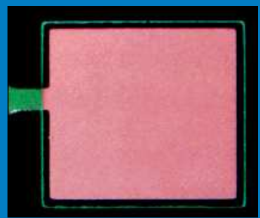
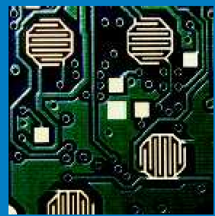
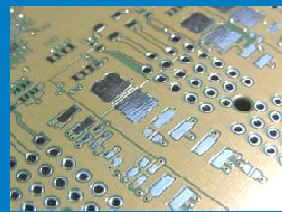
alpha

PCB Surface Finishes & Cost Effective Pb Free Assembly Materials


OSP


Imm. Silver


Imm. Tin


Pb Free HAL

Organised as a part of Electronics For You expo 2013

Richard Puthota

Director – Business Development & CTS

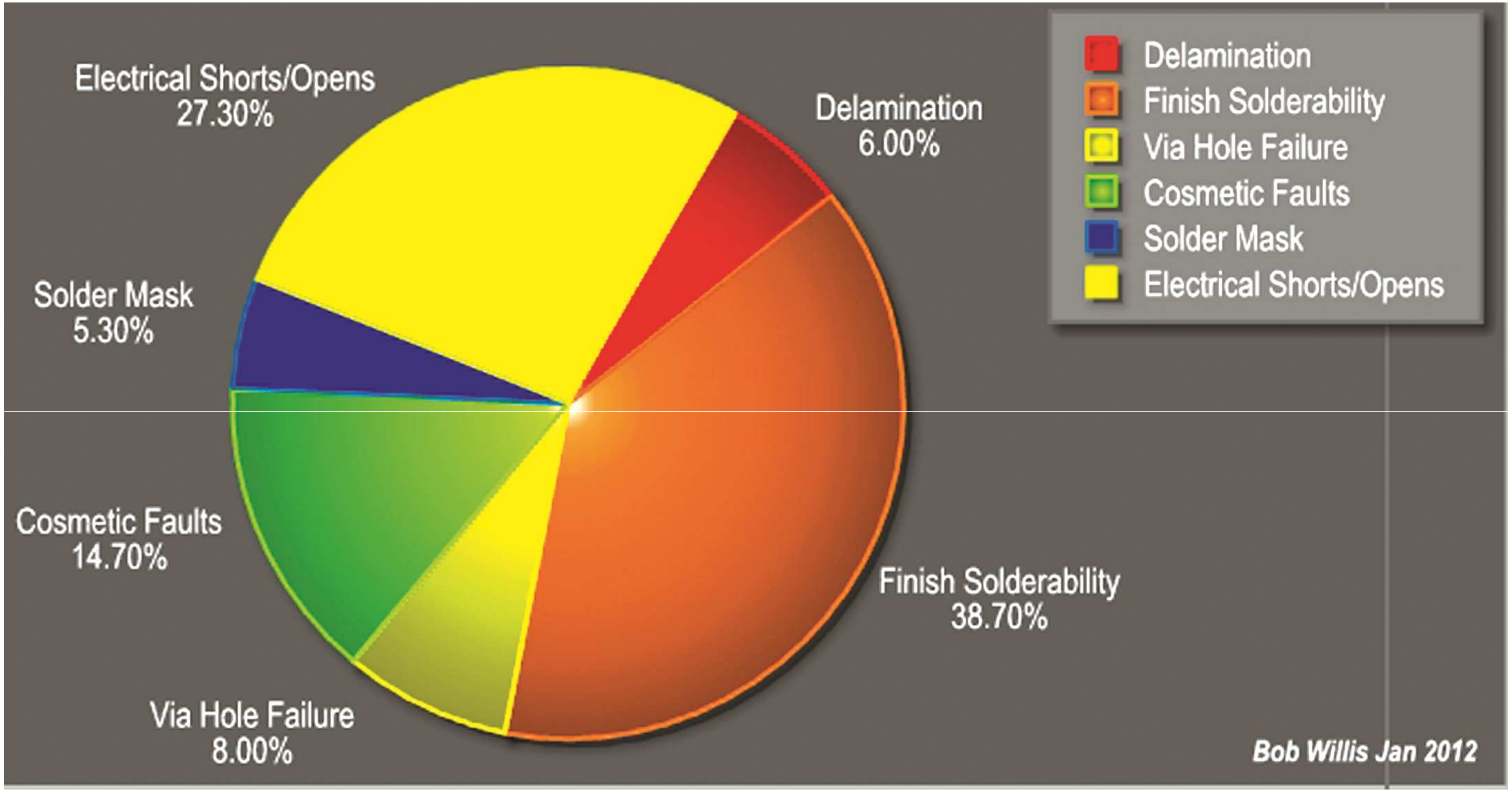
India & Africa

Cookson Electronics

COOKSON ELECTRONICS 無鉛 鉛フリー 무연솔더 LEAD-FREE Pb LEAD-FREE SOLUTIONS

IPC / NPL PCB Problems Survey 2012

alpha



Surface Finish was the single most major contributor !

That's why we chose this topic to address !

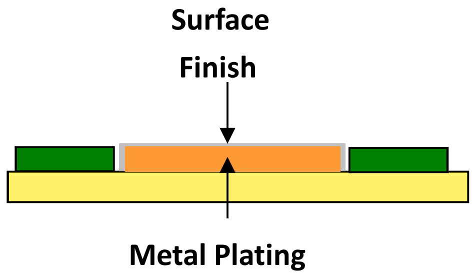
Cookson Electronics

What is a Surface Finish?

alpha

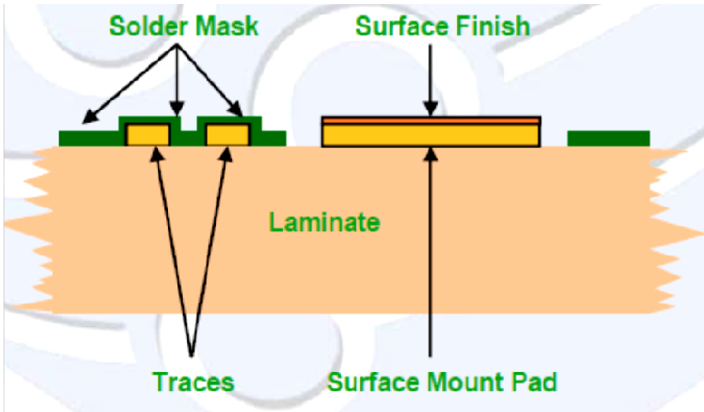
A surface finish may be defined as a "coating"

- located at the outermost layer of a PCB
- (which is dissolved into the solder paste upon reflow or wave soldering)



Two Main Types of Coatings

- Metallic
- Organic



Note:

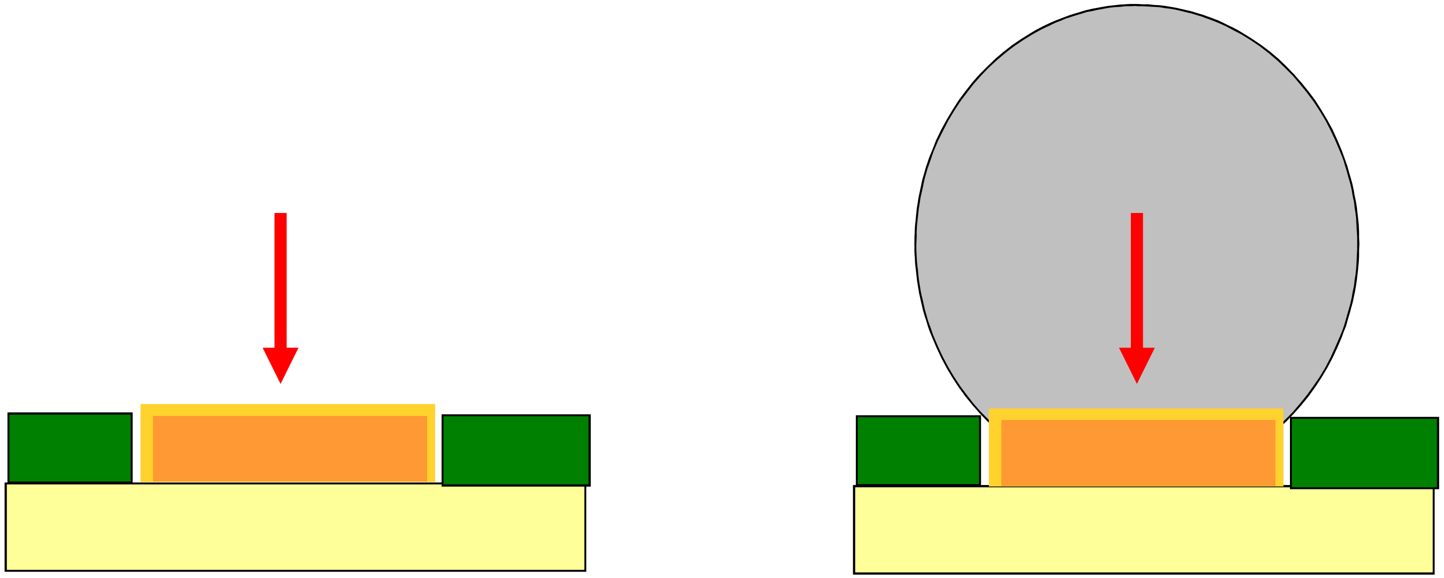
- (Base) Metal Plating is typically copper (in most cases).
- But, in a few (like ENiG) the Nickel-phosphorous

Cookson Electronics

Why use a Surface Finish?

alpha

The surface finish protects the PCB Surface Copper until it's Assembled



Cookson Electronics

Importance of Surface Finish

alpha

- Most important material decision made for the electronic assembly
- Influences the process yield, the amount of rework , field failure rate, the ability to test, the scrap rate, and of course the cost.
- One can be lead astray by selecting the lowest cost surface finish only to find that the total cost is much higher.
- The selection of a surface finish should be done with a holistic approach that considers all important aspects of the assembly.

Cookson Electronics

Many Stake Holders

alpha

Each surface finish has attributes that make it attractive for certain applications; however, this also implies that important tradeoffs are being made.

The best surface finish for your application is the one that considers the impact to all functions and provides the lowest overall cost.

Cookson Electronics

Which one to Choose ?

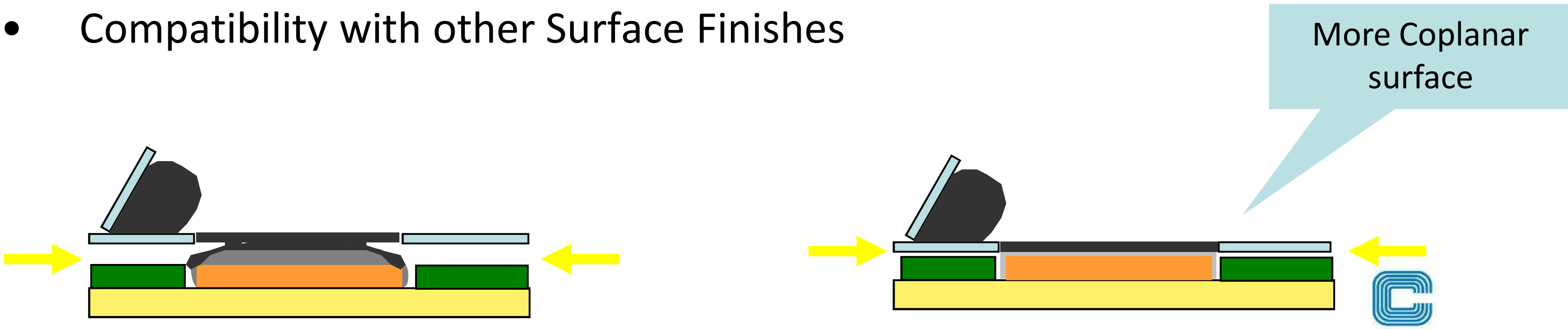
Cookson Electronics

How to Select a Proper Surface Finish?

alpha

Reasons for Finishes

- Coplanarity (See Below)
- Lead-Free (RoHS and WEEE)
- Contact Resistance (Compression Connection)
- Tarnish Resistance
- Press-fit Requirements
- Wear Resistance
- Hardness
- Chemical Resistance
- Wire Bonding (Au or Al?)
- Cost
- Compatibility with other Surface Finishes



Cookson Electronics

Surface Finish Types

alpha

Organic Coatings:

- *OSP (Organic Solderability Preservative)*
- *Carbon Ink (Screened on)*
- *(Or combinations of the two - OSP and Selective ENIG or Hard Gold)*

Metallic Coatings:

- *HASL (Hot Air Solder Level)*
- *ENIG (Electroless Nickel/Immersion Gold)*
- *Electrolytic Ni /Au (Electrolytic Nickel / Gold)*
- *Imm Ag (Immersion Silver)*
- *Imm Sn (Immersion Tin)*
- *Reflow Tin/Lead*
- *Electroless Nickel/Palladium-Immersion Gold*
- *Selective Solder Strip (SSS)*
- *Sn Ni (Tin-Nickel)*
- *Unfused Tin/Lead*
- *Electroless Nickel-Immersion Palladium*

Not common (Selective Solder Strip (SSS); Sn Ni (Tin-Nickel); Unfused Tin/Lead; Electroless Nickel-Immersion Palladium)

Cookson Electronics

Key Product Considerations

alpha

Industry Segments

- ❑ **Medical**
- ❑ **Aerospace/Defence**
- ❑ **Consumer**
- ❑ **Consumer hand held**
- ❑ **Automotive**
- ❑ **Telecommunications**
- ❑ **Industrial**
- ❑ **Lighting**

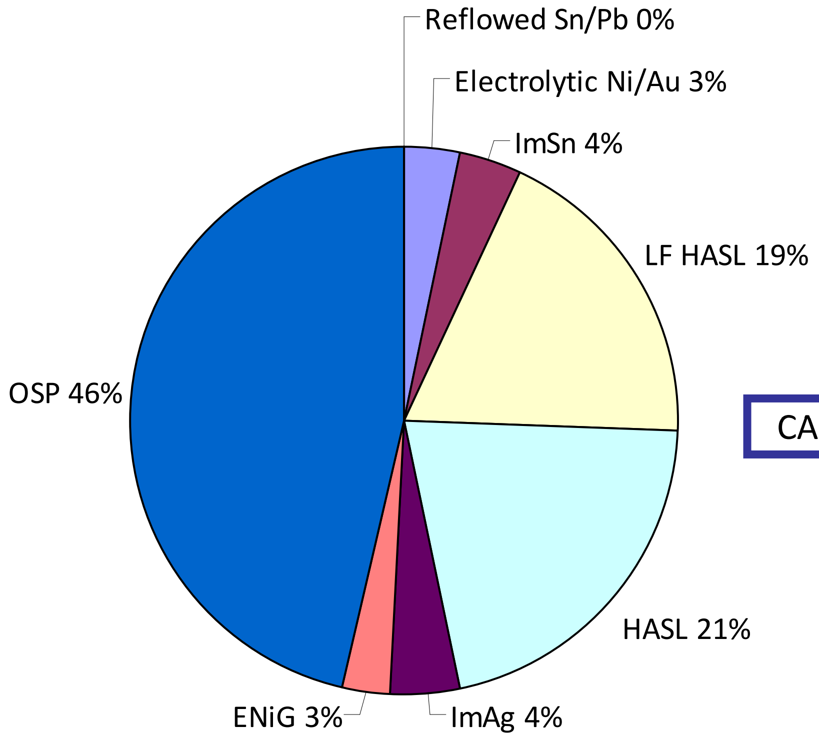
- ✓ What is the cost sensitivity of the product (how important is the surface finish cost)?
- ✓ What are the product volume requirements (high, medium, or low)?
- ✓ Is it a SnPb or Pb-free process?
- ✓ If Pb-free, is shock/drop a concern for your product?
- ✓ Is fine pitch assembly required (how fine)?
- ✓ What is the user environment (is corrosion a concern)?
- ✓ Multiple Reflow Cycles ?
- ✓ Is wave solder required and if so, how thick are the boards? Aspect Ratio ?
- ✓ Hole Fill ?
- ✓ Is high yield in-circuit testing required?
- ✓ Is wire bonding to the PCB SF required?

Cookson Electronics

Surface Finishes Market Outlook

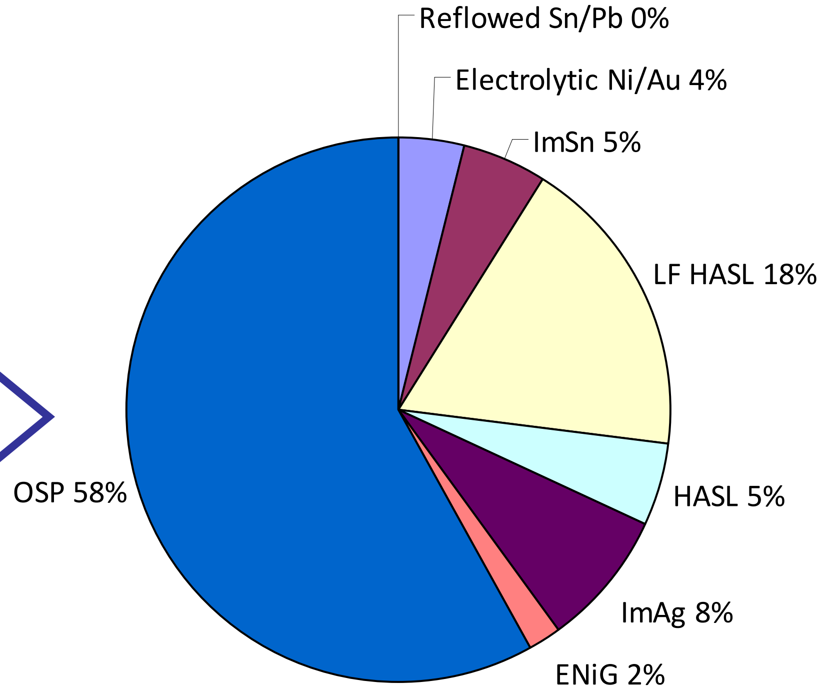
alpha

PCB Materials Finish 2006



CAGR of 5%

PCB Materials Finish 2011



Comparison of RoHS Compliant Final Finish

The use of most well known HASL alternatives seems to be different in each of the world regions. In Europe there appears to be a preference for ENIG and immersion tin final finish, although there seems to be a noticeable interest shift towards immersion silver. In the U.S. fabricators favor ENIG, and in Asia OSPs and immersion silver technologies are being used most extensively. The main reason for this can be tied back to specific OEM preference and specific assembly application.

Surface Finish	%	Mm^2
Electrolytic Ni/Au	4.00	12
ImSn	5.00	14.64
LF HASL	18.00	57.31
HASL	5.00	17.1
ImAg	8.00	25.3
ENiG	2.00	7.5
OSP	58.00	183.7
Reflowed Sn/Pb	0.00%	1.5

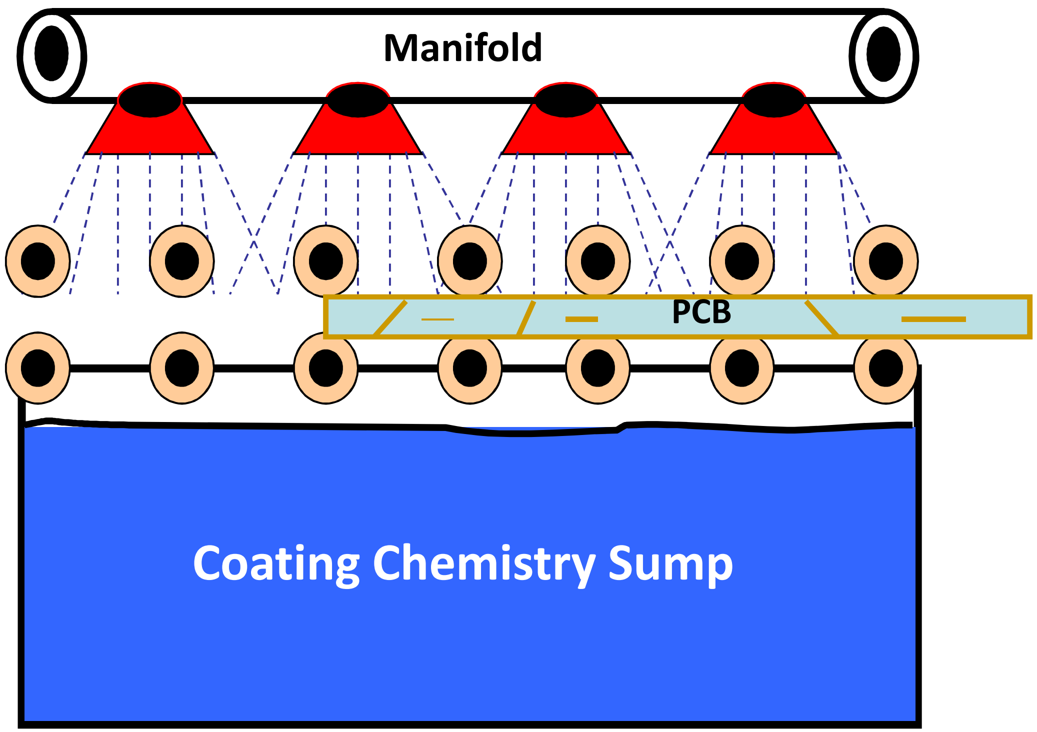
Cookson Electronics

Source: Prismark

OSP (Organic Surface Preservative) emerging as a popular alternate surface finish

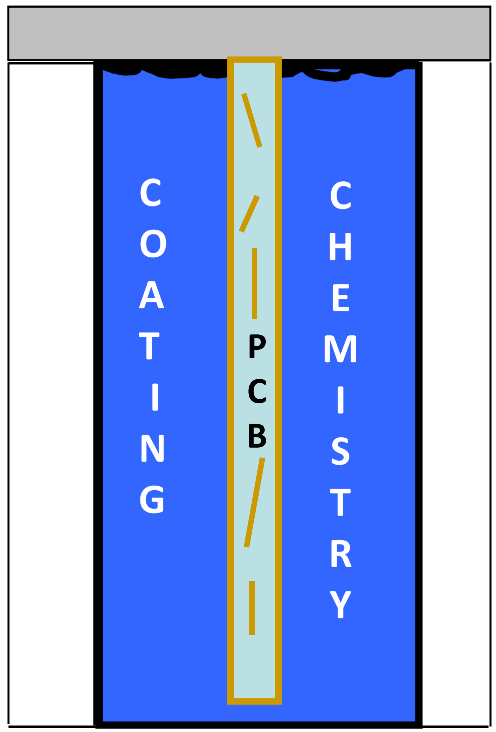
Dip Coatings

- ***HASL (Hot Air Solder Level)***
- ***OSP (Organic Solderability Preservative)***



Conveyorized Dip Module

OR

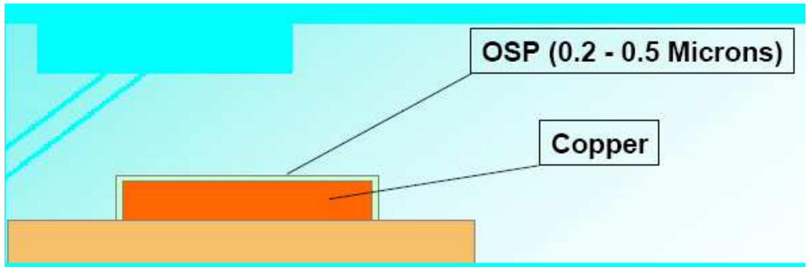


Vertical Dip Tank

Cookson Electronics

Typical Equipment used for the Coating of OSP

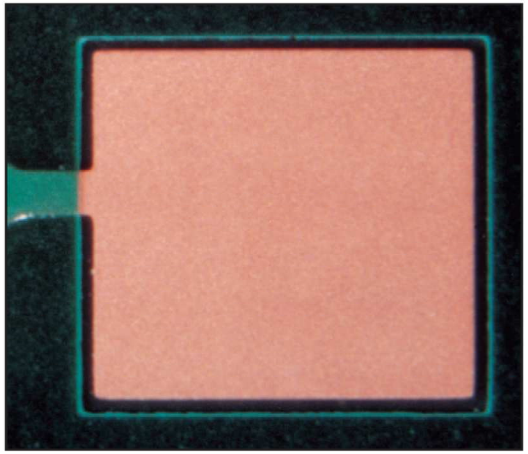
Conveyorized Horizontal OSP and Pre-Flux Line



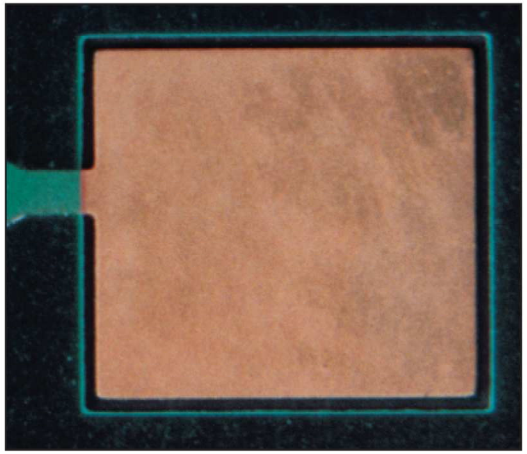
Cookson Electronics

OSP Visual Inspection

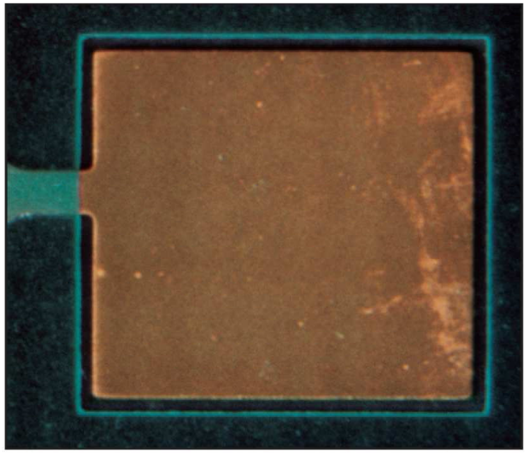
alpha



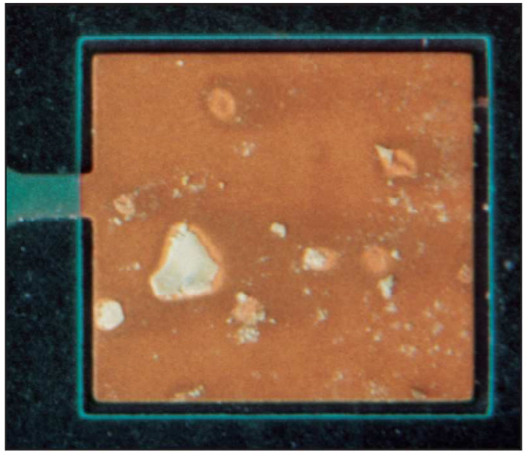
Preferred Coating Appearance
Uniform, matte pink color



Acceptable Coating Appearance
Slightly darker, striated, or spotted



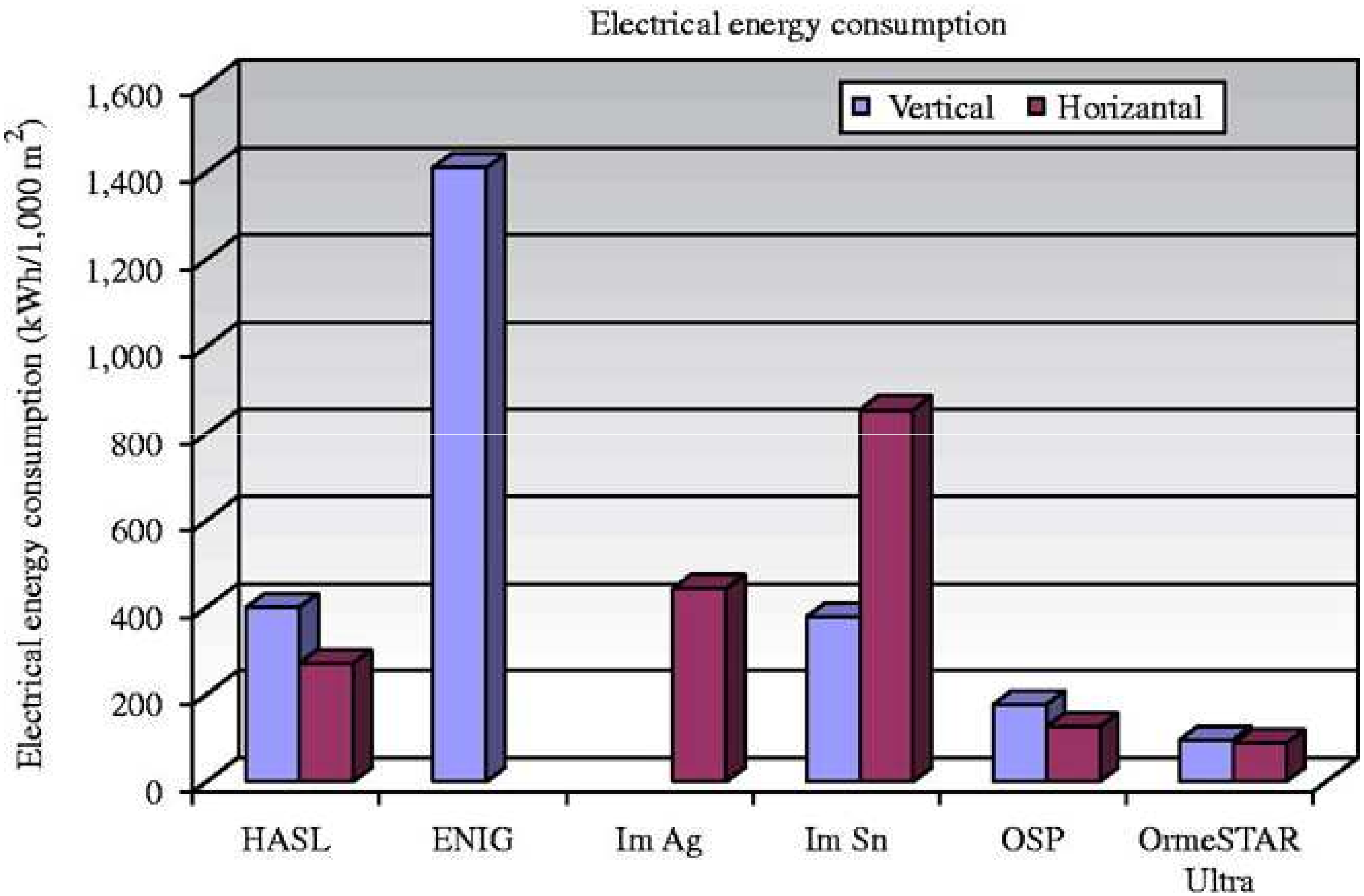
Not Acceptable Coating Appearance
Extremely dark



Not Acceptable Coating Appearance
Crystalline or foreign material

Cookson Electronics

Courtesy : Enthone, Cookson Electronics


Electrical energy consumption
Vertical
Horizantal
Electrical energy consumption (kWh/1,000 m²)
1,600
1,400
1,200
1,000
800
600
400
200
0
HASL
ENIG
Im Ag
Im Sn
OSP
OrmeSTAR Ultra

OSP (Organic Solderability Preservative)

alpha

(Cookson Entek 106A(X), Shikoku Glicote SMD-E2L, Tamura Solderite)

Typical Thickness: 0.2 - 0.6 µm (8 - 24 µ in)

ADVANTAGES

+ Flat, Coplanar pads
+ Reworkable (at PCB Fabricator)
+ Doesn't Affect Finished Hole Size
+ Short, Easy Process
+ Low Cost
+ Benign to Soldermask
+ Cu/Sn Solderjoint

DISADVANTAGES

- Not a "Drop-In" Process (assy adjustments are required)
- Difficult to Inspect
- Questions Over Reliability of Exposed Copper After Assembly
- Limited Thermal Cycles
- Reworked at CM?; Sensitive to Some Solvents Used for Misprint Cleaning
- Limited Shelf life
- Panels Need to be Routed and Tested Prior to Coating (ET Probe Issue)
- Handling Concerns

Cookson Electronics

HT OSP (Organic Solderability Preservative)

alpha

(Entek 106A HT, Shikoku Glicote SMD-F1, Tamura WPF-21)

Typical Thickness: 0.2 - 0.6 µm (8 - 24 µ in)

ADVANTAGES

+ **Flat, Coplanar pads**
+ **Reworkable (by Fabricator)**
+ **Short, Easy Process**
+ **Benign to Soldermask**
+ **Cu/Sn Solderjoint**

DISADVANTAGES

- **Availability**
- **Not a "Drop-In" Process (assy adjustments are required)**
- **Difficult to Inspect**
- **Questions Over Reliability of Exposed Copper After Assembly**
- **Limited Thermal Cycles**
- **Reworked at CM?; Sensitive to Some Solvents Used for Misprint Cleaning**
- **Limited Shelf life**
- **Panels Need to be Routed and Tested Prior to Coating (ET Probe Issue)**
- **Copper Dissolution into Solder Volume**
- **Handling Concerns**

Cookson Electronics

OSP and Selective ENIG

alpha

ADVANTAGES

+ Advantages of OSP for SMT
+ Advantages of ENIG in through-holes
+ Cu/Sn Solderjoint
+ Can be used in Lead-Free

DISADVANTAGES

- Complex process for PCB suppliers
- Larger

Currently being used in today's handheld portable products

(aka, Combi-Finish or SIT)

Cookson Electronics

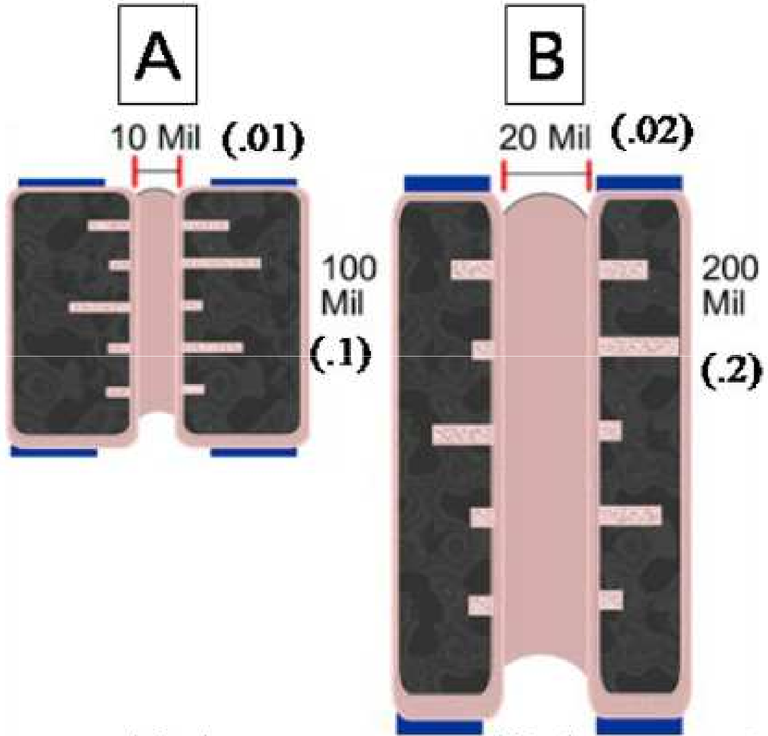
IPC 610-E Hole Fill Requirements

	Class 1	Class 2	Class 3
Minimum Hole Fill Criteria	Not Specified	75% signal 50% ground	75% All

Most stringent class does not require topside solder fillets

DIFFICULTY FACTOR

$$\frac{\text{Panel Thickness}^2}{\text{Hole diameter}}$$



	A	B
• Aspect Ratio	10:1	10:1
• Difficulty Factor	1	2

OSP – Process Challenges (TSVHF)

alpha

Top Side Vertical Hole -fill is driven by capillary action

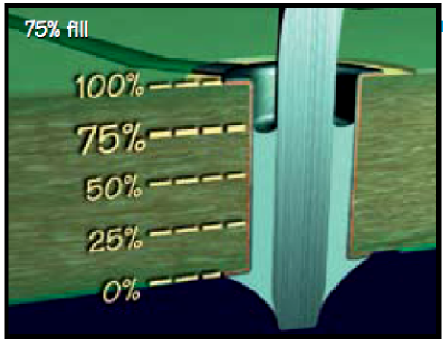
Important parameters which can influence:

- *Hole diameter,*
- *PTH wall Quality*
- *Hole aspect ratio,*
- *Flux*
- *Wetting force,*
- *Contact Time*
- *Selective Pallet Design*

Solder will only fill as long as its molten

- OSP has lower wetting force besides Pb Free Solder Alloys.
- Risk of insufficient hole fill Can lead to single-sided architecture

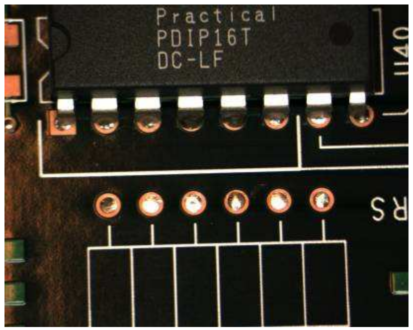
Barrel - Vertical Fill of Solder

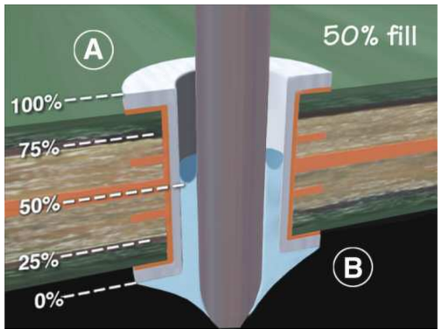


Acceptable Class 2, 3

A minimum of 75% solder fill, or a total maximum of 25% depression including both component (primary) and solder (secondary) sides is permitted.

Notes:
Minimum acceptable condition for vertical fill of solder on Class 1 assemblies is not specified. Less than 100% solder fill may not be acceptable in some applications, e.g., thermal shock.

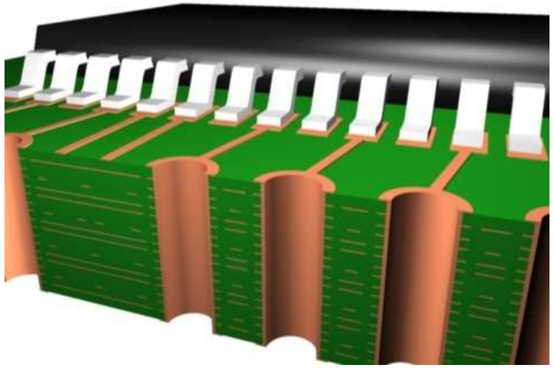


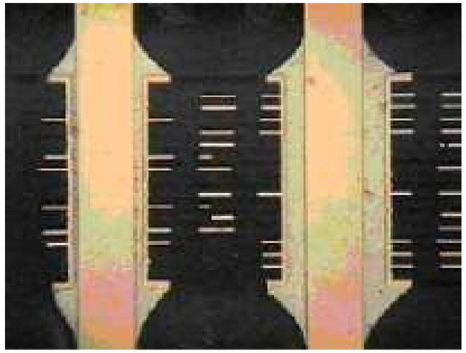


Cookson Electronics

OSP – Solutions (TSVHF)   Top Side Vertical Hole Fill

Solutions:



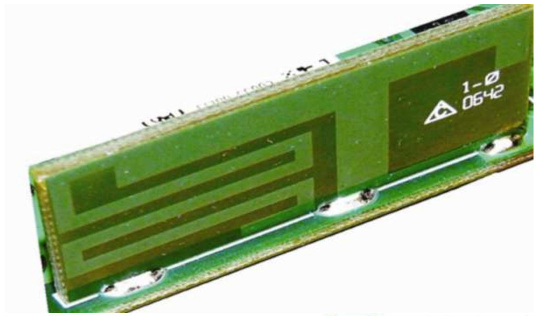


- ❖ Alternate Surface Finish (metallic)
- ❖ Aspect Ratio
- ❖ Increasing top-side preheat
- ❖ Increasing solder pot temperature
- ❖ Increasing the Contact Time
  (Decrease Conveyor Speed – Increased Board Temperature)
- ❖ Increasing the Wave Height (Wave Dynamics)
- ❖ Not recommended!
- ❖ Alternate wave solder alloy combined with the right Flux selection
- ❖ Preserve flux activity through preheat

Table 7-5 Board in Board - Minimum Acceptable Solder Conditions[1]

Criteria	Class 1	Class 2
Vertical fill of solder[2]	75%	
Wetting on primary side (solder destination side) daughter board land to PCA solder connection width	50%	75%
Percentage of land area on PCA (mother board) covered with wetted solder on primary side (solder destination side)	0	
Fillet and wetting solder connection width on secondary side (solder source side) of PCA (mother board) to lands on both sides of daughter board.	50%	75%
Percentage of land area on PCA (mother board) covered with wetted solder on secondary side (solder source side)	75%	

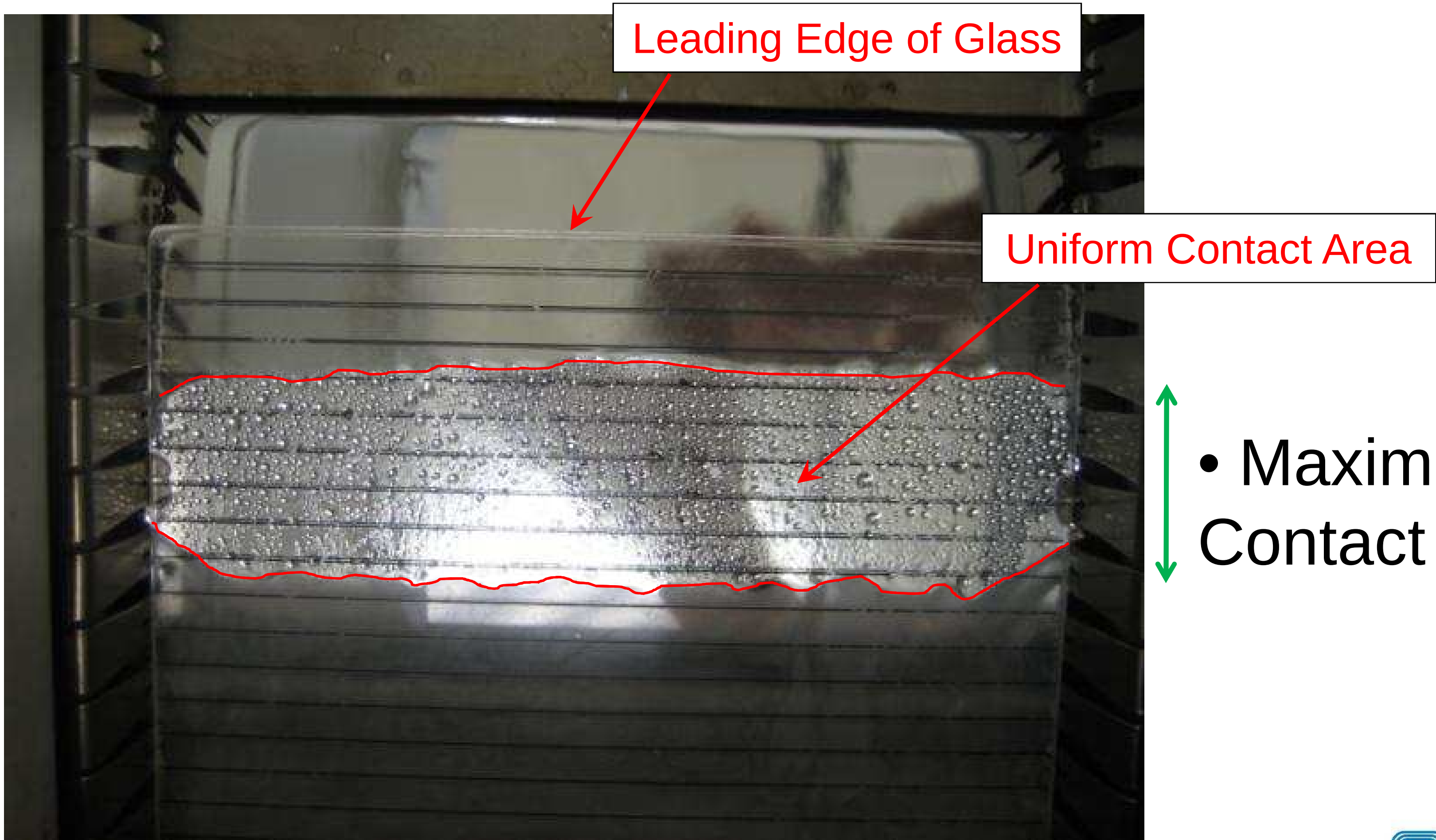
Note 1. Wetted solder refers to solder applied by the solder process.
Note 2. The 25% unfilled height includes both source and destination side depressions.



alpha

Baseline

Good Wave Contact - MUST



- Maximize Contact Area

Cookson Electronics

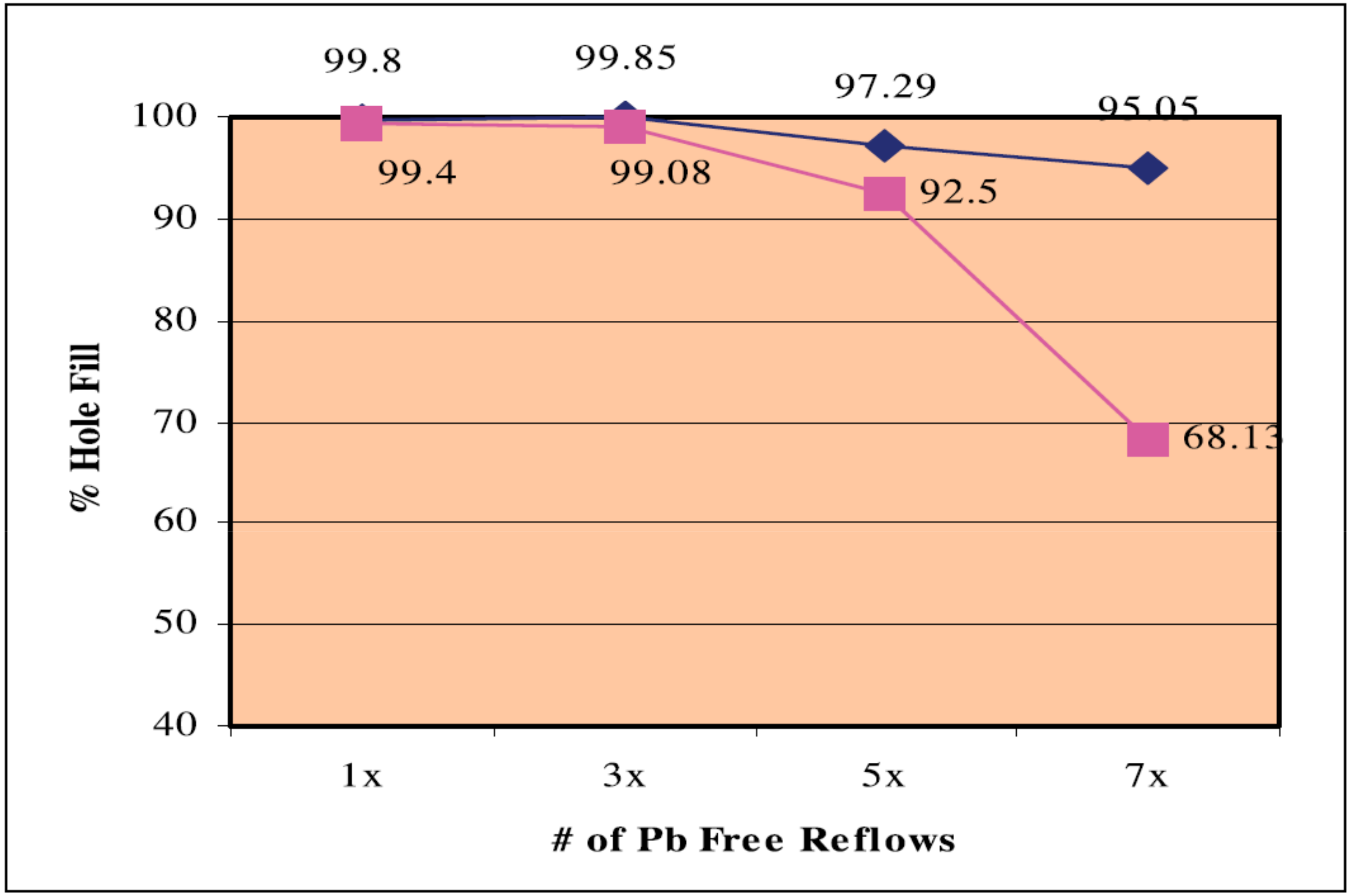


Figure 5. Through-Hole solderability of HT OSP and industry standard OSP (LS 500A flux, SAC 305 solder).

Cookson Electronics

OSP - Advantages

- Provides very flat solder pad surfaces and excellent compatibility for consistent and uniform solder paste application.
- Eliminates solder bridging defects that are commonplace in HASL finished printed circuit boards.
- Excellent solderability for both convection reflow and wave soldering.
- The organic coating does an excellent job eliminating copper oxidation. The solder joint exhibits a tin/copper intermetallic layer.
- Solder wetting is made directly on the copper solder pads to produce extremely strong and reliable solder joints.
- Copper has extremely good affinity to molten solder when it is clean and free of oxidation.
- The new HT OSP finish has the capability of at least 5 reflow cycles without degradation.
- The organic coating is dissolved by the presence of reflow heat and the flux activators in the paste.
- On double-sided SMT assemblies the organic coating is not degraded on the secondary side because it has not been exposed to solder paste flux activators.
- The finish has good rework-ability. In the event that defective coating is received, the material can be sent back to the supplier for recoating. Recoating is easy to do. The PWB is not exposed to structural degradation stemming from thermal stresses in the rework procedure.
- The selection of OSP does not limit supplier PWB availability. Most PWB suppliers offer OSP finishes.
- Under reasonably good ambient conditions the shelf life is about one year.

OSP Disadvantages

alpha

a. Careful material handling procedures must be followed. **Gloves or finger cots** must be worn to protect the OSP coating material from **fingerprints**. **Human salts** are capable of degrading the coating such that the solder ability of the copper will be compromised.

b. Strict practices and controls designed to eliminate **misprinting of solder paste** is paramount. **Mechanical removal** of the solder paste causes solder particles to be spread and imbedded inside via holes. Chemical removal of the paste degrades the organic coating. **Alcohol and other alcohol-blended solvents dissolve** about 75% of the coating material over the copper. **Water cleaning removes about 15**%. Board assemblies that have been treated with cleaning solvents to remove paste misprints must be processed with haste to avoid non-wetting defects resulting from oxidized copper.

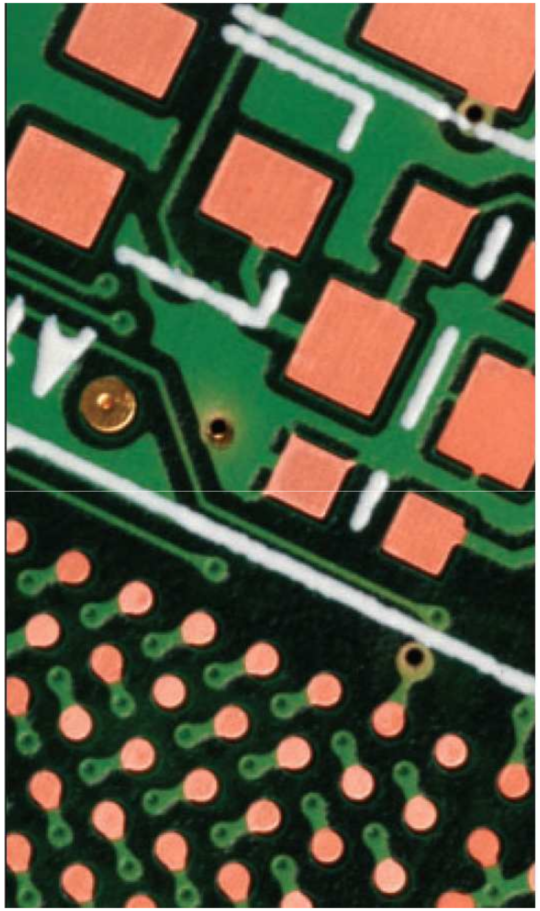
c. OSP finished printed circuit boards **may not be suitable for RF circuitry** assemblies. Most RF boards require a metal shield to be soldered and in contact to the grounding trace, thus providing the necessary shielding. The organic coating and the shield may not provide sufficient electrical shielding (no metal to metal contact).

d. The OSP material **can give ICT test probes difficulty in contacting the test pads** on the board. More expensive multi-point test probes may be required in many cases. More frequent cleaning of the ICT test fixture probes will be necessary. An alternative solution is **to apply solder paste to the test pads** to ensure positive contact. This will not be possible if vias are used in place of test pads.

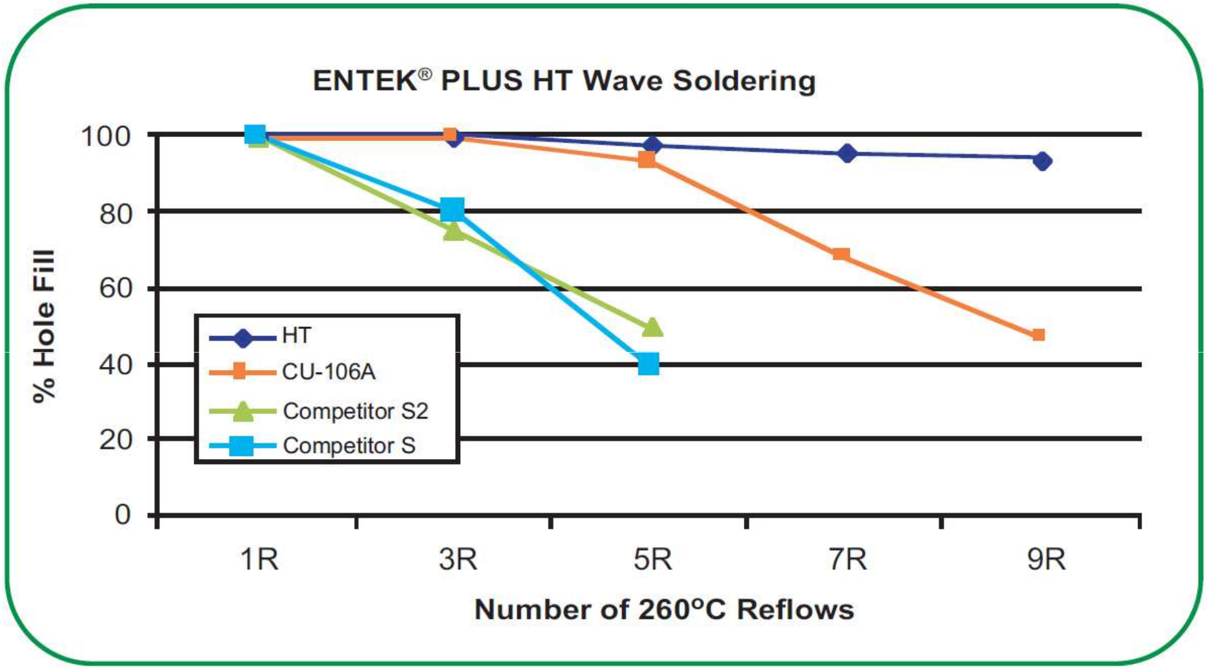
e. **Interleaving paper should be used** to protect the OSP coating from abrasion damage during transit, where boards may slide against one other when stacked. An alternative method, and a more costly one, is to place individual boards in plastic bags.

Cookson Electronics

alpha

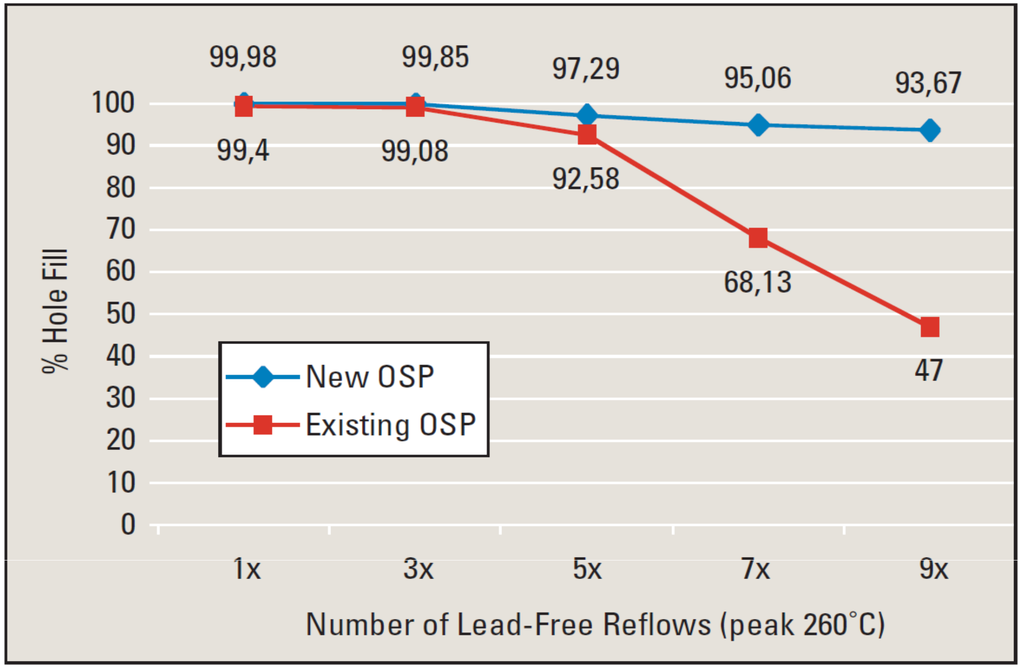


ENTEK PLUS HT Capable of Pb-Free Reflows

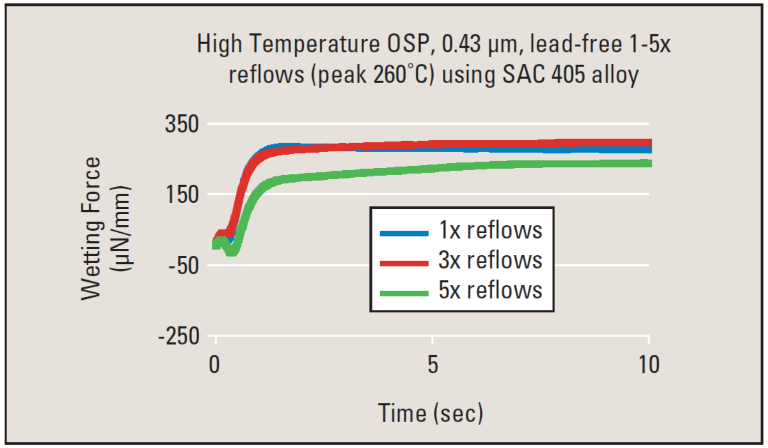


ENTEK PLUS HT has demonstrated a 3x improvement versus other OSPs in Pb-free processes.

Cookson Electronics



Through-hole solderability comparison for traditional and high temperature OSPs.



Cookson Electronics

alpha

General recommendation Handling / Storage condition / Time

A. Handling Recommendations:

It is recommended that gloves are used for handling panels/circuits during all assembly processes. Or at the VERY least, handle the boards without touching the surfaces. Salts/acids from fingerprints will have a negative affect on the solderability.

B. Storage condition and time

The storage environment should not to exceed 30°C and 75% RH (except immersion tin). Boards should be stored in original vacuum packaging to limit air accessing the surface, and the board.

alpha

HASL or HAL

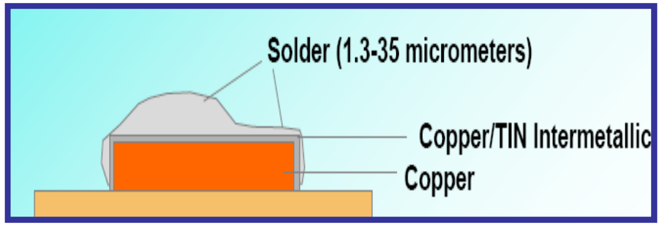
Hot Air Solder Leveling
Or
Hot Air leveling

Cookson Electronics

HASL (Hot Air Solder Level)

alpha

LEADED Version



ADVANTAGES

- "Nothing Solders Like Solder"
- Easily Applied
- Lengthy Industry Experience
- Easily Reworked
- Multiple Thermal Excursions
- Good Bond Strength
- Long Shelf Life
- Easy Visual Inspection
- Cu/Sn Solderjoint

DISADVANTAGES

- Co-Planarity Difference
  Potential Off-Contact Paste Printing
- Inconsistent Coating Thicknesses (on Varying Pad Sizes)
- Contains Lead
- Not Suited for High Aspect Ratios
- Not Suited for fine-pitch SMT and Grid Array Packages
- PWB Dimensional Stability Issues
- Bridging Problems on Fine Pitch
- Subjects the PCB to High Temp

Cookson Electronics

HAL (Hot Air Level)

alpha

UNLEADED Version

Equipment being used for the Coating of Lead-Free HAL
Same as for Leaded Versions but with a few Modifications

- **Higher Temp Steel Solder Pots and Stronger - Higher Temp Pumps**
  (Effective heat transfer by improved alloy circulation)
- Pre-heat panel (pre-dip)
- Longer contact time with PCB
- High temperature resistant chemistries (oils and fluxes)
- Copper control (Drossing – Dilution and Skimming)

Cookson Electronics

HASL (Hot Air Solder Level) Lead-Free

Typical Thickness: 1-40µm

ADVANTAGES

+ “Nothing Solders Like Solder”
+ Easily Applied
+ Industry - Huge Co-Planarity Difference
+ Long Experience
+ Easily Reworked
+ Multiple Thermal Excursions
+ Good Bond Strength Assemblies
+ Long Shelf Life
+ Easy Visual Inspection
+ Low Cost - Not Suitable For HDI Products

DISADVANTAGES

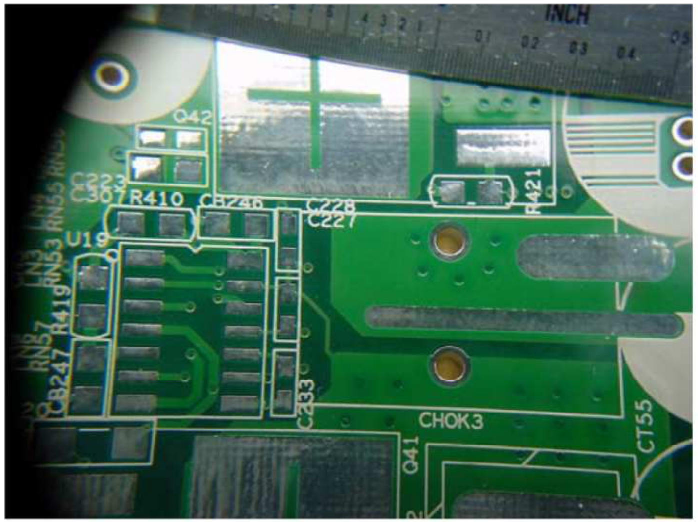
- Not Suited for High Aspect Ratios
- Not Suited for < 20 Mil pitch SMT and BGA
- PWB Dimensional Stability Issues
- Bridging Problems on Fine Pitch
- Inconsistent Coating Thicknesses
- High Process Temperature 260-270 deg C

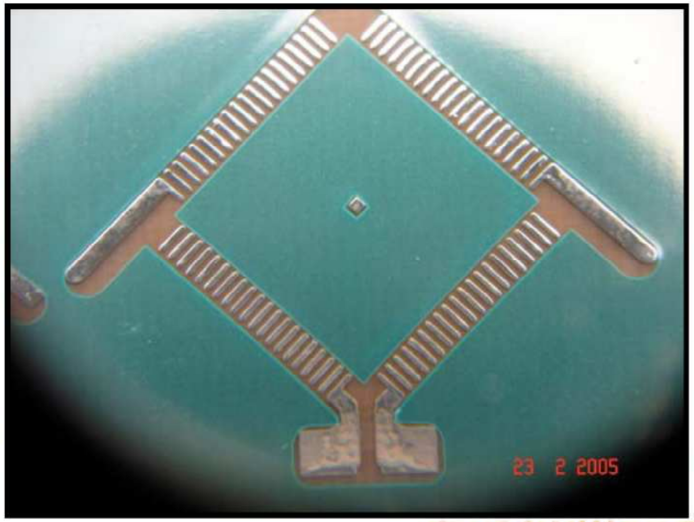
Cookson Electronics

Courtesy: NCAB Group

Lead-Free HASL

- Lead-Free HASL is a reality.
- Cookson Electronics have developed a low cost high reliability Lead-Free alloy that is suitable for the HASL process.
- The alloy has the lowest in class rates of copper dissolution and delivers vary flat pads even on the smallest pads.
- SACX delivers a flatter pad than traditional Tin Lead.

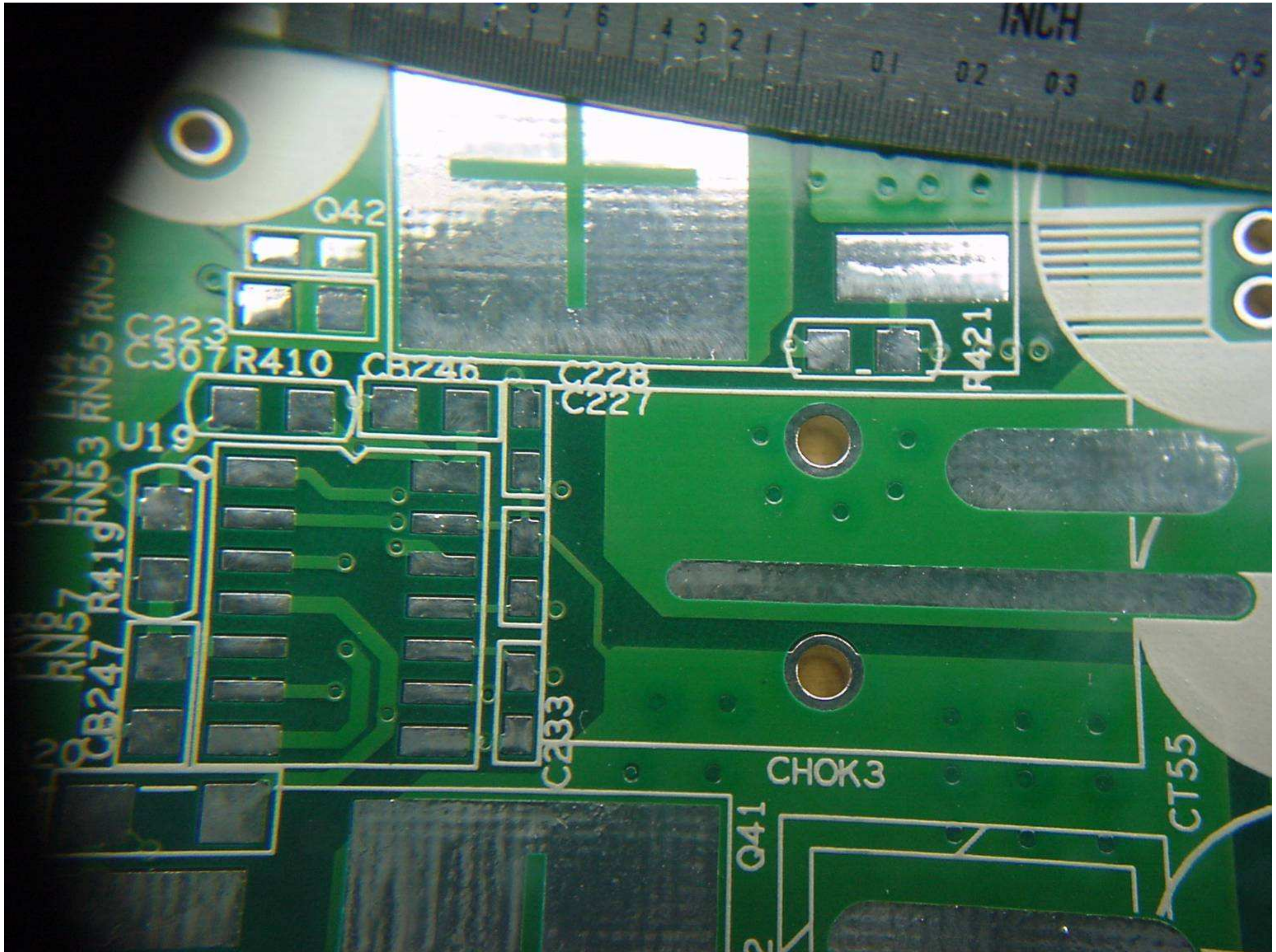




Cookson Electronics

Lead-free HASL Surface Finish

alpha

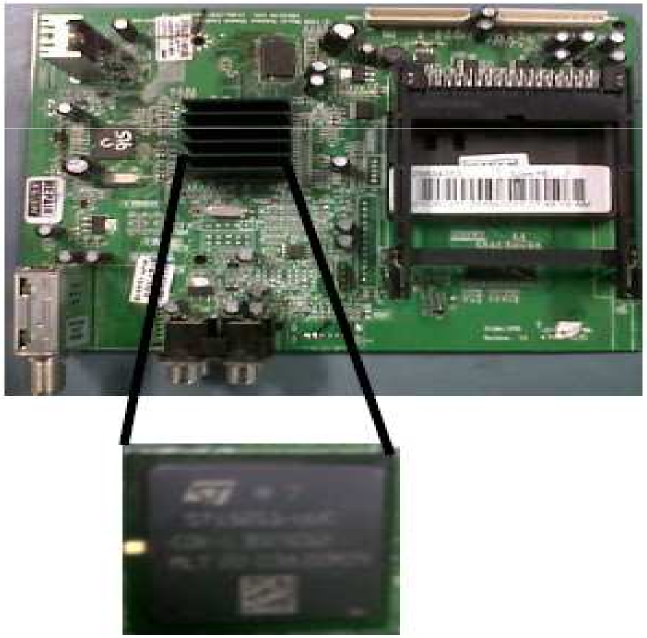


Cookson Electronics

HASL Challenges – at an OEM

- Major challenge for Cookson Technical Team was to control the failure of STB chassis at Functional Testing which was also reflecting at the field.

- Major cause of the chassis failure at FT is PBGA.



Product : Set Top Box
IPC Class – 2
Model – STi5211
PCB Thickness – 1.6 mm
Cu Layer – 04
Pad Finish – HAL
Solder Paste – OM338-T45-SAC405
BGA Ball Alloy – SAC305

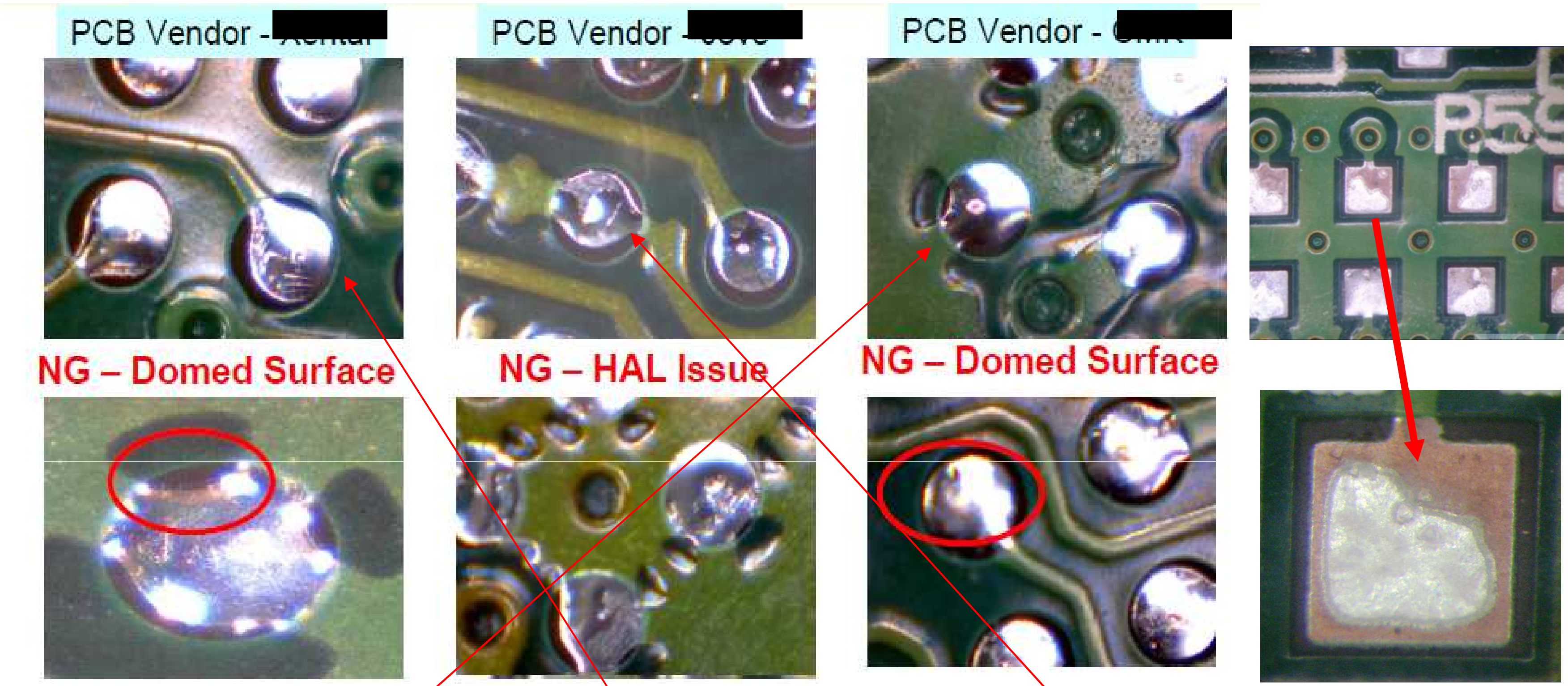
The Probable Causes Verified

alpha

BGA's Co- Planarity	?
Solderpaste Height	✓
Temperature reflow	✓
Big Board Warping's	✓
Solderpaste Tackiness	✓
Spheres Oxidised..	✓
HASL Co-planarity	✓

Cookson Electronics

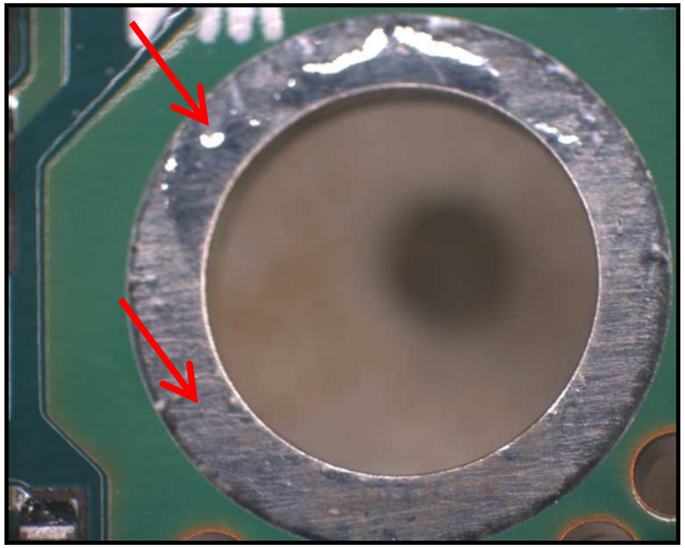
HASL – a major variability

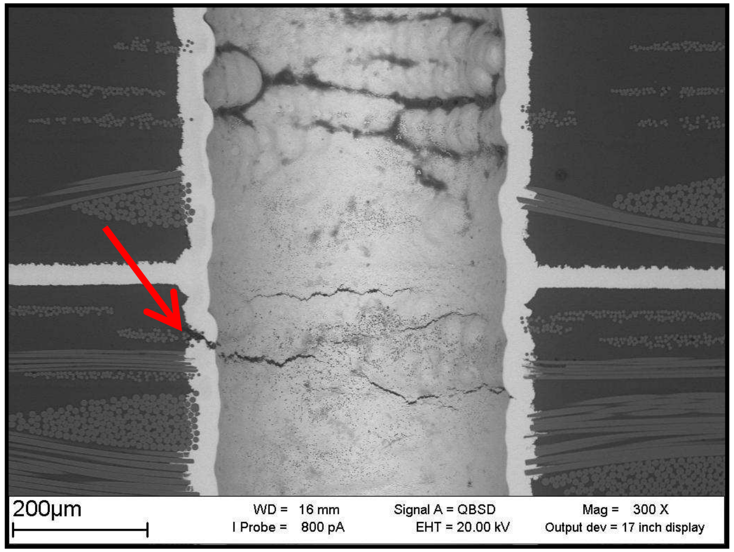


Major cause of the BGA solder joint failure is observed due to poor HASL finish of PCB.

1. Co planarity – Uneven solder surface
2. Too thin coating of HASL leading to migration after 1st reflow itself exposing copper. (Poor solder ability in the subsequent reflows)
3. Solder mask window uneven around the BGA pad.

HASL Surface Variability





PCB barrel cracking (see the picture), delaminations , bow and twist caused by solder bath thermal stress

What do experts say about HASL thickness?

alpha

coverage, and this will take time to get the best, consistent coverage. With users and suppliers working together, the process can

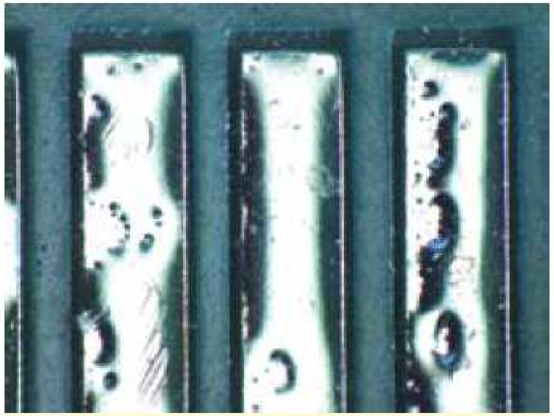


Figure 5. Solder mask residues.

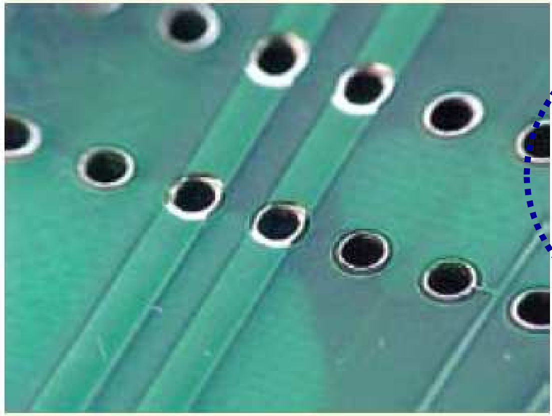


Figure 6. Poor bonding.

know the process and have considerable experience and data to support users and suppliers alike. The levelling process over the last 10 years has been demonstrating satisfactory coatings for lead-free in recent trials on tin/copper/nickel boards for the SMART Group workshops and production lines.

The results in *Figure 8* are XRF measurements taken from sample boards during a SMART Group hands on workshop conducted in 2006. The boards featured a range of different pitches.

As a guide the following specification may be useful. It can used or modified for solder levelled boards. Further inputs to improve these suggestions are always welcomed by the author.

If specified all exposed outer copper surfaces shall be coated with solderable finish of tin/lead or lead-free on the surface of mounting pads, test points and plated through hole. The coating should provide a minimum of 12 months shelf life and meet the solderability requirements of the IPC or IEC standards using a wetting balance. The coating thickness should average be between 10-15 µm on specified pads.

able solder is, test boards produced for the launch of a new wave solder design the "Omega" in 19 are still soldering well today!)

Nothing solders like solder, and its performance is getting better all the time!!

References

- EM&T/SMART Group Glossary "Jargon Buster"
- SMART Group Lead-Free Experience Report
- SMART Group training video "Guide to PCB Solderable Finishes"
- CEMCO Solder Levelling Systems Guide
- Shipley Solder Finish Assembly Evaluation Project

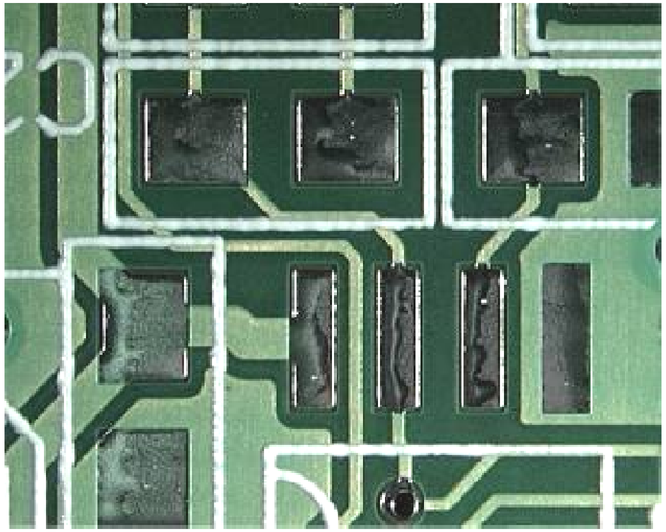
Bob Willis is a process engineer providing engineering support in conventional and surface mount assembly processes. He runs special production features at exhibitions and offers his seminars, workshops and PCB manufacture and assembly audits worldwide. These complement his own practical in-house hands on workshops. For further information go to www.ASKbobwillis.com.

Bob Willis is a process engineer providing engineering support in conventional and surface mount assembly processes. He runs special production features at exhibitions and offers his seminars, workshops and PCB manufacture and assembly audits worldwide. www.ASKbobwillis.com.

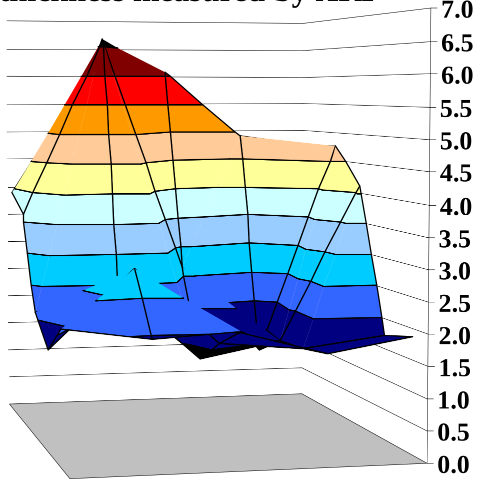
Cookson Electronics

Thickness of the coating

It is a well known fact that finishes produced by the HASL method have non-uniform thickness of the solder coating. The thickness of the coating is determined by operating parameters. The coating should exhibit good-aging properties except for areas where the thickness of the layers is too thin



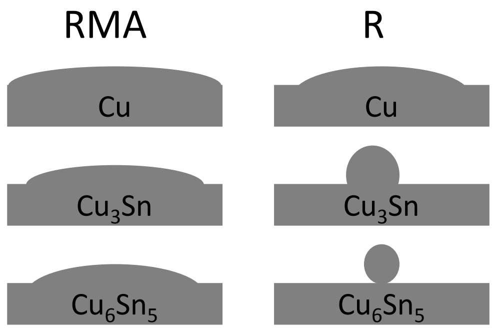
Mapping of one of the pads showing the difference in solder coating thickness measured by XRF



The areas with thin coating would have insufficient wettability after aging due to exposed intermetallic (IMC growth rate much slower at room temperature compare to the elevated temperatures, but still reaction does not stop. If solder layer was too thin, all tin would be consumed by Sn/Cu interfacial reaction)

Wetting characteristics of the Cu, Cu_3Sn and Cu_6Sn_5 surfaces

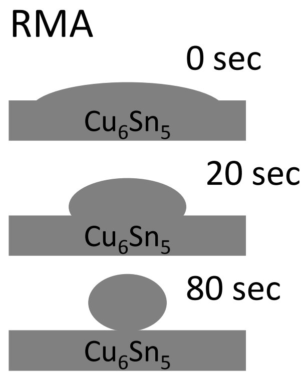
Material /Flux	Wetting Angle (°)	Area (mm^2)
Cu/RMA	3	72
Cu/R	16	19
Cu_3Sn/RMA	10-15	26
Cu_3Sn/R	93-101	4
Cu_6Sn_5/RMA	10-17	23
Cu_6Sn_5/R	180	0



Side view shadowgraph of the areas spread tests on Cu, Cu_3Sn and Cu_6Sn_5 using two different fluxes

Note that:

RMA	*Activated rosin flux*
R	*Non-activated rosin flux*



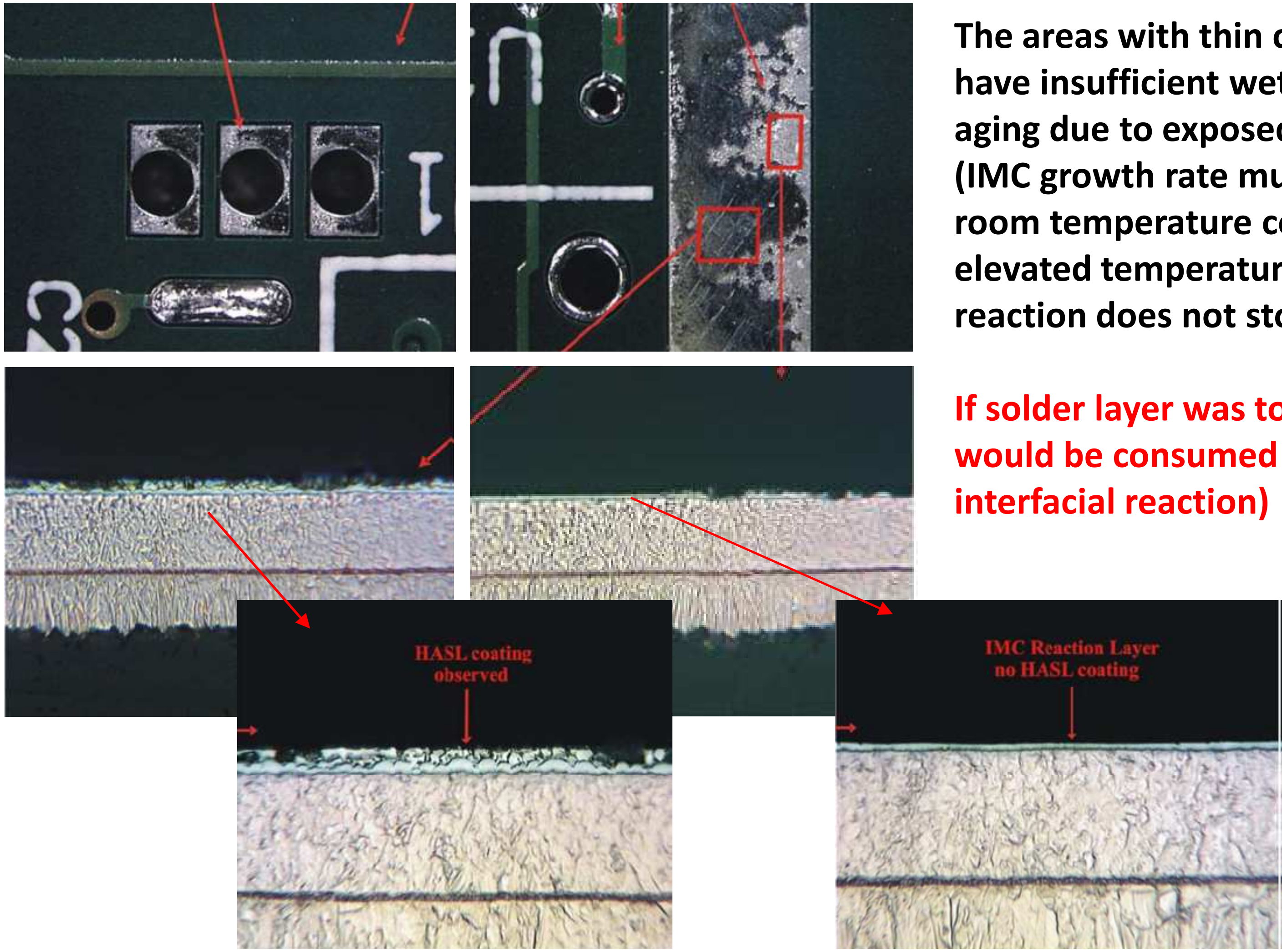
Side view shadowgraph of the areas spread tests on Cu_6Sn_5 after preoxidation at 235°C for various times

Conclusions:

1. The wetting of the Cu_3Sn and Cu_6Sn_5 is poorer than Cu.
2. A strong degradation of the wetting of the intermetallic occurred with increased oxidation (***SnO_2 and SnO was identified as a primary oxides formed on Cu_3Sn and Cu_6Sn_5 during storage in air)***

Cookson Electronics

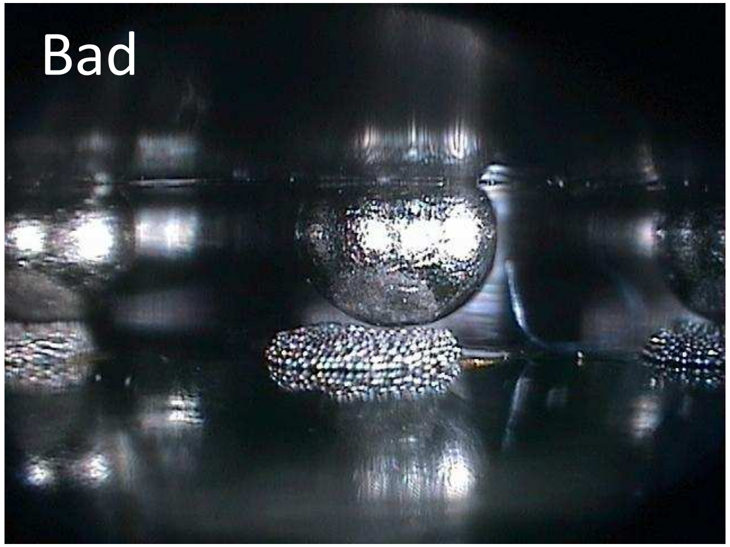
Optical images of the cross sectioned board with HASL

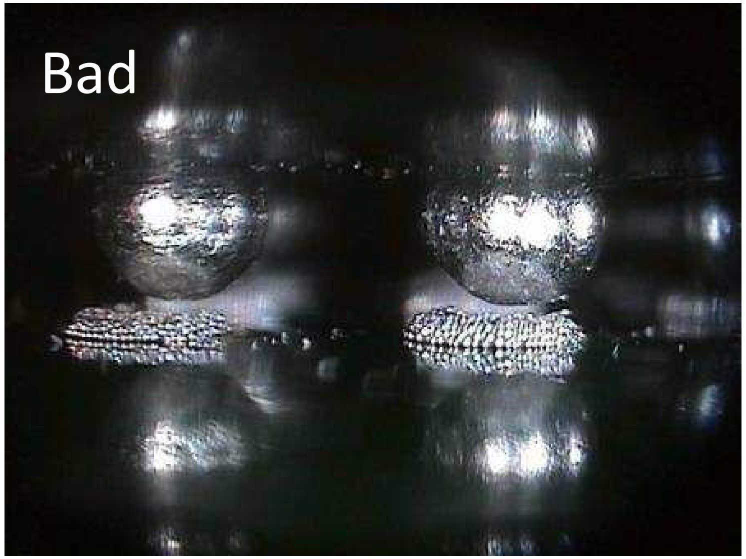


The areas with thin coating would have insufficient wettability after aging due to exposed intermetallic (IMC growth rate much slower at room temperature compare to the elevated temperatures, but still reaction does not stop.

If solder layer was too thin, all tin would be consumed by Sn/Cu interfacial reaction)

BGA's Co- Planarity – Device Supplier





What next ?

Alternate Finish ?

OSP ?

Verifying Most Probable Root Cause

alpha

Based on Alpha India's CTS team's recommendation Txxxx Electronics procured 40K **OSP finish PCBs.** Processed these PCBs with our support in the line.

Result:

Date	Production	BGA Failure_OSP	Rejection %
18.12.2010	14545	2	0.0137
19.12.2010	14499	2	0.0138

With HASL finish PCB the BGA failure was - 0.1 % (1000 PPM)

And now in OSP PCB reported is - 0.0137% (137 PPM).

Just the process failures excluding the field failures

99.00 % Improvement in process

With this experiment , We zeroed the PCB Part Defect contribution in Intermittent BGA Failure

Cookson Electronics

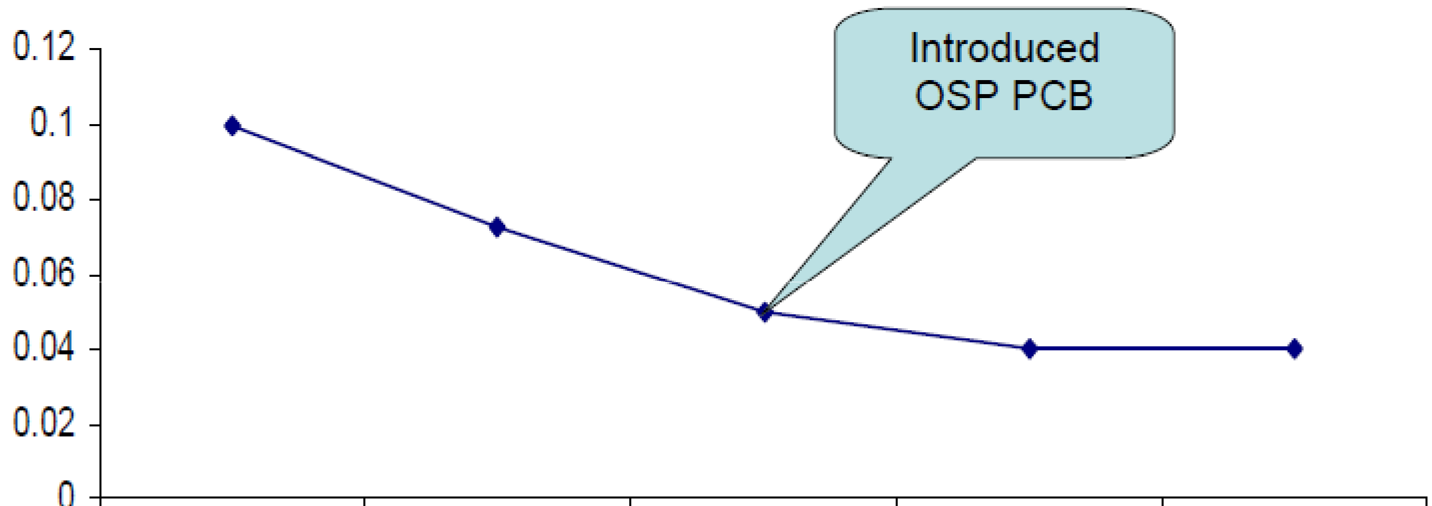
Result

alpha

FT Rejection –BGA

DIRECT HAL CORRECT HAL

FT Rejection-BGA



	Avg 2010.	Jan,11	Feb,11	March,11	April,11
% Rej.	0.1	0.073	0.05	0.04	0.04

Still have the stock of HAL PCB and will shift to OSP after consumption.

Cookson Electronics

Field Failures YTD April 2011

- Tuner = 0.8%
- Flash IC = 0.5%
- SMPS = 0.5%
- BGA = 0.03%
- Others = 0.9%

BGA is 300 ppm now as compared to 2.5% (25000 ppm) April 2010

Lead-Free Solder Options

alpha

ALLOY SYSTEM	COMPOSITION	MELTING RANGE (^oC)
Sn-Ag	Sn-3.5Ag	221
	Sn-2Ag	221-226
Sn-Cu	Sn-0.7Cu	227
Sn-Ag-Bi	Sn-3.5Ag-3Bi	206-213
	Sn-7.5Bi-2Ag	207-212
Sn-Ag-Cu Eutectic	Sn-3.8Ag-0.7Cu	~217
	Sn-4Ag-0.5Cu	~217
	Sn-4.7Ag-1.7Cu	~217
SAC305	Sn-3.0Ag-0.5Cu	218-219?
SACX0307	Sn~0.9Cu~0.17Ag~0.14Bi	217-228
Sn-Ag-Cu-Sb	Sn-2Ag-0.8Cu-0.5Sb	216-222
Sn-Zn-Bi	Sn-7Zn-5Bi	170-190

EUTECTIC ALLOYS

Cookson Electronics

Copper Dissolution - Test Results

- The results showed that the Tin Lead alloy dissolved the least amount of copper.
- The best performance for the Lead-Free alloys was the **SACX** material.
- The worst performance was from SAC305

Surface Finish Attributes

alpha

Surface Finish	Cost	Corrosion Res	ICT	Hole Fill	Fine Pitch	Cosmetics	Comments
Imm Silver	Low	Poor	Good	Mod	Good	Poor	Good surface finish for soldering and testing, tarnish & creep corrosion are the weaknesses
HT OSP	Low	Mod	Poor	Poor	Good	Mod	Requires pasting of test pads/vias. Difficult to achieve LF hole fill, especially on >0.062 boards.
LF HASL	Mod	Good	Good	Good	Mod	Good	Phenolic laminate recommended. New equipment required. Flatness is better than SnPb HASL
Imm Tin	Mod	Good	Good	Mod	Good	Mod	Solderability/hole-fill may be a problem on double sided PCBs. Shelf life.
ENIG	High	Mod	Good	Good	Good	Good	Galvanic driven creep corrosion can occur if Cu is exposed. Ni-Sn interface is brittle with LF. Black pad issues remain.

Cookson Electronics

Final Plating Finish Comparisons:

	HASL (SnPb)	HASL Lead-Free	Electroless Nickel Immersion GOld - ENIG	Immersion Silver-IAg	Organic Solderable Coatings - OSP	Immersion Tin - ISn	Electrolytic Nickel Gold - NiAu
RoHS Compliant	No	Yes	Yes	Yes	Yes	Yes	Yes
Fabrication Costs	Low	Low	Medium	Medium	Low	Medium	High
Shelf Life	1 Year	1 Year	1 Year	9-12 Months*	9-12 Months*	9-12 Months*	1 Year
Assembly Cycle Capacity	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple	Multiple
Multiple Rework Capacity	Limited	Limited	Limited	Yes	No	No	No
Solder Wettability	Excellent	Good	Good	Very Good	Good	Good	Good
Co-planarity	Poor	Good	Excellent	Excellent	Excellent	Excellent	Good/Poor
Solder Joint Integrity	Excellent	Good	Good	Excellent	Good	Good	Poor**
Low Resistance/ High Speed	No	No	No	Yes	N/A	No	No
Aluminium Wire Bond	No	No	No	No	Yes	No	Yes

Surface Finishes Usability Based on Technology

alpha

SURFACE FINISH	THROUGH-HOLES	PRESS-FIT	SMT	FINE-PITCH BGA	EMI SHIELDS	CARD GUIDES	EDGE CONNECTORS	FLIP CHIPS	GOLD WIRE BOND	ALUMINUM WIRE BOND
Selective Solder	OK	OK	OK	OK	OK	OK	OK	OK	No	No
ENIG	OK	OK	OK	No[1]	OK	OK	OK	OK	No	No
HASL	OK	OK	OK	No	OK	OK	OK	No	No	No
Immersion Sn	OK	OK	OK	OK	OK	OK	OK	OK	No	No
Immersion Ag	OK	OK	OK	OK	No[3]	OK	OK	OK	No	No
OSP	OK	OK[2]	OK	OK	No	No	OK	OK	No	OK
Electrolytic Ni-Au[4]	No[5]	OK	OK	OK	OK	OK	OK	OK	OK	OK
Reflow Sn-Pb	OK	OK	No	No	OK	No	OK	No	No	No

[1] Not Suitable for 1.0mm pitch or less.

[2] Not the best or more robust choice.

[3] EMI Shielding OK, but tarnish formed when left unsoldered / exposed

[4] Electrolytic Ni-Au will embrittle solder paste due to excess gold plated in PCB high current density areas.

[5] Not for aspect ratios > 8:1 due to poor throwing power

Cookson Electronics

Examples of Best Fit SF

alpha

ENIG or ENEPIG

- SnPb medical and aerospace
- Small specialty electronics (not Pb-free that is susceptible to shock).

OSP (but must address ICT issues)

- Hand held electronics
- Notebook computers
- Basic desktop computers
- Basic consumer electronics & power supplies
- Pb-free Medical or aerospace (thin PCBs)

Cookson Electronics

Examples of Best Fit SF

alpha

ImAg

- Fully enclosed hand held electronics
- Basic consumer electronics

ImSn

- Simple consumer electronics (not fully enclosed)
- Simple medical or aerospace applications (1 side)
- Low to moderate volume peripheral components

LF HASL

- Thick LF PCBs going into business environments (servers, telecom equipment)
- Complex Pb-Free medical or aerospace?

Cookson Electronics

Alternate Cost Effective Soldering Materials

alpha

Wave Solder Materials

Alloys

Cookson Electronics

What are some key considerations for companies considering next generation Pb-Free alloys?

Same old story…

»Reliability

»Processing Parameters

»Soldering Performance

»Availability and Cost

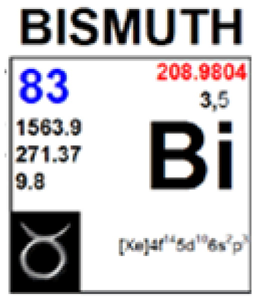
(Assumes alloys have sufficient electrical conductivity)

Reliability

Density / Specific Gravity
Thermal Conductivity
Coefficient of Thermal Expansion
Tensile Strength (M-Pa)
Elongation %
Hardness
Creep Strength (*time to failure*)
Stress Testing – joint strength
Stress Testing - thermal cycling
Tin Whiskers

•Silver improves the fatigue resistance of Lead-Free alloys as it forms IMC Ag3Sn with the tin, these hard platelets increase the fatigue resistance.

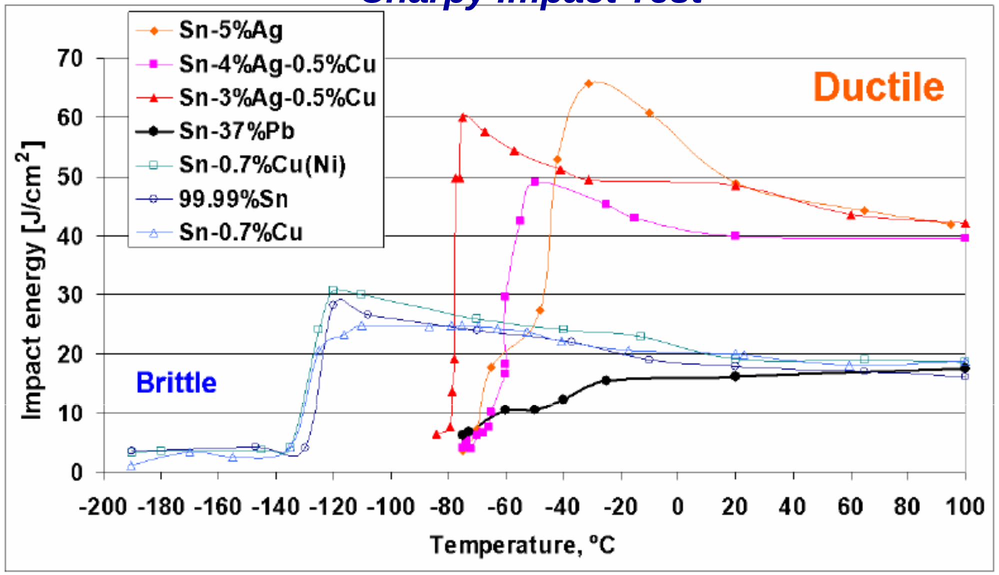
•Small amounts of Bismuth (<3%) improves the fatigue resistance of Lead-Free solder alloys. This is due to the solid solubility of Bismuth in Tin that results in a hardening of the alloy.



Cookson Electronics

Reliability data

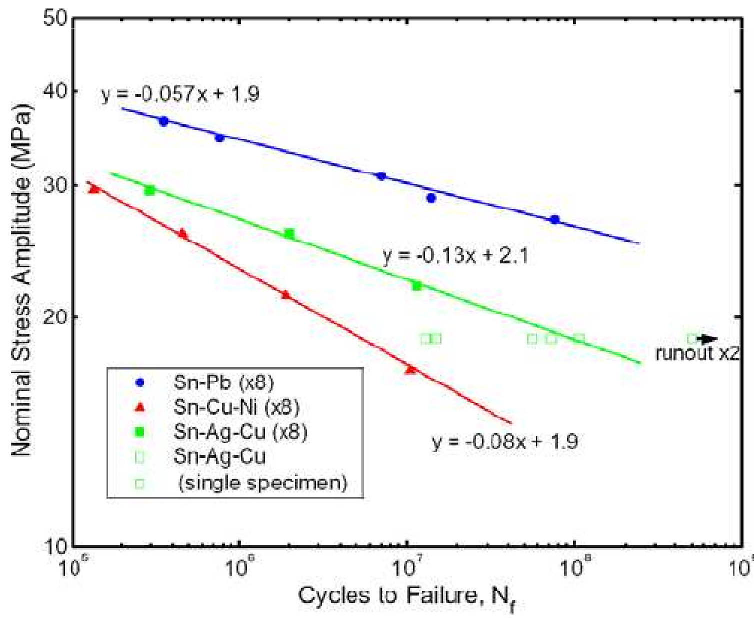
Charpy Impact Test



Silver contributes to alloy strength while also helping to keep it ductile – improving it's ability to absorb and recover from mechanical stress

The Ag3Sn platelets also make the alloy hard

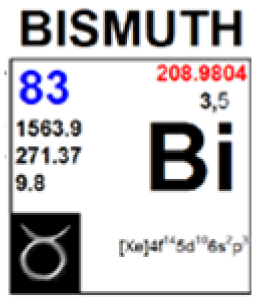
	SAC 0307x	Leading Ag free alloy	SAC 305 alloy
Vickers Hardness *measurements on multiple samples*	14.2	11.1	15.3
	14.1	12.1	15.1
	14.0	10.5	14.8
	13.9	11.3	14.7
	14.1	11.7	15.5
			15.8
Mean	**14.06**	**11.34**	**15.2**
Std dev	0.11	0.61	0.42



High Cycle Fatigue by Gunther Grossman

Cookson Electronics

Processing Parameters



Silver and Bismuth lower the liquidus temperature.

Nickel *lowers copper dissolution but increases the liquidus temperature*

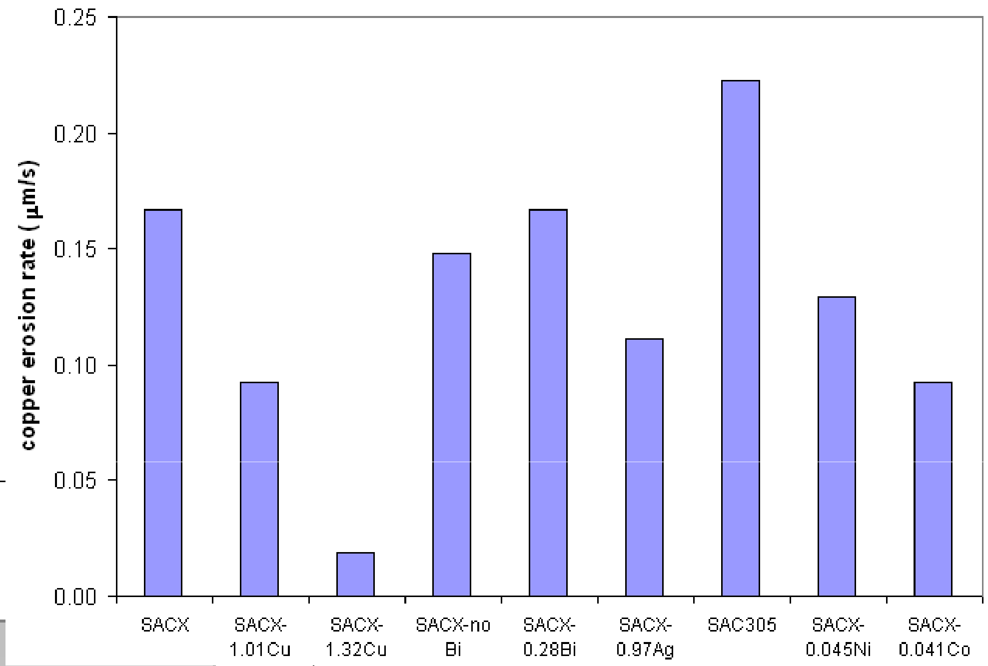
Impurities
Alloy Stability
Liquidus / Solidus Temp
Specific Heat
Copper Erosion Rate
Drossing Rate
Pot Corrosion
Operating Temperature

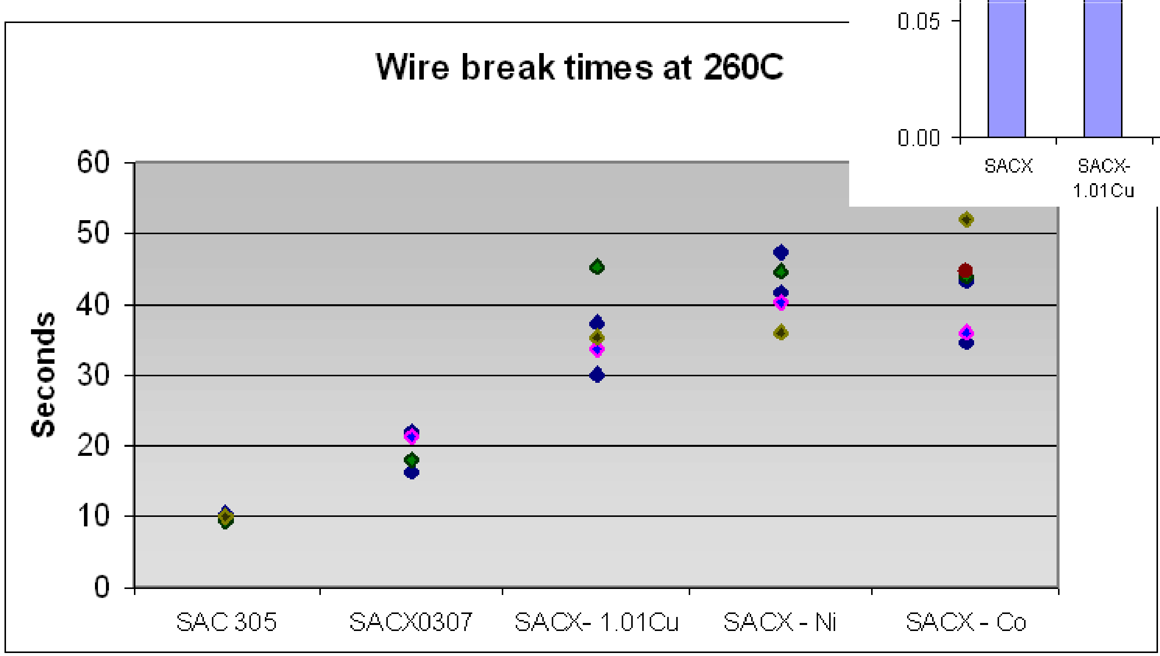
Other additives reduce dross rates

Cookson Electronics

Copper Dissolution Data

- Cu, Ni and Co reduce the erosion rate
- Ag increases Cu erosion rate





Time required for 50µm copper wire to dissolve in 260ºC molten alloy bath.

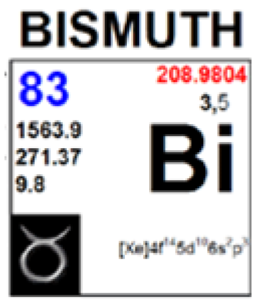
Cookson Electronics

Soldering Performance

Wetting Speed
Wetting Force
Skips
Bridging
Solder Balls
Hole Fill
Spread
Joint Finish

Silver improves wetting speed and force by lowering the surface tension of the SAC alloy. This also lowers defects like bridging and skips when soldering SMT components.

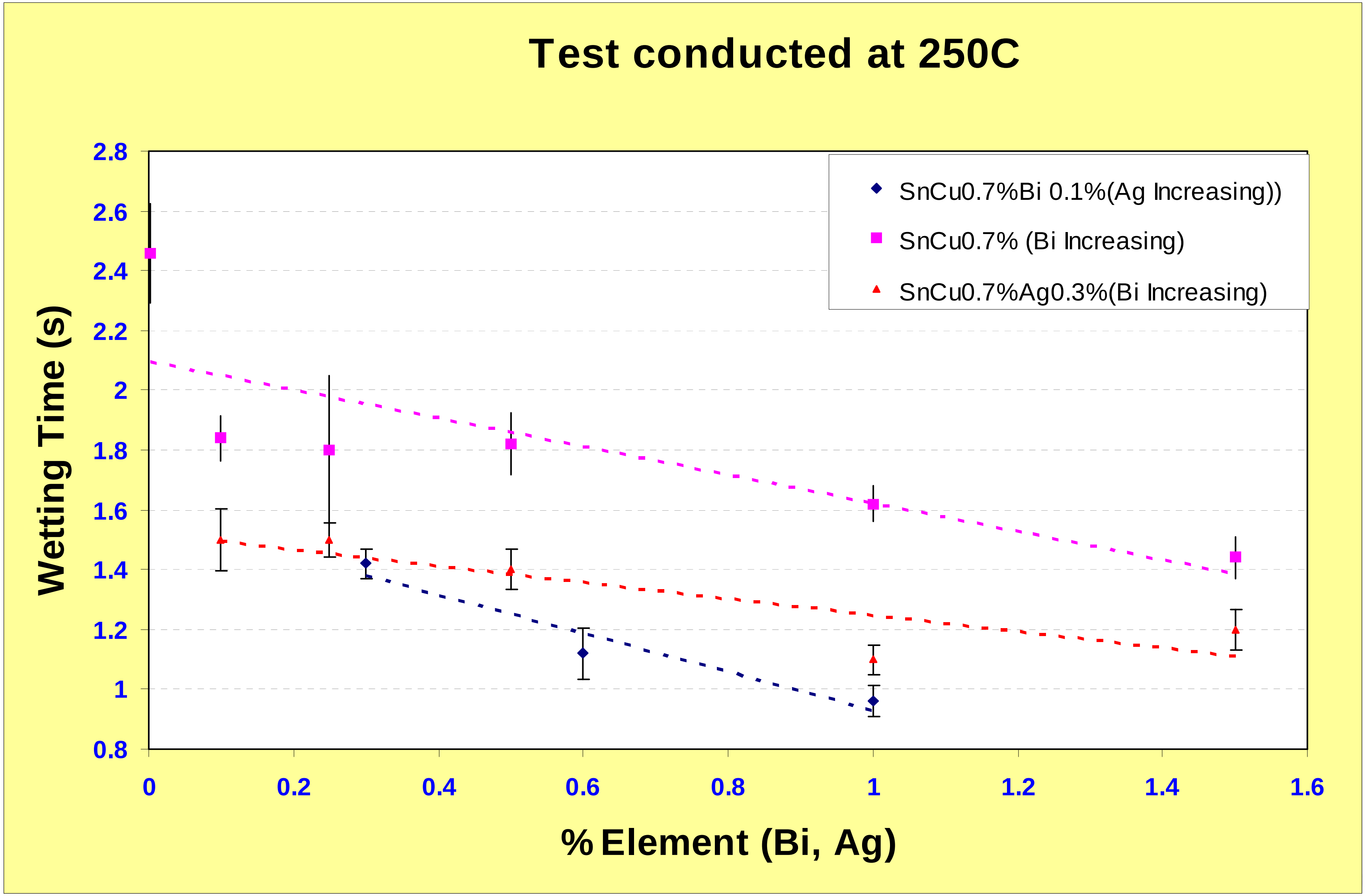
Bismuth improves the wetting speed and force thereby improving hole-fill and spread. Additions of Bismuth compensate for the reduction in Silver in lower Silver SAC alloys to maintain these strong wetting properties.



Nickel *increases surface tension – lowering wetting speed and force.*

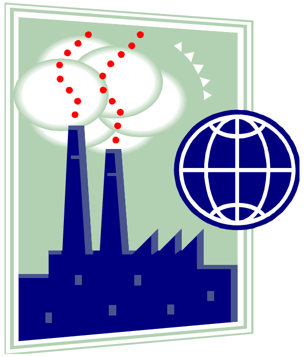
Cookson Electronics

The effect of Bismuth and Silver



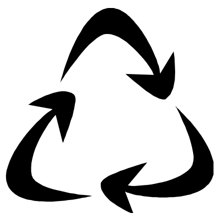
Alloy Availability and Cost

Alloy availability
Alloy cost
Sizes / Shapes
Markings
Packaging
Manufacturing proximity / capacity
Recycling
Regulatory
Intellectual Property



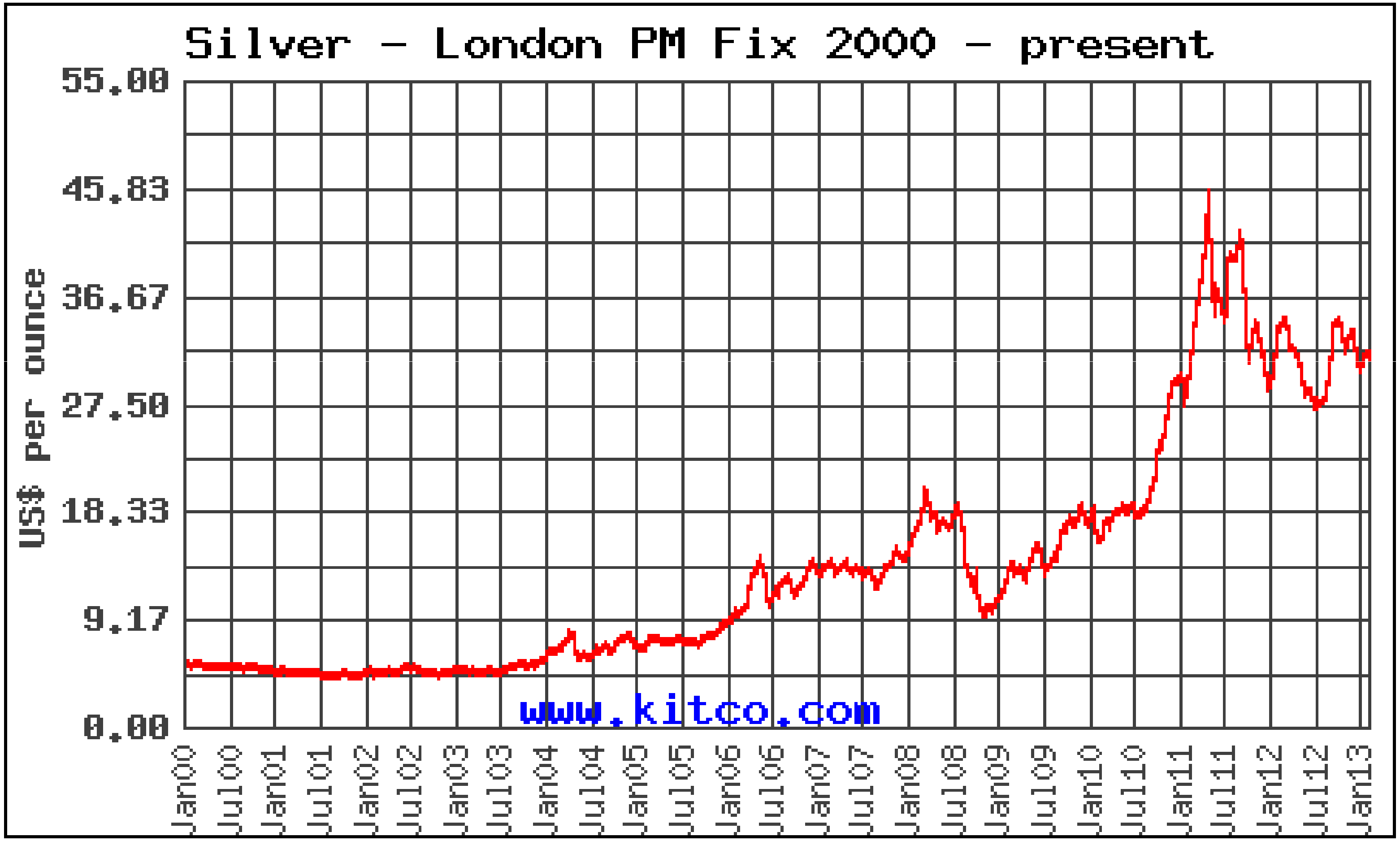
Is the alloy available everywhere you need it?

Silver content has big impact on alloy cost. A 1% decrease in silver results in a 10% decrease in cost.



Are all the alloys constituents recyclable?

Trend of Silver (Ag) : 2000- 2013

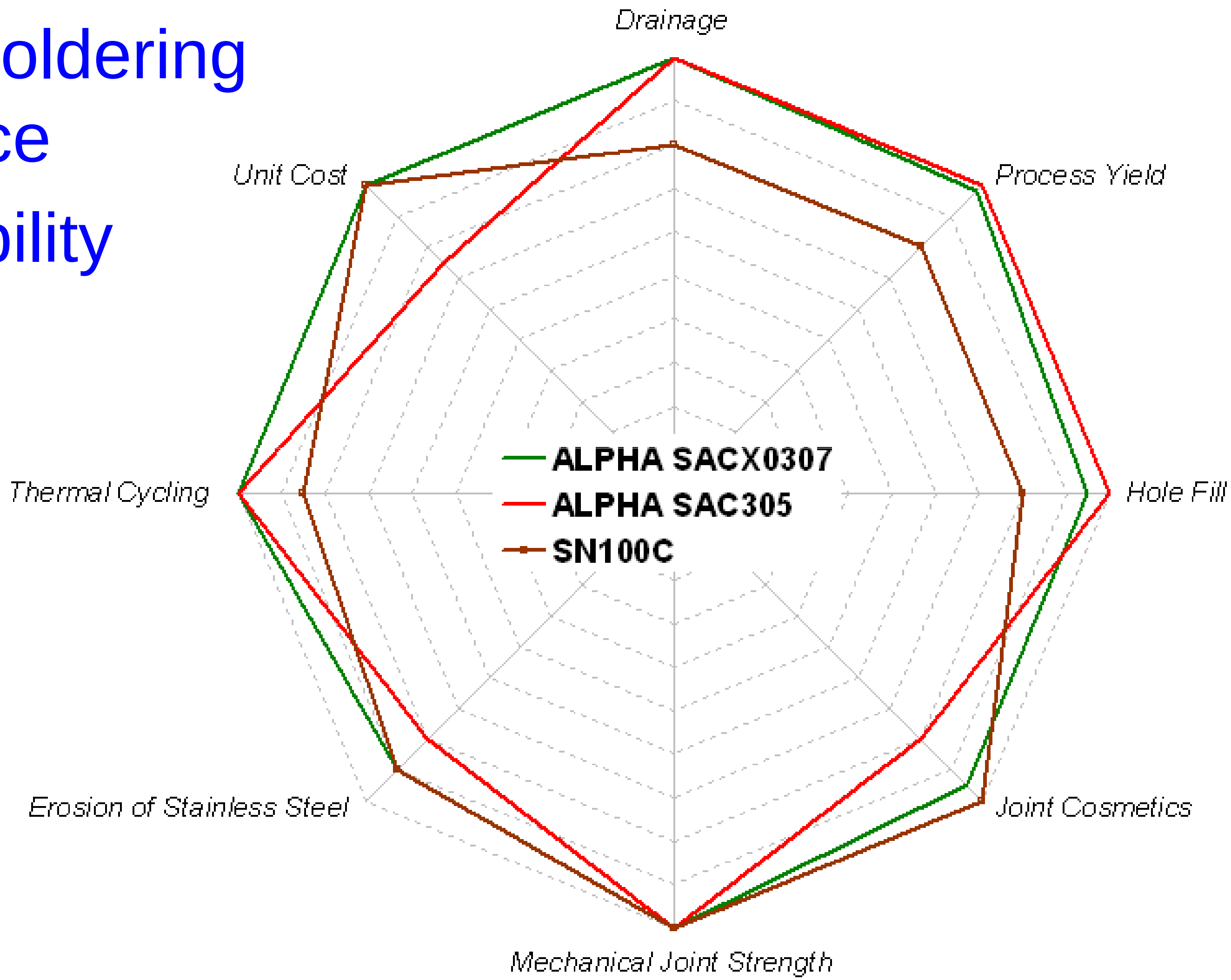


Cookson Electronics

alpha

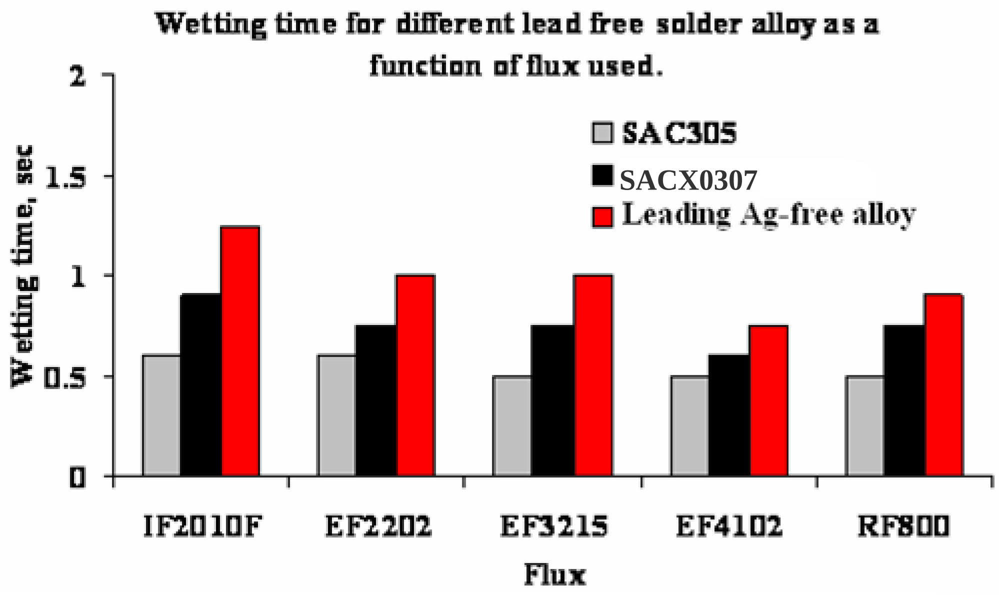
PbFree Wave Solder Alloy Attribute Balance

- Excellent Soldering Performance
- High Reliability
- Low Cost



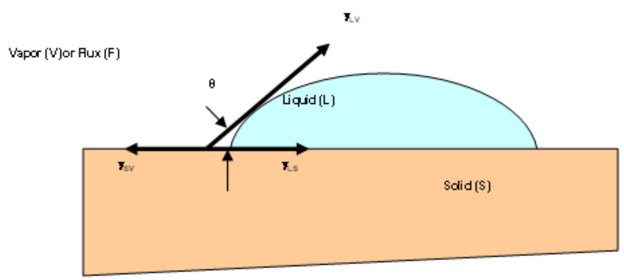
Why SACX?

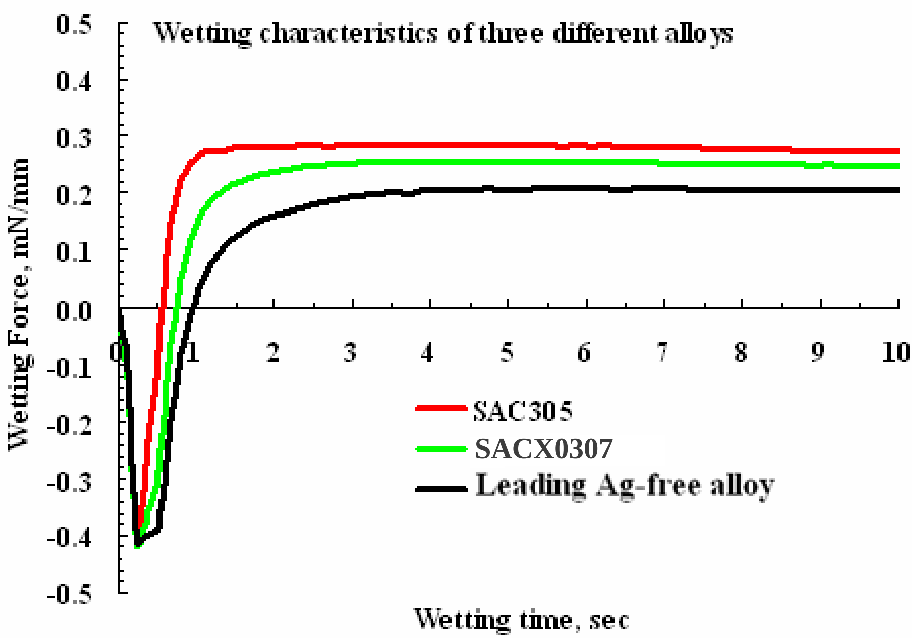
Cookson Electronics



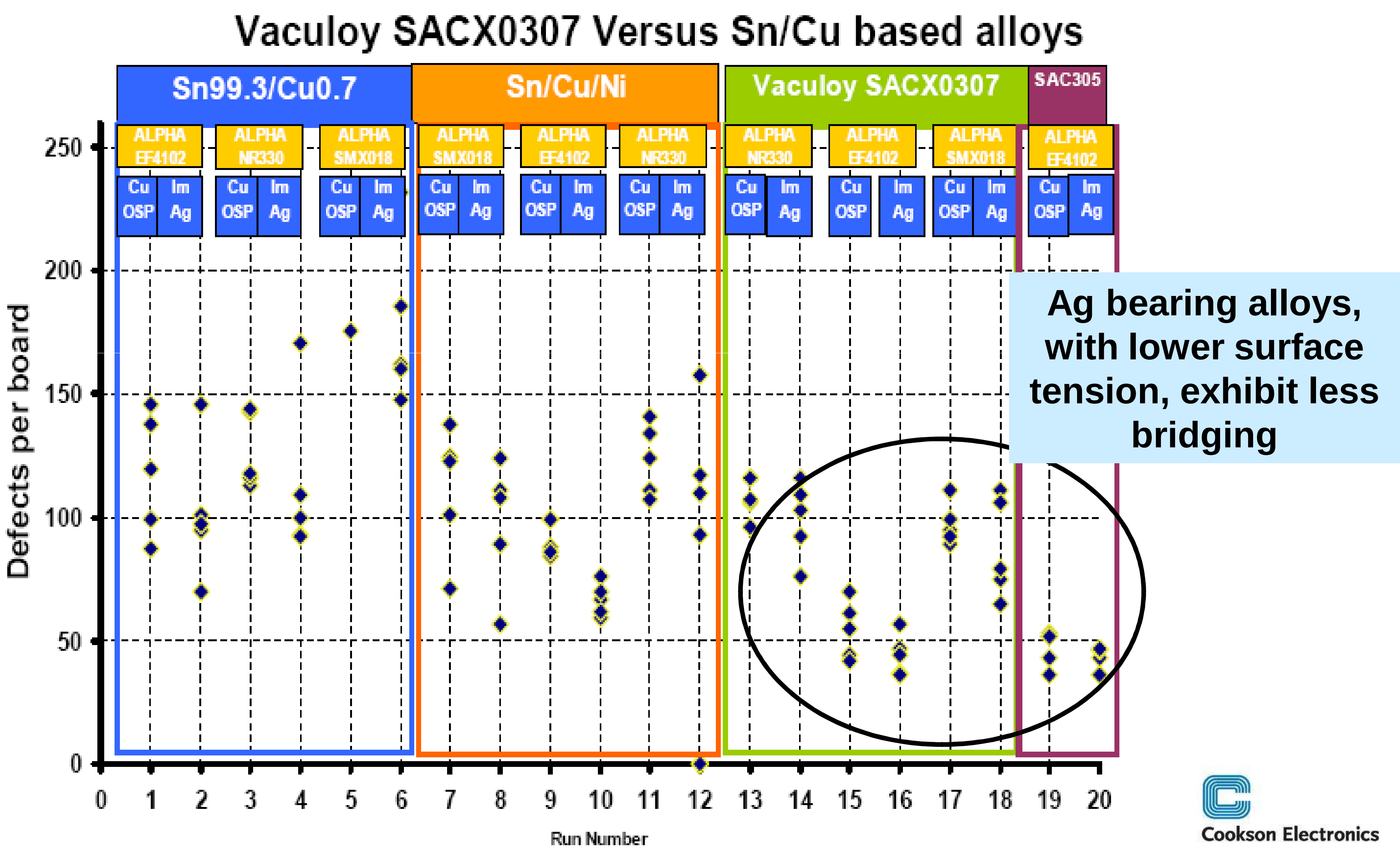
SACX exhibits **higher wetting force** and **faster wetting speed** than non Ag bearing alloys

Wetting Speed and Force is directly correlated to Hole Fill and Drainage performance during wave soldering.





Bridging Performance



Companies that have transitioned to SACX

Over 1000 Companies building nearly half a billion PCB's!

Thermal Cycling

Test Results

- SACX0307 Solder Fillet - no fatigue cracks or grain delineation

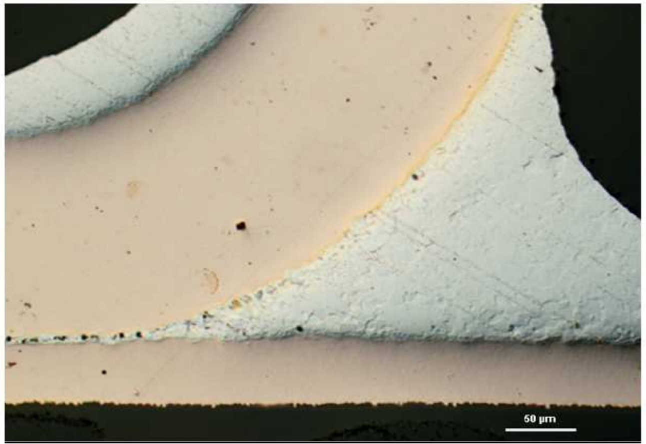
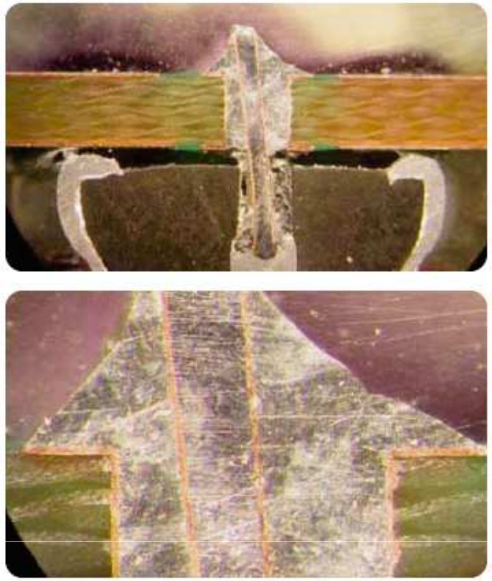


Figure B2. No fatigue cracks can be seen in the heel fillet of the joint at higher magnifications

SACX exhibits equivalent or better reliability than all the leading Pb-free alloys



SACX after cycling – no cracks

Sampling of results from customer thermal cycling tests

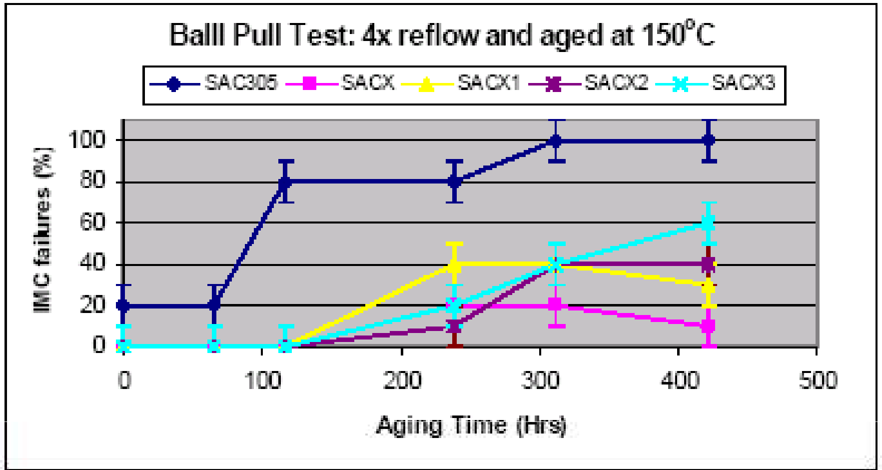
Test Type	Lower	Upper	Cycles	Results
Thermal Cycling	-40	125	2000	*No difference between SACX and SAC305*
Thermal Cycling	-40	85	1000	*Lower failure rate that SAC305*
Thermal Cycling	-40	90	500	*0 failures*
Thermal Shock	-40	80	300	*Lower failures than Sn/Cu/Ni*
Thermal Cycling	0	100	500	*Passes requirements of PC manufacturer*
Thermal Cycling	-40	125	1000	*Equivalent to SAC305 better than Sn/Cu/Ni*

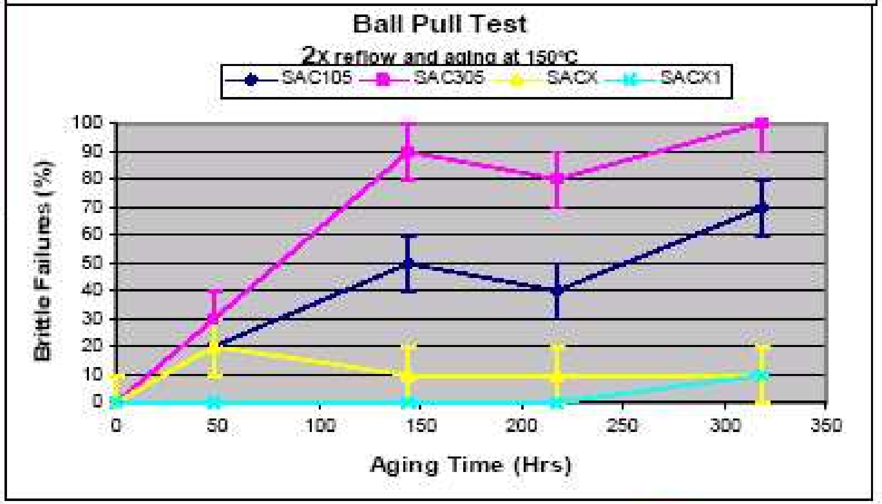
Cookson Electronics

IMC and Test results

Ball Pull Results

- SAC305 shows highest % IMC fracture
- SAC105 is slightly better than SAC305
- SACX shows the lowest % brittle failure
- SACX1 with enhanced oxidation resistance also shows good ductility





SACX exhibits **Higher Strength** vs. SAC305 in a variety of SMT Pull Tests

PQFP208 Lead Pull Tests

Sample ID	SACX/235C	SACX/240C	SACX/250C	SAC/235C	SAC/240C	SAC/250C
	594	508	480	215	352	213
	527	535	500	242	280	253
	538	565	492	221	201	342
	465	662	578	325	245	382
	334	519	495	293	264	250
	576	551	522	339	266	266
	546	576	495	576	253	250
	562	632	401	807	239	272
	522	525	447	826	113	242
	468	498	511	776	126	218
	530	538	595	651	113	237
	490	586	594	240	129	220
	573	527	468	225	136	246
	490	554				
	465	516				
	386	480				
	500	538				
	616	501				
	471	488				
	533	557				
Avr=	509	543				
High=	616	662				
Low=	334	480				

SO16 Lead Pull Tests

	SAC305		SACX0307	
	Pull-Off Strength (kN)	Failure Mode	Pull-Off Strength (kN)	Failure Mode
Section 3 Package Parallel To Wave	0.0133	6	0.0251	8
	0.0153	6	0.0265	8
	0.0142	6	0.0298	8
	0.0138	6	0.0281	4
	0.0134	6	0.0285	4
	0.0156	6	0.0217	6
	0.0158	6	0.0177	6
	0.0155	6	0.0169	6
	0.0150	6	0.0186	6
	0.0262	6	0.0104	6
	0.0269	6	0.0119	6
	0.0277	4	0.0230	8
	0.0250	6	0.0239	6
	0.0289	6	0.0240	8
	0.0123	6	0.0248	6
	0.0129	6	0.0214	6
	0.0116	6	0.0161	6
	0.0110	6	0.0178	6
	0.0135	6	0.208	6
	0.0170	6	0.0216	6
Mean (kN)	0.017		0.021	
Std Deviation (kN)	0.006		0.005	

Connector Pull Tests

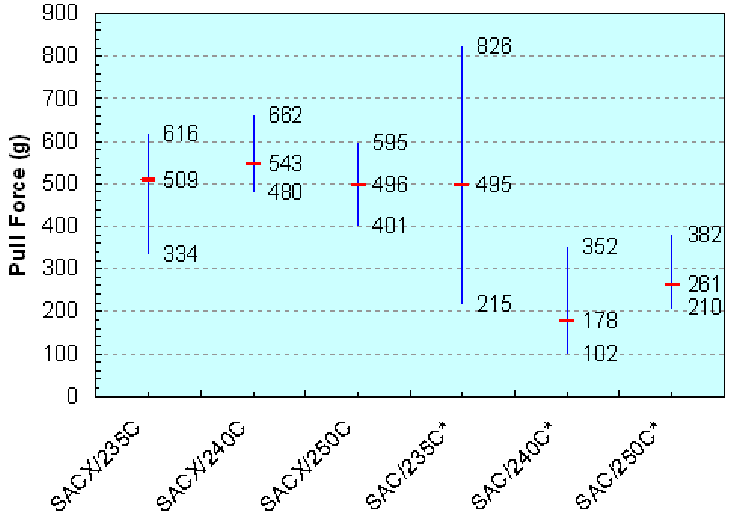
	Alloy Type					
	SAC305		SACX0307		Sn63/Pb37	
	Pull-off Strength (kN)	Failure Mode	Pull-off Strength (kN)	Failure Mode	Pull-off Strength (kN)	Failure Mode
	0.275	5	0.229	6	0.036	5
	0.286	5	0.329	5	0.048	5
	0.315	5	0.332	5	0.300	5
	0.265	5	0.319	5	0.214	5
	0.326	5	0.318	5	0.315	5
	0.329	5	0.332	5	0.237	5
Mean (kN)	0.299		0.310		0.192	
Std. Deviation (kN)	0.027		0.040		0.122	

Code: 5 – Lead failure, 6 – Grip failure

1206 Resistor Pull Tests

	Alloy Type					
	SAC305		SACX0307		Sn63/Pb37	
	Pull-off Strength (kN)	Failure Mode	Pull-off Strength (kN)	Failure Mode	Pull-off Strength (kN)	Failure Mode
	0.059	5	0.079	0	0.070	0
	0.075	5	0.071	[illegible]	[illegible]	[illegible]
	0.054	0	0.061	[illegible]		
	0.075	5	0.061	[illegible]		
	0.054	0	0.070	[illegible]		
	0.078	5	0.093	[illegible]		
			0.068	[illegible]		
	0.066		0.072			
	0.011		0.011			

0 – Unknown Failure Mode
5 – Lead failure



Overview of the SACX Family of Alloys

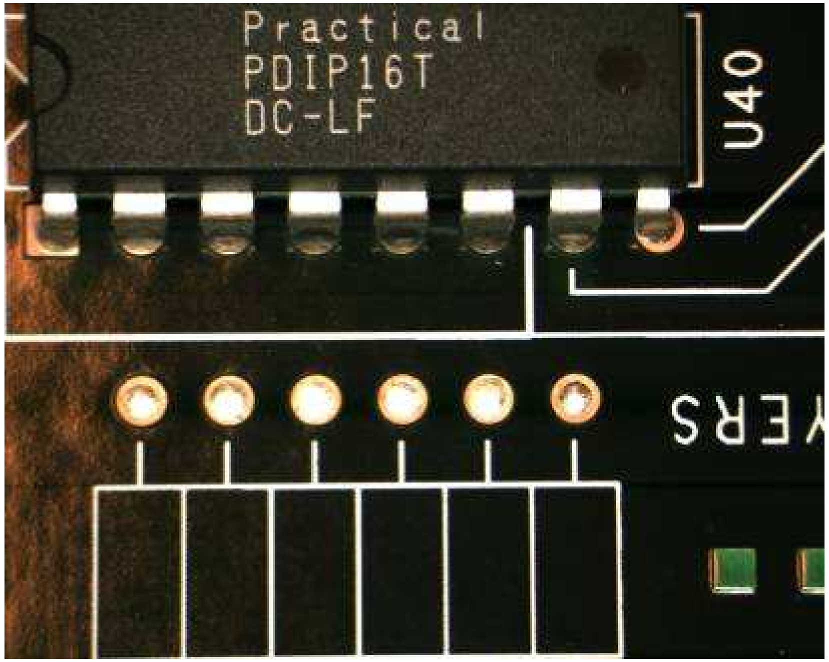
The SACX Family

Alloy	Description	Availability
ALPHA® SACX® DT	Designed to minimize copper erosion associated with the longer contact times during selective soldering and rework operations.	Wire, ingots
ALPHA® SACX® HASL	Designed to produce a smooth, uniform pad finish while minimizing copper erosion during plating.	Bars
ALPHA® SACX® 0807	Soldering performance and reliability similar to SAC305. For use on complex, dual sides assemblies where high wetting force is needed.	Bars, wire, feeder ingots
ALPHA® SACX® 0307	Excellent soldering and reliability for either single sided or standard complexity dual sided assemblies.	Bars, wire, feeder ingots, spheres
ALPHA® SACX® 0107	Basic alloy for use on single sided assemblies where moderate reliability in required.	Bars, wire, feeder ingots

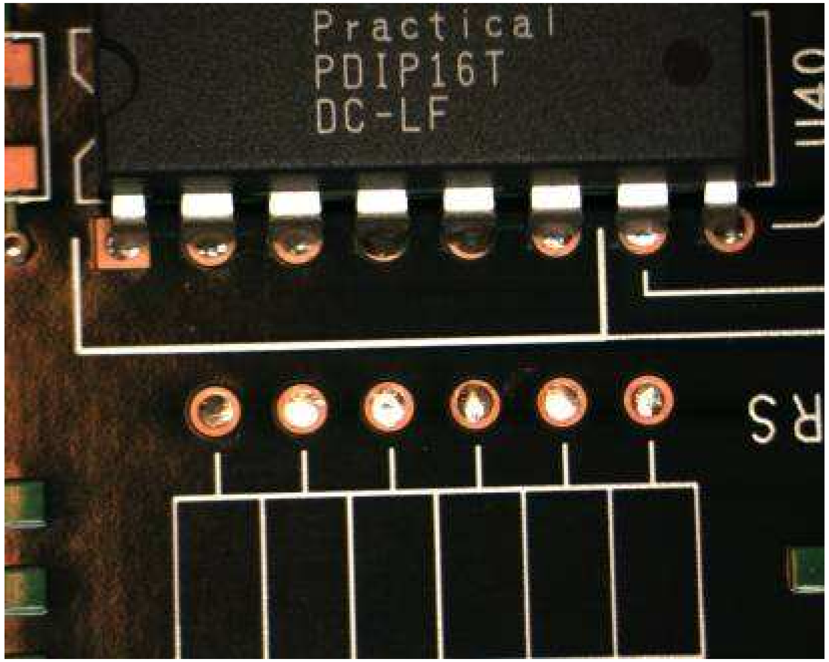
- Each alloy contains constituents to enhance specific areas of performance
- Alloys are fully cross compatible

Cookson Electronics

Hole-Fill Comparison



SACX



SN-C

Introduction

ALPHA SACX® 0807 is a newly designed and tested lead free electronics soldering alloy that uses the latest innovations to deliver best in class soldering performance and reliability. It's also easy to use and can be dropped in to most current SAC 305 wave soldering processes. ALPHA SACX® 0807 contains just the right amount of additives to be the perfect choice for the most challenging assemblies while also helping Assemblers lower their material costs.

Feature	Benefit
Stable Alloy Matrix	Constituents maintain homogenous mixture during use. Virtually no solder bath maintenance requiring alloy "re-balancing" common with less stable alloys
Low Operating Temperature Requirement	Drop in to most current lead free wave soldering machine temperature profiles
Low Dross Rate	Less time and expense realated to dross removal
Low Copper Erosion Rate	Less risk during high temp, high exposure time rework steps
Low Surface Tension Alloy	Fast wetting with high wetting force delivering excellent hole fill and low SMD related defects
Hard, Ductile Joints	Lower warrantly claims related to mechanical joint failures
Low Silver Content	Lower assembly material costs

High Performance Alloys for <u>Every</u> Assembly

<table>
<tr><th rowspan="2"></th><th colspan="4">Assembly Type</th></tr>
<tr><th>Single Side boards</th><th>1.6mm up to 8 layer PTH boards ENIG/ImmAg/LF HASL</th><th>1.6mm up to 8 layer PTH Boards Cu OSP</th><th>>2.4mm >8 layer FR4 PTH</th></tr>
<tr><td>Device Types</td><td>TV Chassis (CRT)
Toys
Set top Box
DVD player
White Goods
Audio System</td><td>PC Motherboard
Gamebox board
PC Peripherals
TV LCD/Plasma
Automotive Engine Mgt</td><td>PC Motherboard
Gamebox board
PC Peripherals
TV LCD/Plasma
Automotive Engine Mgt</td><td>Server board
Network Infrastructure
Telecom Base Station</td></tr>
<tr><td rowspan="4">Assembly</td><td>ALPHA® SACX®0107</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">ALPHA® SACX® 0307</td><td></td></tr>
<tr><td colspan="4">ALPHA® SACX® 0807</td></tr>
<tr><td colspan="4">ALPHA® SAC305, 387, 405</td></tr>
<tr><td>Rework</td><td colspan="4">ALPHA® SACX®DT</td></tr>
<tr><td>HASL</td><td colspan="3">ALPHA® SACX®HASL</td><td></td></tr>
</table>

alpha

Evaluation of Paste CVP390-SACX0807 in A Major EMS in Western region

20 July 2011.

Rajeshwar Andurekar
CTS Engineer – West India

Cookson Electronics

Background

alpha

Presently xxxxx a major EMS player in India is using Alpha OM-345 SAC305 RoHS (96.5% Sn, 3.0% Ag, 0.5% Cu) Composition for their OEM customers from Automotive, Industrial, Telecom & Consumer Electronics Industry segments

The average consumption per month is 850 kg solder paste / month

Continuous pressure from their OEMs to reduce BOM cost was mounting

A meeting was organized for all vendors to review pricing

Cookson (Alpha) proposed the availability of alternate low silver containing solders like SACX0807, SACX037 & SACX0107 alloys in Solder Paste, Solder Bar & wire.

So Cookson & the EMS company decided to promote Alpha CVP390-SACX0807 by conducting evaluation and measure the impact on quality

Cookson Electronics

SACX0807 Solder Paste Trials

- Trials were conducted for small & large batch sizes ranging from 10k to 50K PCBs
- Boards were sent for reliability testing and the data was compared Vs SAC 305 older paste alloy
- A comprehensive report on reliability of solder joints was prepared and reviewed
- The results exceeded their expectation

Value Equation

alpha

"Alpha CVP390 solder paste Introduction in place of Alpha OM345 "

Financial Impact

Category	OM345	CVP390		Savings	Units
Cost of solder paste per Kg	4400	3390		1010	Rs/kg
Consumption of paste per month	830	830			
Total cost of per month	3,652,000	2,813,700		838,300	Rs /Month
Total cost of per year	43,824,000	33,764,400		10,059,600	Rs /year

1 crore 60 thousand Rs

US$ - 223K

Please note there is approximately 10% increase in CVP-390 price since then due to silver price increase correspondingly with SAC 305.

Cookson Electronics

Proposal for XXX on Savings on RoHS Solder

- Average consumption of SAC305 (SFO Cochin) = 700 – 800 kg
- Current selling Price of SAC305 solder = Rs.3471
- Current selling price of SACX0307 solder (SFO Bangalore) = Rs.1757
- The difference = Rs.1714
- Your Savings per month = 1714 X 750 kg = 12.85 Lacs

- **Savings per Annum = 12.85 X 12 = Rs.1.54 Crore**

- The actual and projected data in terms of substrate area processed clearly shows a significant bias towards OSP. That does not mean that OSP should be used as a universal finish. Far from the truth.

- What this does mean is that there are a significant number of PCBs assembled today with OSP as its final finish of choice. This includes networking, computer mother boards, automotive electronics including engine control and disk brake systems, mobile phones and other handheld devices. So, contrary to sentiment in some circles, OSPs are not just for low-end consumer electronics. But, again, there are no free lunches. As with any surface finish, there will always be limitations.

  So it is appropriate to clearly frame up what the PCB fabricator must do to insure a high-quality and solderable PCB for lead-free assembly when using OSP

Summary

alpha

The surface finish you select will have a large influence on quality, reliability and cost.

It is a complex decision that impacts many areas of the business.

Select a finish that optimal for the business (and not just one function).

Know that there are engineering tricks to improve on weak areas of each finish.

Stay current in this field because new developments continue to be made.

Acknowledgements / Credits

alpha

- Cisco Systems, Inc.
- Multek
- SMT Magazine
- "A Study of Lead-Free Hot Air Leveling", David Suraski, Circuits Assembly OCT 2004
- "Effects of Surface Finish on High Frequency Signal Loss using Various Substrate
- Materials", Don Cullen, Bruce Kline, Gary Moderhock, Larry Gatewood - (*1)
- Atotech
- Florida CirTech, Inc.
- Nihon Superior Co., LTD (Osaka, Japan) SN100CL
- Iowa State University
- Senju/Matsushita
- Metal Finishing Industry
- NEMI
- CREEP CORROSION ON LEAD-FREE PRINTED CIRCUIT BOARDS IN HIGH SULFUR ENVIRONMENTS

Randy Schueller, Ph.D.; Dell Inc., Austin, Texas, randy_schueller@dell.com

Randy Schueller, Ph.D., DfR Solutions

- CEMCO – FSL "The Newest Surface Finish Alternative
- LEAD-FREE HASL. It's Development and Advantages"
- Circuit Connection Presentation (Florida CirTech, Inc. Dec-05-05)
- Chris Padilla (Cisco Systems, Inc.)
- *Freeman 1995*
- Special Thanks to the following individuals that have contributed to the slides and animation in this presentation:

Dan Slocum, Craig Davidson, Brad Hammack, Mike Barbetta, Kim Hyland, Glenn Sikorcin

Cookson Electronics