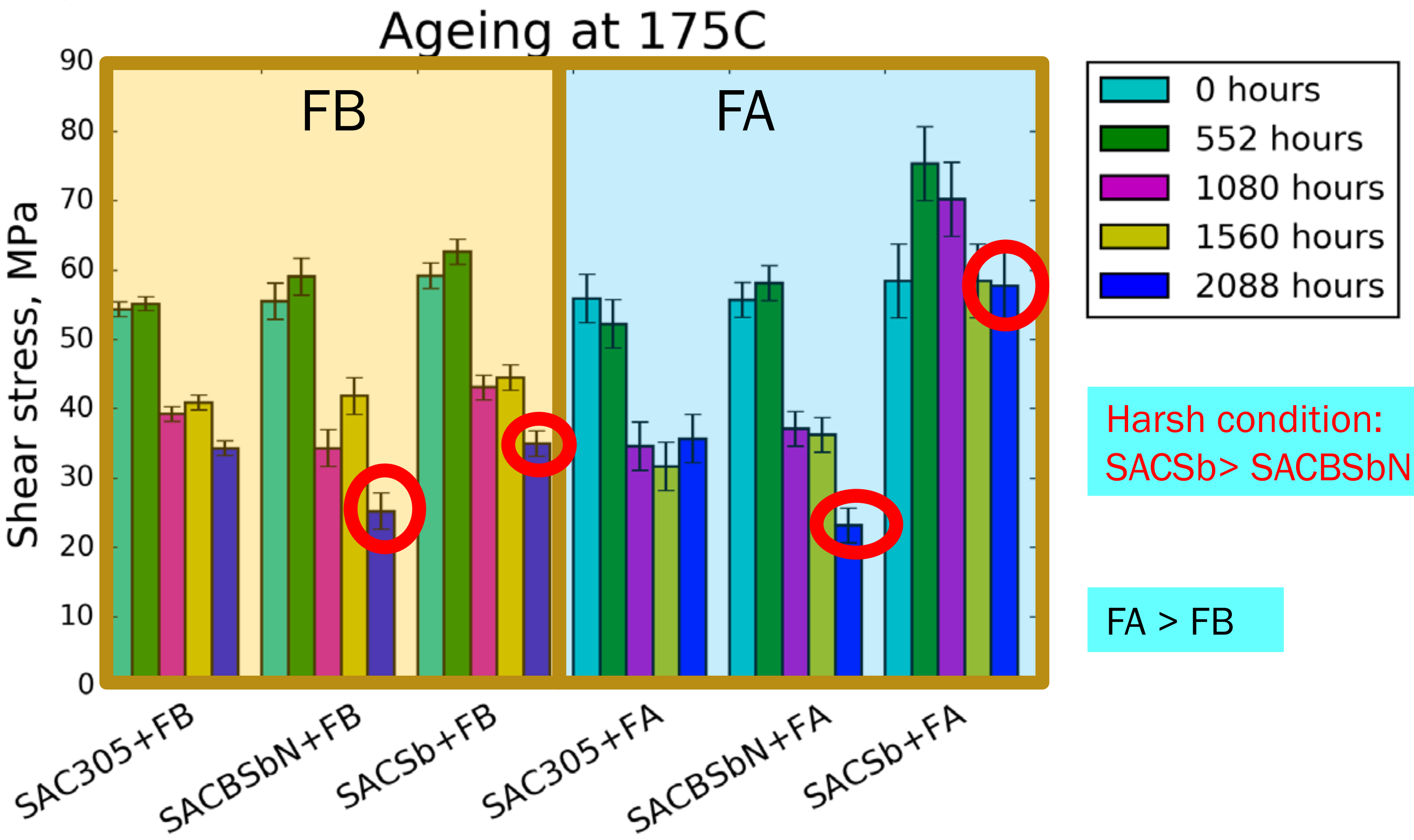
Isothermal ageing at 125°C



Mild condition:
SACSb ~ SACBSbN > 305

FA ~ FB

Isothermal ageing at 175°C

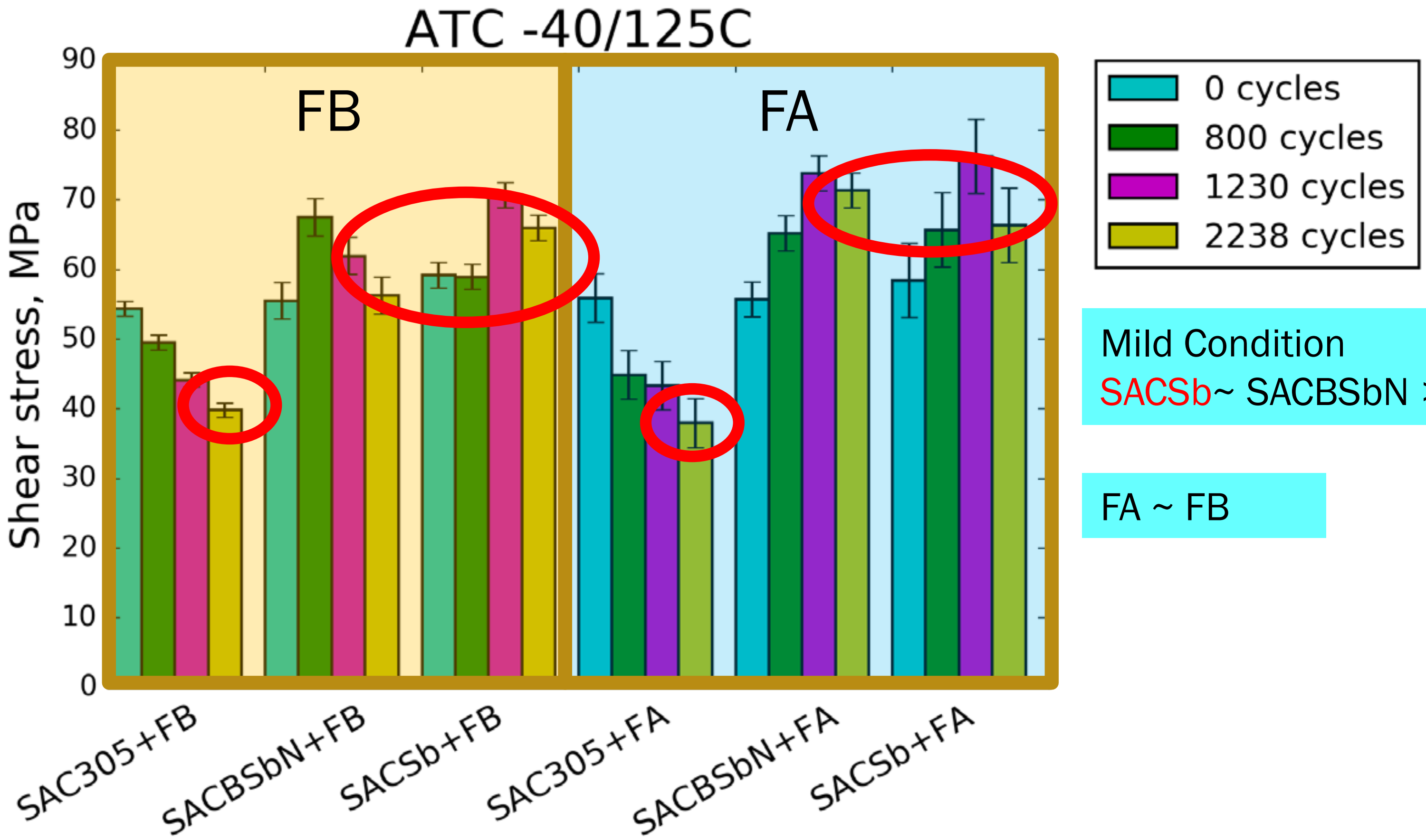


Harsh condition:
SACSb> SACBSbN & 305

FA > FB

SACSb~ 2.5X of SACBSbN

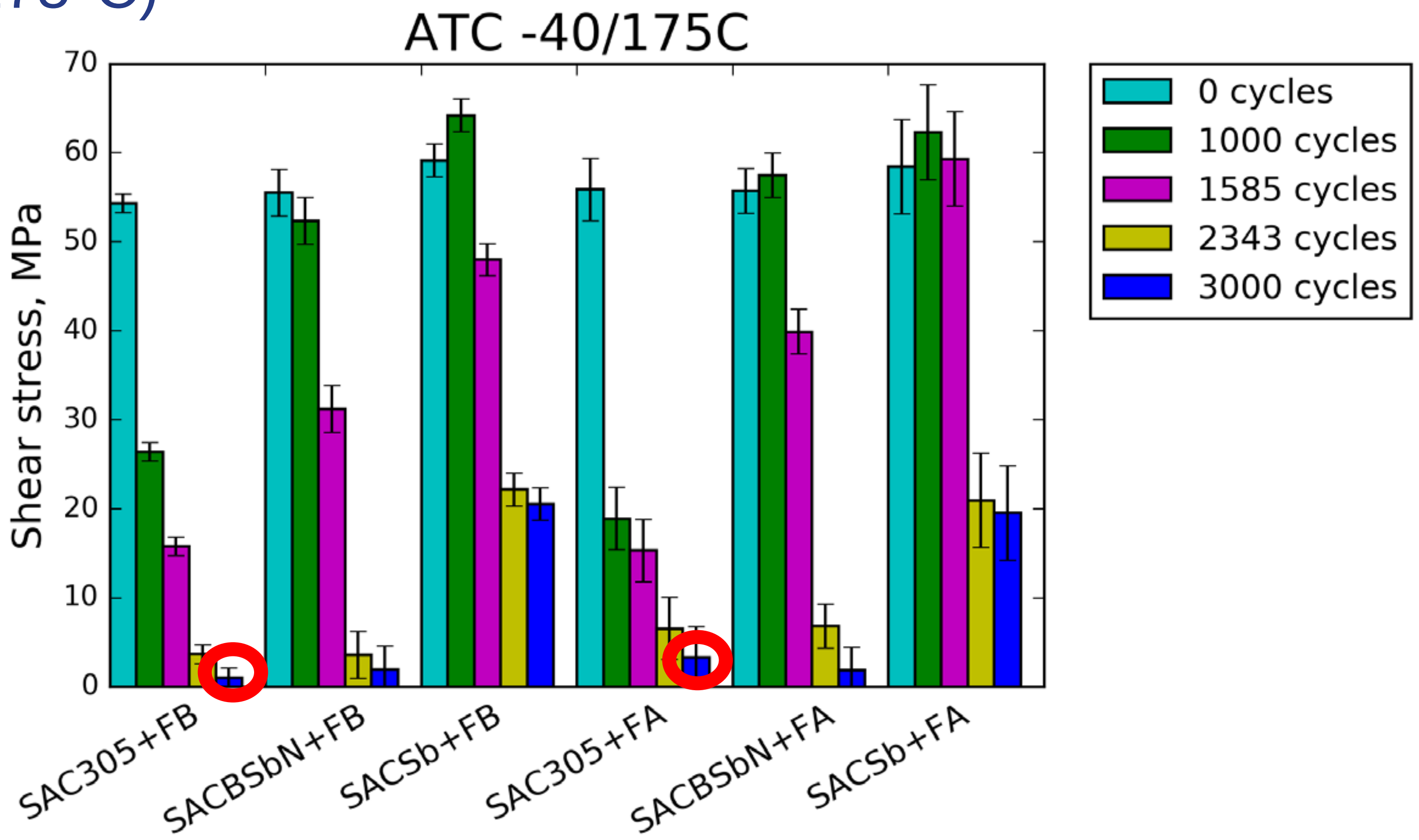
TCT (-40/125°C)



Mild Condition
SACSb~ SACBSbN > 305

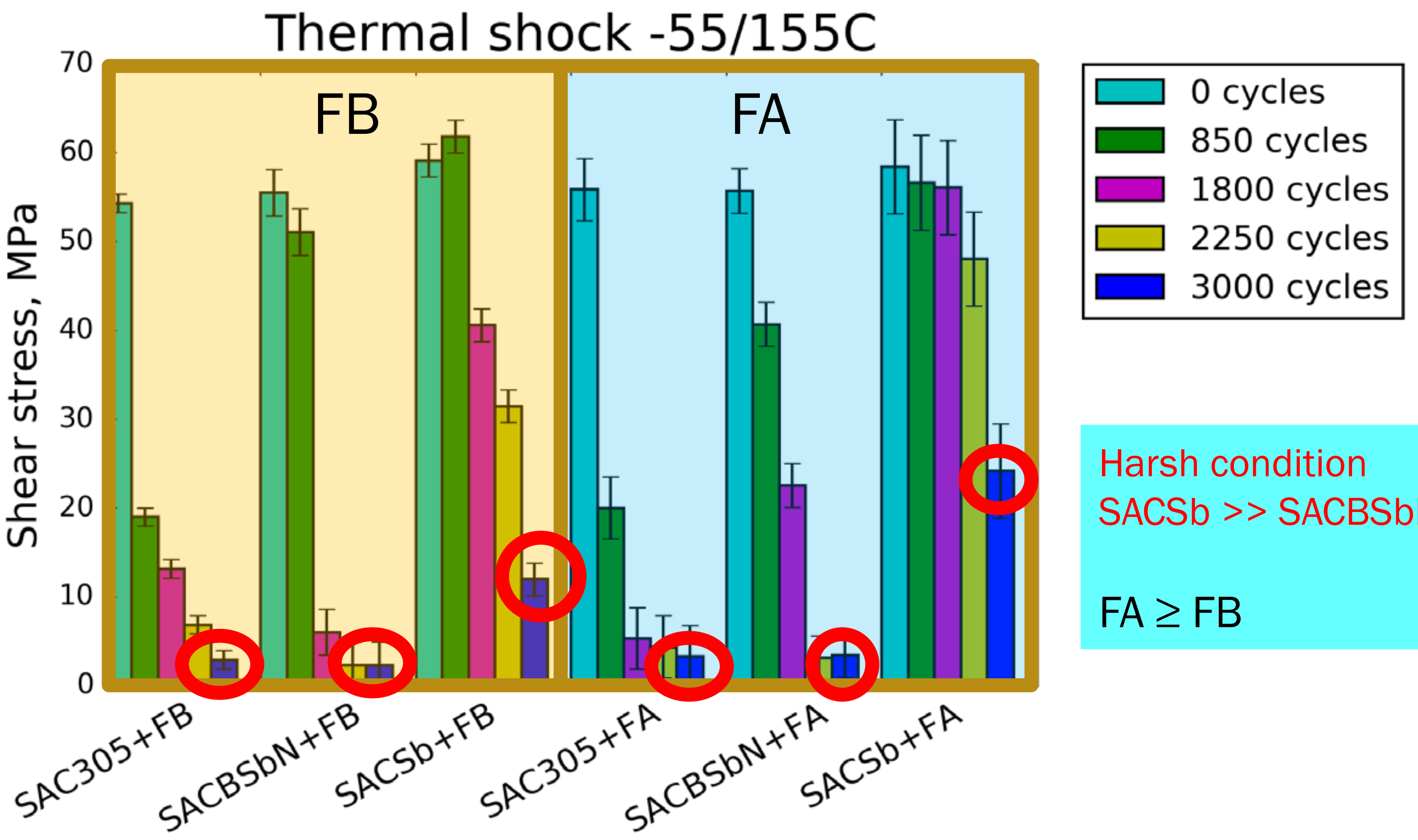
FA ~ FB

TCT (-40/175°C)



After 3000 cycles, SACSb was 11-20X of SACBSbN and SAC305

TST (-55/155°C)

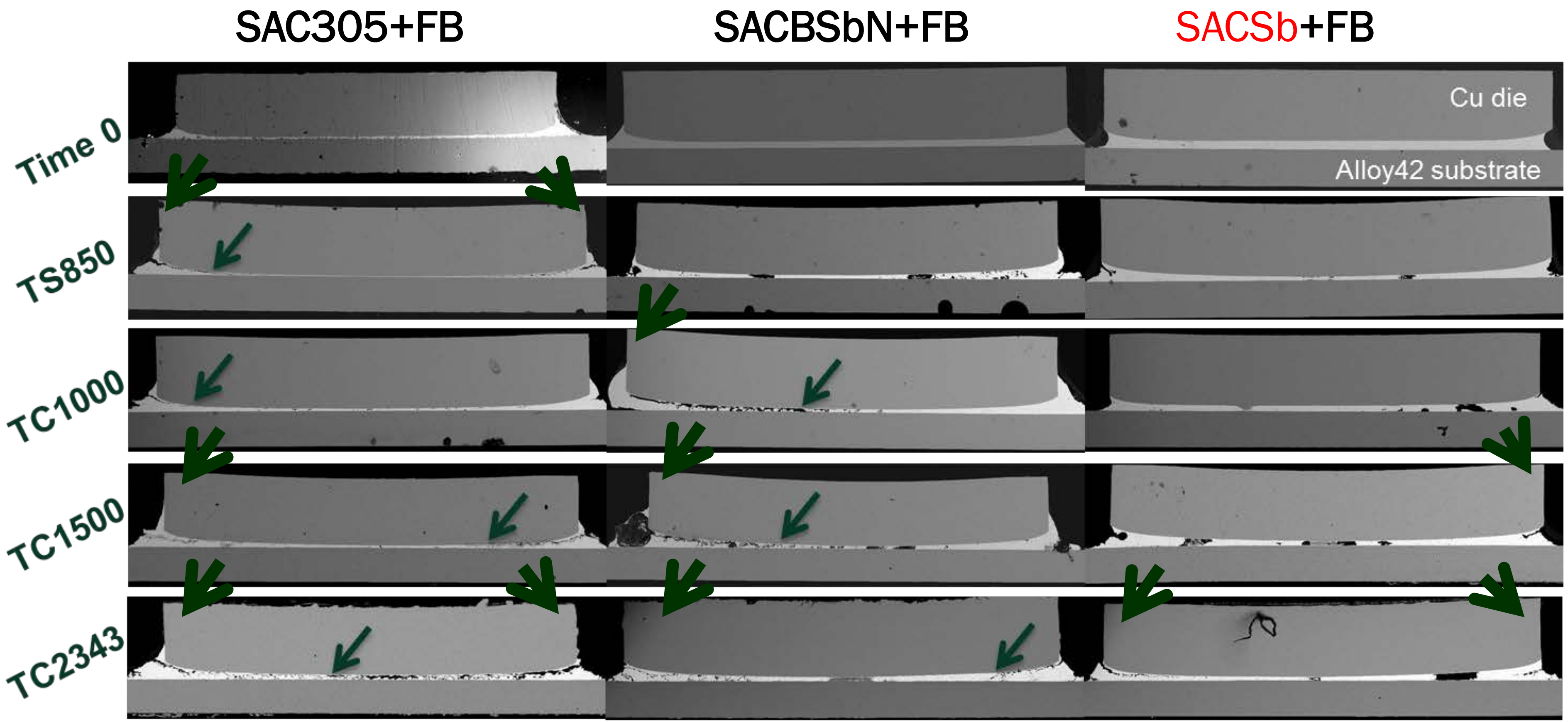


Harsh condition
SACSb >> SACBSbN > 305

FA ≥ FB

After 3000 cycles, SACSb ~ 8X of SACBSbN & SAC305

TCT & TST, overall



TS: thermal shock, -55/155°C

TC: thermal cycling, -40/175°C

Crack resistance: SACSb > SACBSbN > 305

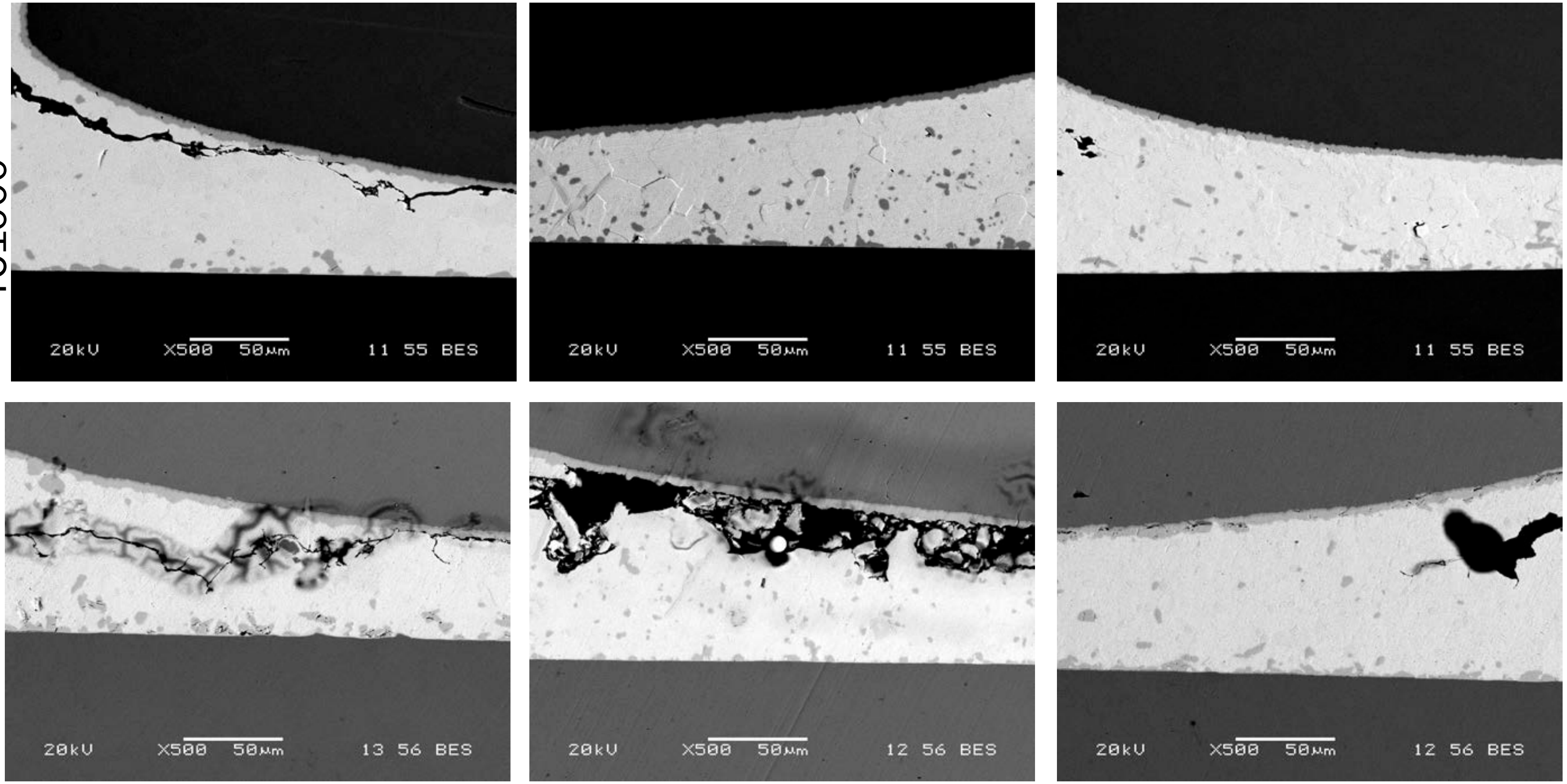
TCT (-40/175C)

Cracks resistance: SACSb> SACBSbN > 305

SAC305+FB | SACBSbN+FB | SACSb+FB

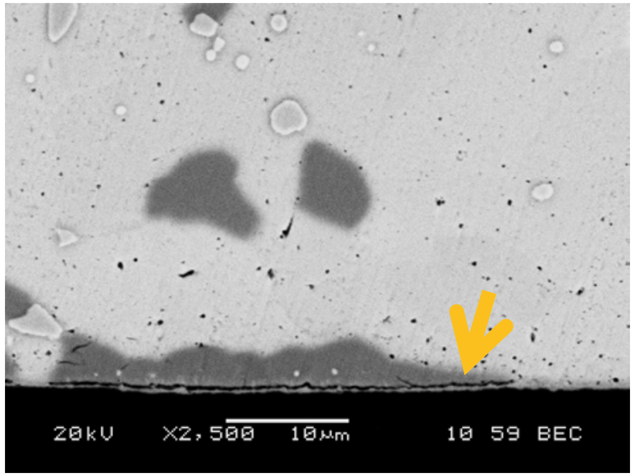
TC1000

TC1500

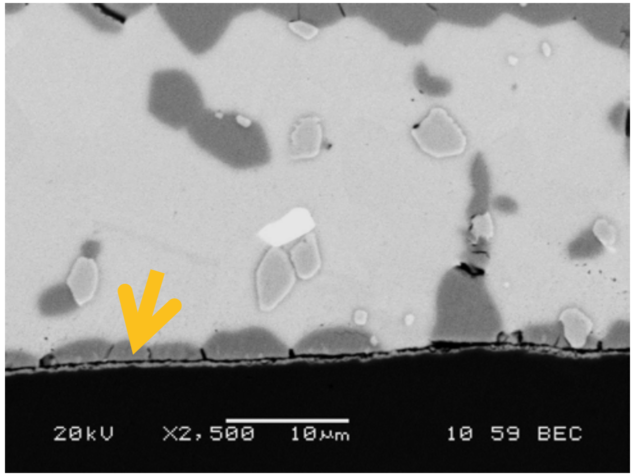


TCT (-40/175°C) 2343 cycles

SAC305+FA

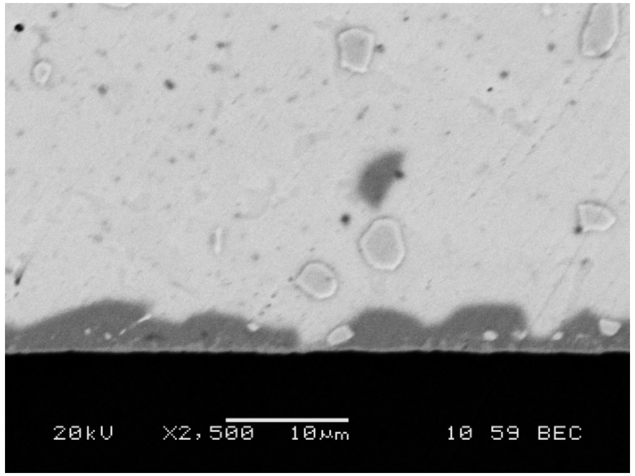


SACBSbN+FA



More particles, prone to be brittle & develop cracks

SACSb+FA



Less particles, less brittle

The crack (as arrowed) extended along the interface between IMC layer and Alloy42 substrate in SAC305 and SACBSbN while no such crack appeared in alloy SACSb.

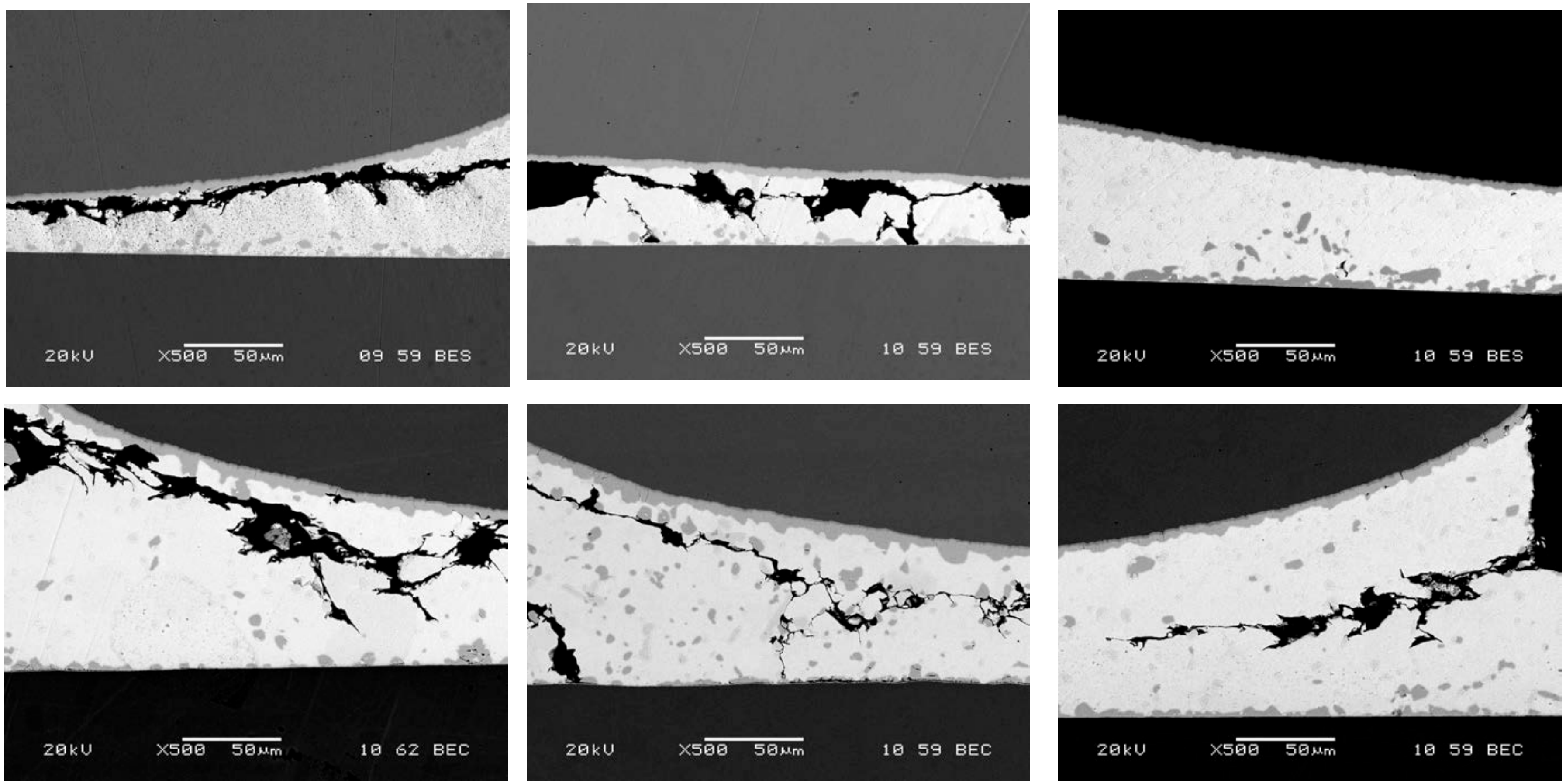
Cracks resistance: SACSb> SACBSbN ~ 305

TST (-55/155C)

SAC305+FA | SACBSbN+FA | SACSb+FA

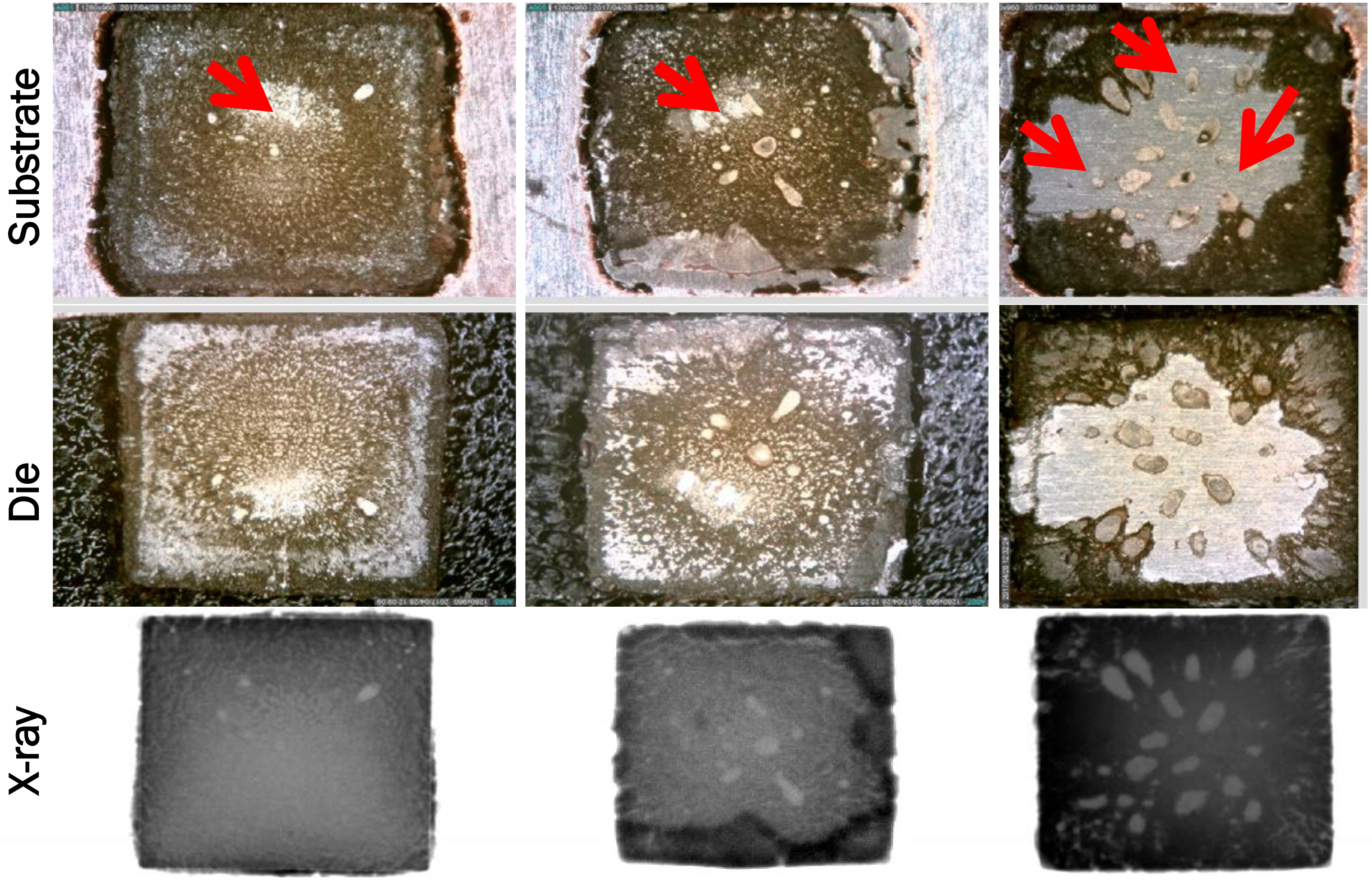
TS850

TS2250



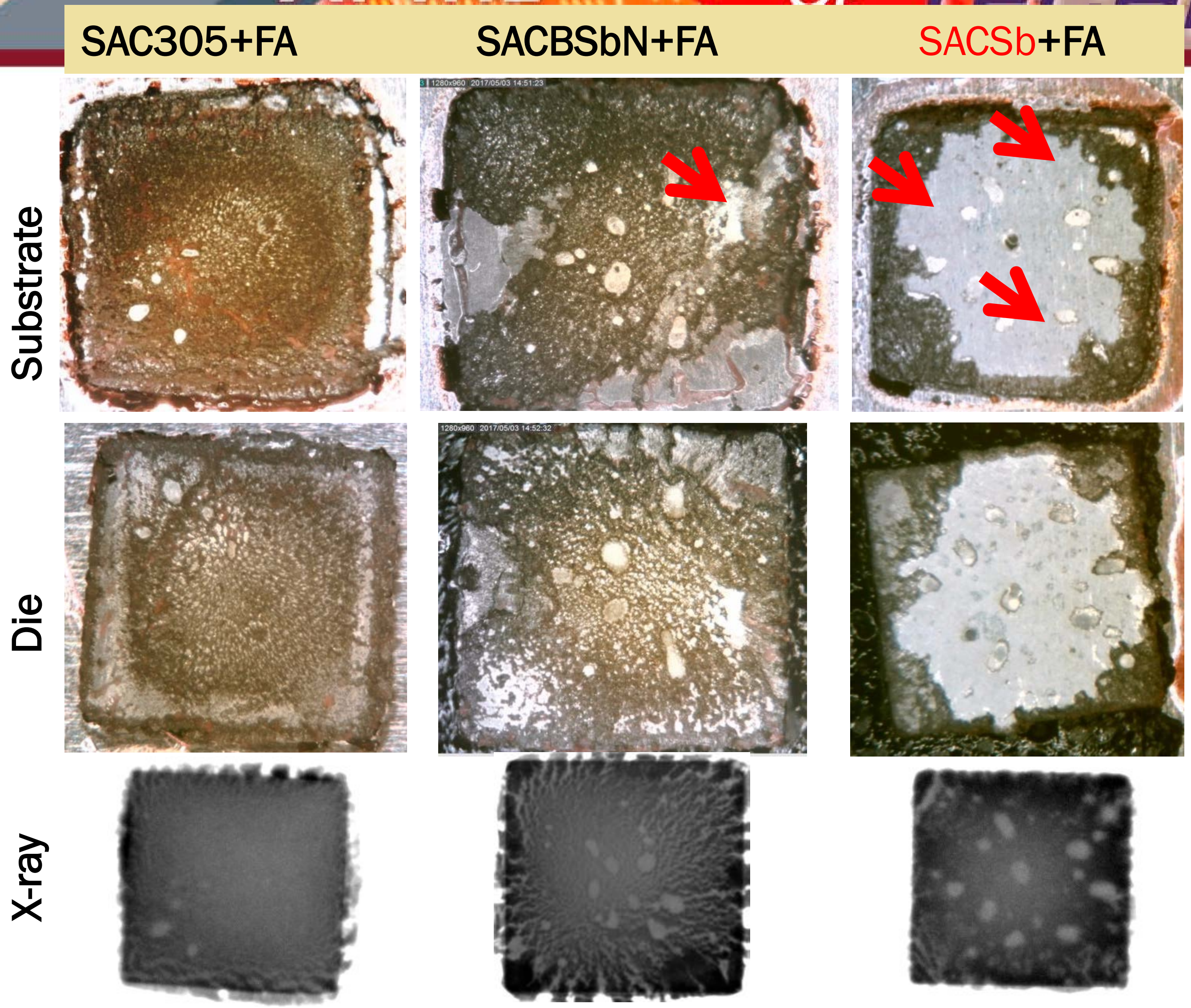
SAC305+FB	SACBSbN+FB	SACSb+FB

TCT (-40/175°C) 2343 cycles, Dye & Pry



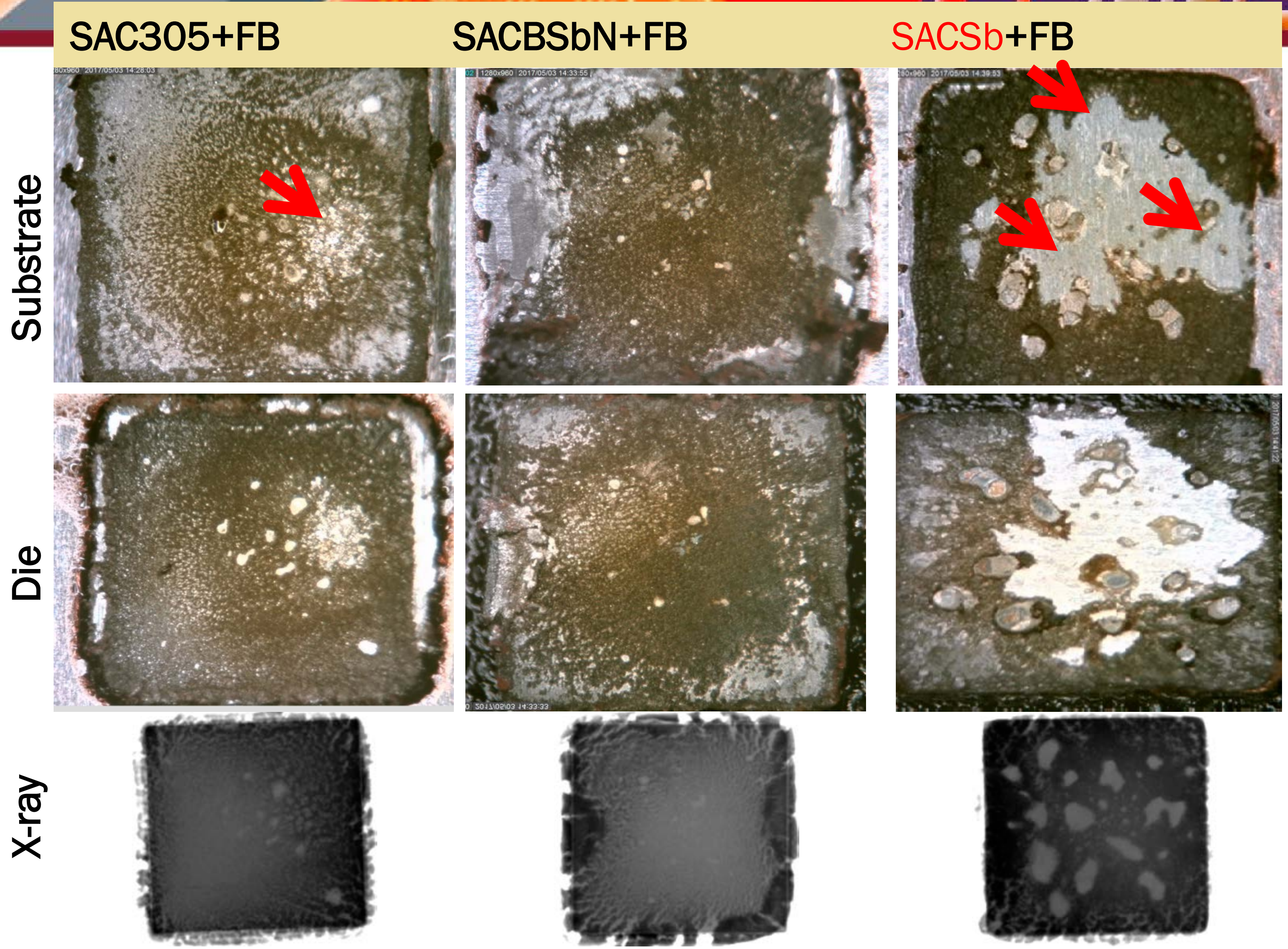
Cracks resistance: SACSb > SACBSbN ~ 305

TST (-55/155°C)
3000 cycles,
Dye & Pry



Cracks resistance: SACSb > SACBSbN ~ 305

TST (-55/155°C)
3000 cycles,
Dye & Pry



Cracks resistance: SACSb > SACBSbN ~ 305

Summary of Reliability Data

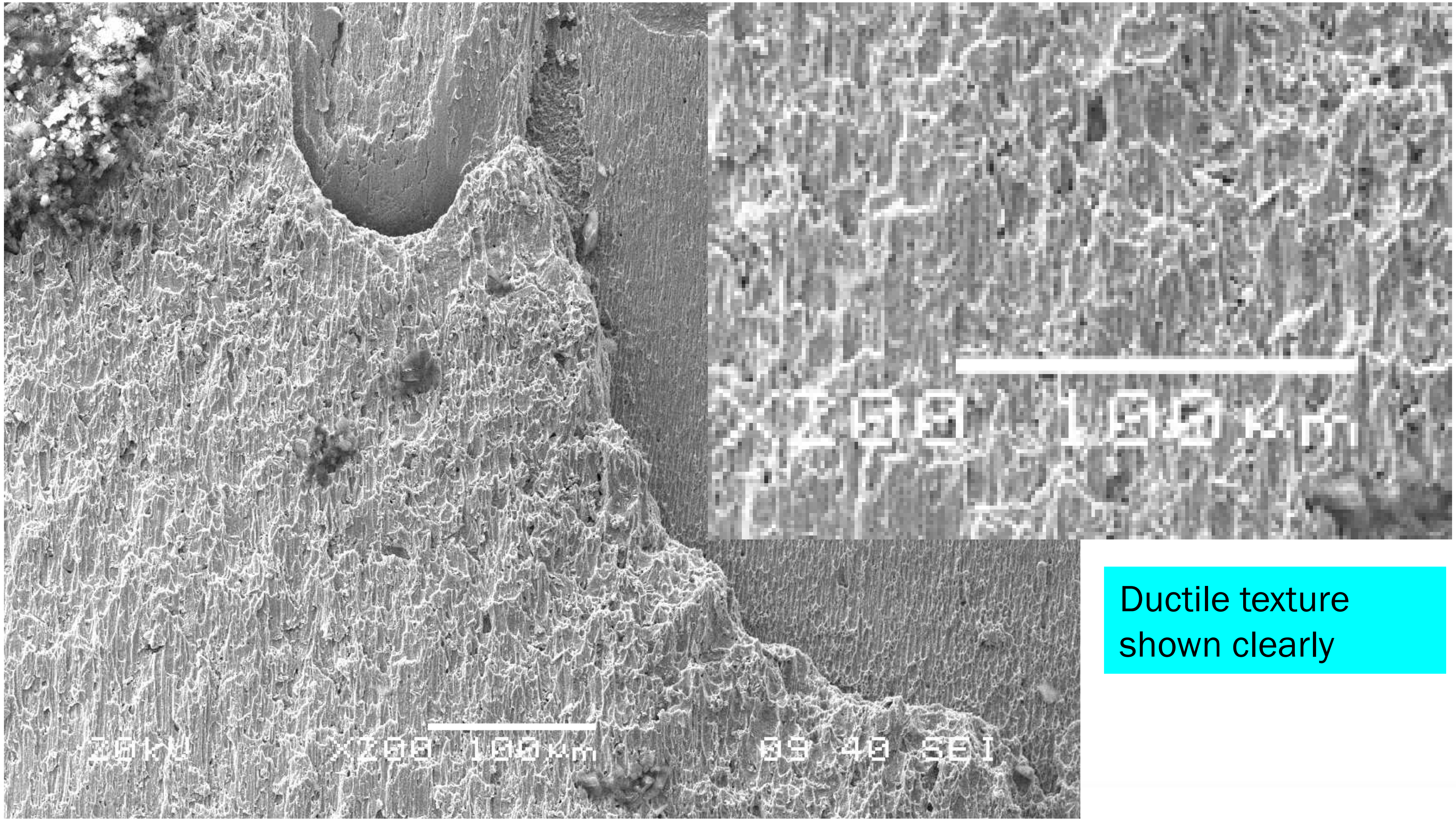
Reliability data summary

Test	Condition	Level	Category		
			Shear Strength	Crack	Dye & Pry
TA	125°C	Mild	SACSb ~ SACBSbN > 305	-	-
	175°C	Harsh	SACSb > SACBSbN ~ 305	-	-
TCT	-40/125°C	Mild	SACSb ~ SACBSbN > 305	-	-
	-40/175°C	Harsh	SACSb >> SACBSbN ~ 305	SACSb > SACBSbN > 305	SACSb > SACBSbN ~ 305
TST	-55/155°C	Harsh	SACSb >> SACBSbN ~ 305	SACSb > SACBSbN > 305	SACSb > SACBSbN ~ 305

Note: 305 – SAC305

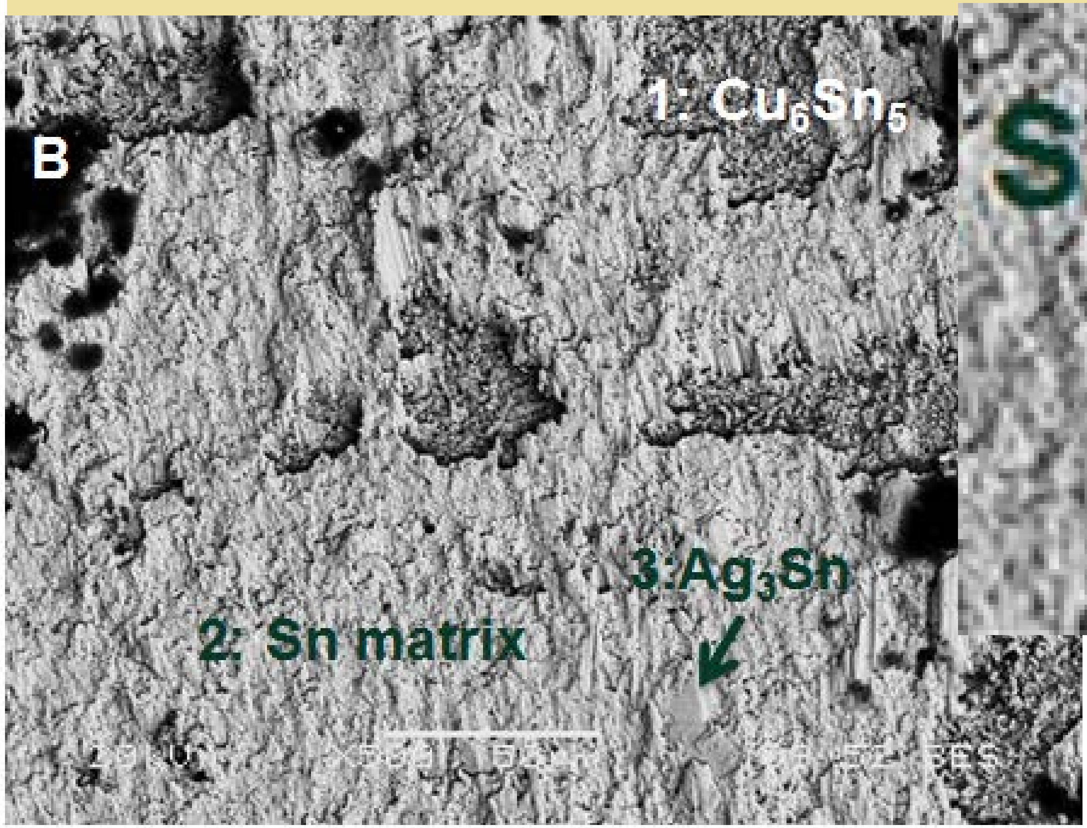
Mild: SACSb ~ SACBSbN > 305
Harsh: SACSb >> SACBSbN ~ 305

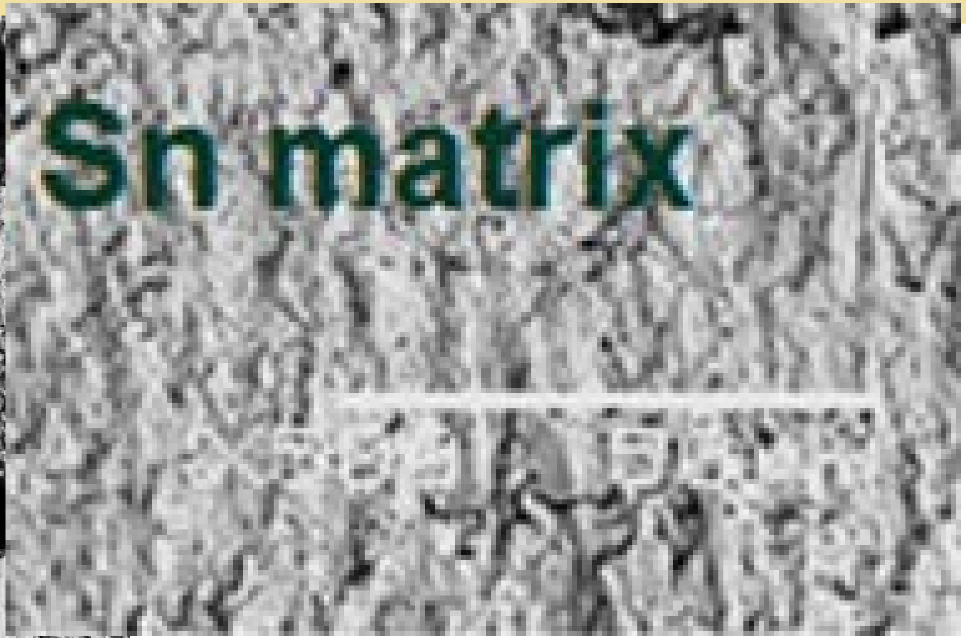
Fractured die back surface of as-reflowed SAC305 joints (200X)



Ductile texture shown clearly

Fractured die back surface of as-reflowed SACBSbN joints (500X)

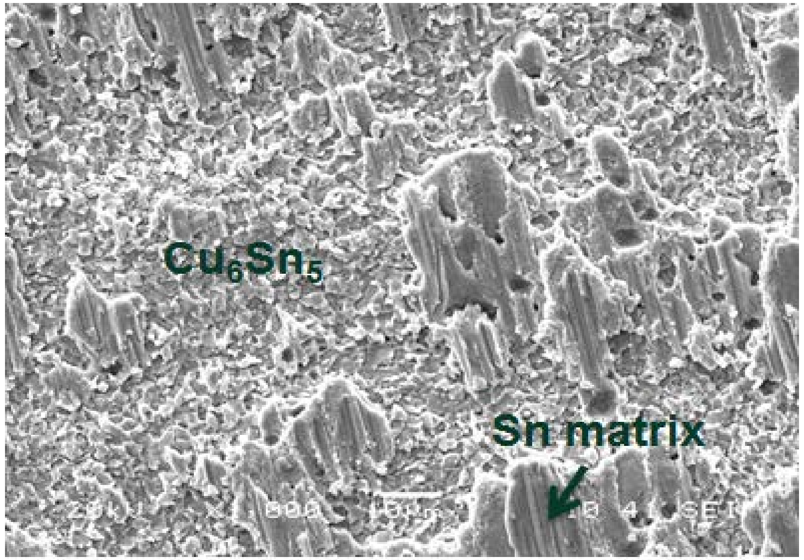




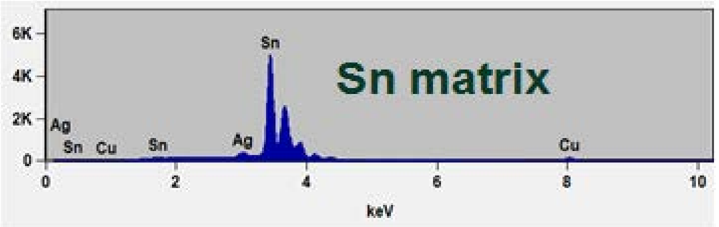
No sign of ductile texture can be discerned

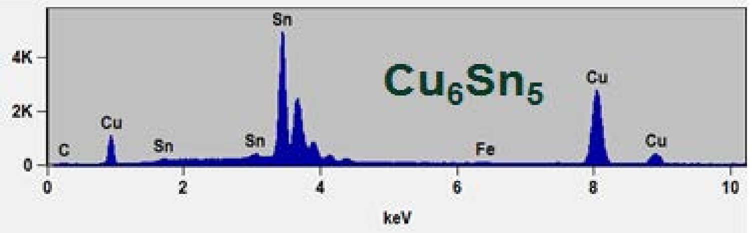
	Ni-K	Cu-K	Ag-L	Sn-L	Bi-M
1	2.25	55.38		42.37	
2		8.51	1.22	88.68	1.60
3			63.65	36.35	

Fractured die back surface of as-reflowed SACSb joints (1000X)

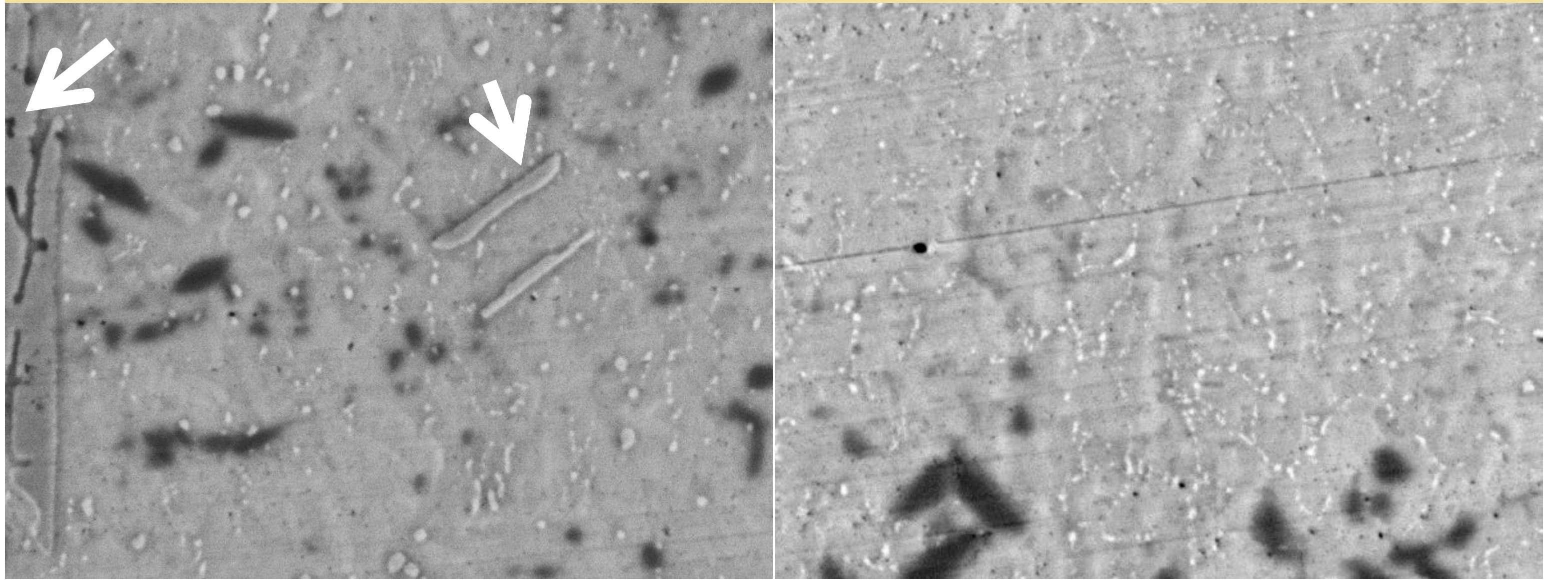


Ductile texture shown clearly





SEM, as-reflowed, peak255



SACBSbN+FA

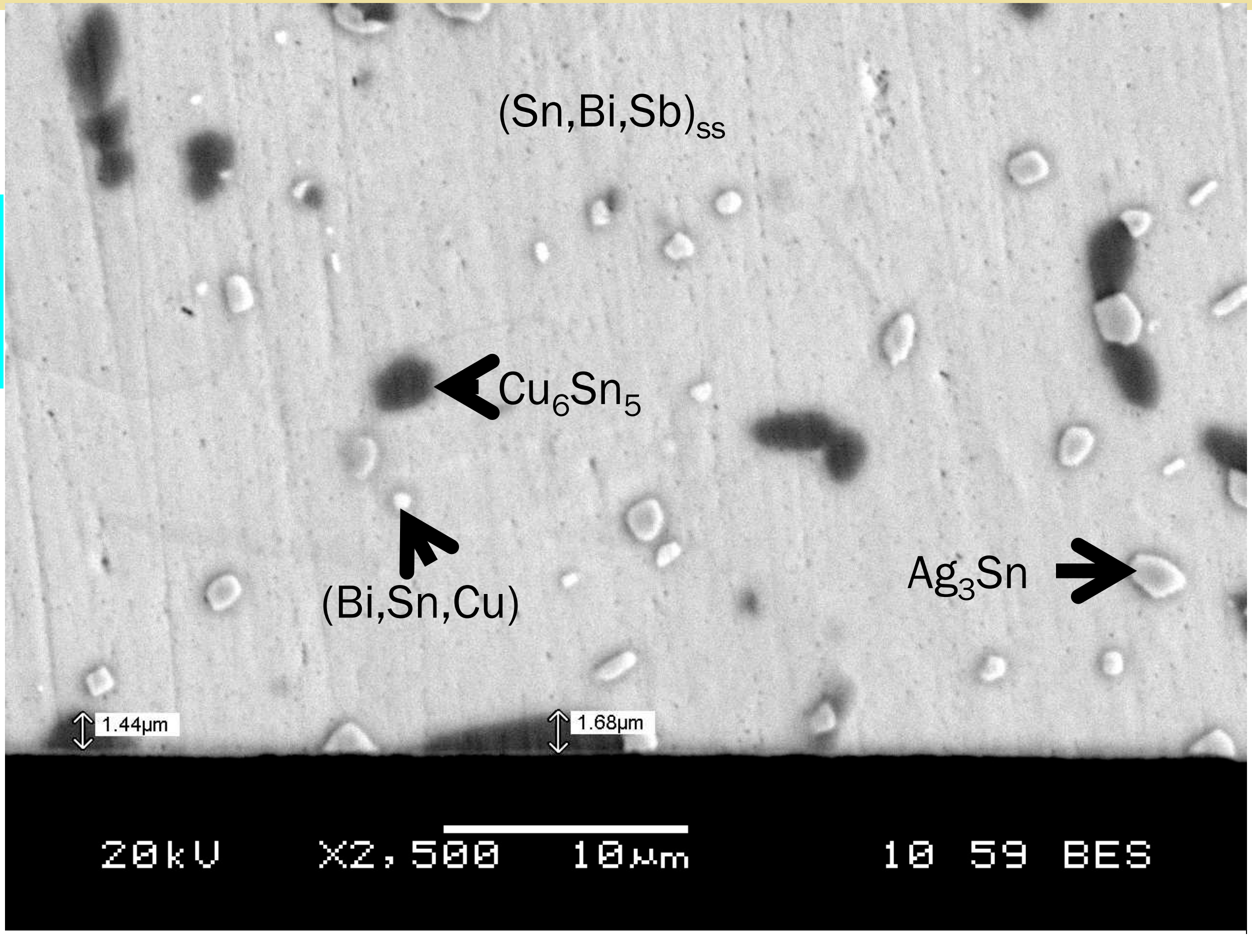
SACSb+FA

Fine, uniform microstructure

1. Ag_3Sn IMC phase is much finer in SACSb than that in SACBSbN.
2. No big blocky Ag_3Sn IMC plates (arrowed) appeared in SACSb.

Phases in SACBSbN+FB TST (-55/155C), 850 cycles

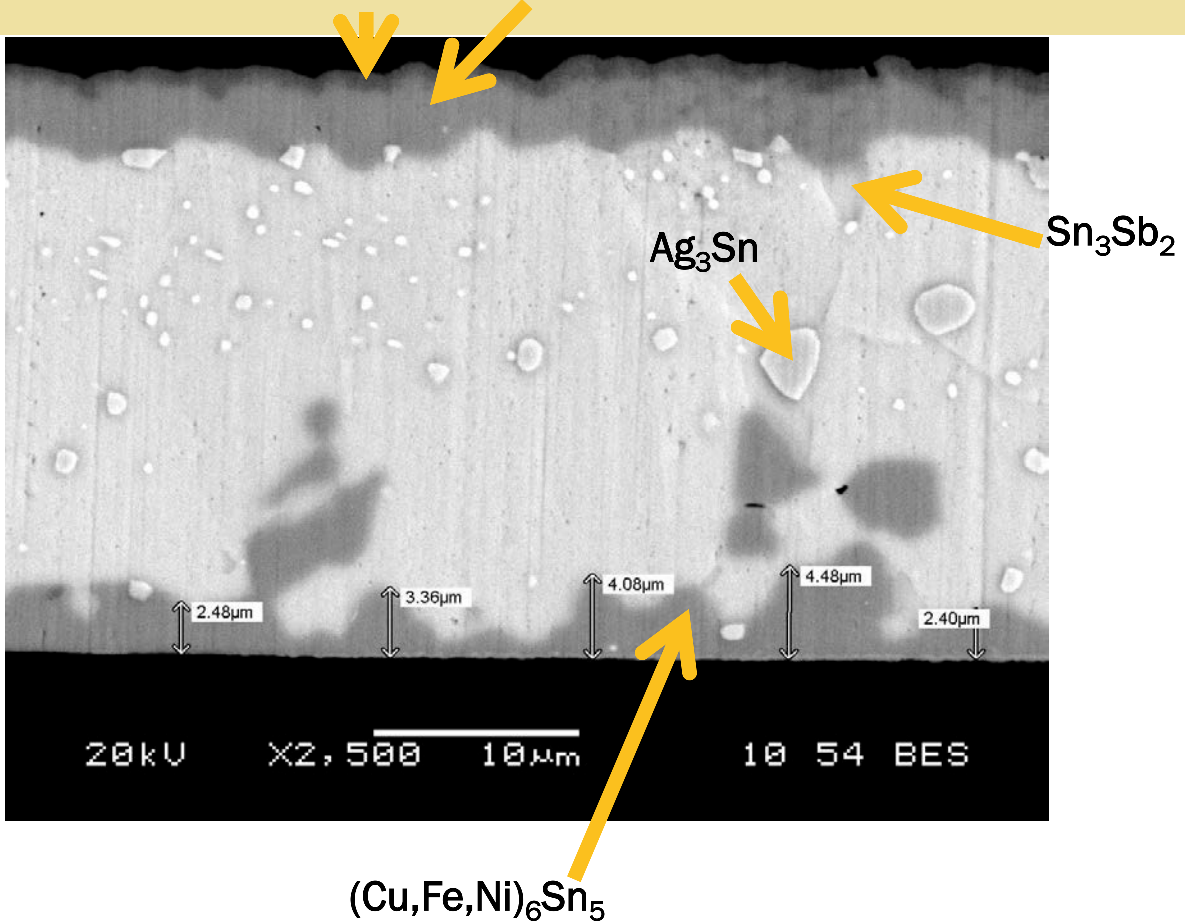
Higher concentration of IMC particles



	Fe-K	Ni-K	Cu-K	Ag-L	Sn-L	Bi-M
818-4-2 CENTER(1)_pt1	1.30		8.38	57.19	33.14	
818-4-2 CENTER(1)_pt2			5.45		24.84	69.70
818-4-2 CENTER(1)_pt3	0.80	1.74	16.76	37.19	43.50	

Phases in SACSb+FB TST (-55/155C), 850 cycles

Lower concentration of IMC particles

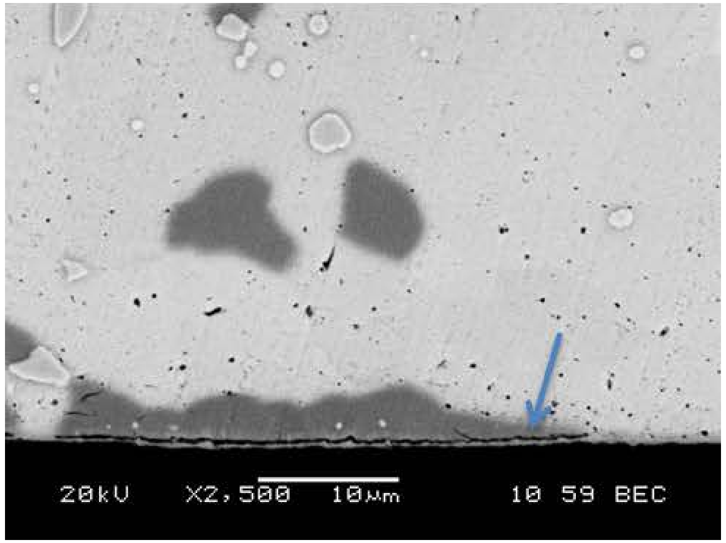


Atom %

	Fe-K	Ni-K	Cu-K	Ag-L	Sn-L	Sb-L
TS 850 818-2-5 CENTER(1)_pt1			3.62		56.04	40.34
TS 850 818-2-5 CENTER(1)_pt2					56.38	43.62
TS 850 818-2-5 CENTER(1)_pt3				65.62	34.38	
TS 850 818-2-5 CENTER(1)_pt4			1.85	70.21	27.93	
TS 850 818-2-5 CENTER(1)_pt5	2.54	2.43	48.60	0.27	46.15	

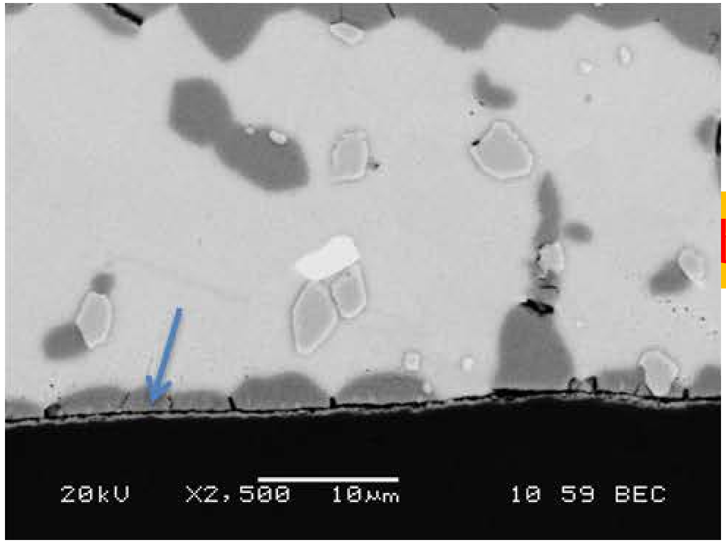
Samples after TCT (-40/175°C) 2343 cycles

SAC305+FA



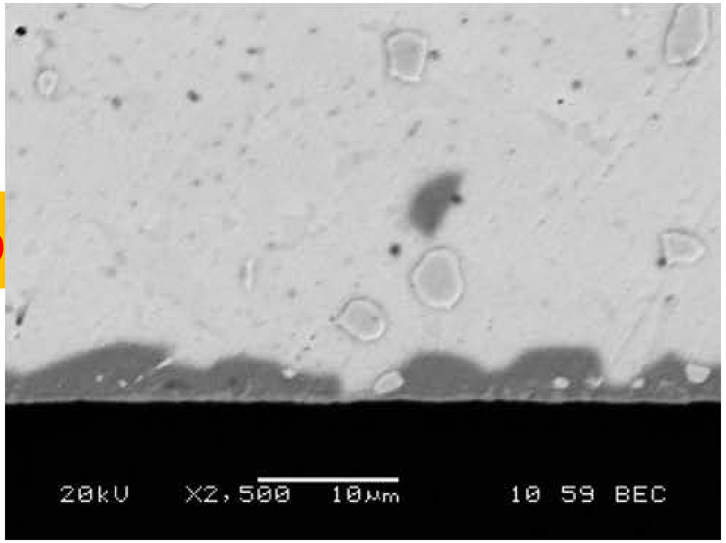
Lower shear stress

SACBSbN+FA



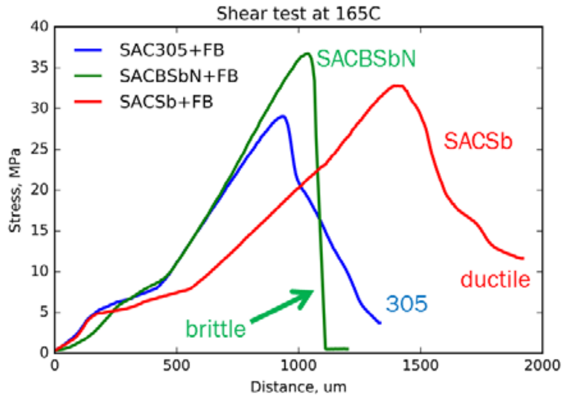
High concentration of IMC particles, more brittle, cracked

SACSb+FA



Low concentration of IMC particles, more ductile, no crack

Conclusions



- 90.6Sn3.2Ag0.7Cu5.5Sb (SACSb) melting range 223 to 232°C
- For less stressed aging condition, at 125C aging, three alloys were comparable. At 175C aging, SACSb up to 2.5X stronger than SACBSbN & SAC305
- At harsh condition, TST -55°C/155°C for 3000 cycles, die shear strength of SACSb was 8X of that of SACBSbN and SAC305. For TCT (-40°C/175°C) for 3000 cycles, die shear strength of SACSb was 11X to 20X of SACBSbN and SAC305
- Both SACSb and SACBSbN are alloys based on SnAgCu, but reinforced with precipitate hardening and solution hardening. SACSb exhibited a finer microstructure with less particles dispersed, while SACBSbN exhibited more particles with some blocky Ag_3Sn plates or rods. SACSb is rigid and ductile, while SACBSbN is rigid but brittle

Conclusions (cont.)

- Under the harsh test condition where ΔT was high, the dimension mismatch between parts and substrate became very significant due to CTE mismatch. This significant dimension mismatch would cause a brittle joint to crack quickly, as seen on SACBSbN. The challenge was more tolerable for a ductile joint, as shown by SACSb.
- Overall, to achieve high reliability under a wide service temperature environment, a balanced ductility and rigidity for solder alloy is critical for success.