Low-Silver SAC Alloys

Indium8.9HF Analysis Project

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From One Engineer To Another®

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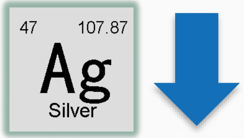
Industry Background

- SAC305 (Sn96.5/Ag3.0/Cu0.5) has been the choice for lead-free solder in the electronics industry for circuit board assembly since the early 2000s.
- However, silver is expensive and the price is volatile.
  - Reducing the silver content in the SAC alloys offers the possibility for cost savings
- Low-silver SAC alloys have been and remain present in the industry.
  - SAC105 (Sn98.5/Ag1.0/Cu0.5)
  - Indalloy®291 (Sn99.25/Cu0.7/Ni0.05/Ge<.01)

Why Consider Low Silver?



- Cost is the primary driver for low-silver initiatives.
- The price of the SAC305 solder alloy is almost double that of SAC105, and more than double that of Indalloy®291.

Recent increase in silver pricing

SAC metal alloy prices (Jan 2021)

Alloy	LME $/lb	LME $/kg
SAC305	$22.07	$48.67
SAC105	$14.10	$31.09
Indalloy®291	$10.30	$22.71

**Silver prices have increased,
and have continued to STAY HIGH**

Other Factors to Consider Regarding Low Silver

- Key performance metrics analyzed between low-silver SAC alloys and SAC305
  - Drop shock reliability
  - Accelerated thermal cycling reliability
  - Solder wetting
  - Coalescence and graping
  - Voiding
  - Viscosity stability
  - Hot and cold slump

Accelerated Thermal Cycling

Thermal Cycling Comparison

Industry Literature Review

- Five different Pb-free solder alloys and a SnPb control were selected
- BGA packaging and PCB test vehicles chosen as listed in Table IV (right)
- Two thermal cycling test profiles in accordance with IPC-9701A test guidelines
  - -40/+125ºC
  - 0/+100ºC
    - Ramp rate 10ºC/minute, 10min hot and cold dwell times

Increased silver consistently improves TCT reliability. Impact is more significant during 0/100ºC testing and on smaller BGAs.

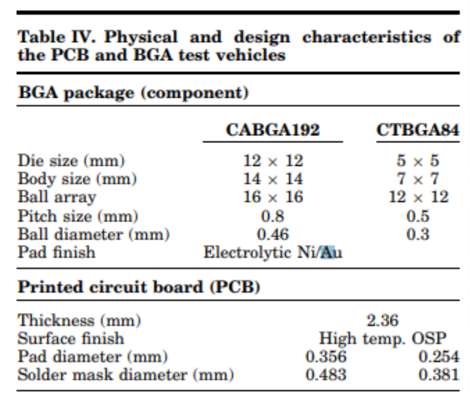
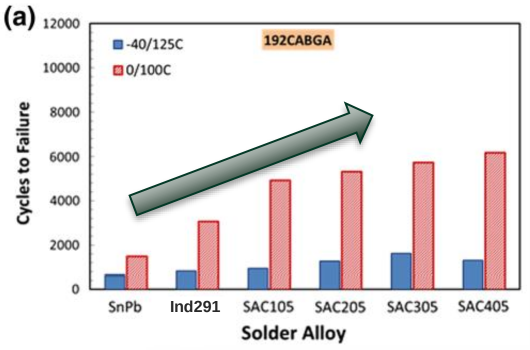
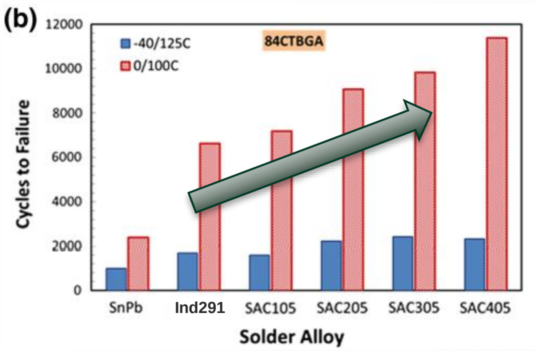


Table IV. Physical and design characteristics of the PCB and BGA test vehicles

BGA package (component)	CABGA192	CTBGA84
Die size (mm)	12 × 12	5 × 5
Body size (mm)	14 × 14	7 × 7
Ball array	16 × 16	12 × 12
Pitch size (mm)	0.8	0.5
Ball diameter (mm)	0.46	0.3
Pad finish	Electrolytic Ni/Au	
Printed circuit board (PCB)		
Thickness (mm)	2.36	
Surface finish	High temp. OSP	
Pad diameter (mm)	0.356	0.254
Solder mask diameter (mm)	0.483	0.381





Solder Ball Final Ag Content

Solder Alloy	84CTBGA analyzed wt.%	192CABGA analyzed wt.%
Indalloy®291	0	0
SAC105	0.99	1.01
SAC305	2.92	2.93

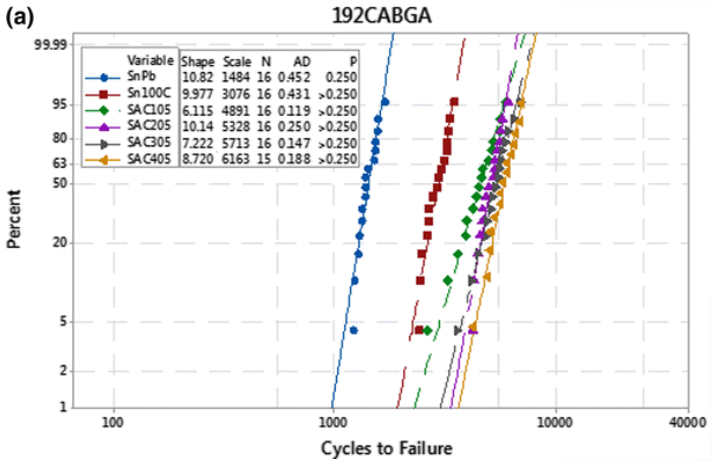
Thermal Cycling Comparison

Industry Literature Review 0/100ºC

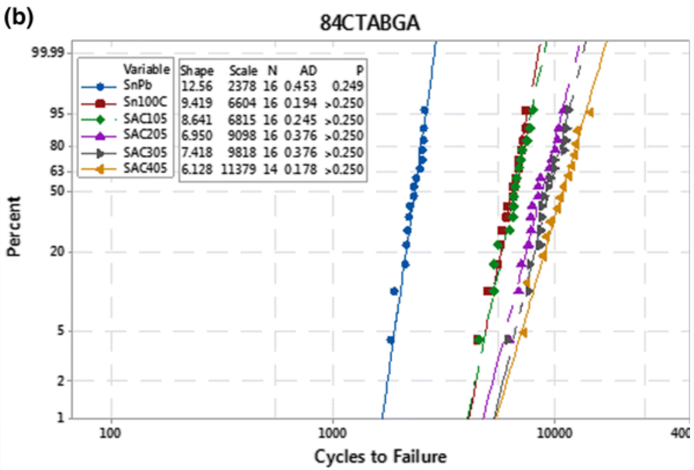
Results:

- Increased silver improved the TCT reliability; the effect was most significant on BGA192s and increasing from 0% to 1–2% Ag
- In BGA84 testing, IND291 and SAC105 show failures at 6000–7000 cycles

The study confirms the direct relationship between Ag content and thermal cycling reliability.



Variable	Shape	Scale	N	AD	P
SnPb	10.82	1484	16	0.452	0.250
Sn100C	9.977	3076	16	0.431	>0.250
SAC105	6.115	4891	16	0.119	>0.250
SAC205	10.14	5328	16	0.250	>0.250
SAC305	7.222	5713	16	0.147	>0.250
SAC405	8.720	6163	15	0.188	>0.250



Variable	Shape	Scale	N	AD	P
SnPb	12.56	2378	16	0.453	0.249
Sn100C	9.419	6604	16	0.194	>0.250
SAC105	8.641	6815	16	0.245	>0.250
SAC205	6.950	9098	16	0.376	>0.250
SAC305	7.418	9818	16	0.376	>0.250
SAC405	6.128	11379	14	0.178	>0.250

Conclusion:

➡ Increasing Ag from 0 to 1% may significantly improve performance on some packages (BGA192)

➡ No and low-silver alloys will fulfill TCT requirements for many applications.

Drop Shock Reliability

Drop Reliability Study on SAC Alloys

Industry Literature Review

Drop Test Condition:

- Acceleration: 1500 G and 0.6m/sec.; drop height: 20cm.
- Drop lifetimes were recorded and categorized by location on the test board (*Figure 4).*

Example of Drop Test Result at Location A (OSP):

- Location A: Four BGAs were located at the four corners on the PBAs.
- The components with SAC305 solder alloy failed after 182, 208, 160, and 196 drops.
  - Average of 187 drops
- The components with SAC105 solder alloy failed after 162, 193, 209, and 220 drops.
  - Average of 196 drops

W.H. Zhu, Luhua Xu , John HL Pang … Industry data "Drop Reliability Study of PBGA Assemblies with SAC305, SAC105 and SAC105-Ni Solder Ball on Cu-OSP and ENIG Surface Finish" …

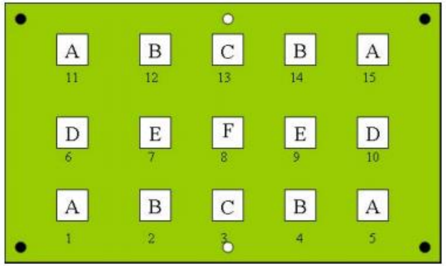


Figure 4. The components at different locations on a test board, A to F.

Drop Impact on SAC305 and SAC105		
Location A	SAC305	SAC105
1	182	162
5	208	193
11	160	209
15	198	220

Average # Drops to Failure	OSP	ENIG
SAC305	187	~110
SAC105	196	~165
Indalloy®291	N/A	N/A

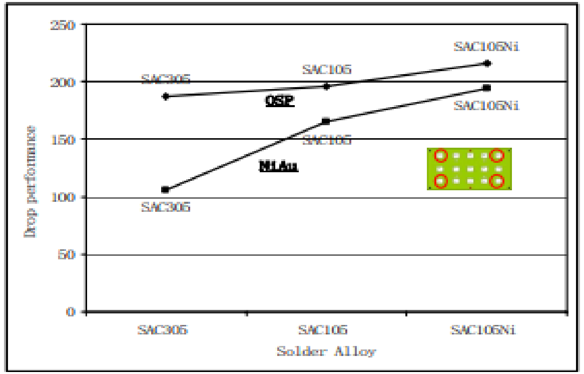
Input-G Corresponding Drop Height	
Acceleration and Duration	Drop Height
1560 G, 0.60 msec	20 cm

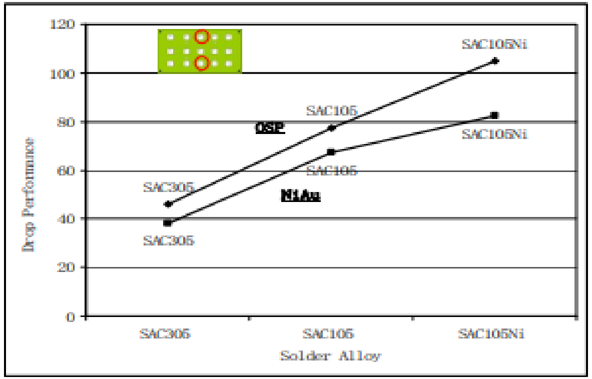
Conclusion:

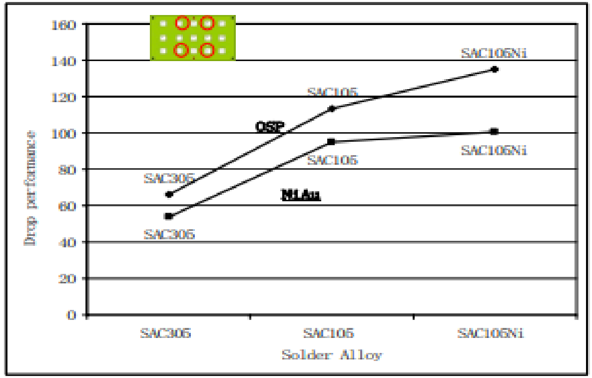
- The low-silver SAC105 alloy performed better than the SAC305 in drop testing.

Drop Reliability Study on SAC Alloys *(Cont’d)*

The board-level drop test reliability performance testing shows the relative influence of different solder ball alloys (SAC305 and SAC105), two surface finishes (Cu-OSP and NiAu), and board location.







SAC105 shows better drop performance than SAC305 on both OSP and ENIG surface finishes.

Summary of Drop and ATC Test Studies

Summary Tables:

Drop and ATC Average Tests on BGAs

	Drop Test	ATC
SAC305	187	9,000
SAC105	196	7,000
Indalloy®291	N/A	6,000

Article Number	Article Title	Drop Test	Accelerated Thermal Cycling (ATC)
1	Thermal Fatigue Evaluation of Pb-Free Solder Joints: Results, Lessons Learned, and Future Trends	N/A	Accelerated thermal cycling is better on smaller BGA packaging sizes. Pb-free solders are more reliable in accelerated thermal cycling than the SnPb alloy.
2	Drop Reliability Study of PBGA Assemblies with SAC305, SAC105 and SAC105-Ni Solder Ball on Cu-OSP and ENIG Surface Finish	SAC105 has better drop impact performance than SAC305 for either OSP or NiAu surface finish. The OSP surface finish showed a better drop lifetime than the NiAu surface finish regardless of the type of solder used in the assemblies.	N/A

Response-to-Pause Printing Test

Response-to-Pause Printing Test

Purpose:

Evaluation of print performance of solder pastes with varying Ag content.

Equipment and Materials:

- Solder pastes: Indium8.9HF, T4, 88.5% metal load for SAC105, SAC305, and Indalloy®291.
- Stainless steel, laser cut, electro-polished stencil with nanocoating, 4 mils (100µm) thick.
- Paste evaluation test boards.
  - Different aperture sizes and configurations included on each board
  - BGA 35mm pads and 0201 250x270µm pads were analyzed
- Dek screen printer with metal squeegee blades.
- Koh Young (KY8030-3) 3D solder paste inspection machine.

Procedure:

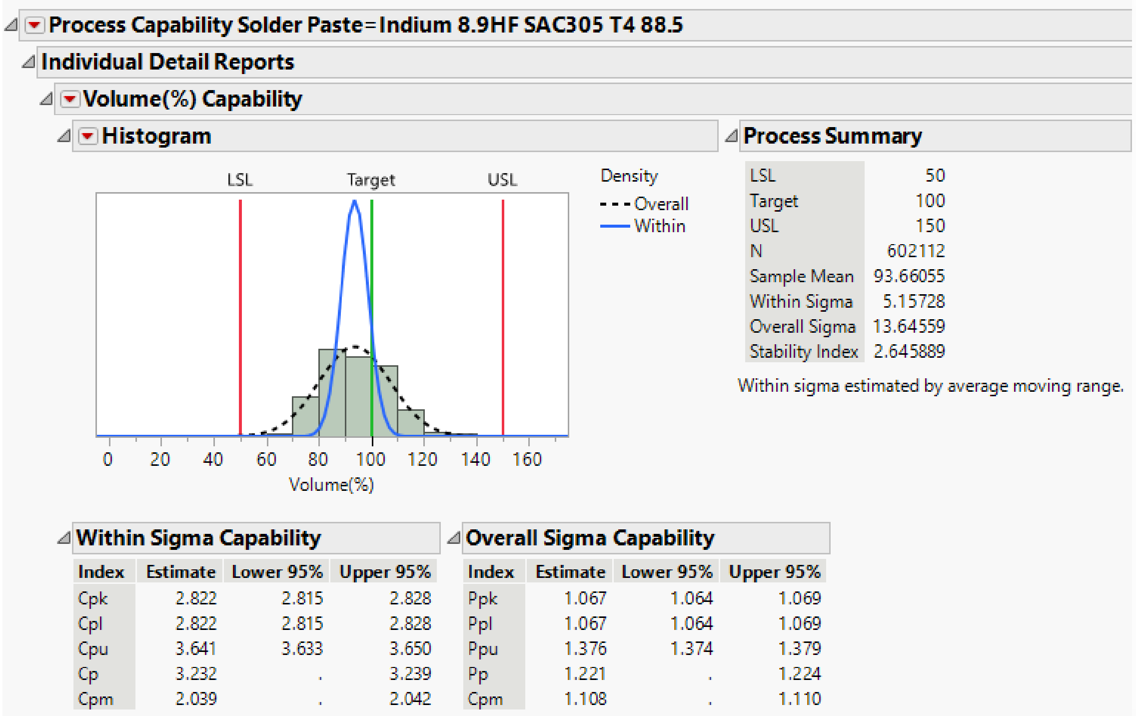
- Load program, set up, and record the Dek screen printer machine data.
- Screen print solder pastes on 20 boards consecutively, then wipe the stencil apertures.
- Pause 1 hour then print 6 boards, perform stencil wipe, print 6 more boards.
- Koh Young inspects and records the solder paste volume data.

Response-to-Pause Printing Test *(Cont'd)*

Summary of Dek screen printer machine settings data:

DEK, Solder Paste, Stencil, and Environmental Setting Data			
Alloy	SAC305 (Sn96.5/Ag3/Cu0.5)	SAC105 (Sn98.5/Ag1/Cu0.5)	Indalloy®291 (Sn99.25/Cu0.7/Ni.05/Ge<.01)
Flux	Indium8.9HF	Indium8.9HF	Indium8.9HF
Metal Load	88.5%	88.5%	88.5%
Mesh Size	T4 (Mesh -400/+635)	T4 (Mesh -400/+635)	T4 (Mesh -400/+635)
Humidity	40.20%	39.40%	32.50%
Temperature	25.1°C	26°C	26°C
Print Speed	50mm/sec	50mm/sec	50mm/sec
Separation Speed	5mm/sec	5mm/sec	5mm/sec
Separation Distance	2mm	2mm	2mm
Squeegee Pressure	5.6kg	5.6kg	5.6kg

Overall Solder Paste Volume Data Analysis on SAC305, Indium8.9HF, T4, 88.5%



Process Capability Solder Paste=Indium 8.9HF SAC305 T4 88.5

Individual Detail Reports

Volume(%) Capability

Histogram

Process Summary

LSL	50
Target	100
USL	150
N	602112
Sample Mean	93.66055
Within Sigma	5.15728
Overall Sigma	13.64559
Stability Index	2.645889

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	2.822	2.815	2.828
Cpl	2.822	2.815	2.828
Cpu	3.641	3.633	3.650
Cp	3.232	.	3.239
Cpm	2.039	.	2.042

Overall Sigma Capability

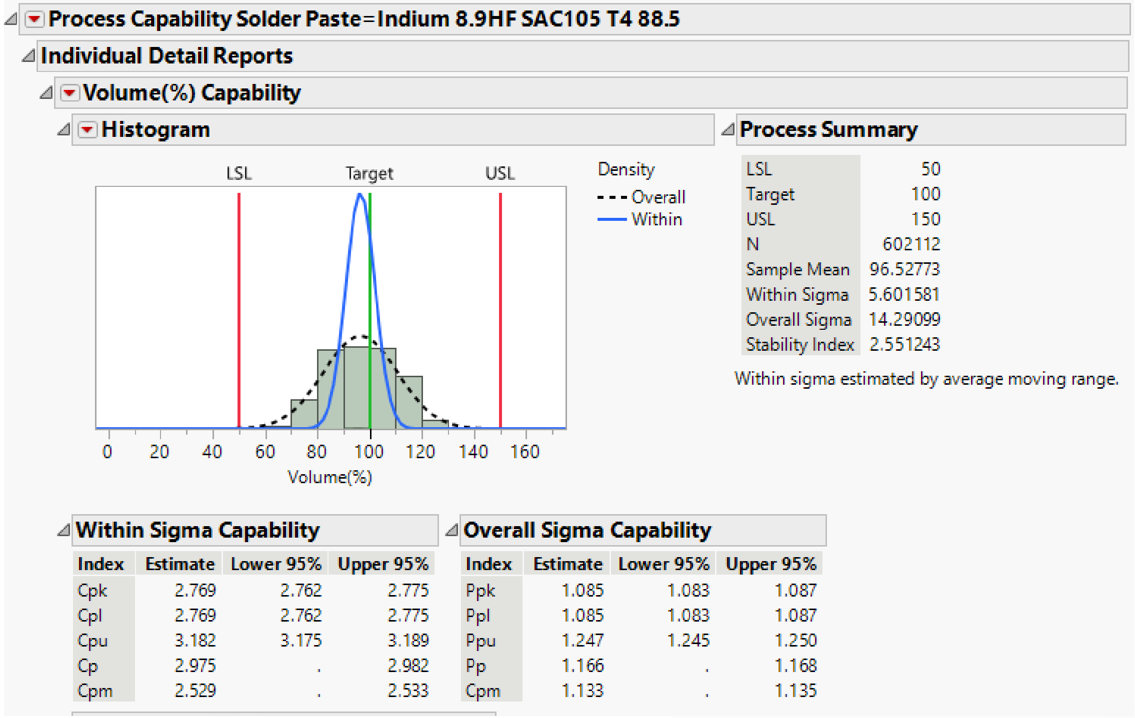
Index	Estimate	Lower 95%	Upper 95%
Ppk	1.067	1.064	1.069
Ppl	1.067	1.064	1.069
Ppu	1.376	1.374	1.379
Pp	1.221	.	1.224
Cpm	1.108	.	1.110

- Collected data points: 602,112
- The mean of the deposited solder paste deposit volume on SAC305 is 92.96%; its data is distributed within the lower limit of 50% and upper limit of 150%.
- **Cpk is 2.822.** The process is capable when Cpk is >1.33.

Conclusion:

- Indium8.9HF using SAC305 T4 powder is capable of a controlled process for the tested print conditions.

Overall Solder Paste Volume Data Analysis on SAC105, Indium8.9HF, T4, 88.5%



Process Capability Solder Paste=Indium 8.9HF SAC105 T4 88.5

Individual Detail Reports

Volume(%) Capability

Histogram

Process Summary

LSL	50
Target	100
USL	150
N	602112
Sample Mean	96.52773
Within Sigma	5.601581
Overall Sigma	14.29099
Stability Index	2.551243

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	2.769	2.762	2.775
Cpl	2.769	2.762	2.775
Cpu	3.182	3.175	3.189
Cp	2.975	.	2.982
Cpm	2.529	.	2.533

Overall Sigma Capability

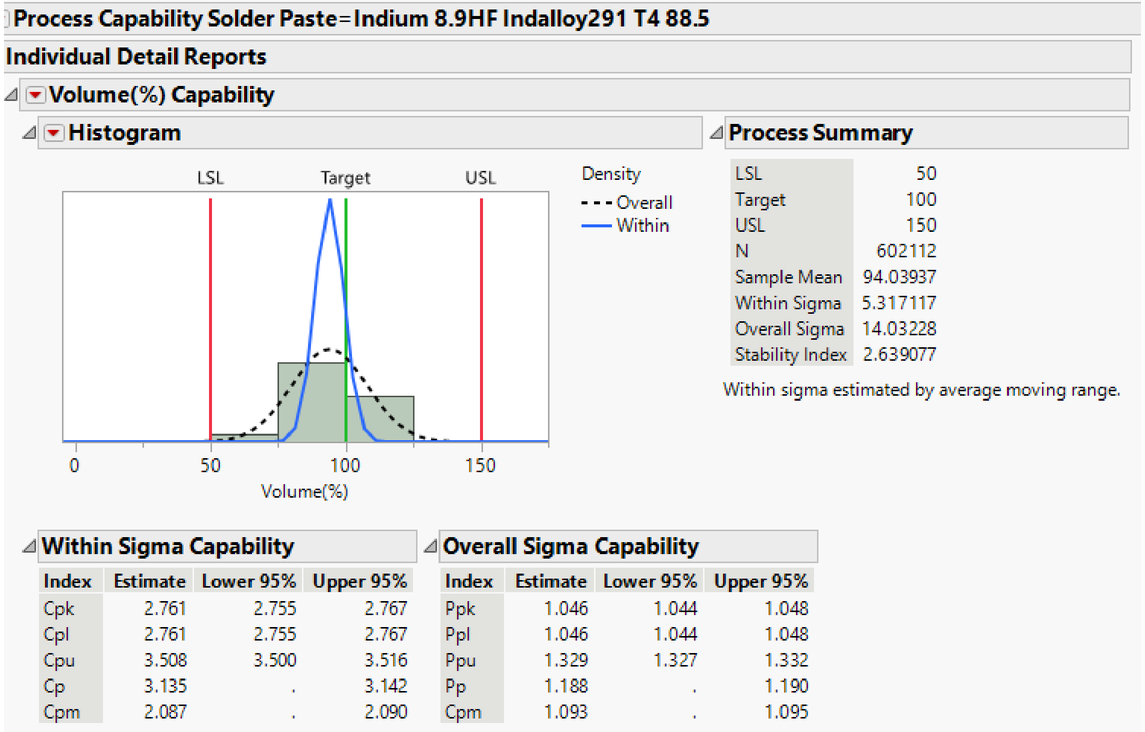
Index	Estimate	Lower 95%	Upper 95%
Ppk	1.085	1.083	1.087
Ppl	1.085	1.083	1.087
Ppu	1.247	1.245	1.250
Pp	1.166	.	1.168
Cpm	1.133	.	1.135

- Collected data points: 602,112
- The mean of the deposited solder paste deposit volume on SAC105 is 93.66%; its data is distributed within the lower limit of 50% and upper limit of 150%.
- **Cpk is 2.769.** The process is capable when Cpk is >1.33.

Conclusion:

- Indium8.9HF using SAC105 T4 powder is capable of a controlled process for the tested print conditions.

Overall Solder Paste Volume Data Analysis on Indalloy®291, Indium 8.9HF, T4, 88.5%



Process Capability Solder Paste=Indium 8.9HF Indalloy291 T4 88.5

Individual Detail Reports

Volume(%) Capability

Histogram

Process Summary

LSL	50
Target	100
USL	150
N	602112
Sample Mean	94.03937
Within Sigma	5.317117
Overall Sigma	14.03228
Stability Index	2.639077

Within sigma estimated by average moving range.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	2.761	2.755	2.767
Cpl	2.761	2.755	2.767
Cpu	3.508	3.500	3.516
Cp	3.135	.	3.142
Cpm	2.087	.	2.090

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	1.046	1.044	1.048
Ppl	1.046	1.044	1.048
Ppu	1.329	1.327	1.332
Pp	1.188	.	1.190
Cpm	1.093	.	1.095

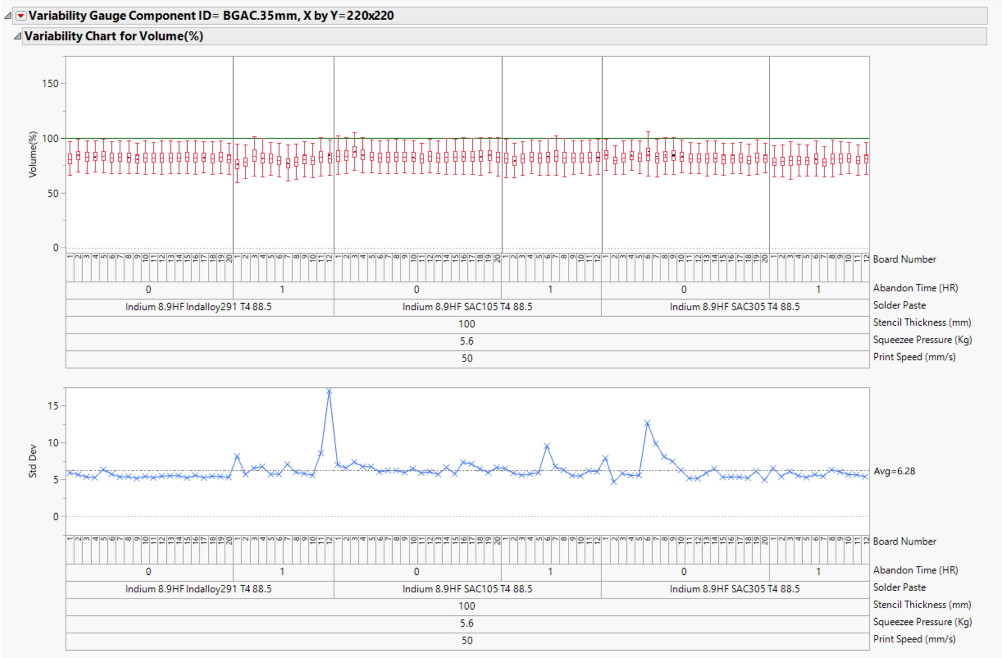
- Collected data points: 602,112
- The mean of the deposited solder paste deposit volume on Indalloy®291 is 94.03%; its data is distributed within the lower limit of 50% and upper limit of 150%.
- **Cpk is 2.76.** The process is capable when Cpk is >1.33.

Conclusion:

- Indium8.9HF using Indalloy®291 T4 powder is capable of a controlled process for the tested print conditions.

Paste Volume Data Analysis on BGAC35mm

Chip Component Size 220x220, Area Ratio 0.55



Test Conditions:

- 32 boards were tested for each paste
- 244,224 data points were measured and collected.
- BGA 0.35mm apertures
- Area ratio = 0.55

Conclusion:

- Solder paste volume percent of all three alloys on the BGA0.35 mm pads is acceptable within the limit of 50% to 150%.
- Standard Deviation = 6.28
- Cpk = 2.468

Solder Paste Volume Data Analysis on 0201

Chip Component Size 250x270, Area Ratio 0.259

Test Conditions:

- 32 boards were tested for each paste
- 110,592 data points were measured and collected
- CHP0201 0.25x0.27 apertures
- Area ratio = 0.259

Conclusion:

- Solder paste volume percent of all three alloys on 0201 pads is acceptable within the limit of 50% to 150%.
- Standard Deviation = 6.01
- Cpk = 3.412

Response-to-Pause Printing Test Conclusion

Koh Young data from 1,806,235 test points were collected and analyzed for three different solder pastes over 96 boards.

	Solder Paste Volume Average (%)	Target %	Cpk	StDev	Observations (Collected Data Points)
SAC305 – All solder joints	92.96	100	2.496	5.73	556,032
SAC105 – All solder joints	95.89	100	2.398	6.38	556,032
Indalloy®291 – All solder joints	98.89	100	2.391	6.04	556,032
BGAC.35 mm (200x200)	82.67	100	2.468	6.28	244,224
0201 Chip Capacitors (250x270)	108.32	100	3.412	6.01	110,592

The solder paste of all tested SAC alloys with Indium8.9HF performed well and meet the acceptable limit of 50% to 150%.

Coalescence / Graping Test

Coalescence / Graping Test

Purpose:

Evaluation of coalescence and graping after reflow using solder pastes with varying Ag content.

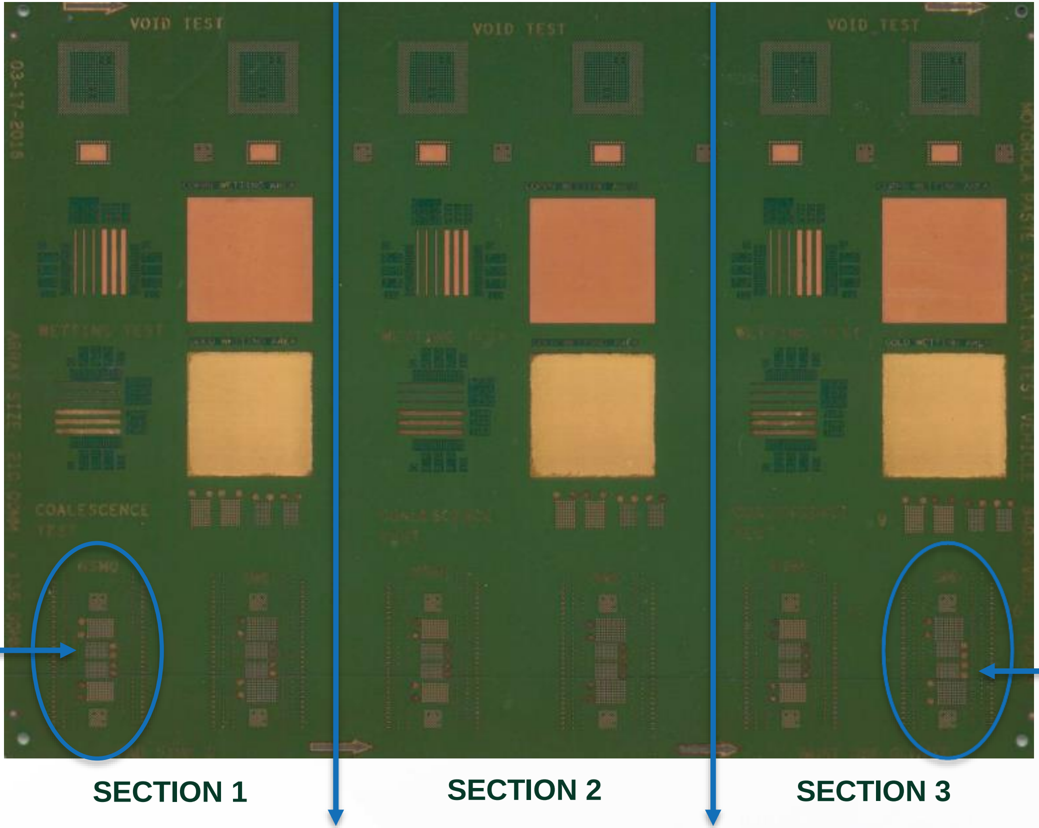
Equipment and Materials:

- Solder pastes: Indium8.9HF, T4, 88.5% metal load for SAC305, SAC105, and Indalloy®291.
- Stainless steel, laser cut, electro-polished stencil with nanocoating, 4 mils (100µm) thick.
- Paste evaluation test boards.
- Ceramic capacitors: 01005 and 0201 sizes.
- MPM Momentum screen printer with metal squeegee blades.
- BTU convection oven using the reflow program in air atmosphere.

Procedure:

- Screen print nine boards for each solder paste.
- Use the Juki to pick and place all chip components on nine boards.
- Use the BTU oven to reflow on all PBAs in air atmosphere.
- Reflow profile setting:
  Peak temperature: 245˚C; time above liquidous: 90 seconds; ramp rate <1˚C/sec.

Coalescence / Graping Test Board



NSMD
0201 & 01005
Capacitors

SMD
0201 & 01005
Capacitors

SECTION 1

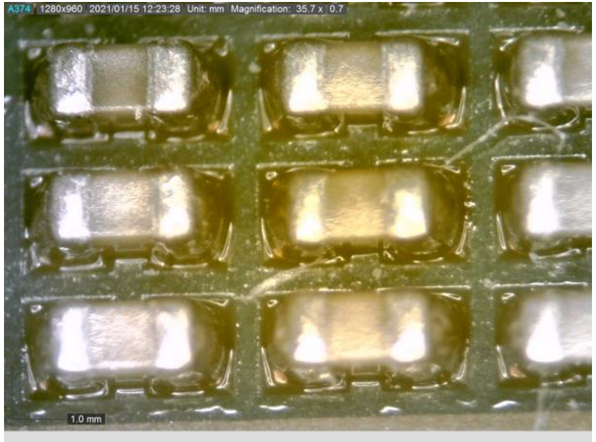
SECTION 2

SECTION 3

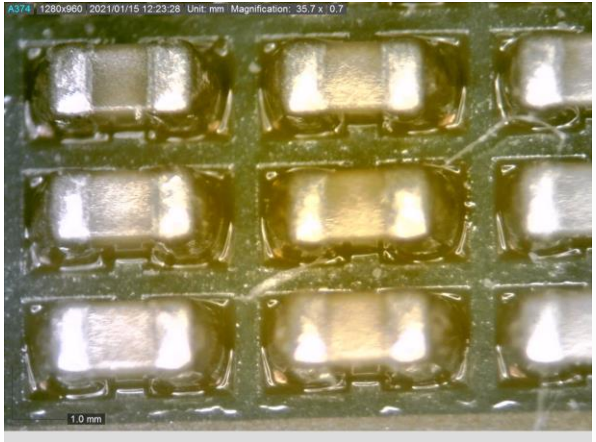
Coalescence, Graping, and Dewetting Test

on 0201 Chip Capacitors

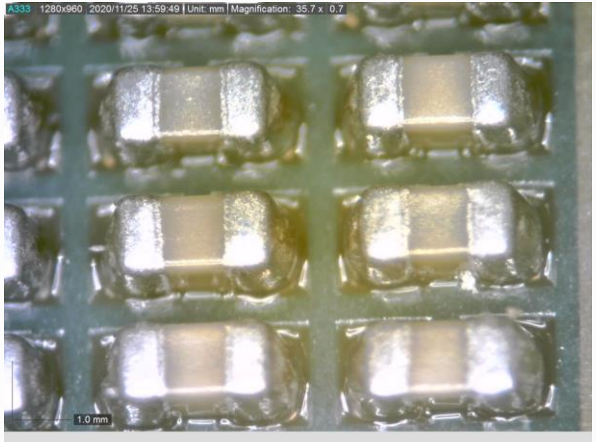
SAC305



SAC105



Indalloy®291



Result:

- No graping found after reflow on all 0201 chip components.

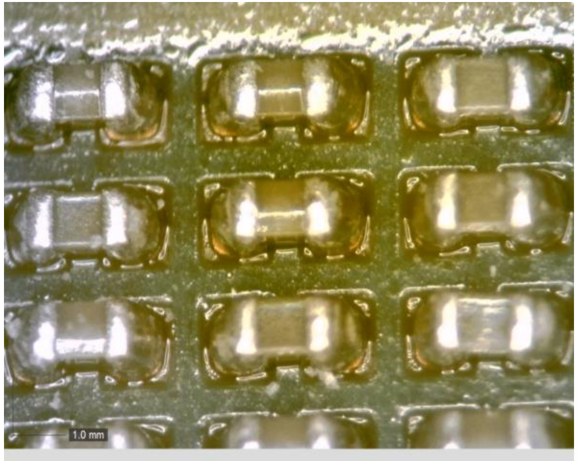
Conclusion:

- Reduced Ag did not result in graping found on 0201 chip components.

Coalescence, Graping, and Dewetting Test

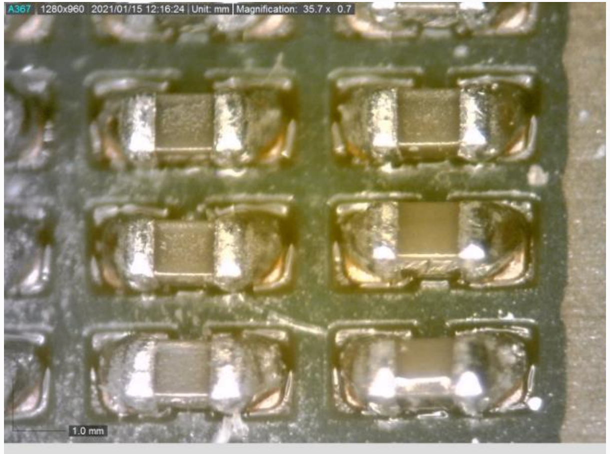
on 01005 Chip Capacitors

SAC305



SAC105

Indalloy®291



Result:

- No graping found after reflow on all 01005 chip components.

Conclusion:

- Reduced Ag did not result in graping found on 01005 chip components.

Wetting Test

Wetting Test

Purpose:

Evaluation of the wetting capability of solder pastes with varying Ag content on OSP-Copper (Cu-OSP) and ENIG plating.

Equipment and Materials:

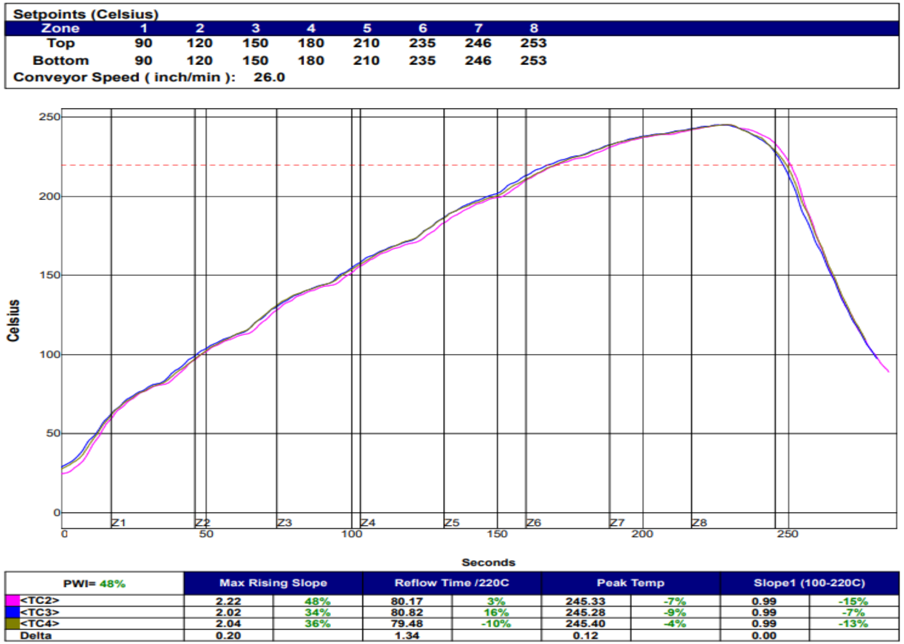
- Solder pastes: Indium8.9HF, T4, 88.5% metal load for SAC305, SAC105, and Indalloy®291.
- Stainless steel, laser cut, electro-polished stencil with nanocoating, 4 mils (100µm) thick.
- Use six PCBs (paste evaluation test boards) per solder paste.
  - Total of 18 test boards for three different pastes
- MPM Momentum screen printer with metal squeegee blades.
- BTU convection oven using the straight ramp reflow profile.

Procedure:

- Obtain three (virgin) non-reflowed test boards.
- Obtain three additional test boards and reflow in the BTU oven three times at the air atmosphere before screen print.
- Screen print six boards (non-reflowed and reflowed).
- Use the BTU oven to reflow boards according to set temperature profile.
  - Peak reflow temperature at 241°C, in 70 seconds, ramp at 1°C/s.
- Repeat the same process for the remaining two solder pastes.
- Inspect and take pictures.

Wetting Test *(Cont’d)*

- Three different solder pastes were deposited on the test boards and reflowed.
  - Test variables: bare board surface finish and preconditioning
- Solder pastes used Indium8.9HF, T4, 88.5% metal load: SAC305, SAC105, and Indalloy®291.
- Bare board preconditioning:
  - Non-reflowed (virgin)
  - Reflowed three times
- Copper OSP and ENIG plating pads:
  - Thin and wide pads
  - Circular and rectangular deposits on surface finish without defined pads
- Reflow profile:
  - Peak temperature = 245˚C
  - Time above liquidus = 90 sec
  - Ramp rate <2˚C/sec



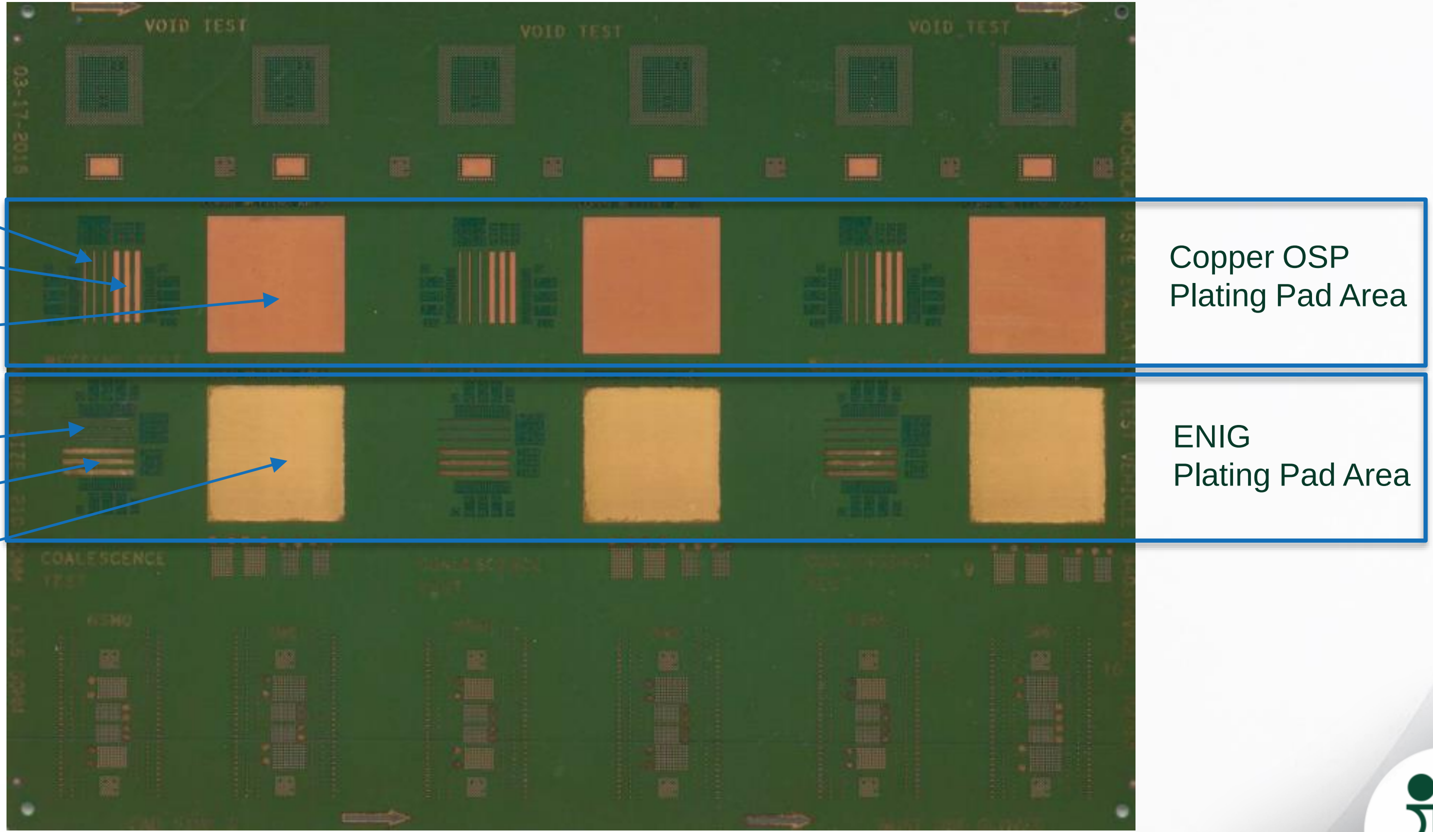
Setpoints (Celsius)

Zone	1	2	3	4	5	6	7	8
Top	90	120	150	180	210	235	246	253
Bottom	90	120	150	180	210	235	246	253

Conveyor Speed (inch/min): 26.0

PWI= 48%	Max Rising Slope		Reflow Time /220C		Peak Temp		Slope1 (100-220C)	
🟪 <TC2>	2.22	48%	80.17	3%	245.33	-7%	0.99	-15%
🟦 <TC3>	2.02	34%	80.82	16%	245.28	-9%	0.99	-7%
🟫 <TC4>	2.04	36%	79.48	-10%	245.40	-4%	0.99	-13%
Delta	0.20		1.34		0.12		0.00	

Wetting Test Board



Cu-OSP Thin Pads

Cu-OSP Wide Pads

Cu-OSP Circular and Multiple Apertures

Copper OSP Plating Pad Area

ENIG Thin Pads

ENIG Wide Pads

ENIG Circular and Multiple Apertures

ENIG Plating Pad Area

Test Boards – Non-Reflowed (Virgin)

This test determined how well the Indium Corporation solder pastes with varying Ag content perform on Cu-OSP and ENIG surface finishes.

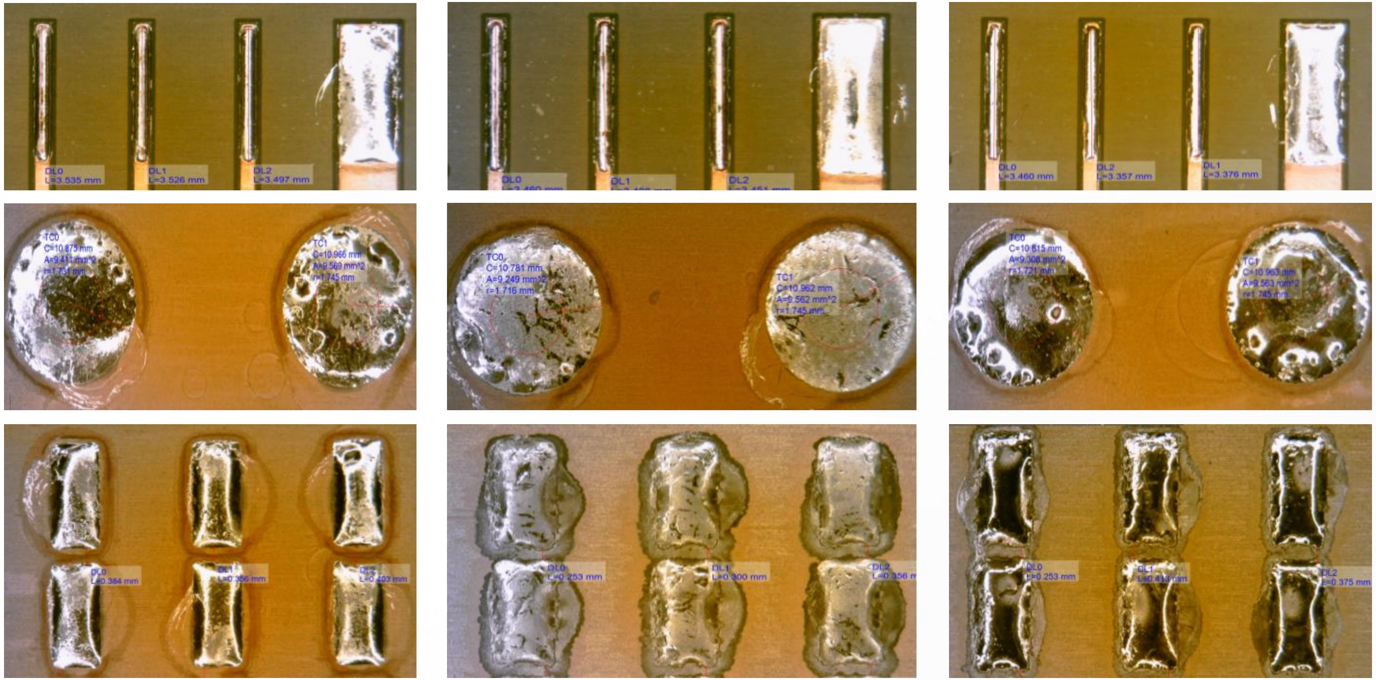
Procedure:

- Use three non-reflowed (virgin) test boards for each paste.
- Use MPM screen printer to deposit solder pastes on three boards with three different SAC alloys.
- Use two different platings on the same test boards:
  - Copper-OSP (Cu-OPS) and ENIG
- Deposit solder pastes on nine test boards (three per paste) and reflow in the BTU oven.
- Take pictures at different locations on the test boards for solder wetting analysis.

Non-Reflowed (Original) Cu-OSP Finished Pads

Non-reflowed PBA – Cu-OSP finished pads

SAC305 **SAC105** **Indalloy®291**



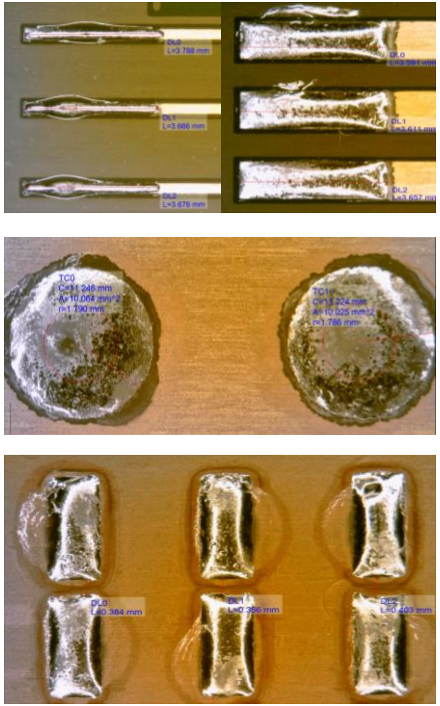
Conclusion:

- SAC305 vs. SAC105 and Indalloy®291 have good wetting on Cu-OSP finished pads.

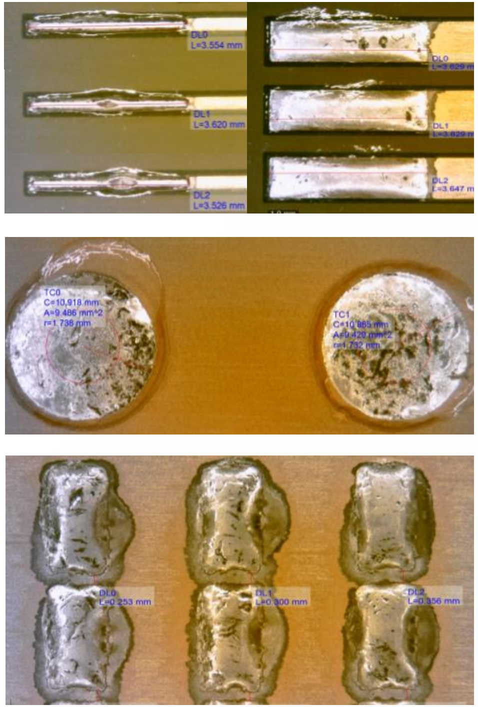
Non-Reflowed (Original) ENIG Finished Pads

Non-reflowed PBA – ENIG finished pads

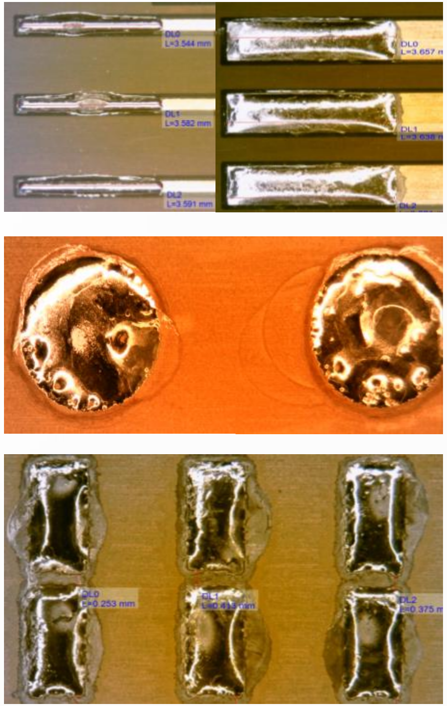
SAC305



SAC105



Indalloy®291



Conclusion:

- SAC305, SAC105, and Indalloy®291 have good wetting on ENIG finished pads.

Test Boards – Reflowed Three Times

This test determined how well the Indium Corporation solder pastes with varying Ag content perform on baked Cu-OSP and ENIG surface finishes.

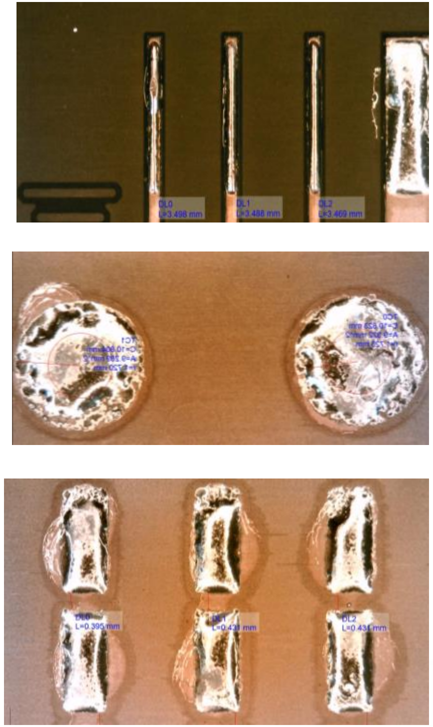
Procedure:

- Send three MPETV test boards for each paste into the BTU oven and reflow three times in the air atmosphere.
- Use two different platings on the same test boards:
  - Cu-OPS and ENIG
- Cool boards to room temperature before screen printing.
- Deposit solder pastes on nine test boards (three per paste) and reflow in the BTU oven.
- Take pictures at different locations on the test boards for solder wetting analysis.

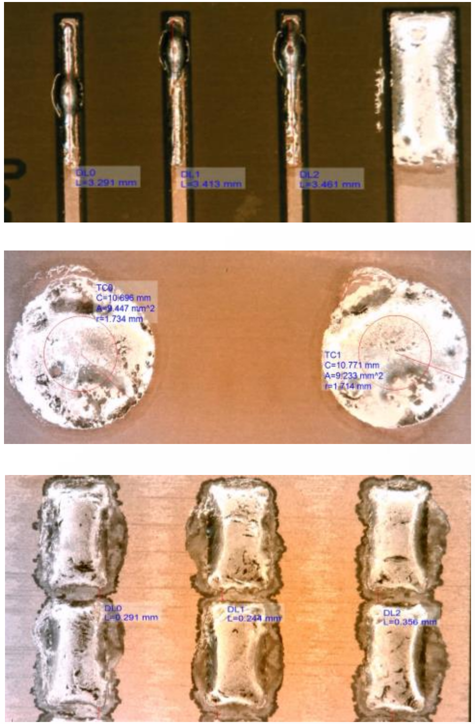
Cu-OSP Finished Pads – Reflowed Three Times

OSP-Copper finished pads

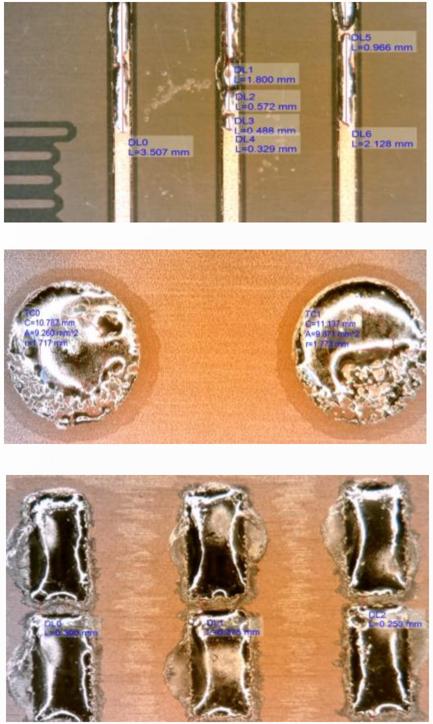
SAC305



SAC105



Indalloy®291



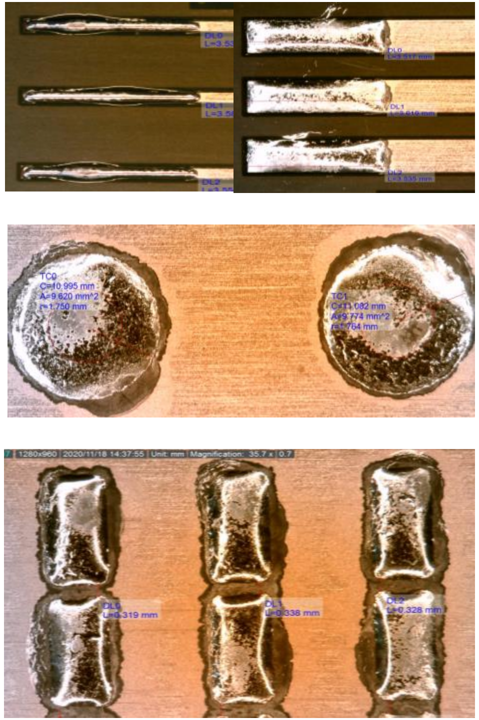
Conclusion:

- SAC305 and SAC105 have good wetting. Indalloy®291 experienced some dewetting on OSP copper plating pads after the bare boards were preconditioned by heat three times.

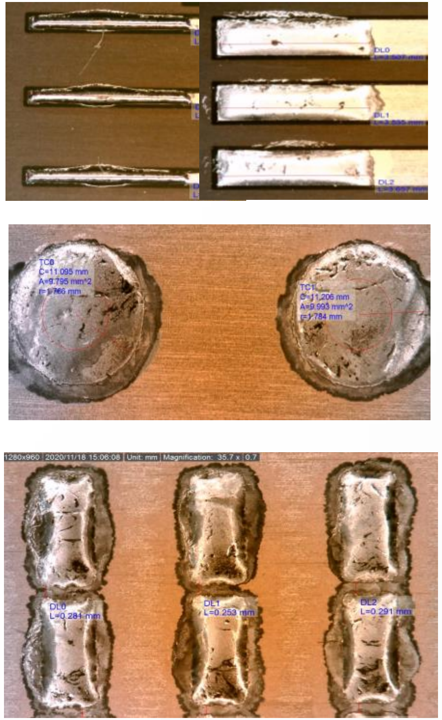
ENIG Finished Pads – Reflowed Three Times

ENIG finished pads

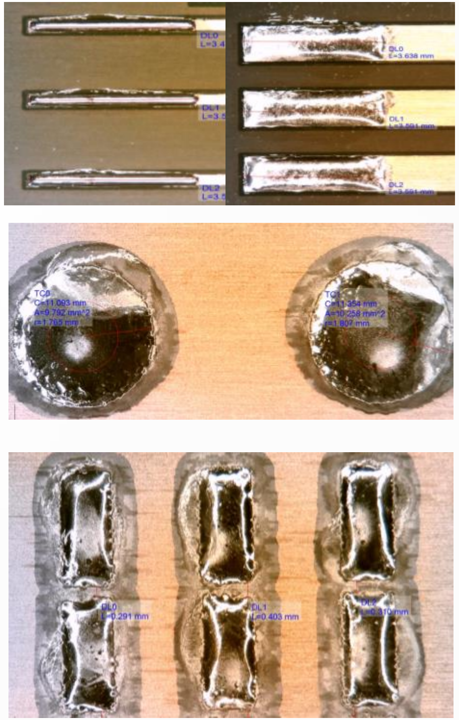
SAC305



SAC105



Indalloy®291



Conclusion:

- SAC305, SAC105, and Indalloy®291 have adequate wetting on ENIG plating pads after bare boards were preconditioned by heat three times.

Wetting Test Summary

ENIG Plating Wetting Test Summary			
	SAC305	**SAC105**	**Indalloy®291**
Non-reflowed	Good wetting	Good wetting	Good wetting
Reflowed three times	Good wetting	Good wetting	Good wetting
Cu-OSP Plating Wetting Test Summary			
Non-reflowed	Good wetting	Good wetting	Good wetting
Reflowed three times	Minor dewetting	Minor dewetting	More dewetting

Conclusion:

- SAC305, SAC105, and Indalloy®291 have good wetting on both virgin and preconditioned ENIG surface finishes.
- SAC305, SAC105, and Indalloy®291 have good wetting on virgin Cu-OSP finished pads.
- SAC105, and SAC305 have minor dewetting on preconditioned Cu-OSP but are acceptable per IPC requirements.
- Indalloy®291 has some dewetting on preconditioned Cu-OSP pads.

QFN Voiding

QFN Voiding Data Analysis

SAC305, SAC105, and Indalloy®291

Purpose:

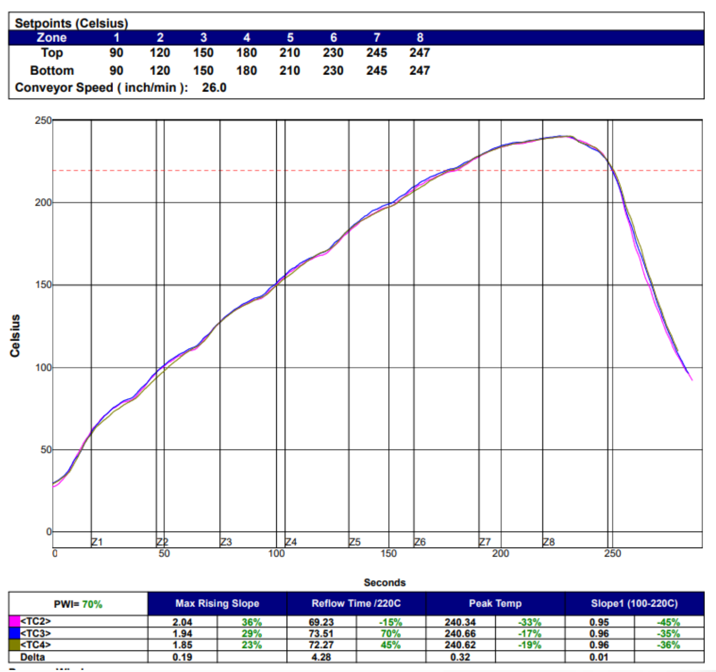
Evaluation of the QFN voiding characteristics of solder pastes with varying Ag content after reflow.

Equipment and Materials:

- Solder pastes: Indium8.9HF for SAC105, SAC305, and Indalloy®291
- Stainless steel, laser cut, electro-polished stencil with nanocoating, 5-mils thick
- Three test boards per paste (nine boards total)
- 12 QFNs per board (36 per paste)
  - Total of 108 QFNs per three different pastes
- MPM Momentum screen printer with metal squeegee blades
- BTU convection oven using air atmosphere
- YXLON X-ray machine

Procedure:

- Screen print three test boards for each paste.
- Use the Juki machine to pick & place QFN components.
- Use the BTU oven to reflow:
  - Peak temperature: 245°C; time above liquidous: 90 seconds; ramp rate 2°C/sec.



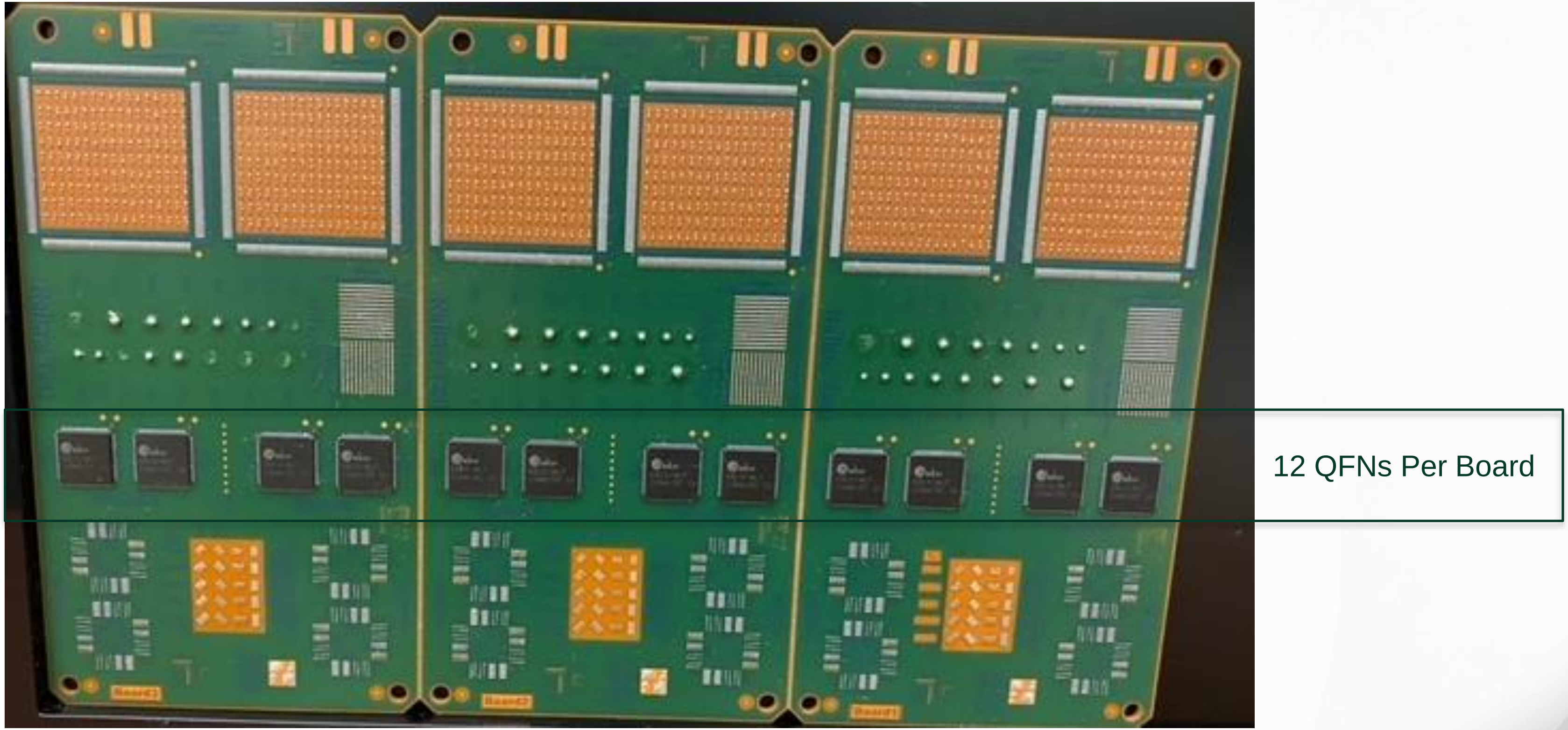
Setpoints (Celsius)

Zone	1	2	3	4	5	6	7	8
Top	90	120	150	180	210	230	245	247
Bottom	90	120	150	180	210	230	245	247

Conveyor Speed (inch/min): 26.0

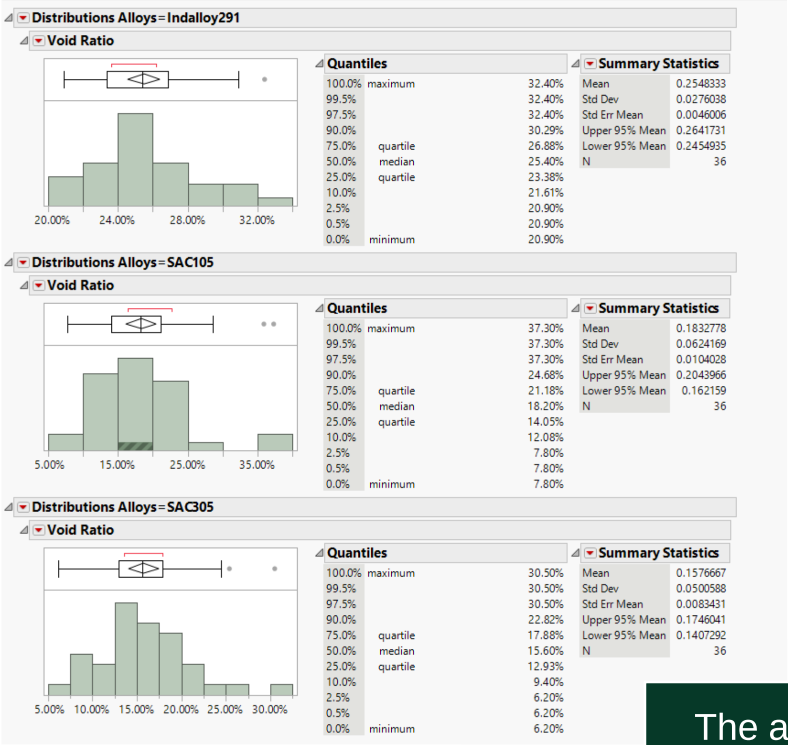
PWI= 70%	Max Rising Slope		Reflow Time /220C		Peak Temp		Slope1 (100-220C)	
🟪 <TC2>	2.04	36%	69.23	-15%	240.34	-33%	0.95	-45%
🟦 <TC3>	1.94	29%	73.51	70%	240.66	-17%	0.96	-35%
🟫 <TC4>	1.85	23%	72.27	45%	240.62	-19%	0.96	-36%
Delta	0.19		4.28		0.32		0.01	

QFN Test Board



12 QFNs Per Board

QFN X-ray Voiding Ratio and Standard Deviation



Distributions Alloys=Indalloy291

Void Ratio

Quantiles

100.0%	maximum	32.40%
99.5%		32.40%
97.5%		32.40%
90.0%		30.29%
75.0%	quartile	26.88%
50.0%	median	25.40%
25.0%	quartile	23.38%
10.0%		21.61%
2.5%		20.90%
0.5%		20.90%
0.0%	minimum	20.90%

Summary Statistics

Mean	0.2548333
Std Dev	0.0276038
Std Err Mean	0.0046006
Upper 95% Mean	0.2641731
Lower 95% Mean	0.2454935
N	36

Distributions Alloys=SAC105

Void Ratio

Quantiles

100.0%	maximum	37.30%
99.5%		37.30%
97.5%		37.30%
90.0%		24.68%
75.0%	quartile	21.18%
50.0%	median	18.20%
25.0%	quartile	14.05%
10.0%		12.08%
2.5%		7.80%
0.5%		7.80%
0.0%	minimum	7.80%

Summary Statistics

Mean	0.1832778
Std Dev	0.0624169
Std Err Mean	0.0104028
Upper 95% Mean	0.2043966
Lower 95% Mean	0.162159
N	36

Distributions Alloys=SAC305

Void Ratio

Quantiles

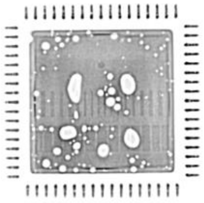
100.0%	maximum	30.50%
99.5%		30.50%
97.5%		30.50%
90.0%		22.82%
75.0%	quartile	17.88%
50.0%	median	15.60%
25.0%	quartile	12.93%
10.0%		9.40%
2.5%		6.20%
0.5%		6.20%
0.0%	minimum	6.20%

Summary Statistics

Mean	0.1576667
Std Dev	0.0500588
Std Err Mean	0.0083431
Upper 95% Mean	0.1746041
Lower 95% Mean	0.1407292
N	36

Indalloy®291:

- Voiding percent is 20.9% to 32.4%
- Average voiding percent is 25.4%



SAC105:

- Voiding percent is 7.8% to 37.3%
- Average voiding percent is 18.2%

SAC305:

- Voiding percent is 6.2% to 30.5%
- Average voiding percent is 15.6%

The average voiding percent of the low-silver SAC alloys is higher than SAC305, but overall, it meets the IPC requirements.

Viscosity Test

Viscosity Test

Purpose:

Evaluating the consistent viscosity of solder pastes with varying Ag content.

Procedure:

- One jar tested for each solder paste (three jars total)
  - Solder pastes: Indium8.9HF with SAC105, SAC305, and Indalloy®291
- Bring solder paste jars from storage to room temperature by placing them in a warm water container.
- Do not stir the paste prior to viscosity reading.
- Record the viscosity after 5 minutes.

Equipment and Materials:

- Refrigerator (5°C)
- 25°C incubator to warm up the solder pastes
- Malcom Viscometer PCU 205
- Spatula
- Stopwatch
- Beaker Isopropyl Alcohol (IPA)
- Brush

Viscosity Test Results

Result:

The viscosity test was performed by QE and the test result is shown here:

Paste	SAC305	SAC105	Indalloy®291
Viscosity (poise)	1,718	1,736	1,710

Conclusion:

The viscosities of SAC105 and Indalloy®291 are functionally the same as SAC305 when using 8.9HF.

Cold and Hot Slumping Tests

Cold and Hot Slumping Tests

Purpose:

Evaluating the bridging and slump performance of solder pastes with varying Ag content, both at room temperature and inside a preheating oven.

Equipment and Materials:

- Pallet V1
- Solder pastes: Indium8.9HF for SAC105, SAC305, and Indalloy®291
- Six (2″ x 2″) alumina coupons
  - Use test pattern per IPC-A-20 for 100µm stencil thickness, J-STD-005, and IPC-TM-650 2.4.35 for slump tests.
  - Use test pattern per IPC-A-21 for 200µm stencil thickness, J-STD-005, and IPC-TM-650 2.4.35 for slump tests.
- Stainless steel, laser cut, electro-polished stencils with nanocoating, 100µm- and 200µm-thick
- Dek screen printer with metal squeegee blades

Procedure:

- Screen print solder pastes on six coupons in the Dek printer.
- Load six screen-printed coupons in the chamber, which was set to 25˚C for 10 minutes for cold slump test.
- Load four screen-printed coupons in the bake oven, which was set to 185˚C for 10 minutes for hot slump test.
- Remove solder paste coupons from the ovens after 10 minutes for each test.

Cold and Hot Slumping Tests *(Cont'd)*

Stencil:

- Stencil name: Slump Test; thickness: 200µm
- Stencil apertures were cut per IPC-A-21 pattern *(Figure 1)*

Coupons:

- Six (2" x 2") coupons were used for hot and cold slump tests

Dek Printer Set Up:

- Print speed: 25mm/s
- Print pressure: 8 kg
- Separation speed: 5 mm/s
- Humidity: 21.2%
- Temperature: 24.7°C.

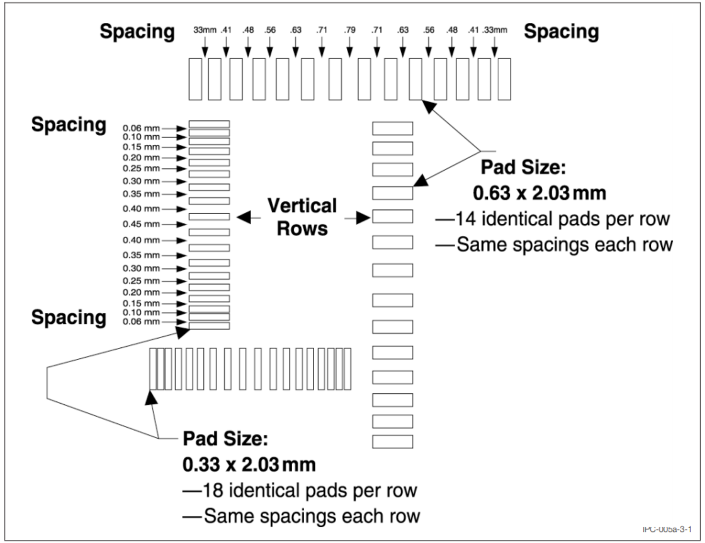


Figure 1: 200µm-thick (IPC-A-21 pattern)

Inspection:

The pass and fail criteria per test method 2.4.35 shall show:

- The 0.63 x 2.03mm pads of IPC-A-21 *(Figure 1)*, when tested in accordance with paragraph 5.2.1 in IPC-TM-650, method 2.4.35, shall show no evidence of bridging between pads when spacing is 0.56mm or greater. When tested in accordance with paragraph 5.2.2 in IPC-TM-650, method 2.4.35, the specimen shall show no evidence of bridging between pads when the spacing is 0.63mm or greater.
- The 0.33 x 2.03mm pads *(Figure 1)* of the IPC-A-21 pattern, when tested in accordance with paragraph 5.2.1 in IPC-TM-650, method 2.4.35, shall show no evidence of bridging at spacing of 0.25mm or greater, and when tested in accordance with paragraph 5.2.2 of IPC-TM-650, method 2.4.35, shall show no evidence of bridging at spacing of 0.30mm or greater.

Cold and Hot Slumping Tests *(Cont'd)*

Stencil:

- Stencil name: Slump Test; thickness: 100µm
- Stencil apertures were cut per IPC-A-20 pattern *(Figure 2)*

Coupons:

- Six (2" x 2") coupons were used for hot and cold slump tests

Dek Printer Set Up:

- Print speed: 25mm/s
- Print pressure: 8 kg
- Separation speed: 5 mm/s
- Humidity: 21.2%
- Temperature: 24.7˚C.

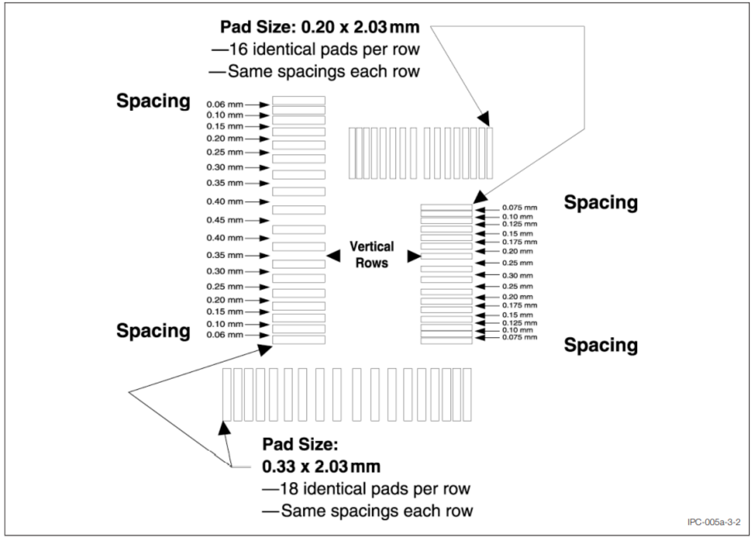


Figure 2: 100µm-thick (IPC-A-20 pattern)

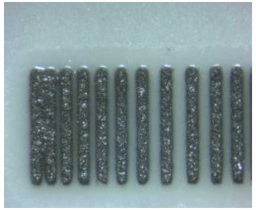
Inspection:

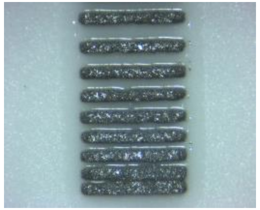
The pass and fail criteria per test method 2.4.35 shall show:

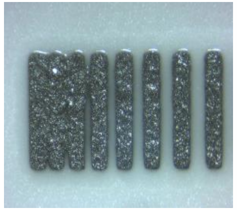
- The 0.33 x 2.03mm pads of IPC-A-20 *(Figure 2),* when tested in accordance with paragraph 5.2.1 in IPC-TM-650, method 2.4.35, should show no evidence of bridging between pads when spacing is 0.25mm or greater. When tested in accordance with paragraph 5.2.2 in IPC-TM-650, method 2.4.35, shall show no evidence of bridging between pads when the spacing is 0.30mm or greater.
- The 0.2 x 2.03mm pads *(Figure 2)* of the IPC-A-20 pattern, when tested in accordance with paragraph 5.2.1 in IPC-TM-650, method 2.4.35, shall show no evidence of bridging at spacing of 0.175mm or greater, and when tested in accordance with paragraph 5.2.2 of IPC-TM-650, method 2.4.35, shall show no evidence of bridging at spacing of 0.20mm or greater.

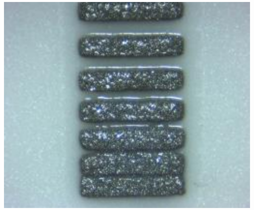
Cold and Hot Slumping Test Results – SAC305

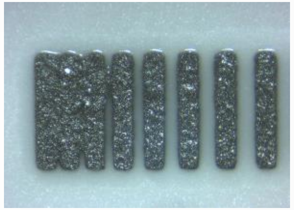
SAC305 Cold Slump Test Result


IPC-A20 0.20 x 2.03mm
Horizontal Cold


IPC-A20 0.20 x 2.03mm
Vertical Cold

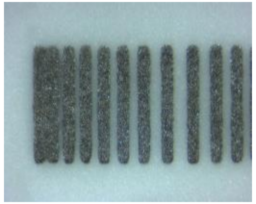

IPC-A20 0.33 x 2.03mm
Horizontal Cold

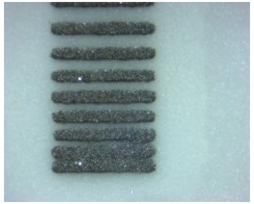

IPC-A20 0.33 x 2.03mm
Vertical Cold

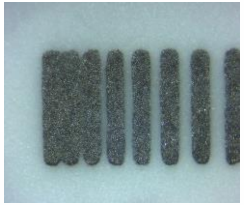

IPC-A21 0.33 x 2.03 mm
Horizontal Cold

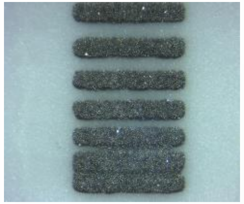

IPC-A21 0.33 x 2.03mm
Vertical Cold

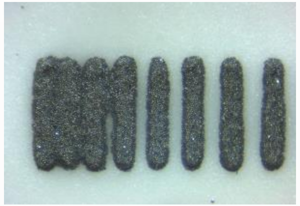
SAC305 Hot Slump Test Result

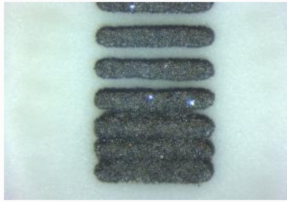

IPC-A20 0.20 x 2.03 mm
Horizontal Hot


IPC-A20 0.20 x 2.03 mm
Vertical Hot


IPC-A20 0.33 x 2.03 mm
Horizontal Hot


IPC-A20 0.33 x 2.03 mm
Vertical Hot


IPC-A21 0.33 x 2.03 mm
Horizontal Hot


IPC-A21 0.33 x 2.03 mm
Vertical Hot

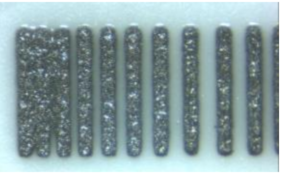
Conclusion:

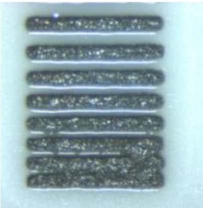
The solder bridges on the coupons are less than three spaces from the left to right or from the bottom to top.

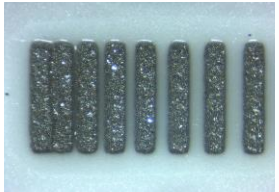
Indium8.9HF with SAC305 passes per IPC-TM-650, method 2.4.35

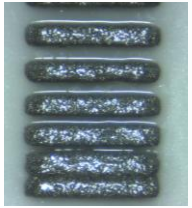
Cold and Hot Slumping Test Results – SAC105

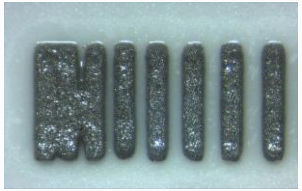
SAC105 Cold Slump Test Result per IPC-A-20

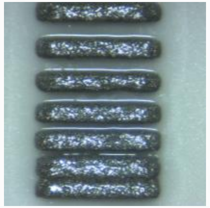

IPC-A20 0.20 x 2.03mm
Horizontal Cold


IPC-A20 0.20 x 2.03mm
Vertical Cold

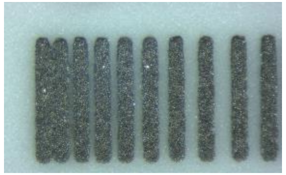

IPC-A20 0.33 x 2.03mm
Horizontal Cold


IPC-A20 0.33 x 2.03mm
Vertical Cold

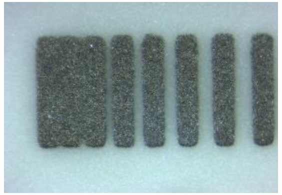

IPC-A21 0.33 x 2.03 mm
Horizontal Cold

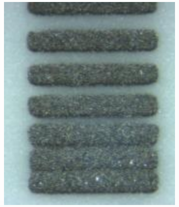

IPC-A21 0.33 x 2.03mm
Vertical Cold

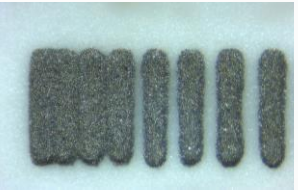
SAC105 Hot Slump Test Result per IPC-A-21

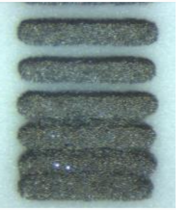

IPC-A20 0.20 x 2.03 mm
Horizontal Hot


IPC-A20 0.20 x 2.03 mm
Vertical Hot


IPC-A20 0.33 x 2.03 mm
Horizontal Hot


IPC-A20 0.33 x 2.03 mm
Vertical Hot


IPC-A21 0.33 x 2.03 mm
Horizontal Hot


IPC-A21 0.33 x 2.03 mm
Vertical Hot

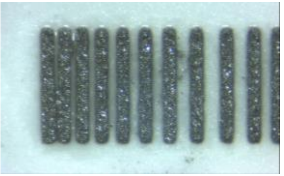
Conclusion:

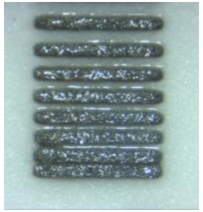
The solder bridges on the coupons are less than three spaces from the left to right or from the bottom to top.

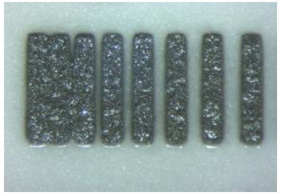
Indium8.9HF with SAC105 passes per IPC-TM-650, method 2.4.35

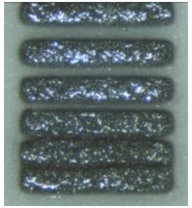
Cold and Hot Slumping Test Results – Indalloy®291

Indalloy®291 Cold Slump Test Result per IPC-A-20


IPC-A20 0.20 x 2.03mm
Horizontal Cold


IPC-A20 0.20 x 2.03mm
Vertical Cold

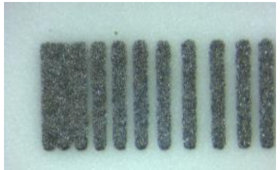

IPC-A20 0.33 x 2.03mm
Horizontal Cold


IPC-A20 0.33 x 2.03mm
Vertical Cold

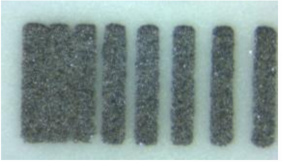

IPC-A21 0.33 x 2.03 mm
Horizontal Cold


IPC-A21 0.33 x 2.03mm
Vertical Cold

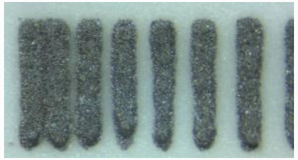
Indalloy®291 Hot Slump Test Result per IPC-A-21

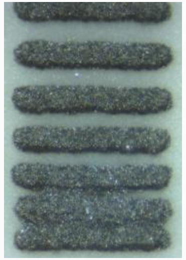

IPC-A20 0.20 x 2.03 mm
Horizontal Hot


IPC-A20 0.20 x 2.03 mm
Vertical Hot


IPC-A20 0.33 x 2.03 mm
Horizontal Hot


IPC-A20 0.33 x 2.03 mm
Vertical Hot


IPC-A21 0.33 x 2.03 mm
Horizontal Hot


IPC-A21 0.33 x 2.03 mm
Vertical Hot

Conclusion:

The solder bridges on the coupons are less than three spaces from the left to right or from the bottom to top.

Indium8.9HF with Indalloy®291 passes per IPC-TM-650, method 2.4.35

Summary Table	SAC305	SAC105	Indalloy®291
Print Performance	☑	☑	☑
Graping	☑	☑	☑
Slump	☑	☑	☑
Viscosity	☑	☑	☑
Wetting	☑ ☑ ☑	☑ ☑ ☑	☑ ☑
Voiding	☑ ☑ ☑	☑ ☑ ☑	☑ ☑
Thermal Cycling	☑ ☑ ☑	☑ ☑	☑
Drop Shock	☑ ☑	☑ ☑ ☑	☑ ☑ ☑

Final Test Results

Summary Table for All Tests

	SAC305	SAC105	Indalloy®291
Coalescence, Graping	No graping	No graping	No graping
Solder Paste Volume Average %	92.96	95.89	93.35
Wetting on No Reflow PCBs with Cu-OSP Plating	Good	Good	Good
Wetting on 3 Time Reflow PCBs with Cu-OSP Plating	Minor dewetting	Minor dewetting	More dewetting
Wetting on No Reflow PCBs with ENIG Plating	Good	Good	Good
Wetting on 3 Time Reflow PCBs with ENIG Plating	Good	Good	Good
QFN Voiding % Minimum	6.2	7.8	20.9
QFN Voiding % Maximum	30.5	37.3	32.4
QFN Voiding % Average	15.6	18.2	25.4
Viscosity Test	1,718 poise	1,736 poise	1,710 poise
Cold Slump Test	Pass	Pass	Pass
Hot Slump Test	Pass	Pass	Pass
TCT 0/100 ℃ BGA192 Characteristic Lifetime	5713	4891	3076
TCT 0/100 ℃ BGA84 Characteristic Lifetime	9818	6815	6604
Drop Shock # Drops to Failure – OSP	187	196	N/A
Drop Shock # Drops to Failure – ENIG	110	165	N/A

Conclusion

- Reduced silver **does not impact** most solder performance metrics
  - Slump, long-term stability, printing, and graping performance
- Reduced silver has a **positive effect** on drop shock reliability
  - SAC105 has better performance on the BGAs on the drop shock than SAC305.
- Eliminating silver has a **modest negative impact** on wetting and voiding
  - No impact to wetting ENIG; increased dewetting on reflowed OSP
  - QFN voiding percent is higher than SAC305, but meets the IPC requirement
- Reduced silver **negatively impacts** thermal cycling reliability
  - SAC105 TCT reliability was reduced from that of SAC305 but was superior to Indalloy®291

With rising silver prices, a non-silver or low-silver alloy such as SAC105 provides a cost-effective solder joint with good overall performance.

References

1. Richard J. Coy. "Thermal Fatigue Evaluation of Pb-Free Solder Joints Results, Lessons Learned, and Future Trends."
2. W.H. Zhu, Luhua Xu, John HL Pang, et al. "Drop Reliability Study of PBGA Assemblies with SAC305, SAC105, and SAC105-Ni Solder Ball on Cu-OSP and ENIG Surface Finish."
3. Ranjit Pandher and Tom Lawlor, Cookson Electronics Assembly Materials. "Effect of Silver in Common Lead-free Alloys."
4. Ranjit S. Pandher, Brian G. Lewis, Raghasudha Vangaveti, and Bawa Singh, Cookson Electronics. "Drop Shock Reliability of Lead-Free Alloys – Effect of Micro-Additives."
5. Michael A. Previti, Mitch Holtzer, and Tom Hunsinger, Cookson Electronics. "Four Ways To Reduce Voids In BGA/CSP Package To Substrate Connections."
6. Gregory Henshall, Hewlett-Packard Co. Palo Alto, CA. "Comparison of Thermal Fatigue Performance of SAC105 (Sn-1.0Ag-0.5Cu), Sn3.5Ag, and SAC305 (Sn-3.0Ag-0.5Cu) BGA Components with SAC305 Solder Paste."
7. Brook Sandy and Ronald C. Lasky, PhD, PE., Indium Corporation. "Choosing a Low-Cost Alternative to SAC Alloys for PCB Assembly."
8. Simin Bagheri, Polina Snugovesky, Jason Bragg, Russell Brush, and Blake Harper, Celestica International Inc. "Drop Test Performance of BGA Assembly Using Sac105ti Solder Spheres."
9. Jianbiao Pan, Ph.D. Cal Poly State University, Jyhwen Wang, Ph.D. Texas A&M University, and David M. Shaddock GE Global Research Center, "Lead-free Solder Joint Reliability – State of the Art and Perspectives."

References *(Cont'd)*

10. Chongqing Municipal Engineering Research Center of Institutions of Higher Education for Special Welding Materials and Technology (Chongqing University of Technology), Chongqing 400054, China 2 School of Language Studies, Chongqing University of Technology, Chongqing 400054, China 3 College of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China. "Microstructure and Shear Strength of Low-Silver SAC/Cu Solder Joints During Aging".
11. Greg Henshall, Michael Roesch, Kris Troxel, Helen Holder, and Jian Miremadi, HP Global Engineering Services. "Manufacturability and Reliability Impacts of Alternate Pb-Free BGA Ball Alloys."
12. Gregory Henshall, Hewlett-Packard Co. Palo Alto, CA. "Comparison of Thermal Fatigue Performance of SAC105 (Sn-1.0Ag-0.5Cu), Sn3.5Ag, and SAC305 (Sn-3.0Ag-0.5Cu) BGA Components with SAC305 Solder Paste."
13. Vikram Srinivas, Nicholas Williard, Preeti Chauhan, and Michael Osterman, Center for Advanced Life Cycle Engineering, Department of Mechanical Engineering University of Maryland College Park, MD, USA. "Board Level Reliability Evaluation Of Low Silver (Ag) Content Lead-free Solder Joints At Low Strain Rates."
14. Yee Mei Leong and A.S.M.A. Haseeb, Centre for Advanced Materials, Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603. "Soldering Characteristics and Mechanical Properties of Sn-1.0Ag-0.5Cu Solder with Minor Aluminum Addition."
15. Howard P. Stevens, Metallic Resources, Inc. Twinsburg, Ohio. "A Test Comparison of SAC and Non-SAC Lead-Free Solders."
16. Joelle Arnold, DfR Solutions College Park, MD, USA and Keith Sweatman, Nihon Superior Co., Ltd. Osaka, Japan. "Reliability Testing of Ni-Modified SnCu and SAC305 – Accelerated Thermal Cycling."
17. Preeti Chauhan. "Thermal Cycling Reliability of SAC305, SAC105, Sn100C, and SnPb Solders under Isothermal Aging and an Active Current."

Questions / Concerns

Notes

1. Indium8.9HF on SAC105 (Sn98.5/Ag1.0/Cu0.5) and Indalloy®291 (Sn99.25/Cu0.7/Ni.05/Ge <.01) alloys have higher melting points than SAC305 (Sn96.5Ag3Cu0.5).
2. Motorola Board:
   - Top side has three sections for the voiding test (BGA and LGA), wetting test, and coalescence test
   - Copper OSP (Organic Solderability Preservative) and ENIG (Electroless Nickel Immersion Gold-Plating)
   - Bottom side has SMD and NSMD pads
3. Jabil Board:
   - Three boards per panel and four QFNs per board for a total of 12 QFNs per panel
4. Universal Board:
   - Six BGAs (256 or 192 balls) per board
5. Profiles:
   - P1 = 237℃ in 60 seconds, ramp at 1℃/s
   - P5 = 241℃ in 70 seconds, ramp at 1℃/s
   - P9 = 245℃ in 90 seconds, ramp at 1℃/s
6. Run the wetting and coalescence tests at the same time
   Run the hot and cold slump tests at the same time
7. Powder Type 4 = 20-38µ →
8. Collected data points for three solder pastes: 1,806,336 (602,112/paste)
9. Collected data points per board: 602,112 / 32 PBAs = 18,816/board

Powder Type	Powder Size (Micron)
II	45-75µ
III	25-45µ
IV	20-38µ
V	15-25µ
VI	5-15µ

Notes

Slide number 18 (SD = 6.28, mean = 82.67) can be explained as follows:

- **One standard deviation accounts for 68% of the sample population being studied:** 82.67%–76.39% paste volume.

  The average with a standard deviation of 6.28% in this solder paste volume percent data analysis means that about 68% (assuming a normal distribution) has a percent of 6.28% within the mean (88.85–76.39) percent.

  (82.67% + 6.28 = 88.95 and 82.67% - 6.28 = 76.39%)

- **Two standard deviations account for 95% of the sample population being studied:** 95.23%–70.11% paste volume.

  The average with a standard deviation of 12.56% (6.28% x 2 = 12.56%) in this solder paste volume percent data analysis means that about 95% (assuming a normal distribution) has a percent of 12.56% within the mean (95.23–70.11) percent.

  (82.67% + 12.56 = 95.23 and 82.67% - 12.56 = 70.11%)

- **Three standard deviations account for 99.7% of the sample population being studied:** 101.47%–63.83% paste volume.

  The average with a standard deviation of 18.84% (6.28% x 3 = 18.84%) in this solder paste volume percent data analysis means that about 99.7% (assuming a normal distribution) has a percent of 18.84% within of the mean (101.47–63.83) percent.

  (82.67% + 18.84 = 101.47 and 82.67% - 18.84 = 63.83%)

Notes

- **Standard Deviation (SD)** is a measure of how precise the average is, that is, how well the individual numbers agree with each other.
- **RSD**: Relative Standard Deviation. It is expressed in percent and is obtained by multiplying the standard deviation by multiplying the standard deviation by 100 and dividing by the average (100**SD**/Mean).
- **Cp**: Process capability index as the ratio of the spec width to the process width. Cp counts for only the spread (or variation) of the process. It measures whether the process spread is narrower than the specification width.
- **Cpk:** Process Capability Index. Cpk counts for both the spread (or variation) and location of the process. It measures both the centering of the process as well as the spread of the process relative to the specification width.
- **Process Width:** The difference between the largest value and the smallest value this process could create.
- **Process Capability Analysis**: A process capability study uses data from an initial run of parts to predict whether a manufacturing process can repeatably produce parts that meet specifications.
- **Area Ratio (** > 0.66): The area beneath the stencil aperture opening divided by the area of the inside aperture wall. For a rectangular aperture, the area ratio = [(LxW)/2(L+W)T)], where L and W are the aperture length and width, respectively, and T is stencil thickness.
- **G or g:** An acceleration equal to the acceleration of gravity, 9.81 meter/second-squared, approximately 32.2 feet per second^2.

Notes

- **P_{pk} vs. C_{pk} indices**
    - The terms C_{pk} and P_{pk} are often confused; when quality or process engineers refer to the C_{pk} index, they often actually intend to mean P_{pk} indices.
    - P_{pk} is used to assess the *long-term*, overall variability, whereas C_{pk} is the capability index for *short-term*.
- Consider the illustration on the next slide. Suppose that during a full-week period, measurements have been collected day after day. Suppose also that the process we are monitoring is cyclical. The amount of variability within one day is quite small, but because of the cyclical behavior or process instability from day-to-day, the overall variability during the whole week is much larger than the variability within single days. The P_{pk} is estimated from the dispersion of all individual values during the whole period, whereas the C_{pk} is based on variations only within subgroups (within days in this example).
- It is important to differentiate short-term variability from long-term variability, because if a process is affected by drifts and systematic long-term trends, it will become unstable and therefore unpredictable. A P_{pk} that is estimated today may not be valid tomorrow because of a long-term process shift. Process stability and fluctuations due to random/common causes are necessary to ensure a predictable behavior. The P_{pk} (overall capability) index should therefore be as close as possible to the C_{pk} (short term) estimate.

Notes

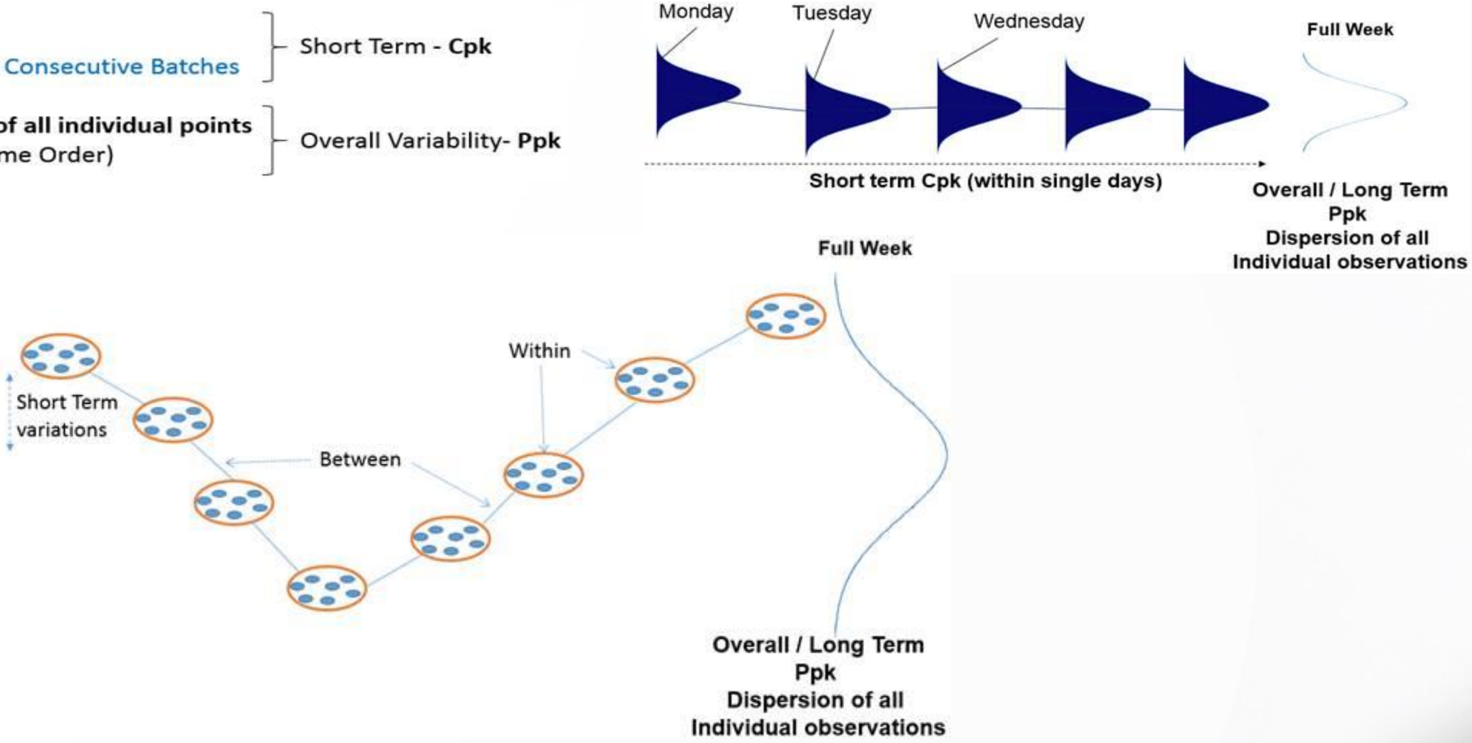
A Simple Guide to Between/Within Capability

- **Within**
- **Between** Consecutive Batches

Short Term - **Cpk**

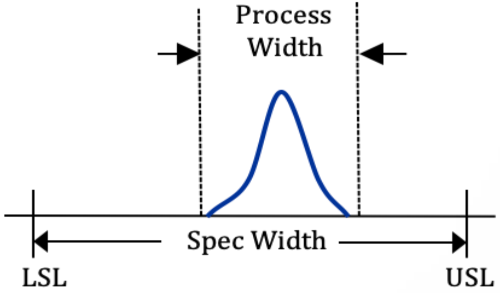
- **Capture of all individual points** (not in time Order)

Overall Variability- **Ppk**



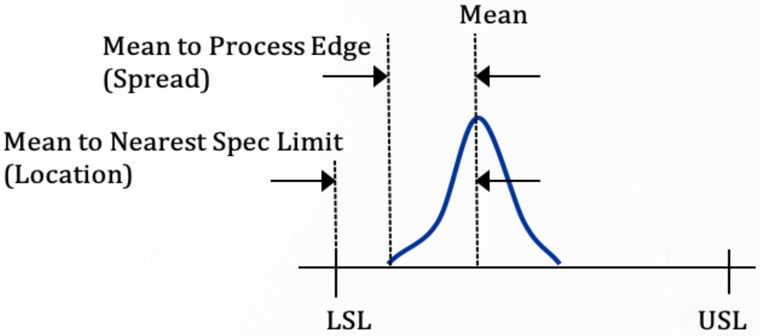
Notes

$$\mathbf{Cp} = \frac{\text{Specification Width}}{\text{Process Width}}$$



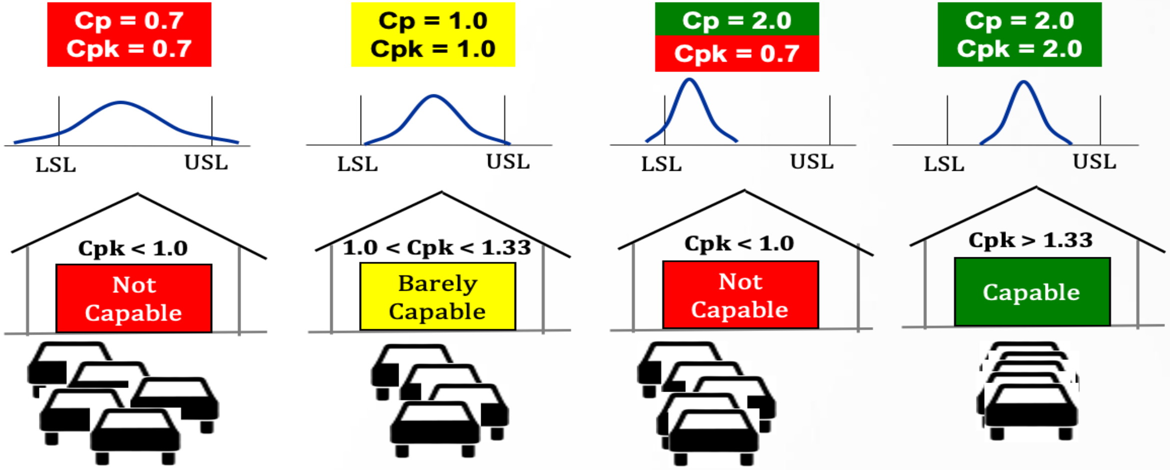
Cp accounts for only the spread (or variation) of the process.

$$\mathbf{Cpk} = \frac{\text{Distance from Mean to Nearest Spec Limit}}{\text{Distance from Mean to Process Edge}}$$



Cpk accounts for both the spread and location of the process.

Notes



The driver is unsteady. The car often scrapes the walls. You will produce defect parts unless process width is reduced and process is centered.

The driver is still unsteady but better than before. He often comes too close to the walls. You are likely to have a defect unless the process width is reduced.

The driver is unable to center the car. But he's consistent – always too close to one side. You are likely to have a defect, unless the process is re-centered.

The driver always parks successfully without scraping the sides. The process is centered, and with a narrow distribution. You are unlikely to have defects even if the process shifts slightly to either side.