Development of a Functional Pb Free Solder Paste for High Reliability Applications

Almit Technology Ltd.

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1. What is meant by 'High Reliability'?
2. What are the alternative metals to Pb?
3. Alloy Selection
4. Flux Reliability and 'Workability'
5. Pb Free Paste 'Spreadability'
6. Pb Free SMT Issues

HIGH RELIABILITY

A high reliability assembly must be able to withstand the conditions it is expected to operate in. As these conditions can vary enormously we must be confident we are manufacturing the most reliable solder joint possible. Whether we are making a hand held digital camera or an assembly for use in an aerospace application we follow much the same process to make the solder joint.

Once we are confident we are manufacturing the most reliable joint possible then we have an assembly whose life expectancy will not be affected by the solder joint. Where we have successfully used tin/lead based solders for many years we need to satisfy ourselves we can produce the same joints with lead free alloys using the same processes.

Basic Tests for High Reliability

Thermal Cycling

Temperature/Humidity Testing

Destructive Joint Tests

WHAT HELPS GUARANTEE A HIGH RELIABILITY SMT SOLDER JOINT ?

1. CONSISTENT PRINT PERFORMANCE
   a. Guarantees joint after joint has ideal paste volume
2. GOOD FLUX SOLDERABILITY
   a) Must have good wetting to base metals
   b) Reworked joints are weaker joints
3. 'STRONG' SOLDER ALLOY
   a) Select the correct lead free alloy
4. HIGH RELIABILITY FLUX RESIDUE
   a) Eliminates circuit failure due to corrosion etc

2) What are the alternative metals to Pb?

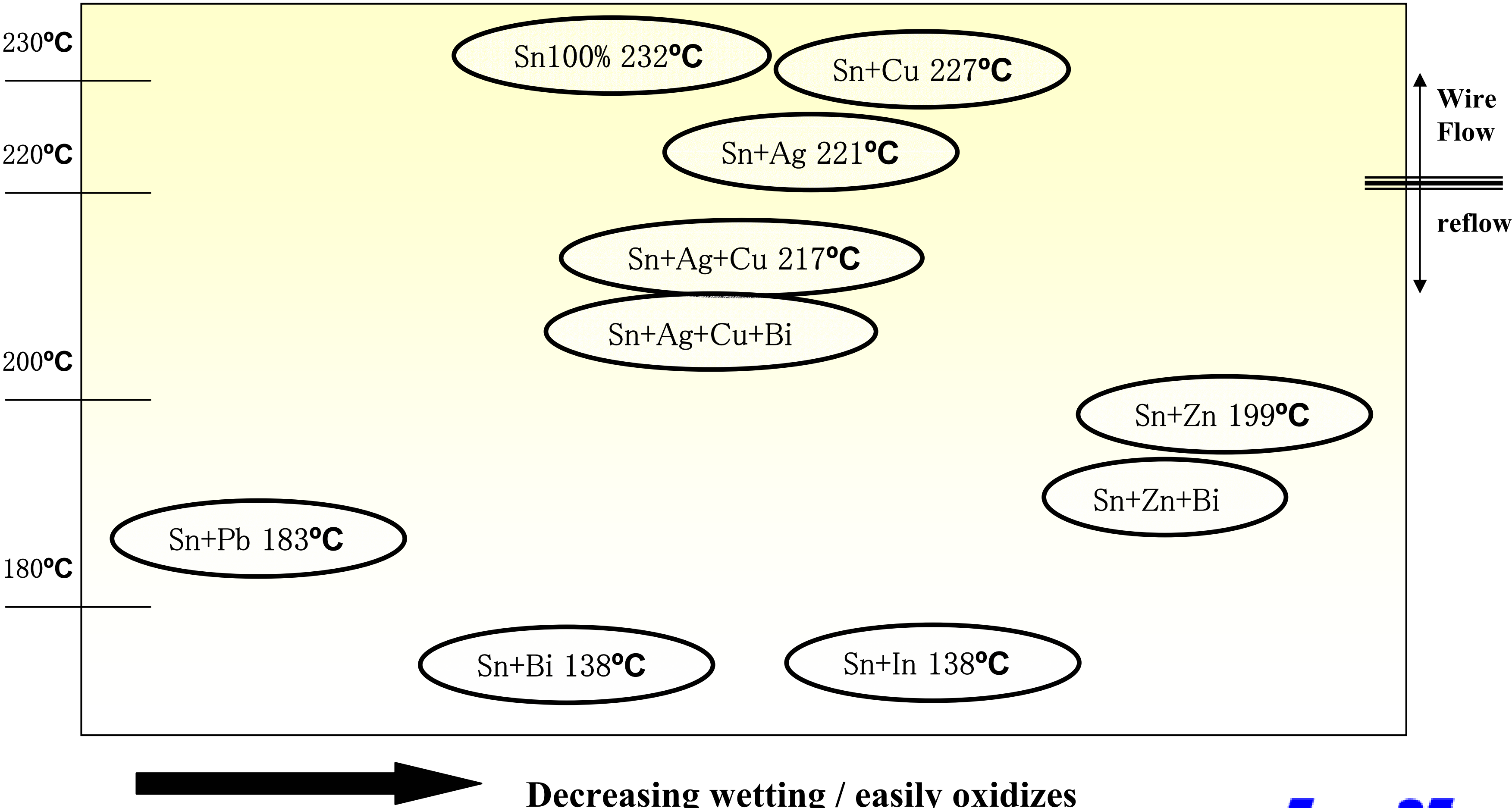
1) Characteristics of alternative metals.

Requirements of a solder (Sn62Pb36/Ag2)

1. Low melting temperature
2. Moderate price
3. Good wetting
4. Metal slow to oxidize

Sn	**as a main constituent**
Ag	**high price**
Cu	**as an additive metal**
Bi	**low melting temperature** **strength problem**
Zn	**Quick to oxidize** **moderate price**
In	**high price** **low melting temperature**
Sb	**as an additive metal**

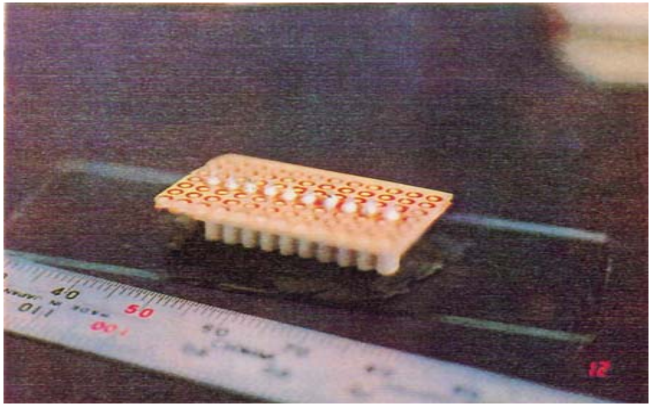
The eutectic point of the potential alloy



3) Some ALMIT Pb Free Alloys

• LFM- 8	Sn+Ag3+Cu0.7+Bi3 (m.p.213 ºC)
• LFM-14	Sn+Ag+Cu (Eutectic alloy)
• LFM-22	Sn+Cu0.7 (m.p.227ºC)
• LFM-23	Sn+Cu0.7+Ni
• LFM-27	Sn+Ag2.5+Cu0.5+Bi1
• LFM-31	Sn+Zn8+Bi3
• LFM-37	Sn+Ag2.8+Cu0.7
• LFM-38	Sn+Ag2.95+Cu0.5
• LFM-39	Sn+Ag4+Ni0.1
• LFM-41	Sn+Ag0.3+Cu2
• LFM-48	Sn+Ag3+Cu0.5 (m.p.221ºC)
• LFM-50	Sn+Ag+Cu+Ni+Ge
• LFM-51	Sn+Bi+Ag+Cu+Ni+Ge

3. Strength -a - 1; heat cycle / 500 cycle



10 pin : No.1 from left side,
No.10 to the right side

Terms:
1. Paper PCB
2. Pin clearance 2.5mm
3. Solder quantity on each pin 10mg.
4. Flux RA
5. Iron temperature 350 degree C
6. –40+120 degree C each 15 min, interval 15 min

	1	2	3	4	5	6	7	8	9	10
Sn63	X	X	X	O	O	O	△	△	X	X
LFM-22	X	△	△	O	O	O	O	△	X	X
LFM-48	X	△	△	O	O	O	O	O	O	△
LFM-8	△	O	O	O	O	O	O	O	O	△

LFM-22 / Sn + 0.7Cu

LFM-48 / Sn + 3.0Ag + 0.5Cu

LFM-8 / Sn + 3.0Ag + 0.7Cu + 3.0 Bi

O = no crack

△ = part cracking

X = 100% crack

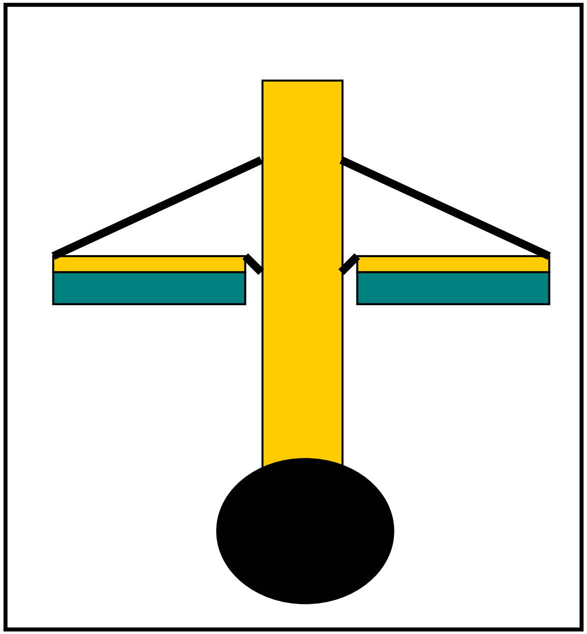
-a-2; heat cycle / 1,000 cycles

	1	2	3	4	5	6	7	8	9	10
Sn63	X	X	Δ	Δ	O	O	Δ	X	X	X
LFM-22	X	Δ	Δ	Δ	O	O	Δ	Δ	X	X
LFM-48	X	Δ	Δ	O	O	O	O	O	Δ	X
LFM-8	X	Δ	O	O	O	O	O	Δ	Δ	Δ

From 500 cycles and 1,000 cycles.

Result: Sn63 = LFM-22 < LFM-48 < LFM-8

3-b; Creep



Terms : 1. Pattern size / diameter 3.0mm

2. Hole size / diameter 1.0mm

3. Copper wire size / diameter 0.9mm

4. Solder quantity / 30mg

5. Weight / 1kg

6. 130 degree C atmosphere

Result : Sn63 / Dropped off after 2.58h

LFM-22 / Not dropped after 1,000h, so we stopped test.

LFM-48 / same as above

LFM-8 / same as above

Each Pb Free metal is better than Sn 63.

3c) Peel Off Strength

(0.5mm 100 Pin QFP. Cut off component body. Pull leads up at 45º, 5mm per min. PCB = 1.6mm thick, Copper Pads on pcb)

Alloy	Min(g)	Max(g)	Average(g)
Sn63	170	350	264
LFM 8	100	320	239
LFM 22	160	348	246
LFM 48	142	321	267

Conclusion of Strength

HEAT CYCLES

Sn63 = LFM-22 < LFM-48 < LFM-8

CREEP

Sn63 < LFM-22, LFM-48, LFM-8

PEEL OFF

Sn63 = LFM-22, LFM-48, LFM-8

- **LFM-8 (Bi contained) is hard, but brittle.**
- **If LFM-8 is used on Sn+Pb plated components, low temperature eutectic (96 Degree C) of Sn+Pb+Bi occurs.**
- **Hence, Bi contained metal is not suitable as Pb Free metal.**
- **LFM-48 (Sn-Ag-Cu) is ideal as Pb Free Solder.**

4) TM-TS Lead Free Paste Flux Considerations

- Flux has to be more ‘efficient’ to compensate for poor alloy flow
- Flux reaction with high Sn% powder must be minimal
- Give paste wide process window
- Flux has to leave ‘safe’ residues
- Many others..
  - Pin testable
  - Cosmetically pleasing
  - Compatible with resists and conformal coatings
  - Withstand double sided reflow

4a) Flux Reliability Test to IPC

• i)	SIR	IPC-TM-650 2.6.3.3
• ii)	Copper Plate Corrosion	IPC/TM/650 2.6.15
• iii)	Halide Test	IPC-TM-650 2.3.33
• iv)	Copper Mirror Test	IPC-TM-650 2.3.32
• v)	Fluoride Content Test	IPC-TM-650 2.3.35.1

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4a-i) IPC SIR Test Data TM-TS Flux

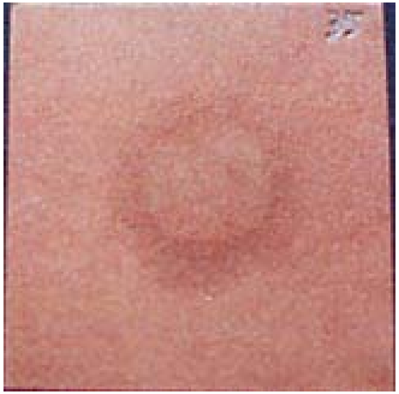
a）SIR Test/Voltage applied moisture resistivity test （Ω）

TM－TS FLUX	Initia l stage	96hr	240hr	500hr	1000hr
SIR	5.17E+12	3.92E+09	4.48E+09	7.31E+09	1.63E+10
Voltage applied moisture resistivity test	1.65E+13	4.01E+09	4.80E+09	8.70E+09	2.12E+10

No electromigration

4a-iii/iv) Halide & Copper Mirror Results for TM-TS Flux

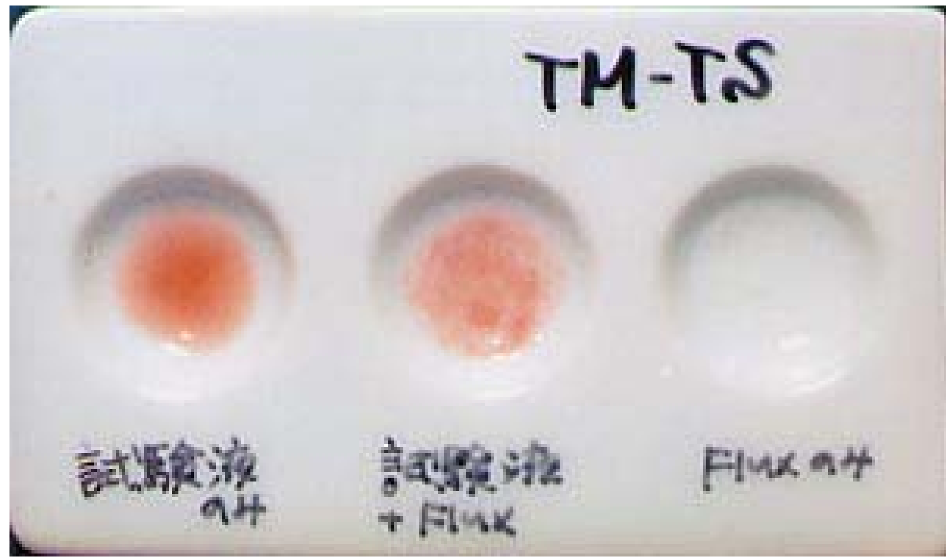
- **Halide Test – Pass**
  - **No White Crystals/Colour Change**



- **Copper Mirror Test - Pass**
  - **No evidence of copper removal**

4a-v) Fluoride Content Test Result

- Fluoride Content Test – Pass
  - No change to yellow colour

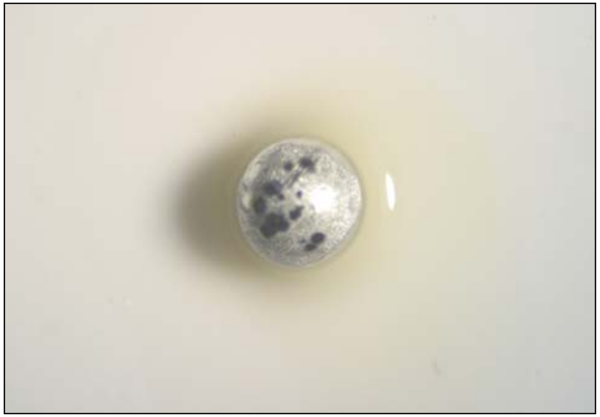


4b) Paste 'Workability' Test to IPC

• i) Slump Test (pass)	IPC-TM-650 2.4.35
• ii) Solder Ball Test	IPC-TM-650 2.4.43
• iii) Tack Force Test	IPC-TM-650 2.4.44
• iv) Wetting Test	IPC-TM-650 2.4.45

4b-ii) LFM 48 X TM-TS SOLDER BALL RESULTS

- Top photo is heated 15 min after print
- Bottom photo is left for 4 hrs at room temp and humidity @40% before reflow
- No solder balls = Pass



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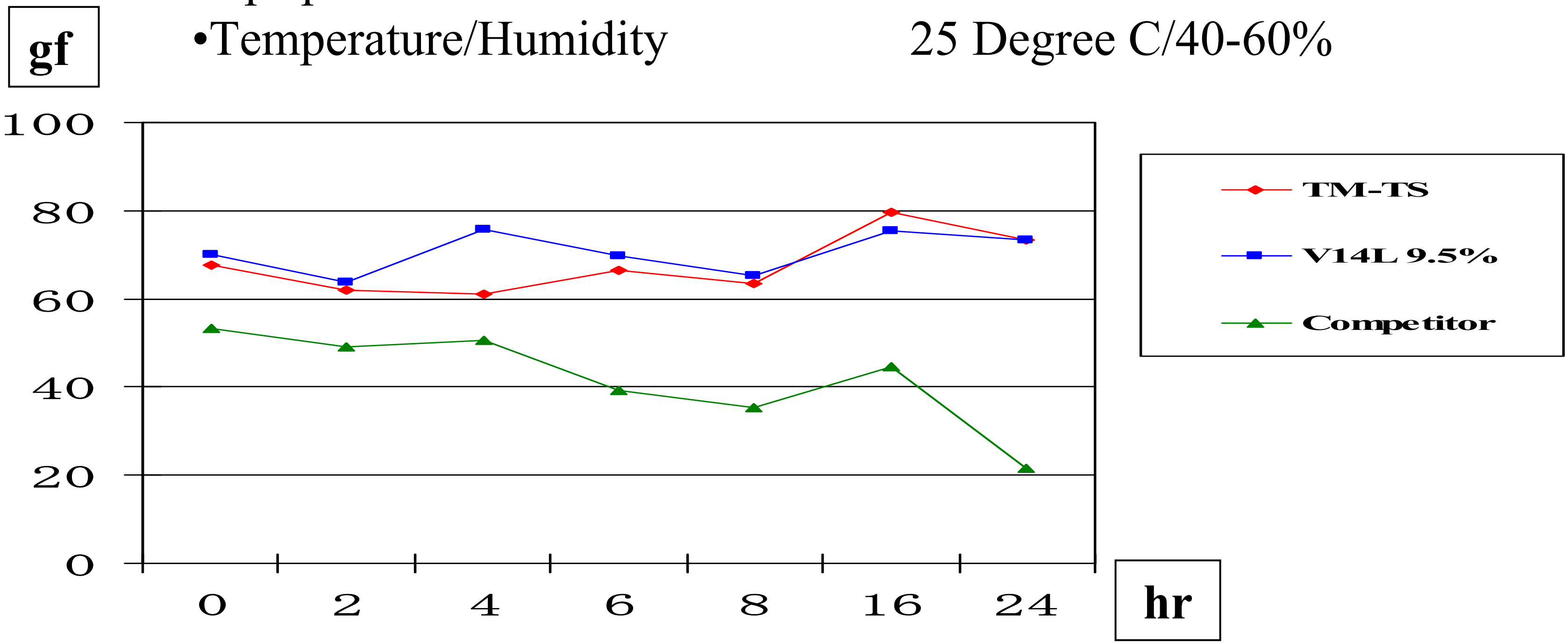
4b-iii) Tack Force

•Printing Thickness	250 micron
•Load	50g
•Pin diameter	5.1mm
•Down speed	12mm / min
•Creep time	0.2 sec
•Up speed	200mm / min
•Temperature/Humidity	25 Degree C/40-60%



4b-iv) IPC Wetting Test

Inspect for poor wetting and dewetting - pass

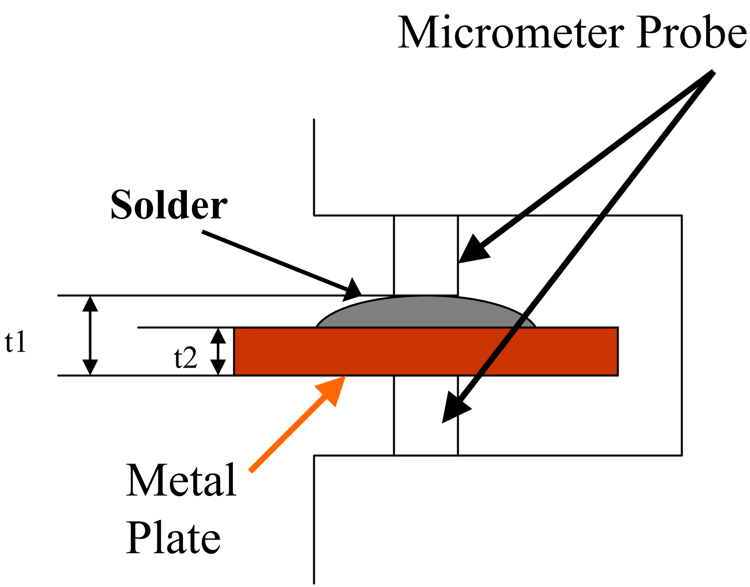
4) FLUX CONCLUSION

- Flux Passes IPC Reliability spec
- Flux passes IPC ‘Workability’ spec
- HOW DOES IT WORK AS A PASTE ?

5) Spreadability on different surfaces

- Metal sample piece $0.3 \times 50 \times 50$(mm) prepared as oxide plate by placing in heat chamber at 150ºC for 1 hour previous to test.

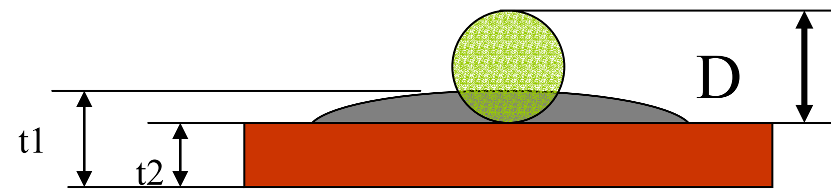
  About 0.3g of solder paste is then measured within 0.001mg of accuracy and placed in the center of each oxide plate. JIS-Z-3197 specification is followed for basic soldering technique.
- Measurement of spreadability



$$\text{Spreadability}(\%) = \frac{D - H}{D} \times 100$$

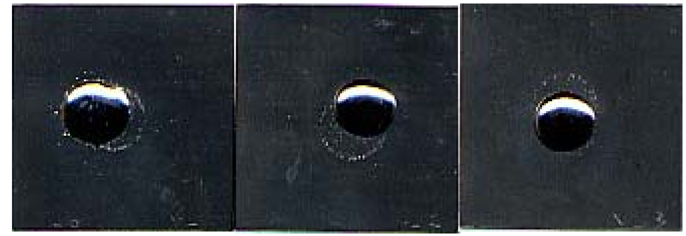
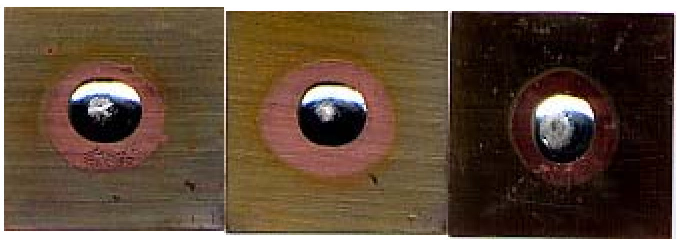
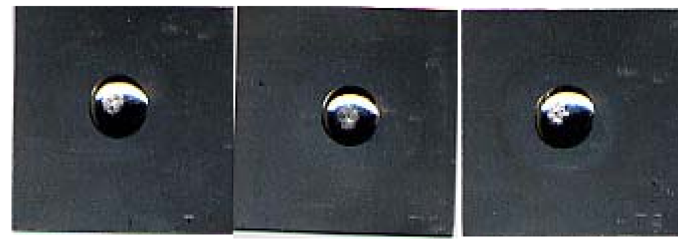
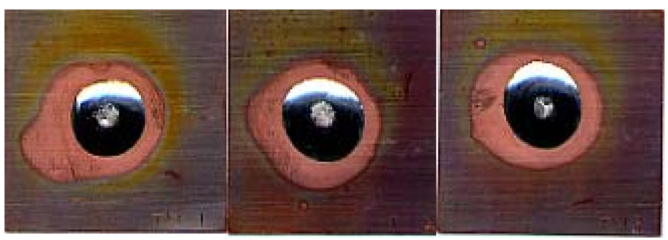
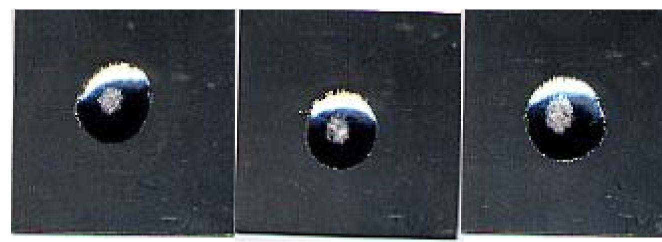
$H = t1 - t2$

D:diameter of solder before melt, assumed as sphere



Spreadability JIS-Z-3197

0.3g / 230 Degree C / 30sec

	Oxidized Cu	Ni Plate
Sn62 V14L	 Spread ratio : 92.5%	 Spread ratio : 72.4%
Competitor Sn62	 Spread ratio : 74.1%	 Spread ratio : 66.2%
LFM-48 X TM-TS	 Spread ratio : 80.6%	 Spread ratio : 78.3%

Ni Plate Peel Off Strength on Long and Short Plate (Part of Cell Phone Assembly. Pass/Fail >2kgf)

PASTE	Min(kgf) (Long)	Max(kgf) (Long)	Ave(kgf) (Long)	Min(kgf) (Short)	Max(kgf) (Short)	Ave(kgf) (Short)
ALMIT	3.72	8.45	5.82	3.96	11.23	6.76
B	2.67	7.56	3.74	1.37	7.00	3.77
C	2.26	8.05	3.66	1.24	5.83	3.54
D	0.59	5.11	2.75	0.2	4.08	1.87

All solder pastes were SAC305 alloy and 'L1' Flux Classification as per IPC Specification

Ni Plate ‘Peel Off’ Conclusion

The joint strength related to peel off is predominantly affected by the ability of the flux to promote good wetting between the base metal and lead free solder.

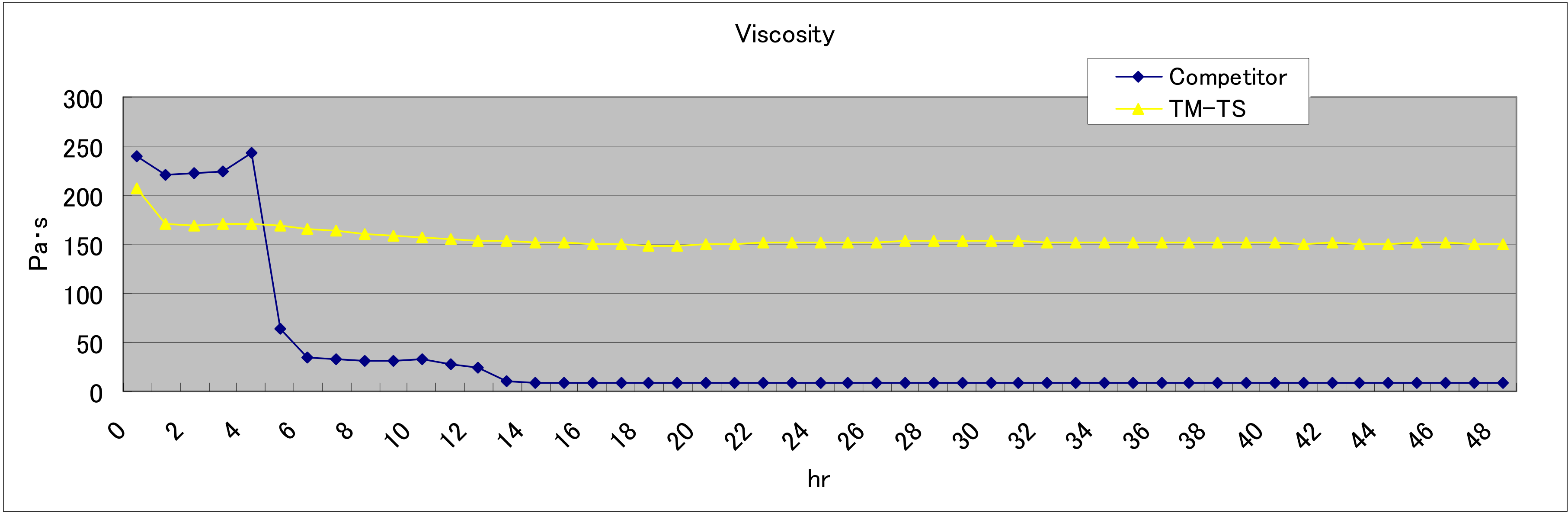
Fluxes with similar classifications can give greatly differing joint strengths and hence different joint reliability.

Solder paste flux chemistry is critical to guaranteeing high reliability solder joints.

6) Pb Free SMT Issues

- a) Stencil Life of Paste
  - Reaction between flux/solder spheres
    - Reaction by-product thickens paste
- b) More chance of ‘voiding’ or ‘porosity’
- c) More care in reflow to minimise ‘Delta T’

6a) Paste Viscosity



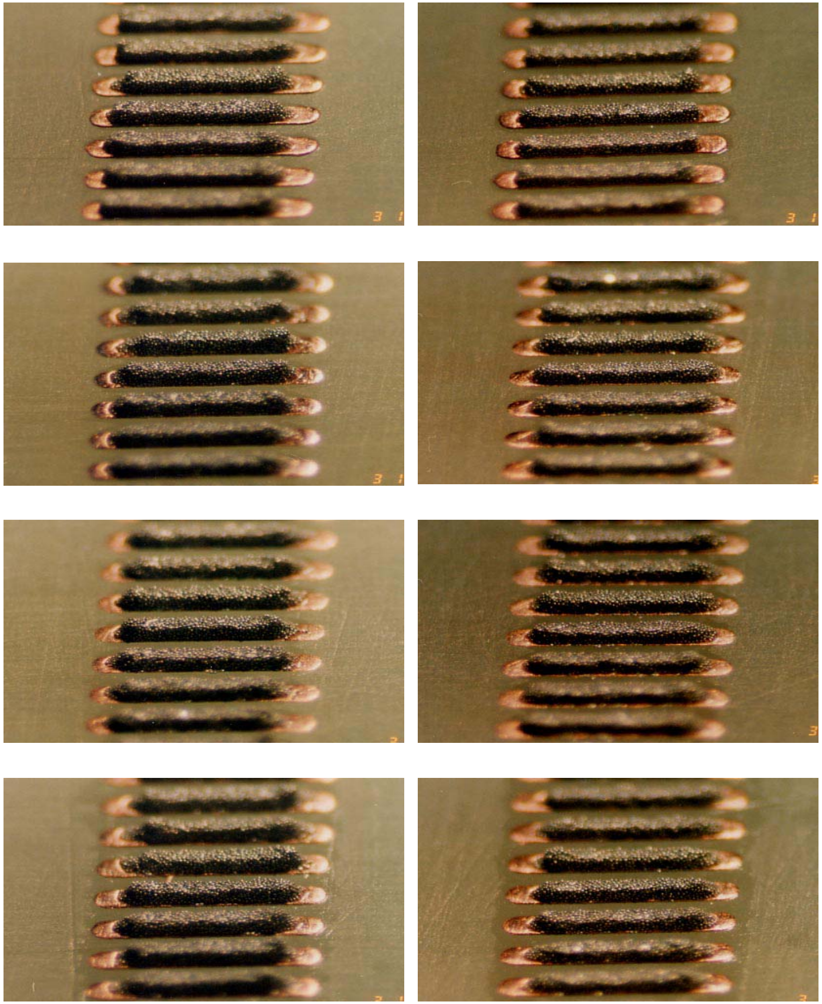
Almit TM flux range has very long stencil life

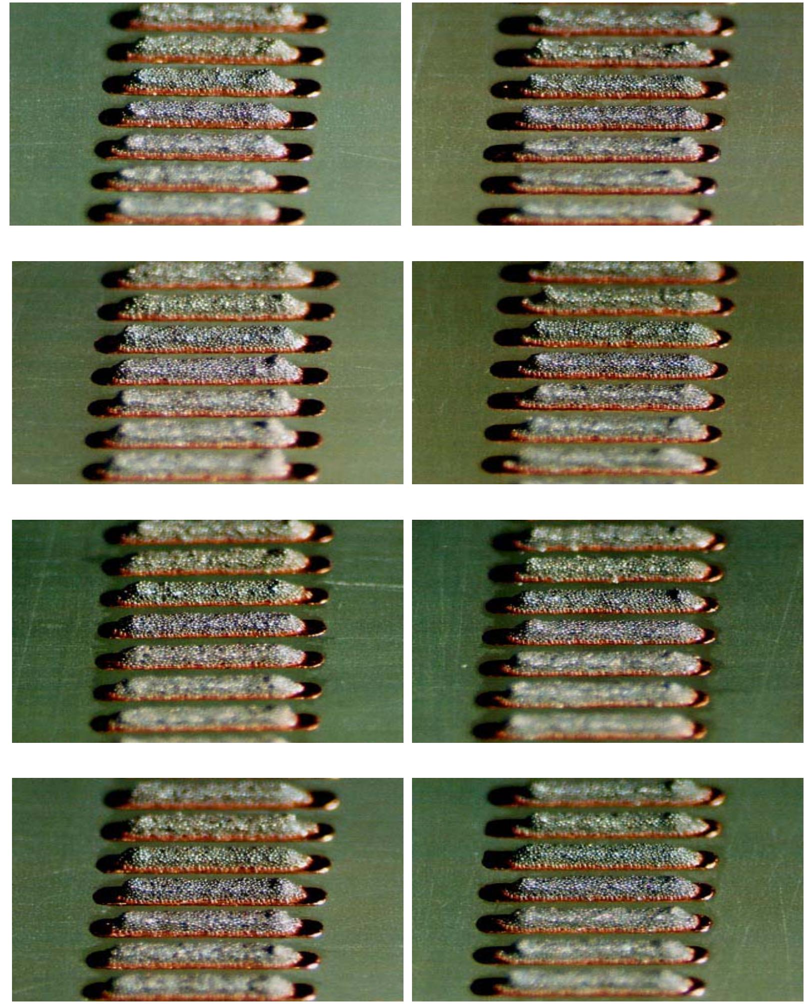
Printability

Initial stage

After 24hr mixing

(8hr X 3days rolling)





6b) Pb Free SMT Issues

Void occurrence
with Pb Free solder paste

Pb Free Solder/Pb Free BGA

↓

Wetting of solder metal is worse.
Viscosity of molten metal is higher.

↓

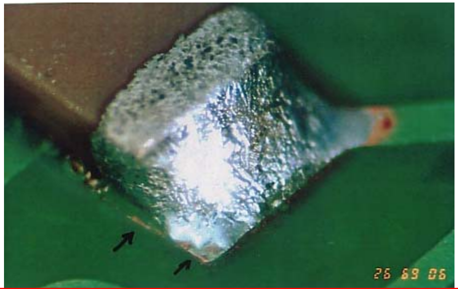
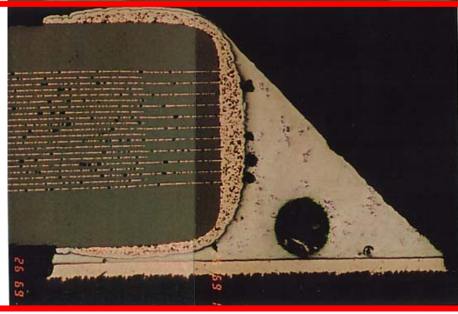
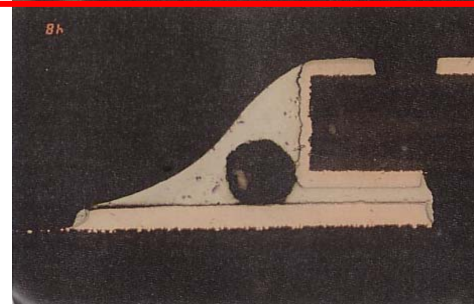
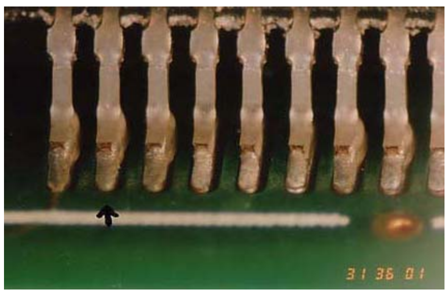
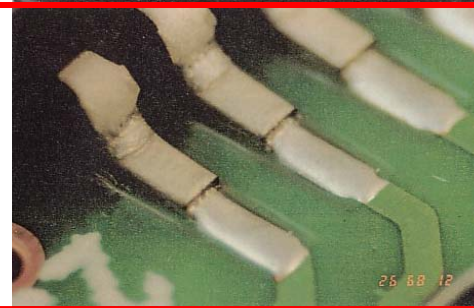
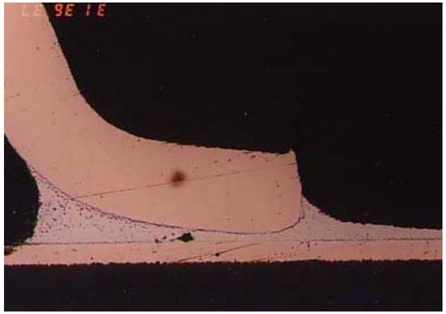
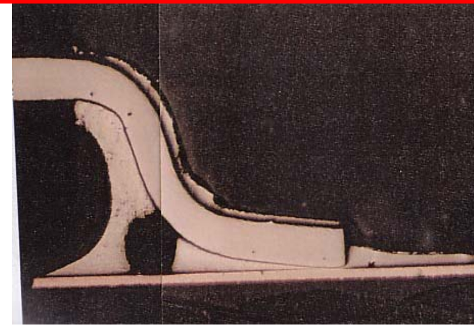
The gas within PCB and solder finds it hard to escape while the solder is melting. Flux produces moisture due to oxidation/reduction process in reflow.

↓

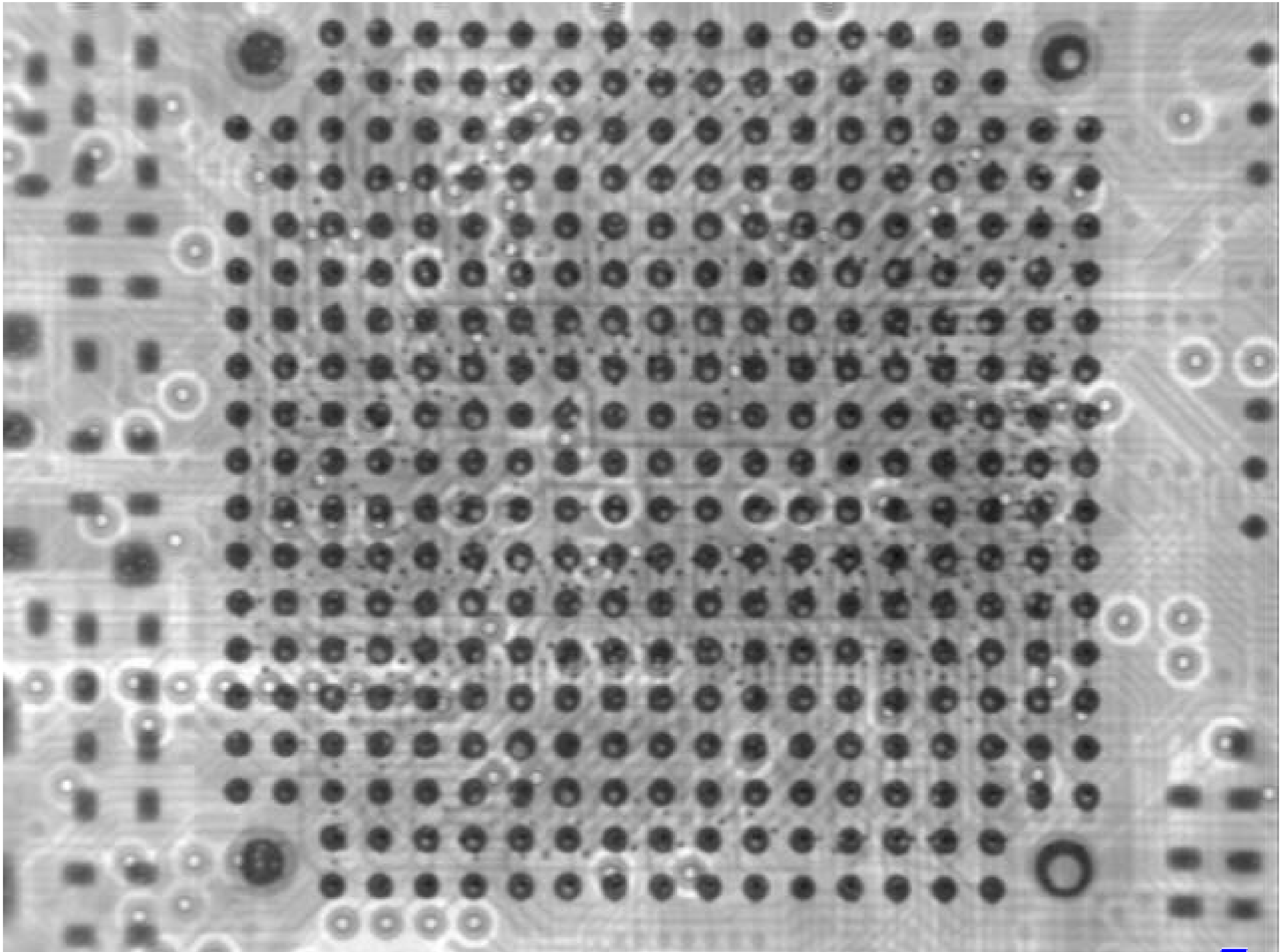
Void occurs

↓

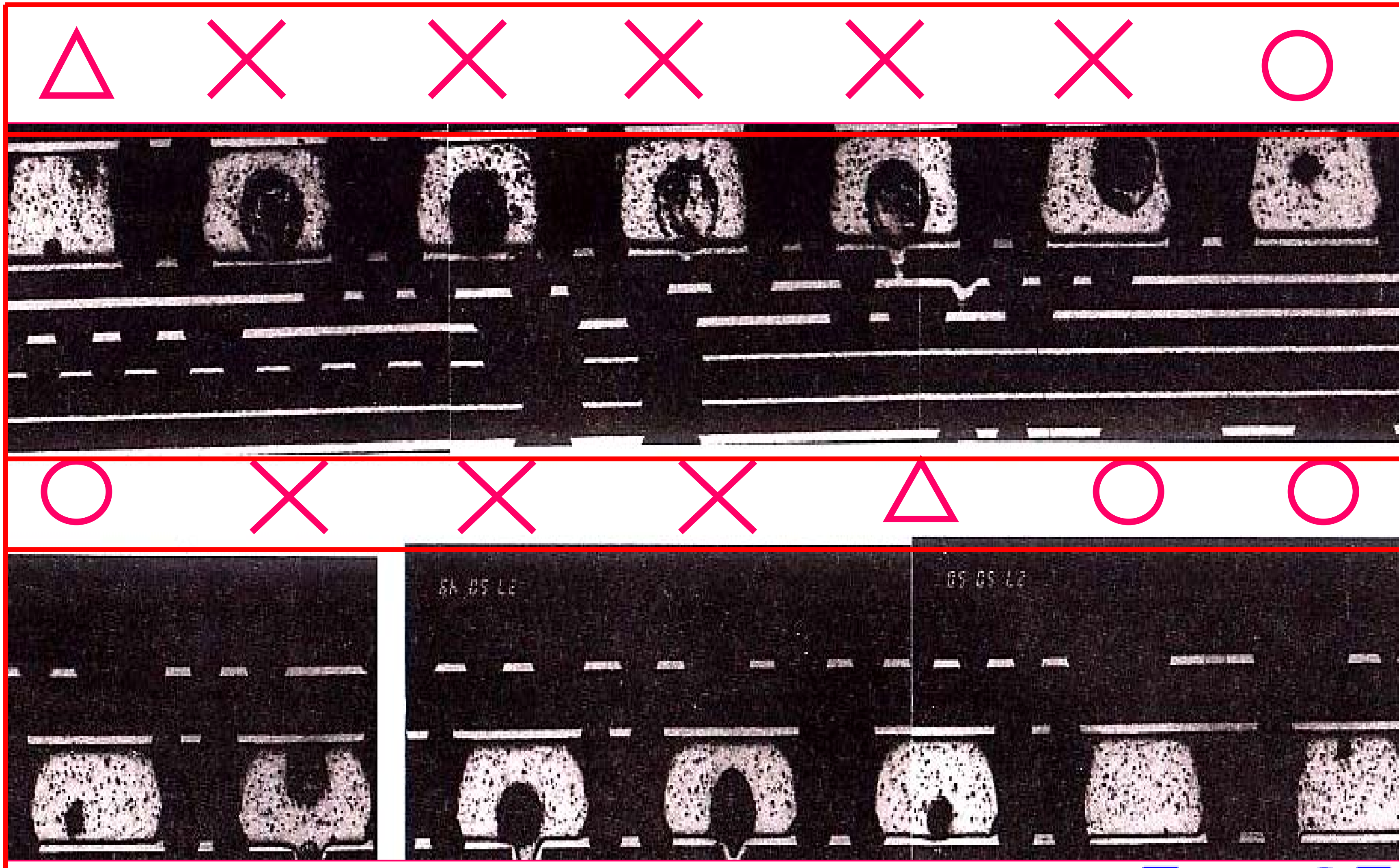
Joint reliability is reduced depending on the location and size of void.

	OK	NG
Appearance of chip component		
Cross-section		
Appearance of IC component		
Cross-section		

Typical Lead Free BGA X-RAY

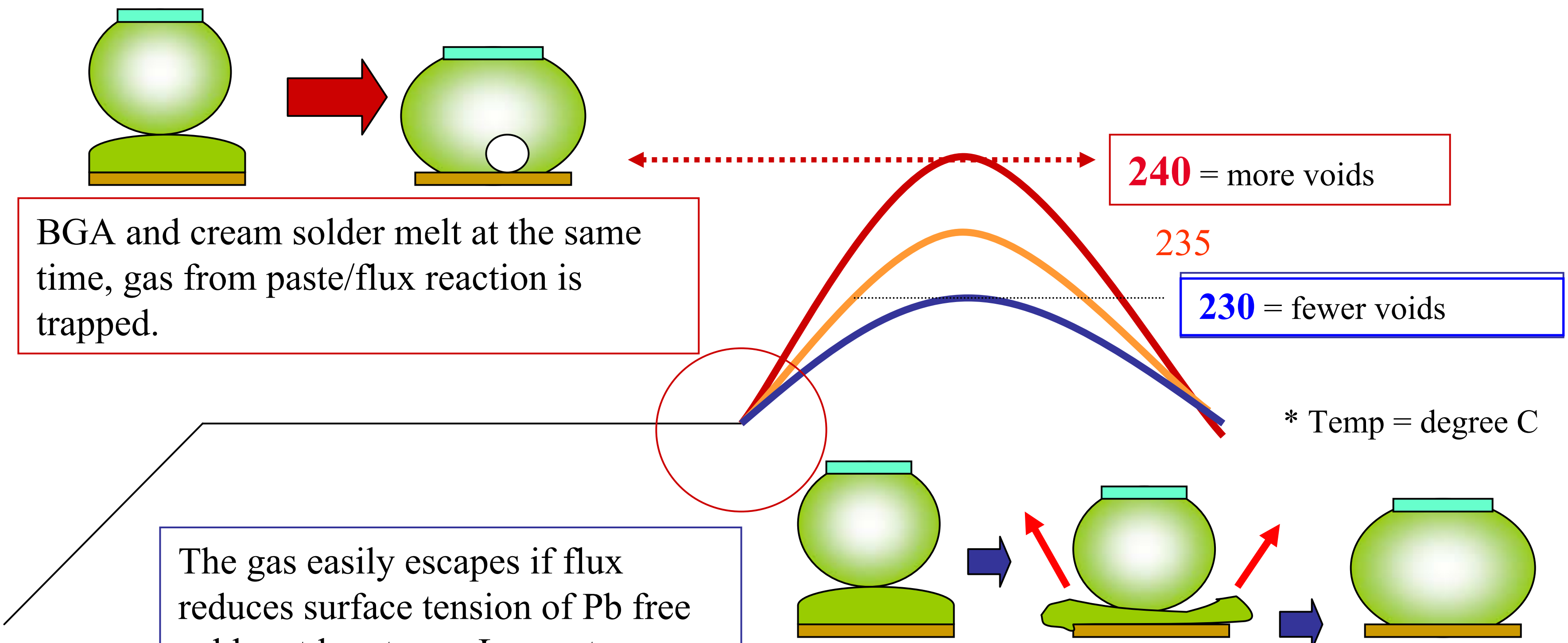


BGA cross-section



Void occurrence in BGA / CSP

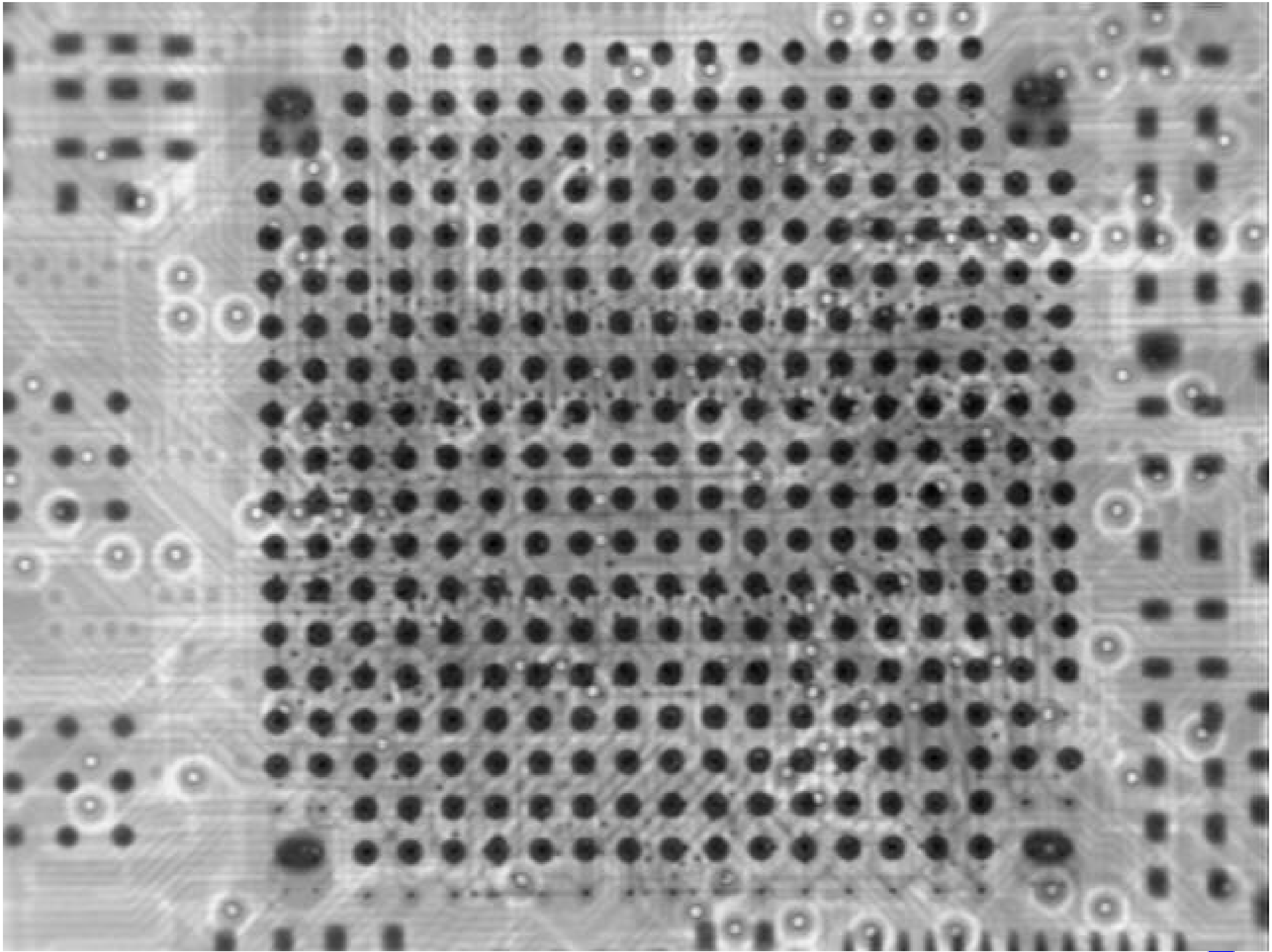
Advantage of low peak reflow temperature using LFM 48 X TM-HP = NO void



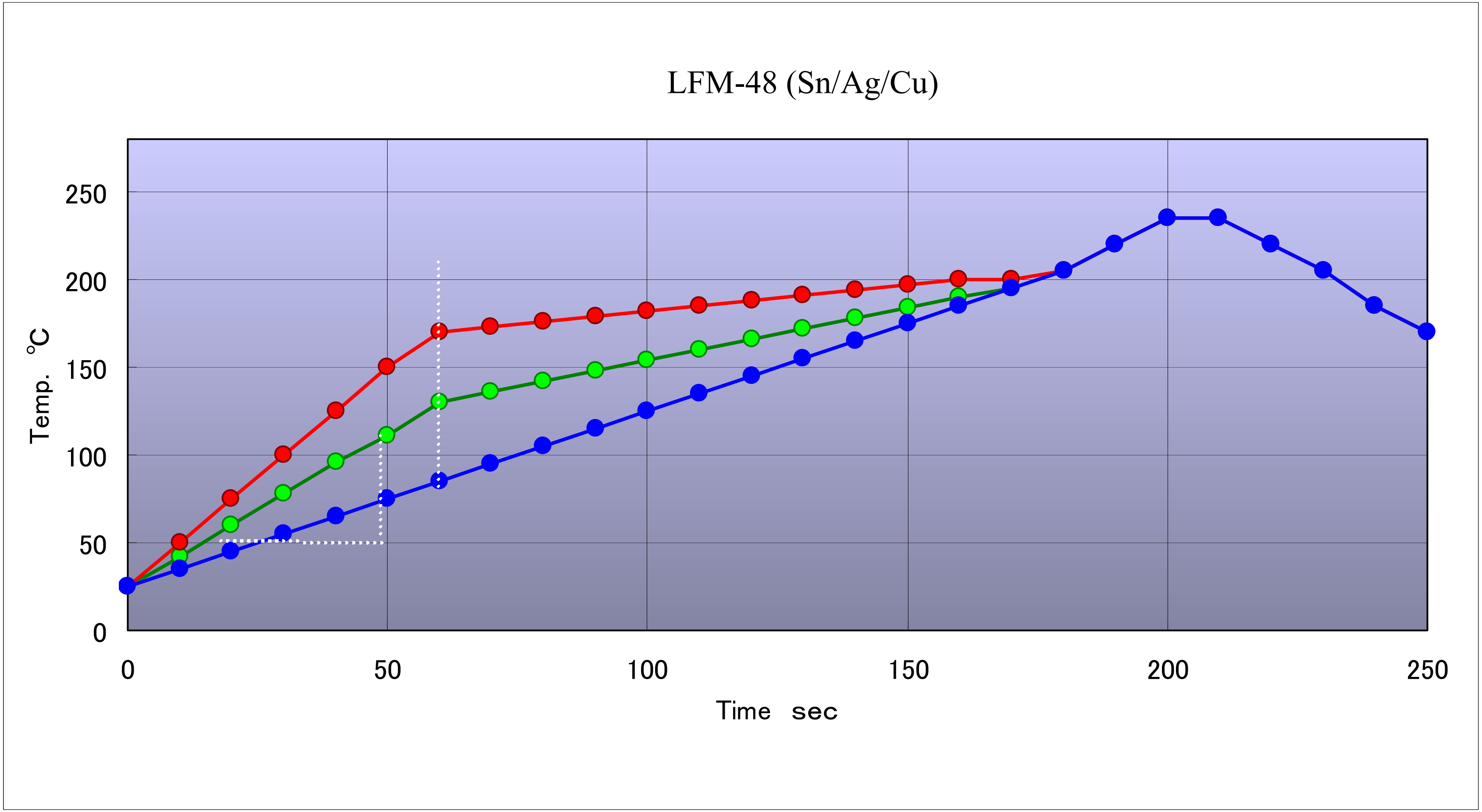
BGA and cream solder melt at the same time, gas from paste/flux reaction is trapped.

The gas easily escapes if flux reduces surface tension of Pb free solder at low temp. Lower temp = less oxidation=less gas from flux reaction=less voids.

LFM 48 X TM-HP X-RAY



6c) Recommended Profile

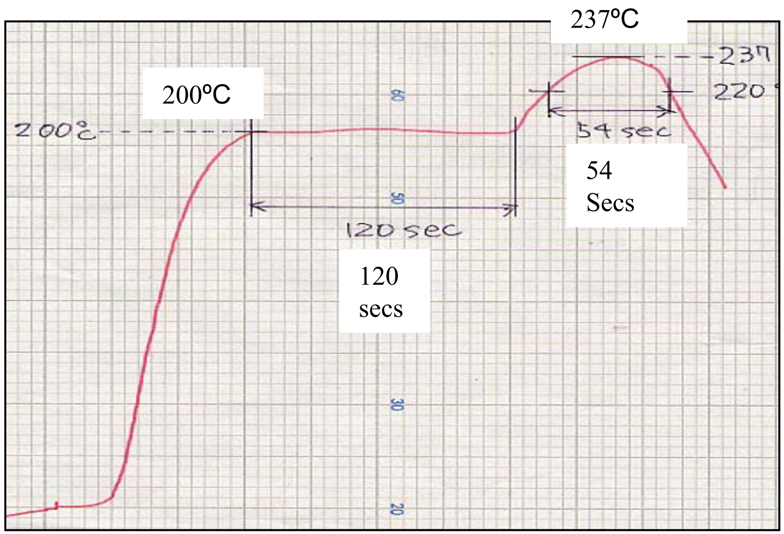


* Create the temperature profile considering the substrate size, heat capacity of components, etc.

Problems in Reflow

- Complex pcbs need high temp. preheats for long time to minimise ‘Delta T’, can paste withstand this ?
  - Is paste solderability affected ?
  - PCB hotspots will potentially give more solder voids.
  - Will moisture sensitive devices survive ?
    - Pre-baking seriously affects component solderabilty and hence more chance of voids.

High Temp Preheat



Reflow Profile

Reflow oven: Eitec tectron

ARS 330WN

Air 4 zone

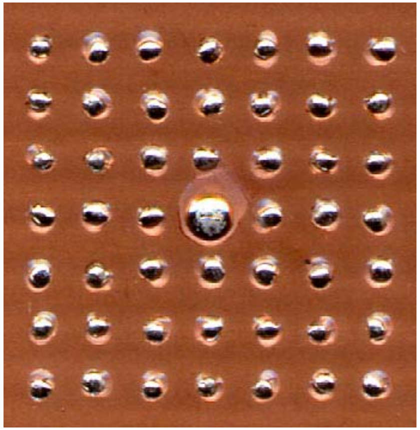
PH constant 200ºC /120sec

Above 220ºC/ 54sec

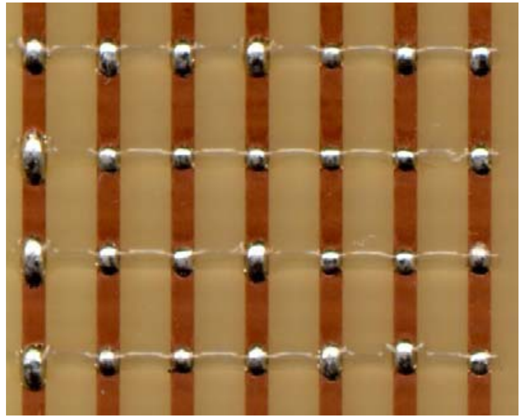
Peak 237ºC

LFM-48 W TM-HP

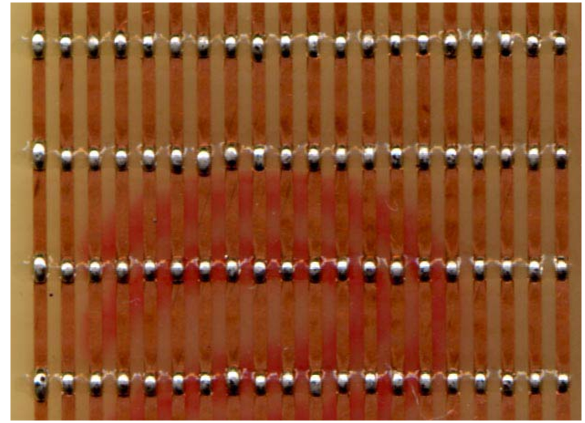
Φ0.3



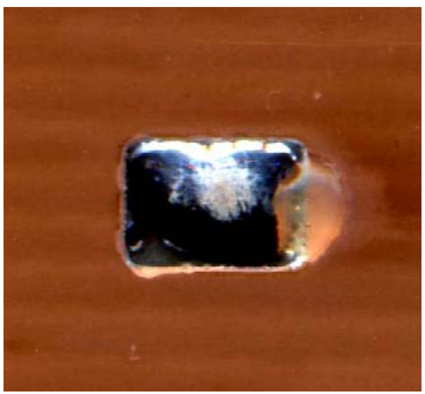
JIS-1



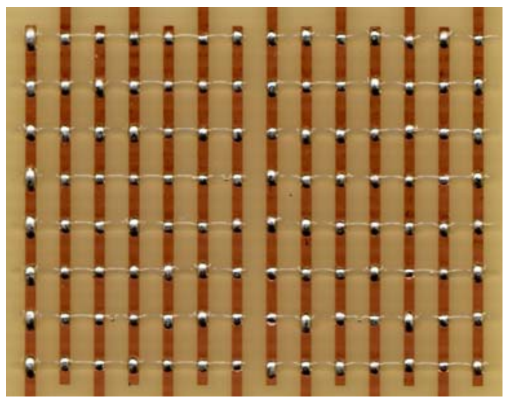
JIS-2



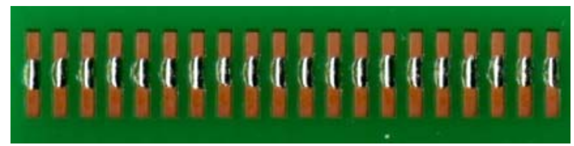
Flat pattern



Overall view of JIS-1

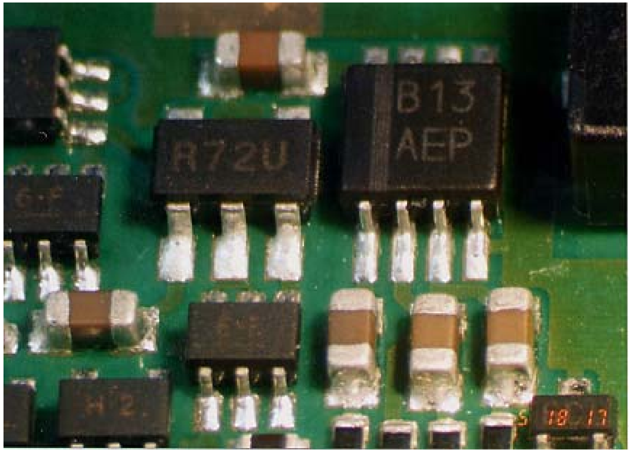


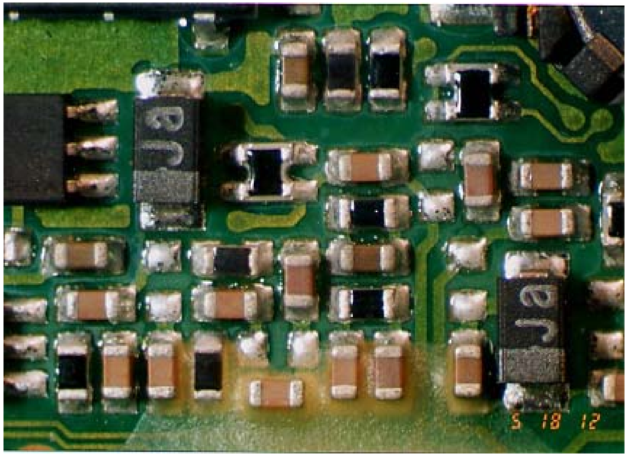
1 dot

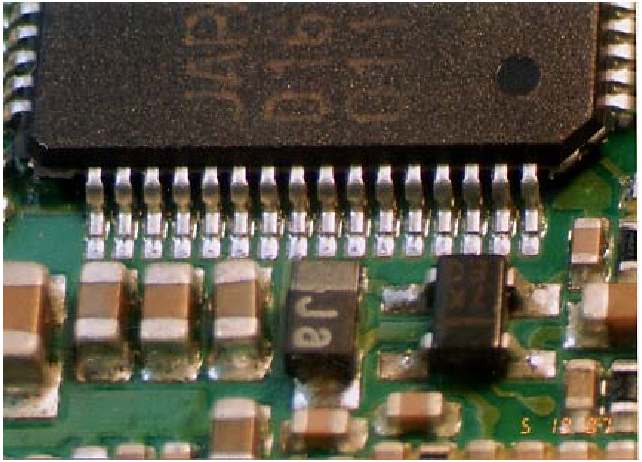


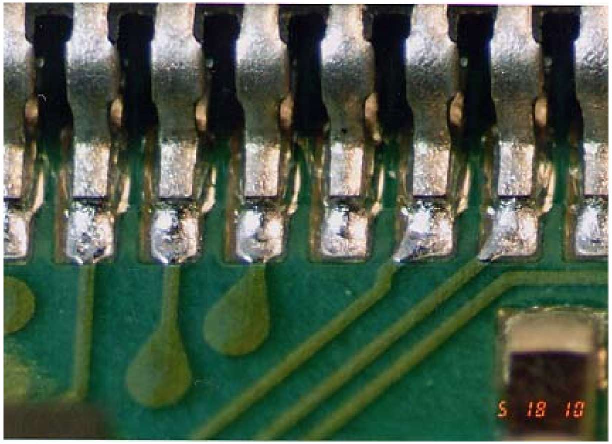
Φ0.3mm	JIS-1	JIS-2	Flat pattern	1 dot
Melt	Solder ball	Coalescence	Surface Finish	Dot spreadability
○	○	○	○	○

Appearance after Reflow









Overall Conclusion 1

- A high reliability lead free joint is achievable.
- Lead free solder ‘stronger’ than tin/lead.
- Flux residue reliability meets IPC standard.

Overall Conclusion 2

- Lead Free solder paste viscosity more unstable and will affect print consistency.
- Joint strength dependent on flux performance rather than alloy selection.
- PCB Delta ‘T’ reduced by using paste with high thermal stability flux enabling use of long/high temp preheats.

Thank You

almit