SnAgCu Lead-Free Solder Paste Selection Experiment using Taguchi Statistical Test Method

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Experimental Layout and Design

Design Of Experiments (DOE) according the Taguchi method is used to investigate the most important variables for the screen printing process and the responses of 6 different lead-free solder pastes to this variables. Furthermore is investigated if a solder paste gives good reflow results with or without a nitrogen environment.

Quality will improve if the distribution of a strong process variable will decrease.
The Taguchi method can help to get to the optimum process setting with the smallest distribution.
Taguchi offers a set of test schemes or orthogonal arrays. By pre-defining the most critical variables it is possible to use the smallest possible array. And by that decrease the number of test runs.

Taguchi terminology

Factor	a defined process variable that can be set to different levels.
Response	reaction on a process variable change that preferably can be quantified by measuring.
Quality Criterion	a defined process result that is quantitative

Project Planning

1) **Cross Functional Team**	- form a team - define the result that is desired - make a planning
2) **Brainstorm session**	- define the quality criteria - define the factors and their levels (as bold as possible)
3) **Layout and Design**	- define any interactions - select the orthogonal array - define sample size - define test method
4) **Preparation of the Experiment**	- make detailed planning - R&R Analysis
5) **Executing of the experiment**	- do the test runs
6) **Data Collection**	- measure the quality criteria
7) **Data Analysis**	- make response graphs - define the factors that influence the process - define the optimum setting - predict the result of the optimum setting
8) **Confirmation Run**	- check the conclusions in a confirmation run using the optimum settings - collect and analyse data
9) **Conclusion and Implementation**	- verify the conclusions in the actual process.

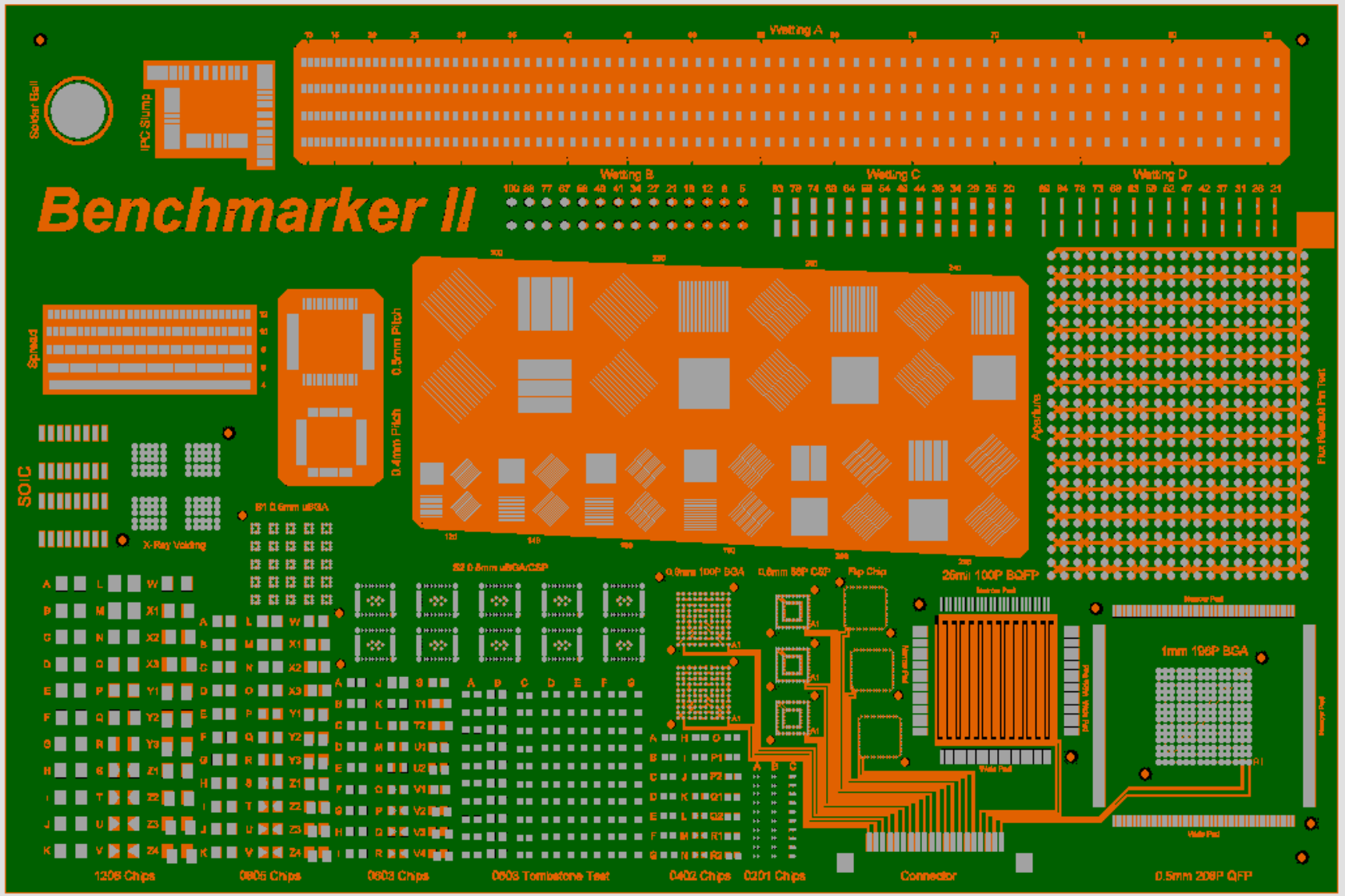
Brainstorm Session

The following main decisions were made during the brainstorm sessions:

- **Solder Paste:** **SAC Alloy** 95,0 - 95,5Sn / 3,0 - 4,0 Ag / 0,5 - 0,7 Cu, Type 3, No Clean
- **Max. 6 Solder Pastes** to be tested
- **Reflow profile** is an average of all advised solder paste profiles by the manufacturers
- **Special Board Design** must be found to get comparative data for the future
- **Easy inspection** of the quality criteria must be possible
- **Board Finish**: Organic Solderability Preservative (**OSP**) Entek Plus
- Fixed test **machines** must be used that are **lead-free compatible**

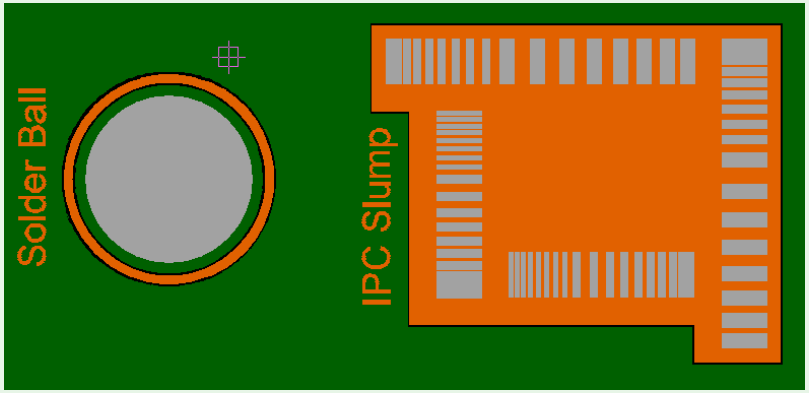
Test Board “Benchmarker II”

The following test board is used during the experiment:



Test Board “Benchmarker II”

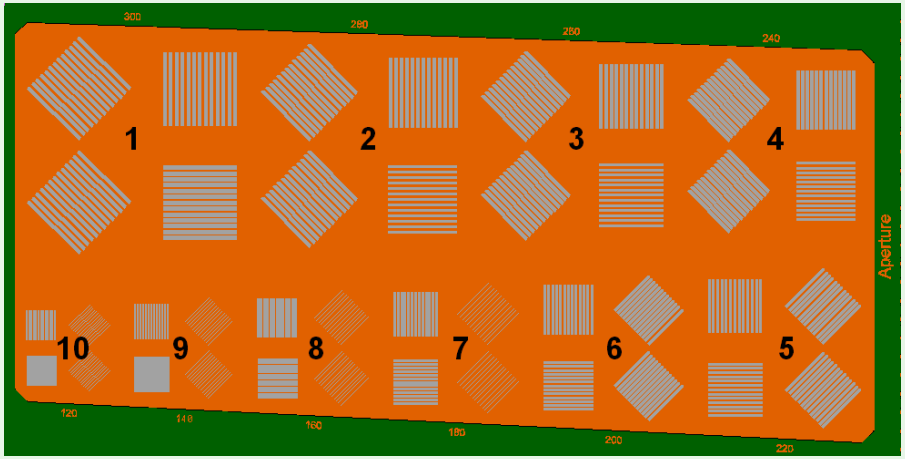
In detail, the quality criteria examined on this “Benchmarker” board are:



Solder Ball: number of satellite solderballs after reflow are counted *(the smaller the better)*

IPC Slump: After printing, the board is left in production environment and after 15 min. the number of shorts are counted for the left and bottom pattern. “Cold Slump” *(the smaller the better)*

Hot Slump: The same principle as IPC Slump, but now the board is left at 150°C for 15 minutes. *(the smaller the better)*

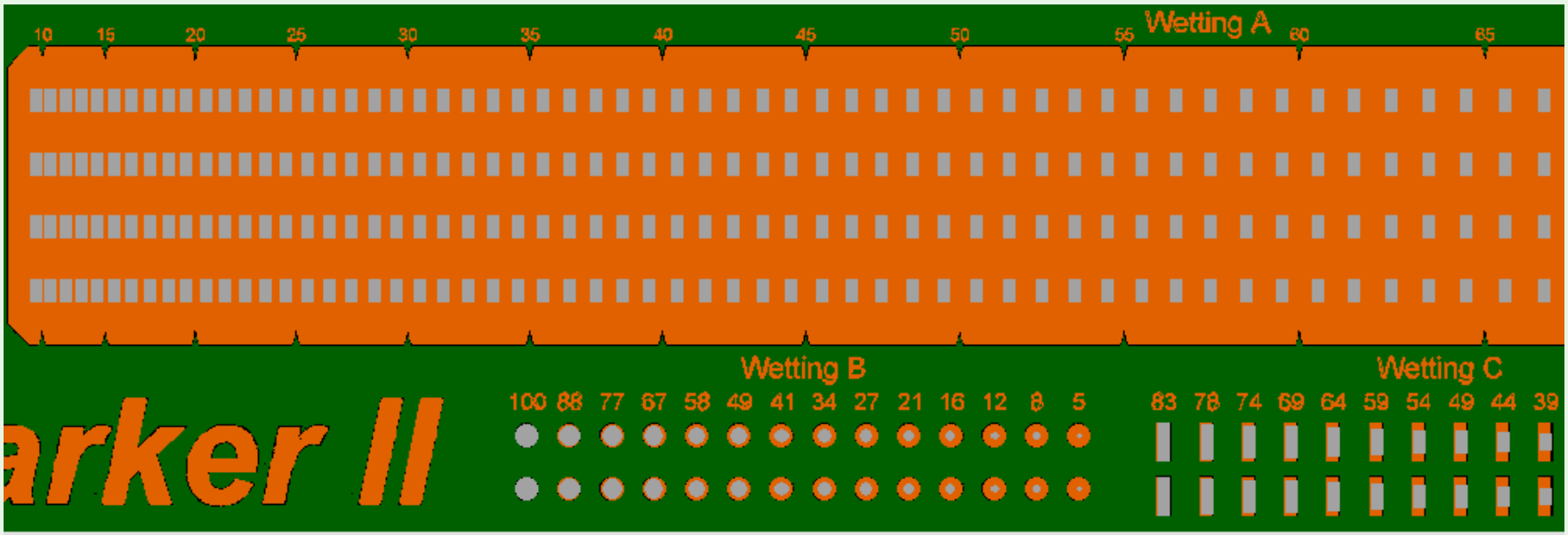


Aperture: The smallest pattern that can be printed without any quality problem gives the highest quantification (1- 10) for aperture result. *(the larger the better)*

tested pitch sizes:

1 = pitch 0,60 mm	6 = pitch 0,40 mm
2 = pitch 0,56 mm	7 = pitch 0,36 mm
3 = pitch 0,52 mm	8 = pitch 0,32 mm
4 = pitch 0,48 mm	9 = pitch 0,28 mm
5 = pitch 0,44 mm	10 = pitch 0,24 mm

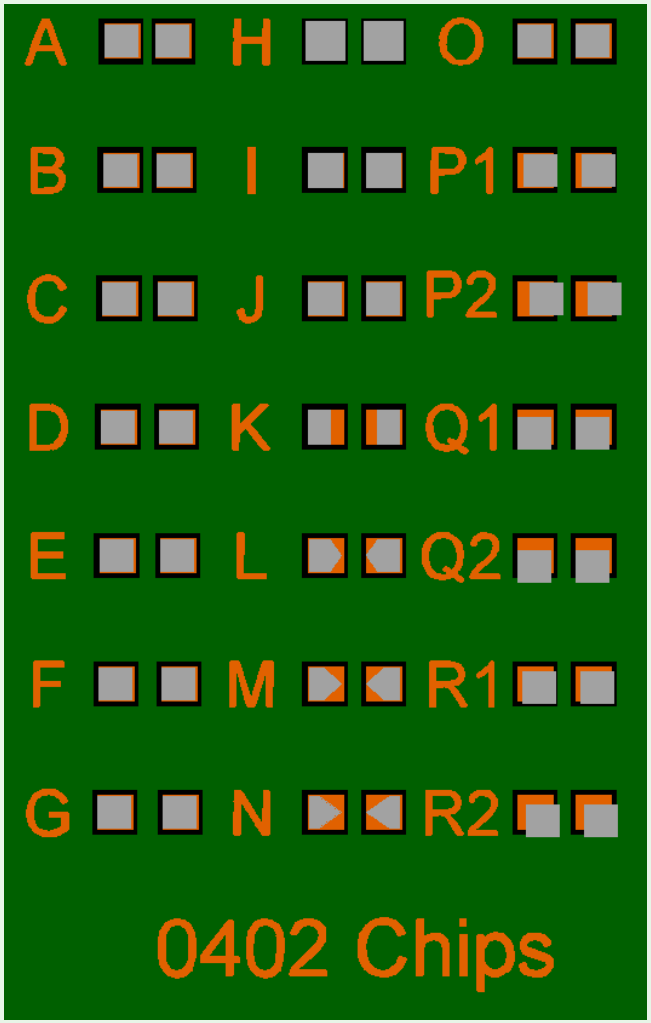
Test Board “Benchmarker II”



Wetting A: The row that has the longest continued wetting results after reflow from left to right, gives the score that is found above the wetting pattern.
(the larger the better)

Wetting B: The circle that is completely covered under solder after reflow, gives the lowest score that is found above that circle.
(the smaller the better)

Test Board “Benchmarker II”



Brainstorm Session

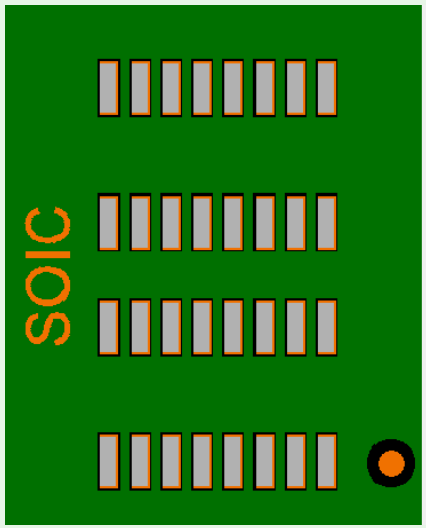
Tombstoning: By giving the solder paste pattern an offset to the solder lands, the tombstoning phenomena is provoked.
Using visual inspection the pattern that causes tombstoning is logged.
Some tombstoning failures can be expected, some can’t.
One out of three boards is equipped with 0402 chip capacitors on the patterns A to R2.
After placement with a chip shooter the components are examined for shifting.
This provides information of paste tacking properties.
The component are placed without offset to the solder lands.

The amount of tombstoning is an indication of paste properties.
(the smaller the better)

Reference

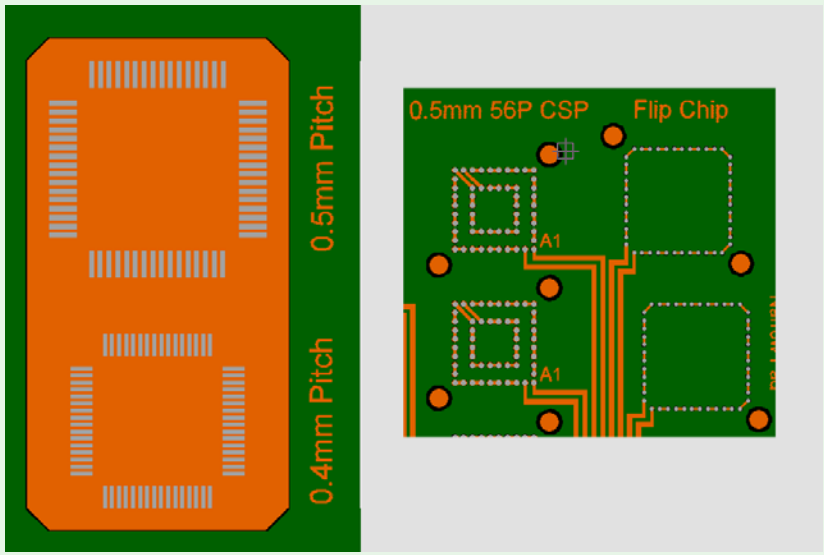
In a SnPb based process tombstoning was seen when the overlap of the termination of the chip 0402 capacitor with the solder paste was less than 0,06 mm^2 in a N_2 environment.
So expected and unexpected tombstoning can be found.

Test Board “Benchmarker II”



Tacking: One out of three boards is equipped with some leaded components.
After placement by a chip shooter the boards are moved for two minutes at high speed by this chip shooter. The amount of shifted components are examined and gives quantitative information about paste tacking.
(the smaller the better)

Indicative information:



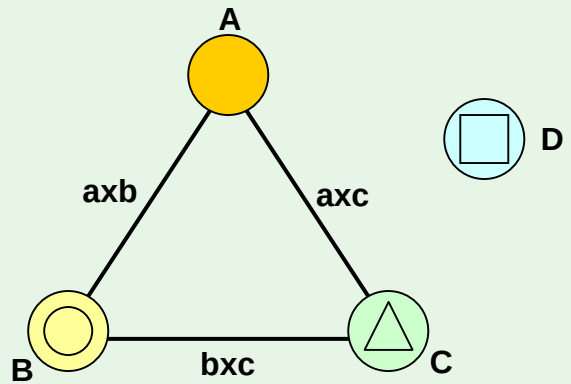
The same leaded components are examined on wetting. This done just indicative.
Also some other areas of the test board are looked at, like 0,4 and 0,5 mm pitch and CSP, Flip Chip printing behavior.
(no data collected)

Layout and Design

Three factors can have interactions and by that, the orthogonal array L8 ($2^{7)}$ can be used.

Testrun No.	Factors						
	Squeegee Pressure	Printing Speed	3	Separation Speed	5	6	Nitrogen in Reflow
1	6	50	-	0,2	-	-	1
2	6	50	-	2	-	-	2
3	6	75	-	0,2	-	-	2
4	6	75	-	2	-	-	1
5	8	50	-	0,2	-	-	2
6	8	50	-	2	-	-	1
7	8	75	-	0,2	-	-	1
8	8	75	-	2	-	-	2
Interaction	A	B	**axb**	C	**axc**	**bxc**	D
Group	1	2		3			

Array L8 (2^{7})



Every test run is started with 1 dummy board to wet the stencil.
The dummy is not collected into the data!
Subsequently 3 boards are printed and reflowed. Every 3rd board is been provided with components.

Test Method

The following equipment is used for the experiment.

Screen Printer

Horizon

SMT Chip Shooter

CP-643E

Reflow Oven

Quantis-Pro III 820N

DeK Horizon Machine Settings

Stencil	Laser cut stainless steel 125 µm thick (no reductions to pad design)
Squeegee	Metal
Paste load on the stencil	Approx. 500 gr.
Fixed board support	Print gap 0 mm
Separation distance	1 mm
Screen cleaning	Every beginning of the test run (wet / vacuum / dry)

FUJI CP-643E Machine Settings

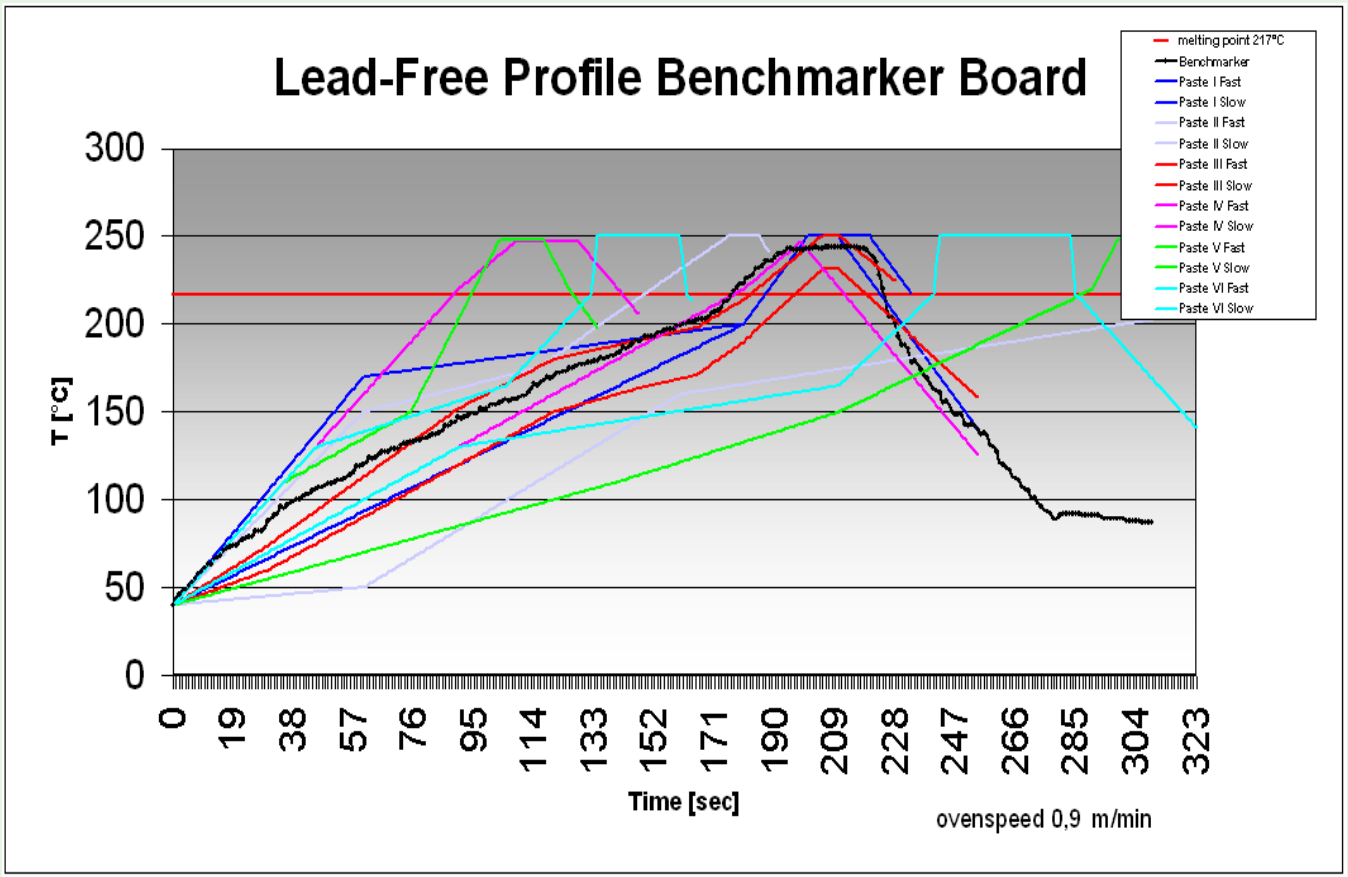
Calibrated	Placing accuracy ±0,1 mm
Table speed	High

Test Method

Vitronics-Soltec Quantis Pro III **Machine Settings**

The reflow profile has been set to fits right in between the limits of all solder pastes

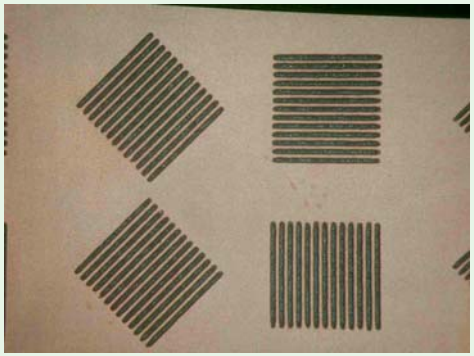
If nitrogen is switched on, there is < 500 ppm oxygen.



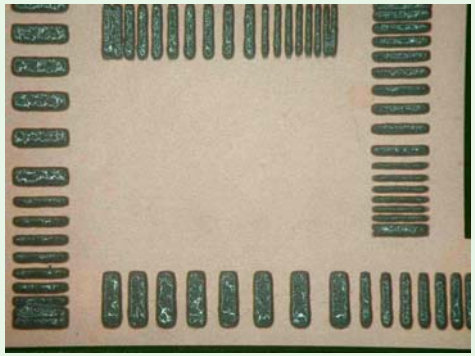
Executing the Experiment

All test runs of all selected solder pastes are executed at the same day. This to get as less noise in the experiment as possible. During the experiment several pictures are taken from the test boards. See the samples below.

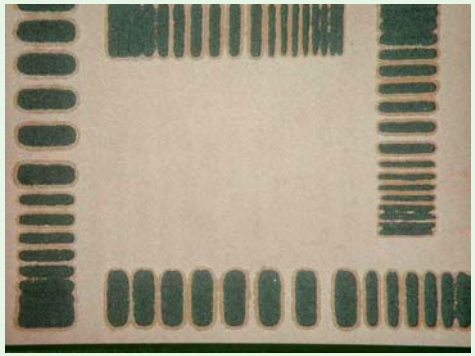
Quality Criteria after screen printing



Aperture

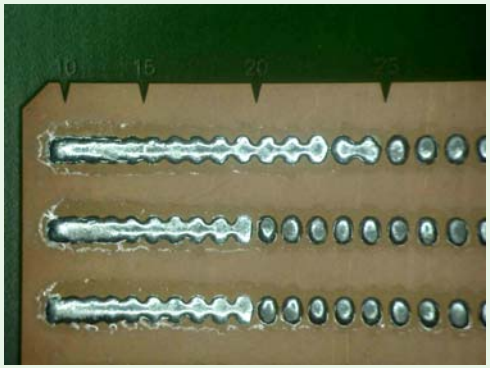


IPC Slump

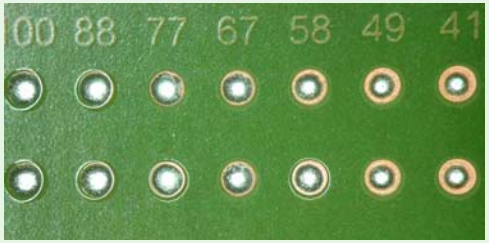


Hot Slump

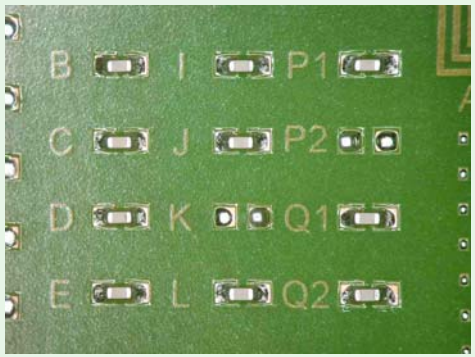
Quality Criteria after reflow



Wetting A



Wetting B

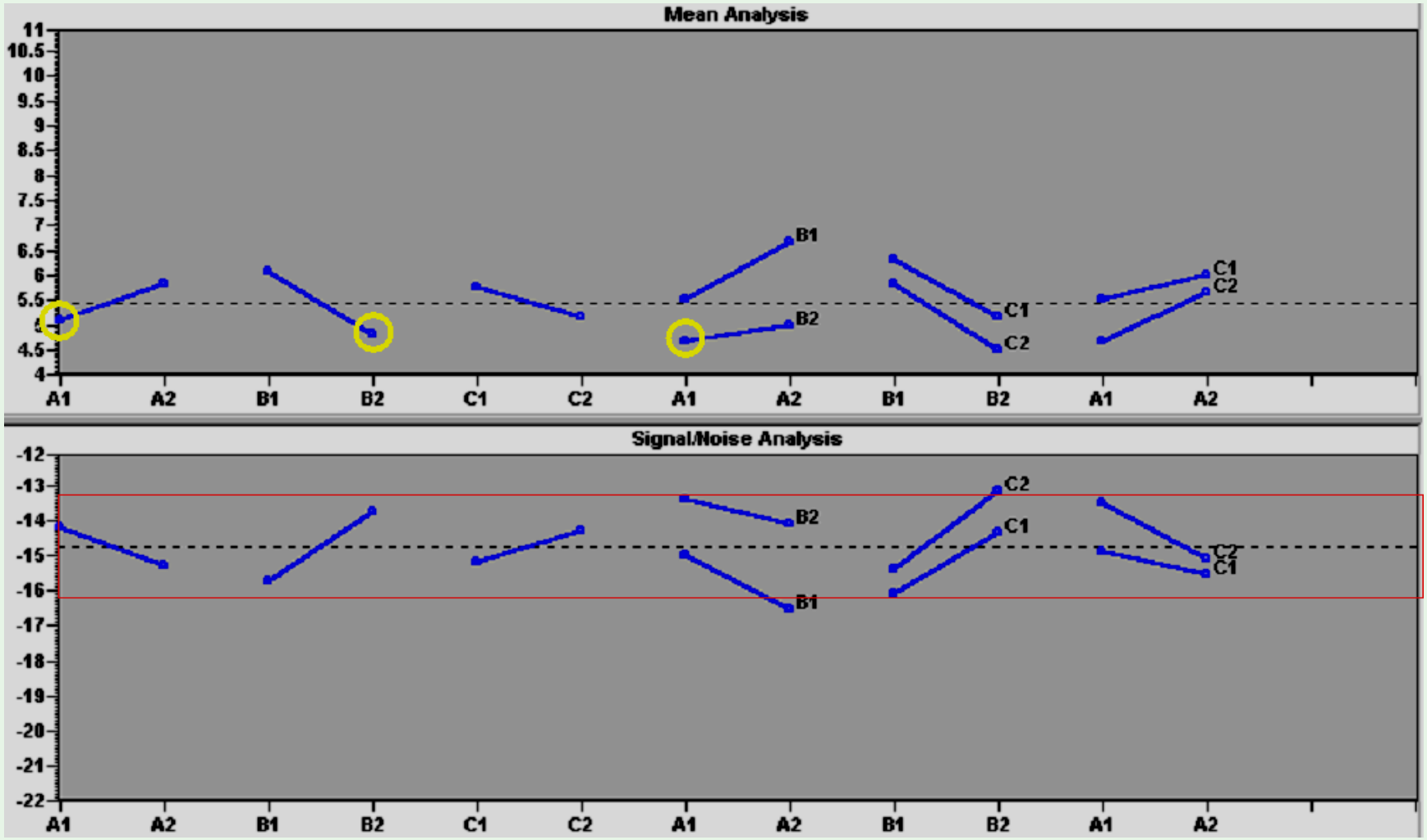


Tombstoning 0402

Data Analysis

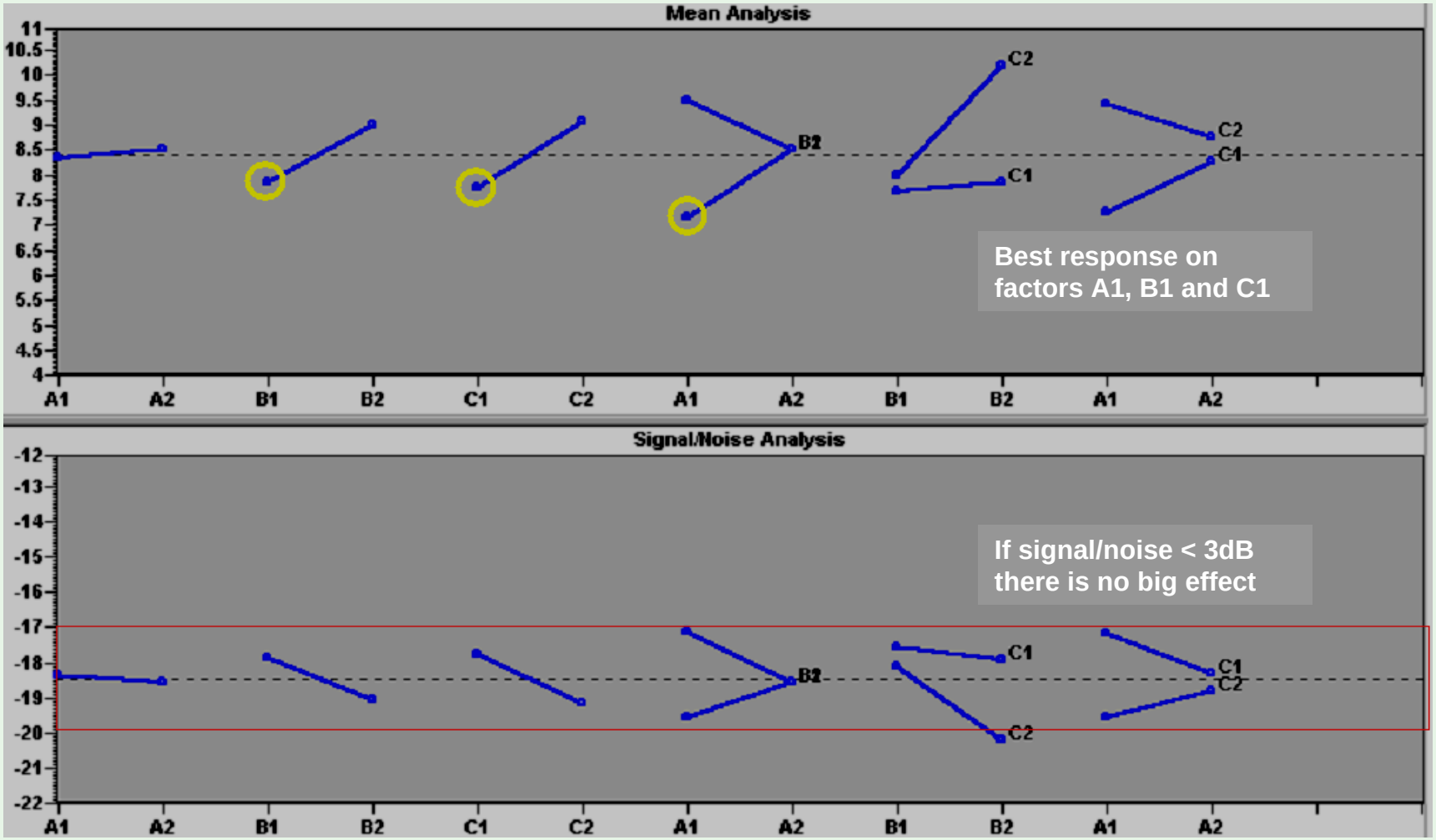
Graphs are made using Anova-TM Analyses Software.

Paste II IPC Slump *(the smaller the better)*



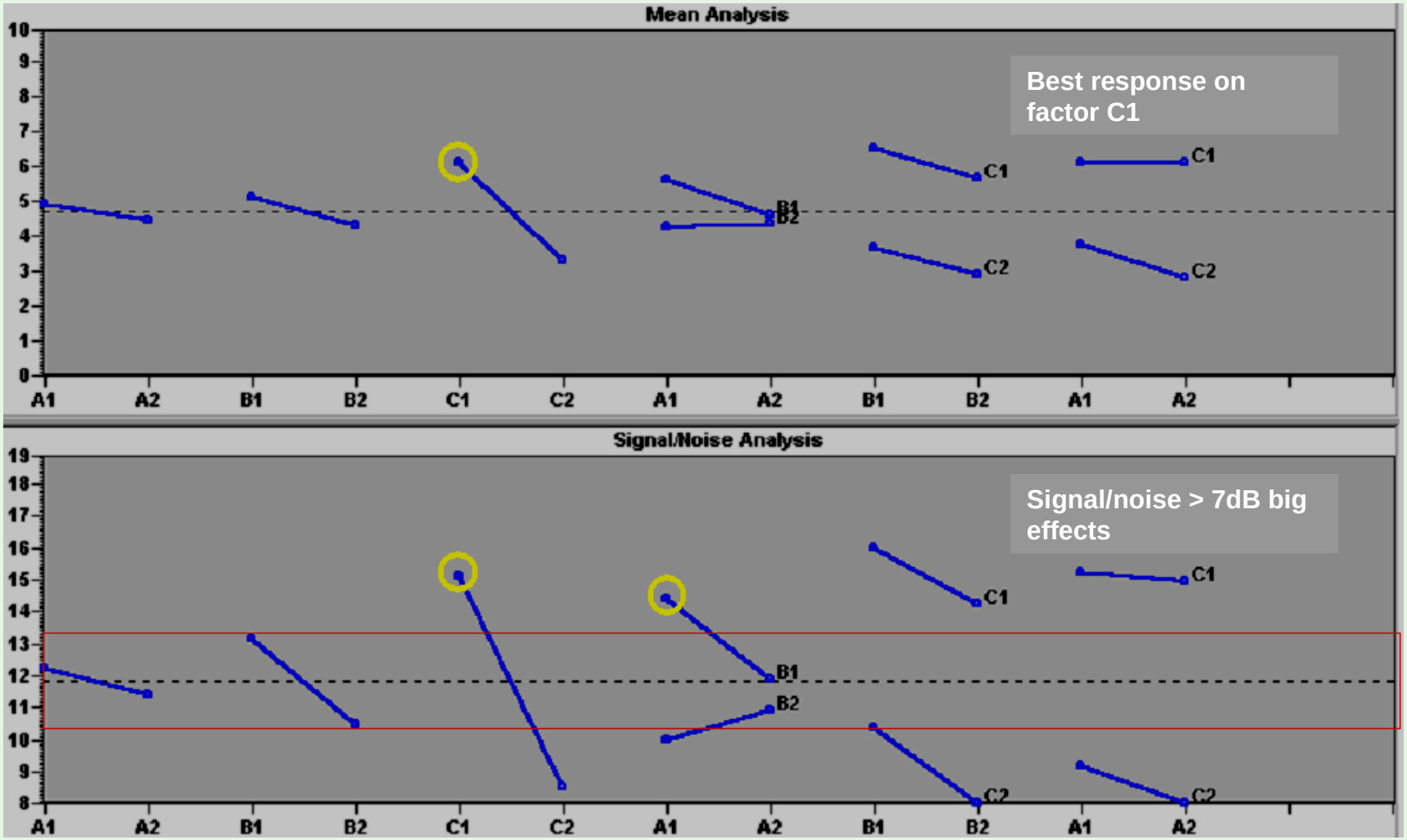
Paste VI IPC Slump *(the smaller the better)*

Response Graphs



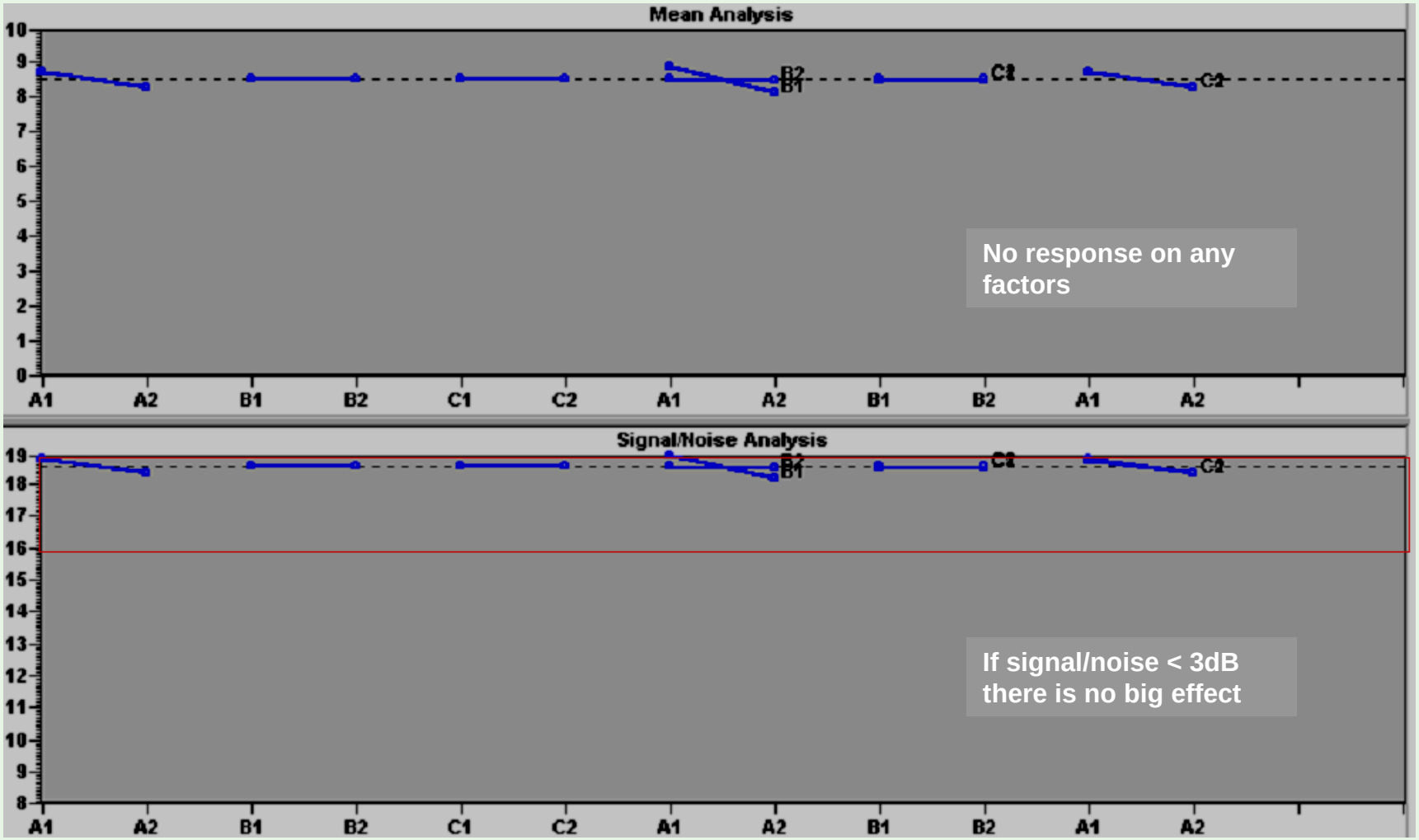
Paste IV Aperture *(the larger the better)*

Response Graphs



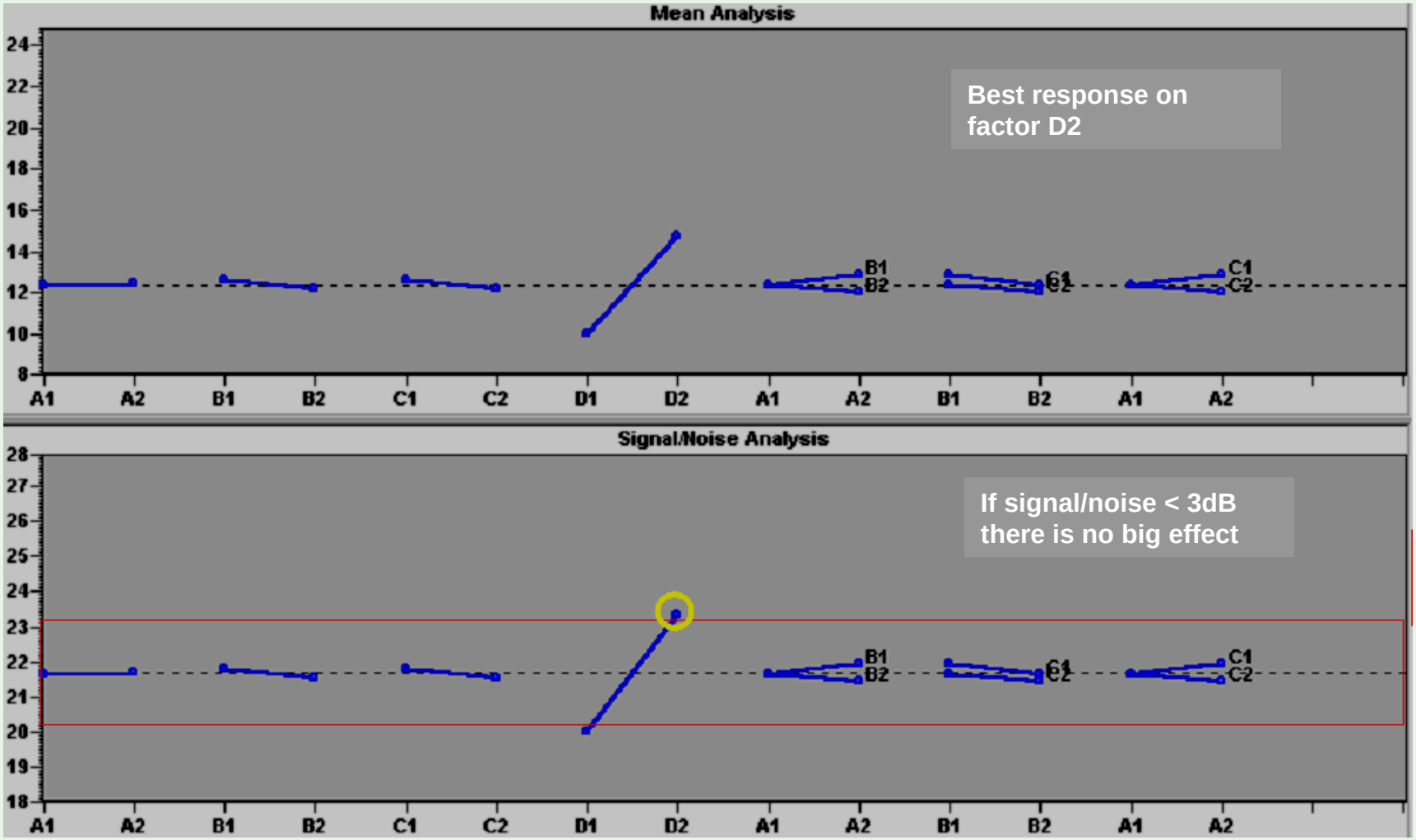
Paste V Aperture *(the larger the better)*

Response Graphs



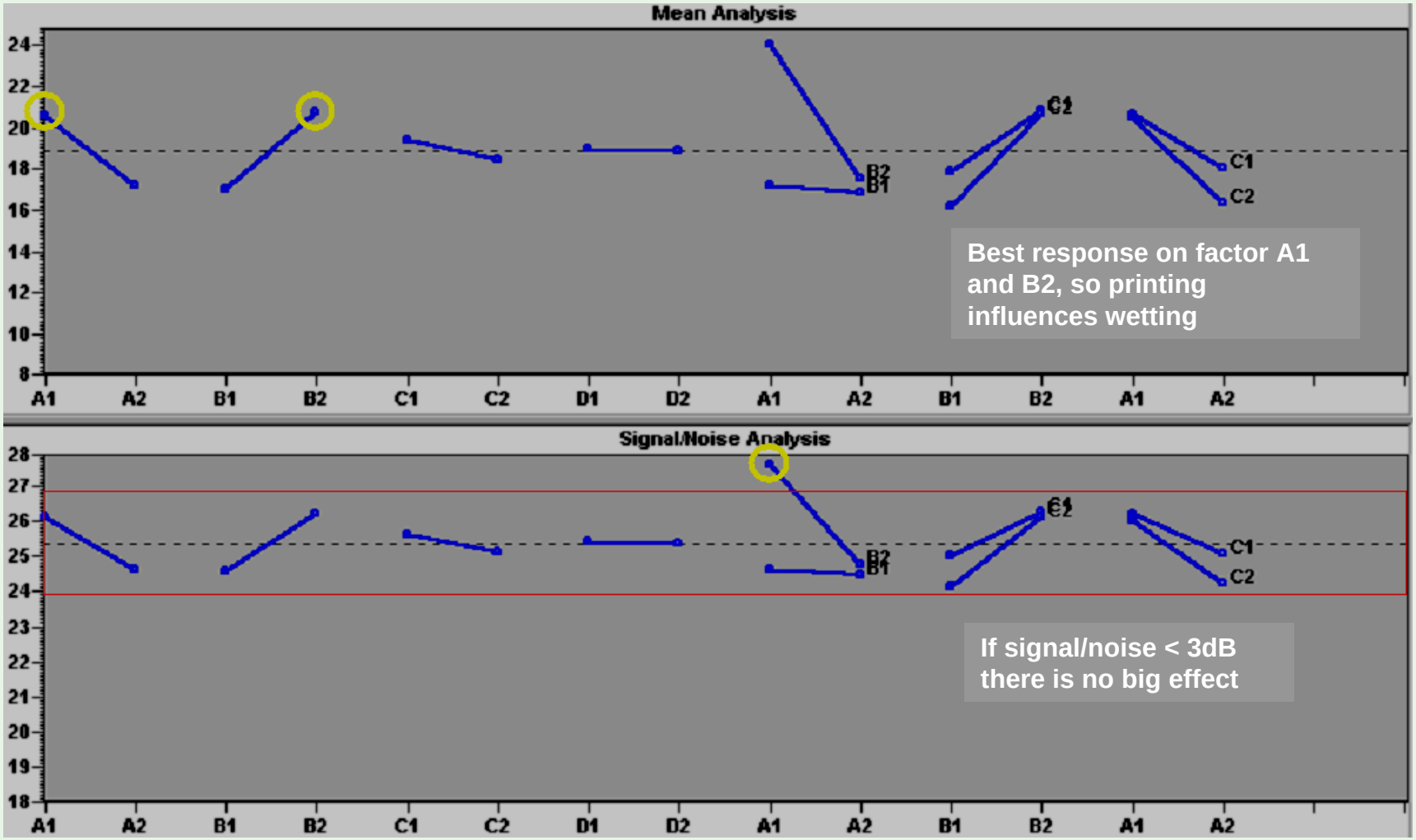
Paste II Wetting A *(the larger the better)*

Response Graphs



Paste VI **Wetting A** *(the larger the better)*

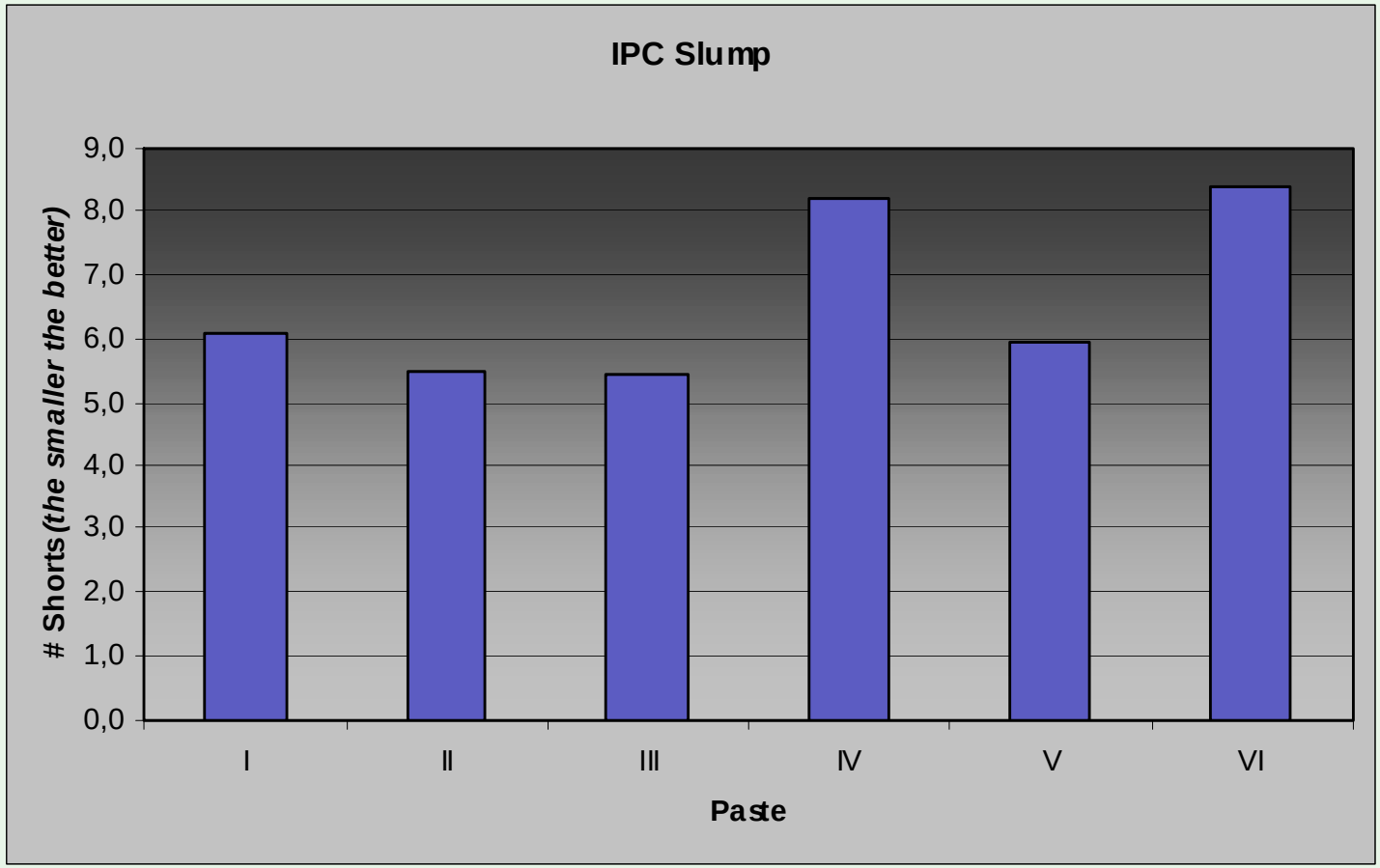
Response Graphs



IPC Slump

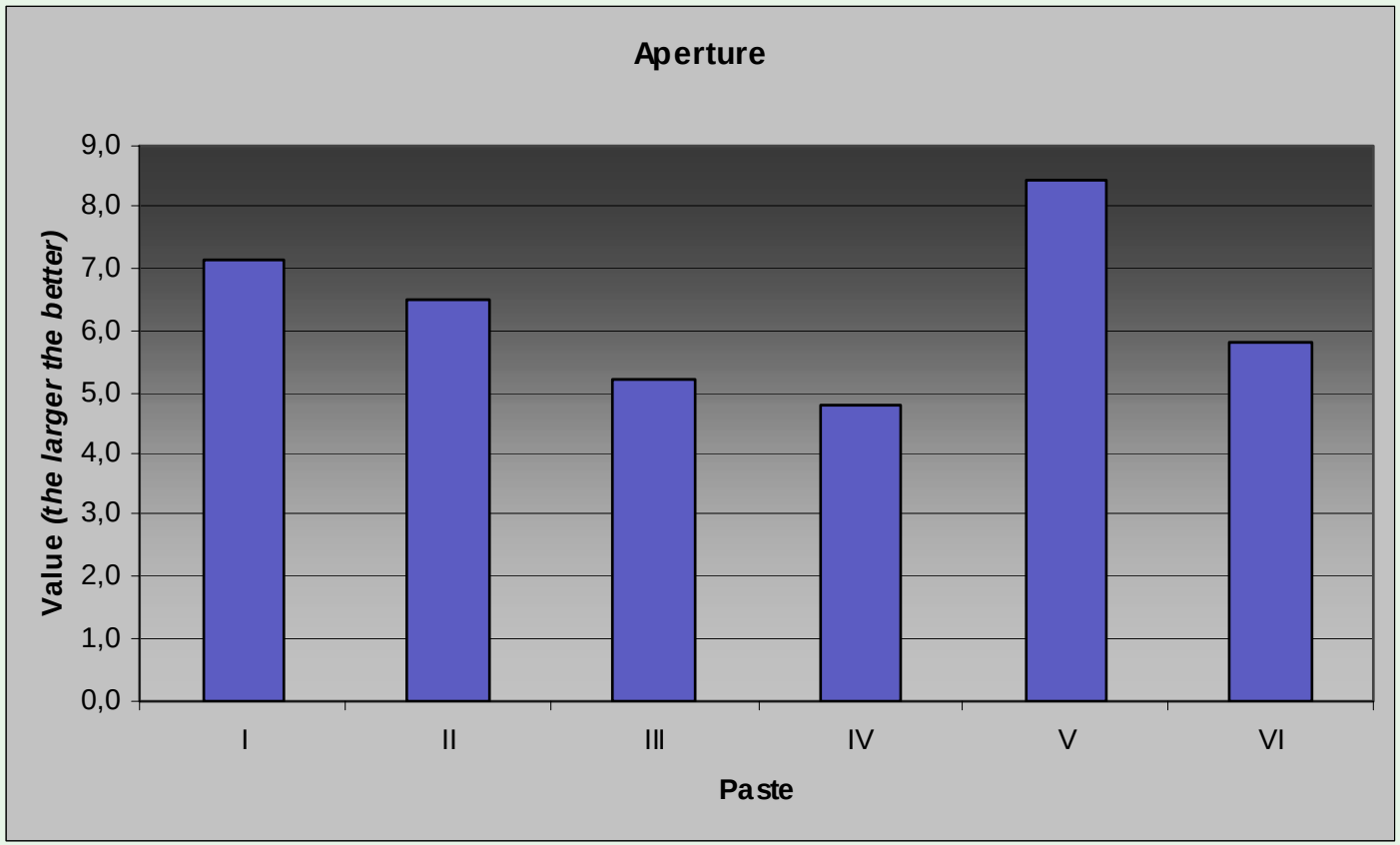
Overview Graphs

Paste IV and VI showed highest slumping effect after screen printing



Aperture

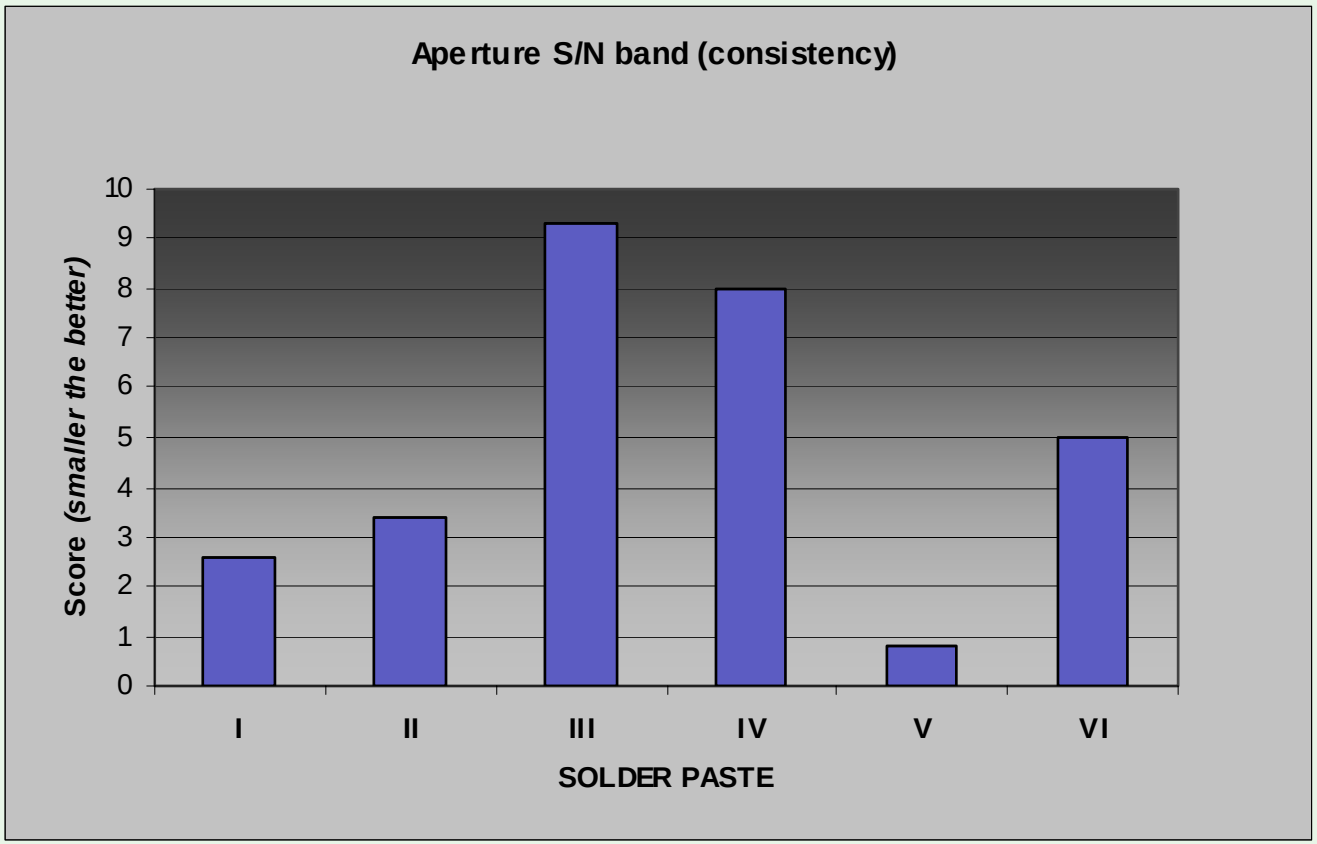
Paste IV showed the worst aperture definition after screen printing. Paste V showed the best.



Aperture Signal to Noise Band

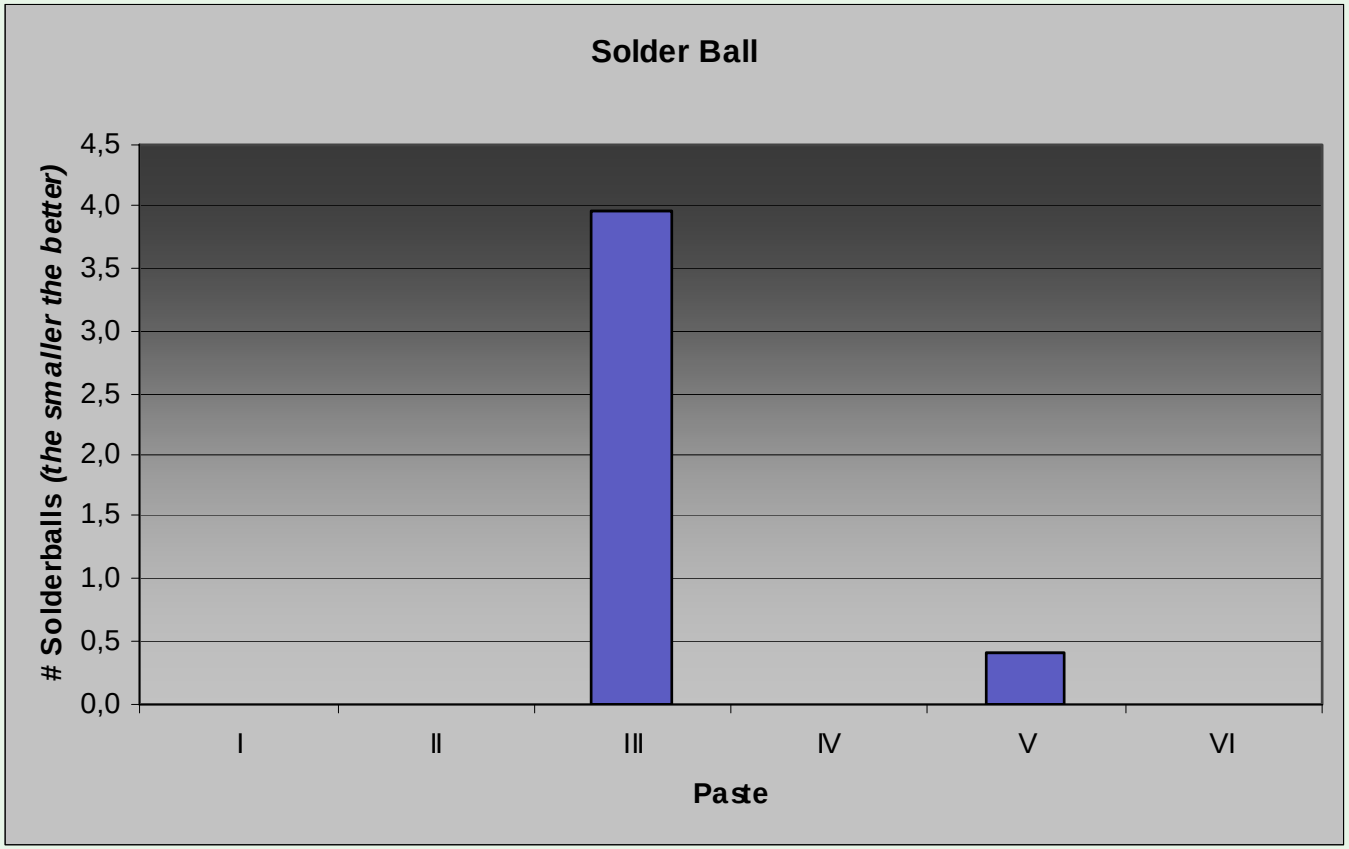
Overview Graphs

Paste III and IV showed the worst aperture consistency after screen printing.



Solder Ball

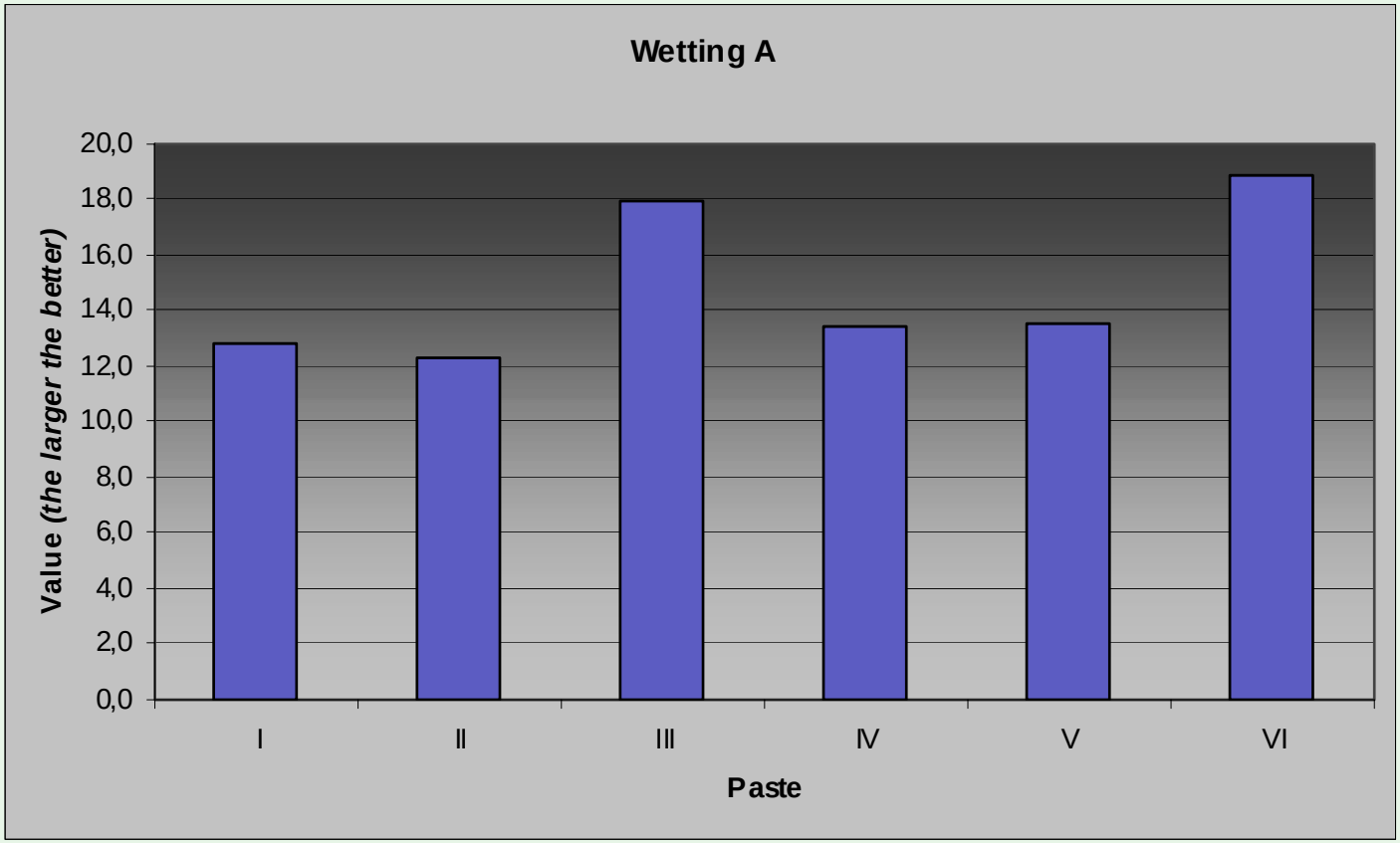
Paste III showed more solder balls than other pastes after reflow.



Wetting A

Overview Graphs

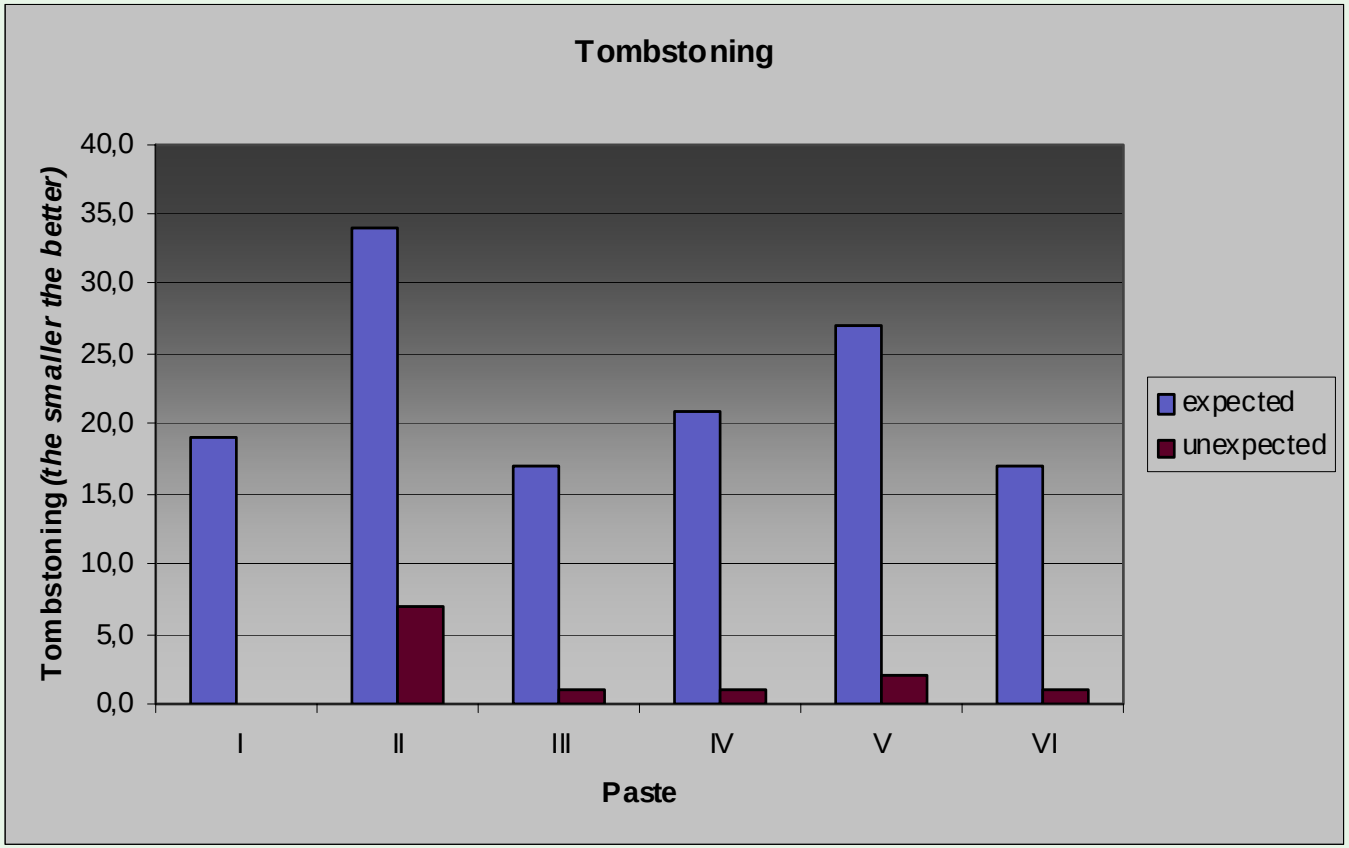
The wetting result was also achieved thanks to the slumping of the paste after printing.
Wetting and Slump have a quite strong relation.



Tombstoning

Overview Graphs

The result of expected and unexpected tombstoning. Paste II showed the most tombstoning



Paste with more slumping show less tombstoning.

Confirmation Run

To confirm the results of the Data Analysis, a Confirmation Run is done based on the optimum settings of **Aperture**.
Of all the quality criteria, **Aperture was defined as the most important**.

Referring to the Aperture Paper Champions, the following settings were chosen for each paste:

Paste	Squeegee Pressure [kg]	Printing Speed [mm/sec]	Separation Speed [mm/sec]	Nitrogen during Reflow
I	8 A2	75 B2	0,2 C1	ON D1
II	6 A1	75 B2	2 C2	OFF D2
V	6 A1	75 B2	2 C2	ON D1
VI	8 A2	50 B1	2 C2	ON D1

Paste III and IV are not tested anymore in the confirmation runs.

Paste III gave no consistent results.
The signal to noise data for aperture and wetting are inadequate to continue.

Paste IV had very poor aperture results caused by flux bleed and separation.

Data Analysis

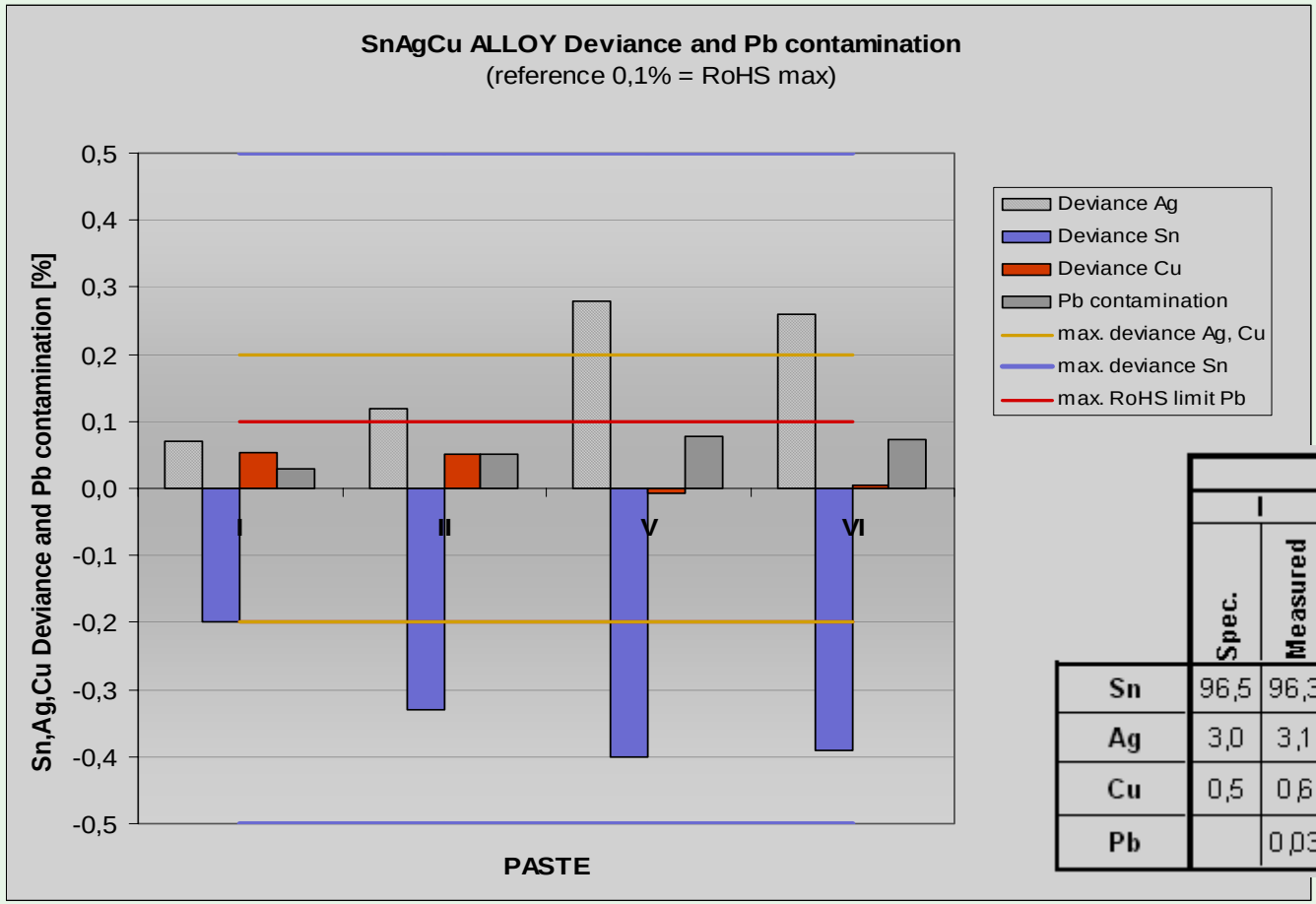
In the table below the results are shown for the 3 quality criteria.

		Quality Criteria Results after the Confirmation Run		
Paste No.	Optimum Setting	IPC Slump	Aperture	Wetting A
I	A2 B2 C1 D1	-	++	-
II	A1 B2 C2 D2	--	+	+
V	A1 B2 C2 D1	-	-	-
VI	A2 B1 C2 D1	-	++	--

(+,++) prediction is confirmed in CR
(-, --) prediction not accomplished

Extra Analysis

For all the CR pastes, the **alloy accuracy** was analyzed.

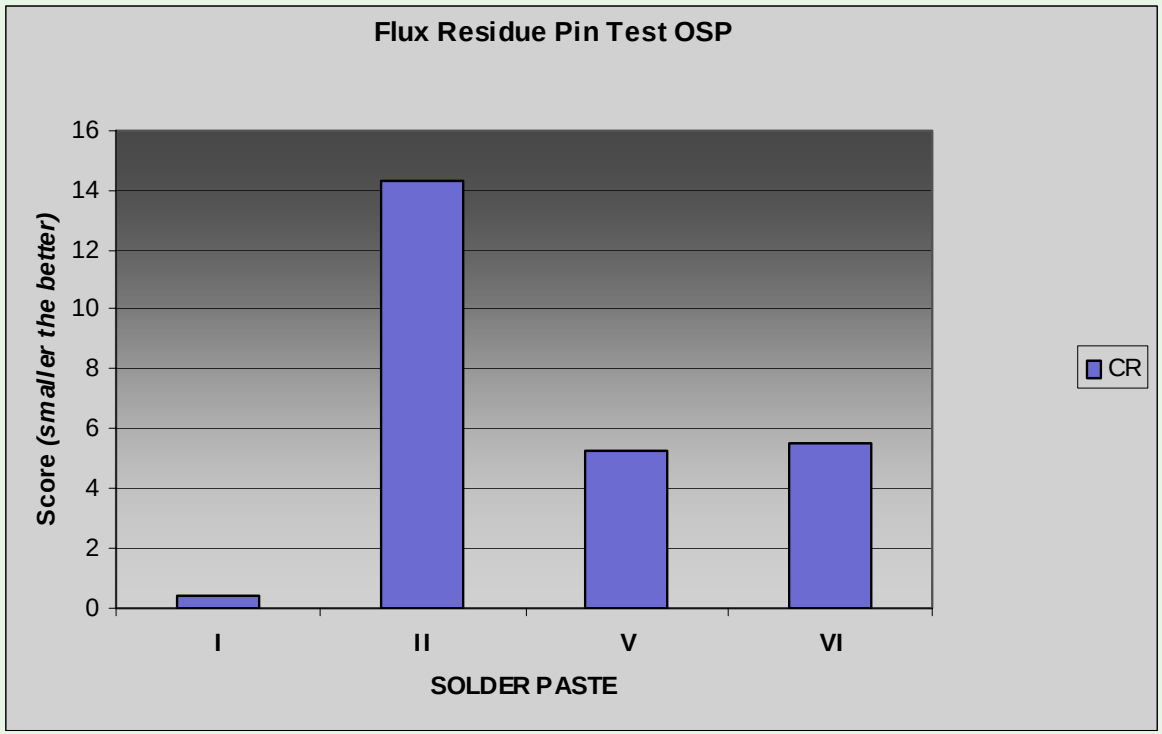


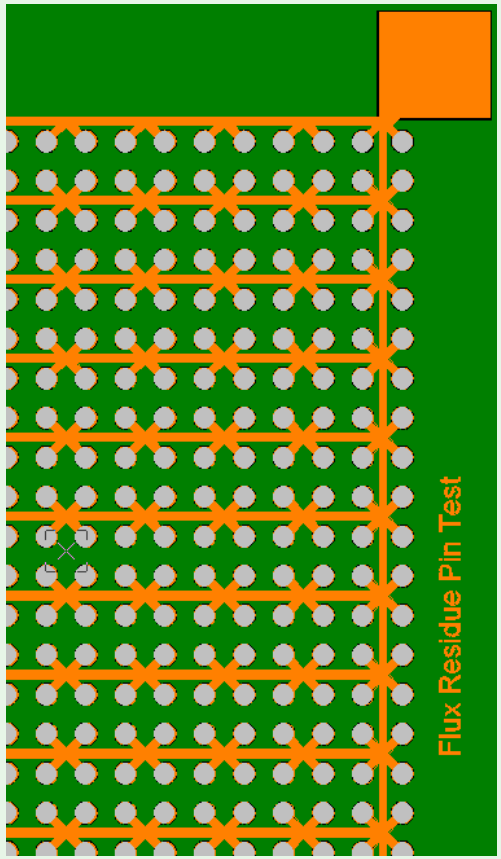
	PASTE							
	I		II		V		VI	
	Spec.	Measured	Spec.	Measured	Spec.	Measured	Spec.	Measured
Sn	96,5	96,3	95,5	95,2	95,5	95,1	95,5	95,1
Ag	3,0	3,1	4,0	4,1	3,8	4,1	3,8	4,1
Cu	0,5	0,6	0,5	0,7	0,7	0,7	0,7	0,7
Pb		0,03		0,05		0,08		0,07

Flux Residue Pin Test

Extra Analysis

Test has been performed for all pastes on OSP using the test pattern on the board.

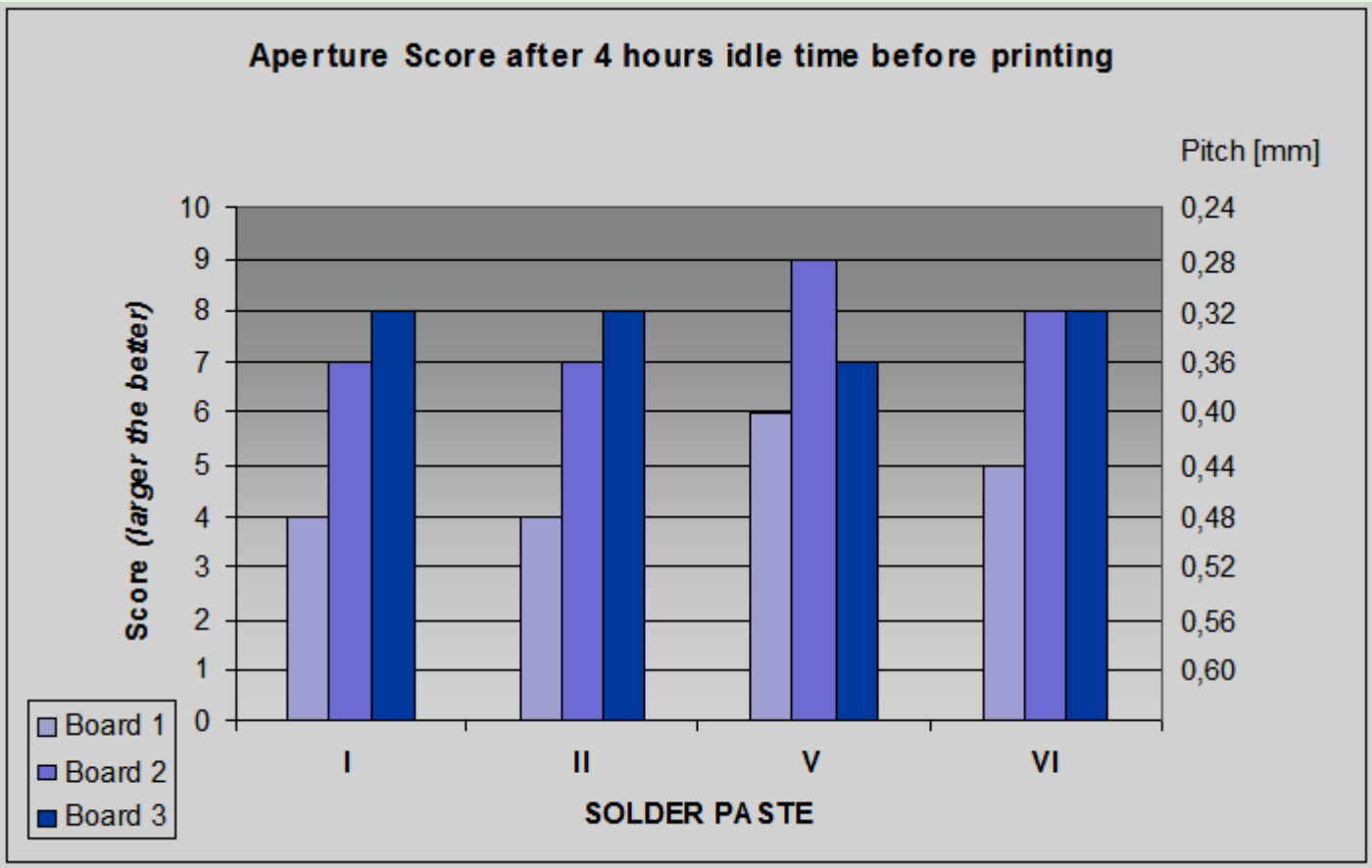




Re-printability after idle time

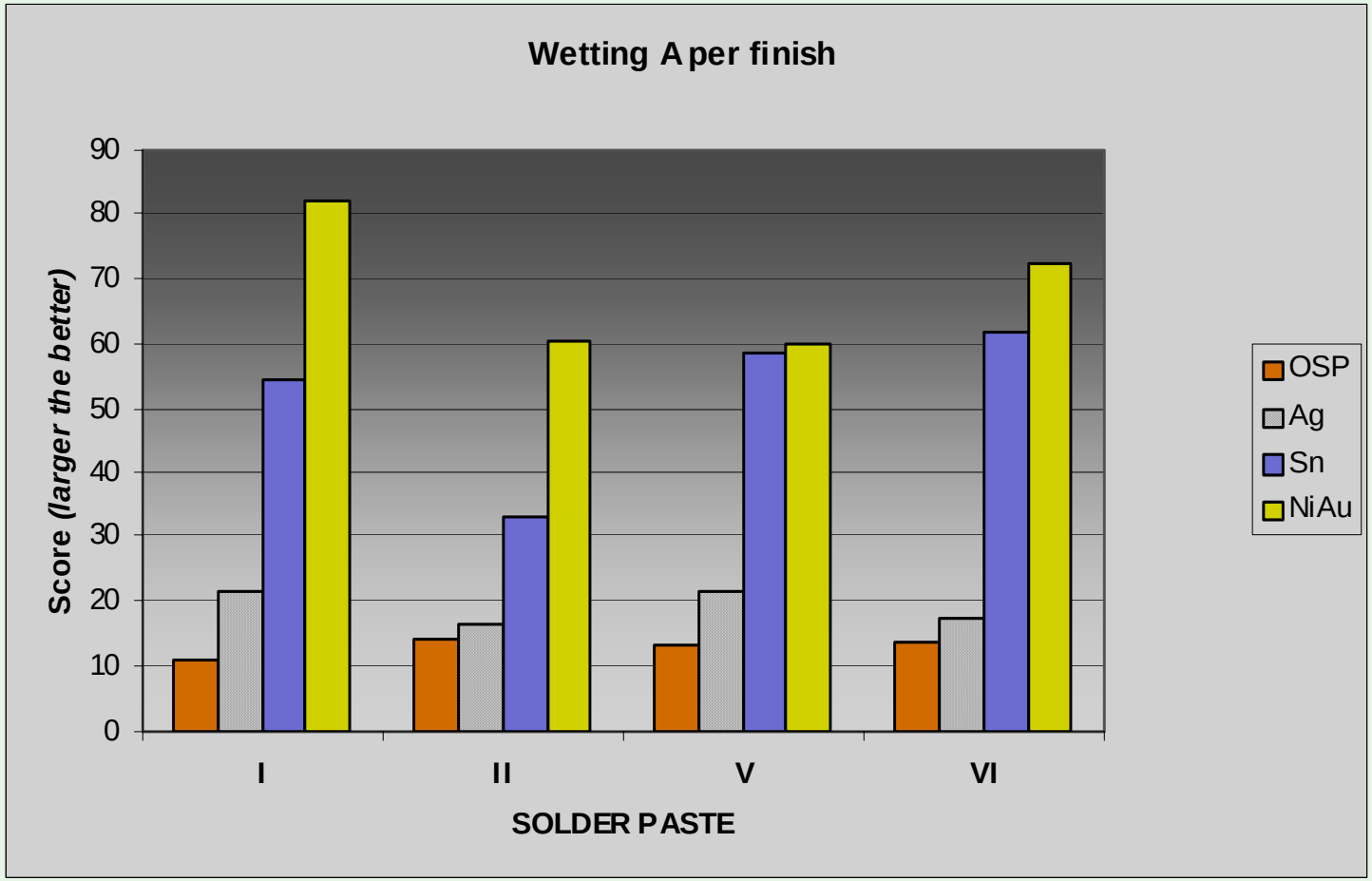
Extra Analysis

The solder pastes was tested by letting the paste rest on the stencil for 4 hours



Different Board Finishes

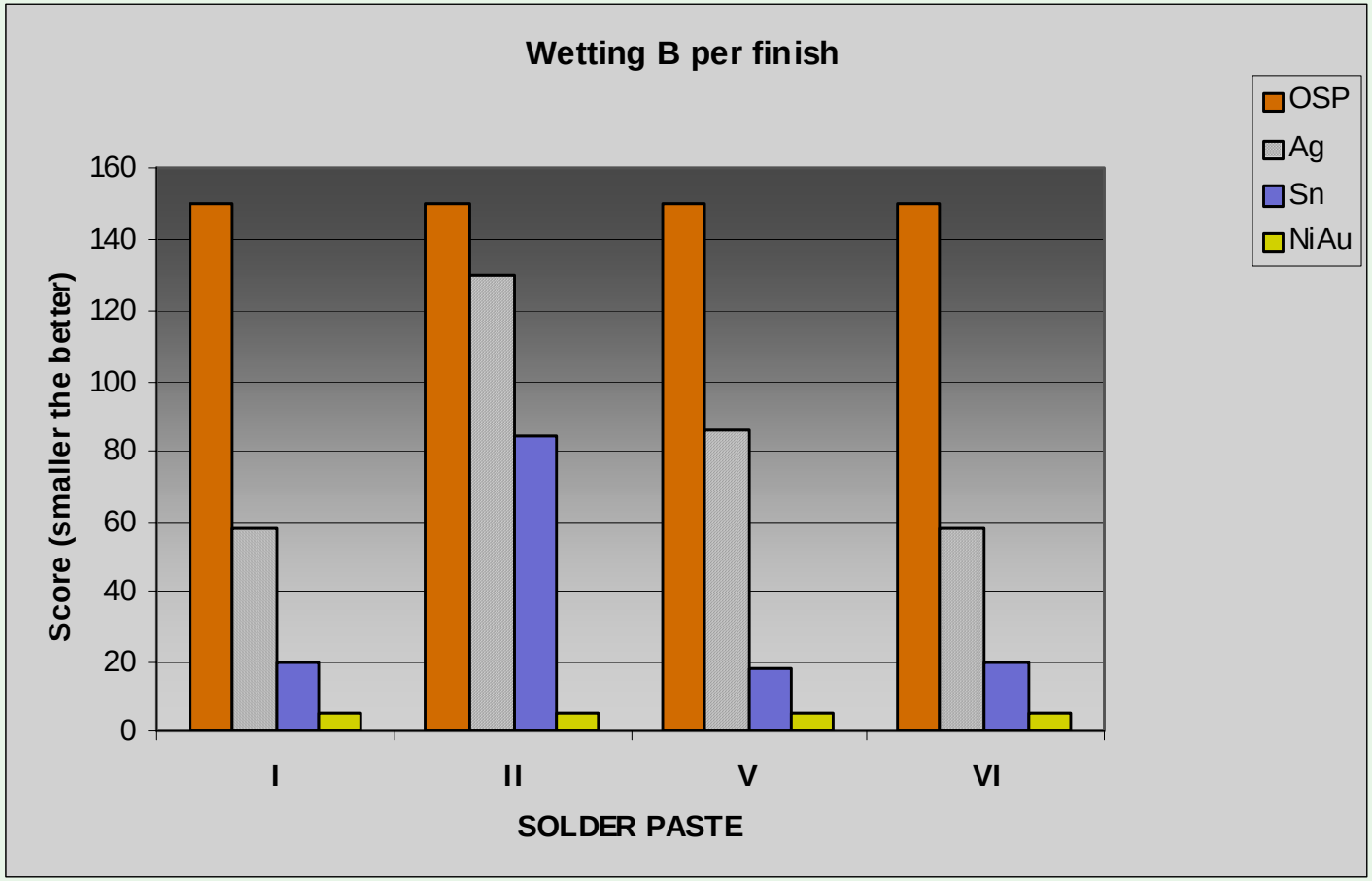
OSP - Immersion Ag - Immersion Sn - ENIG



Confirmation Run

Different Board Finishes

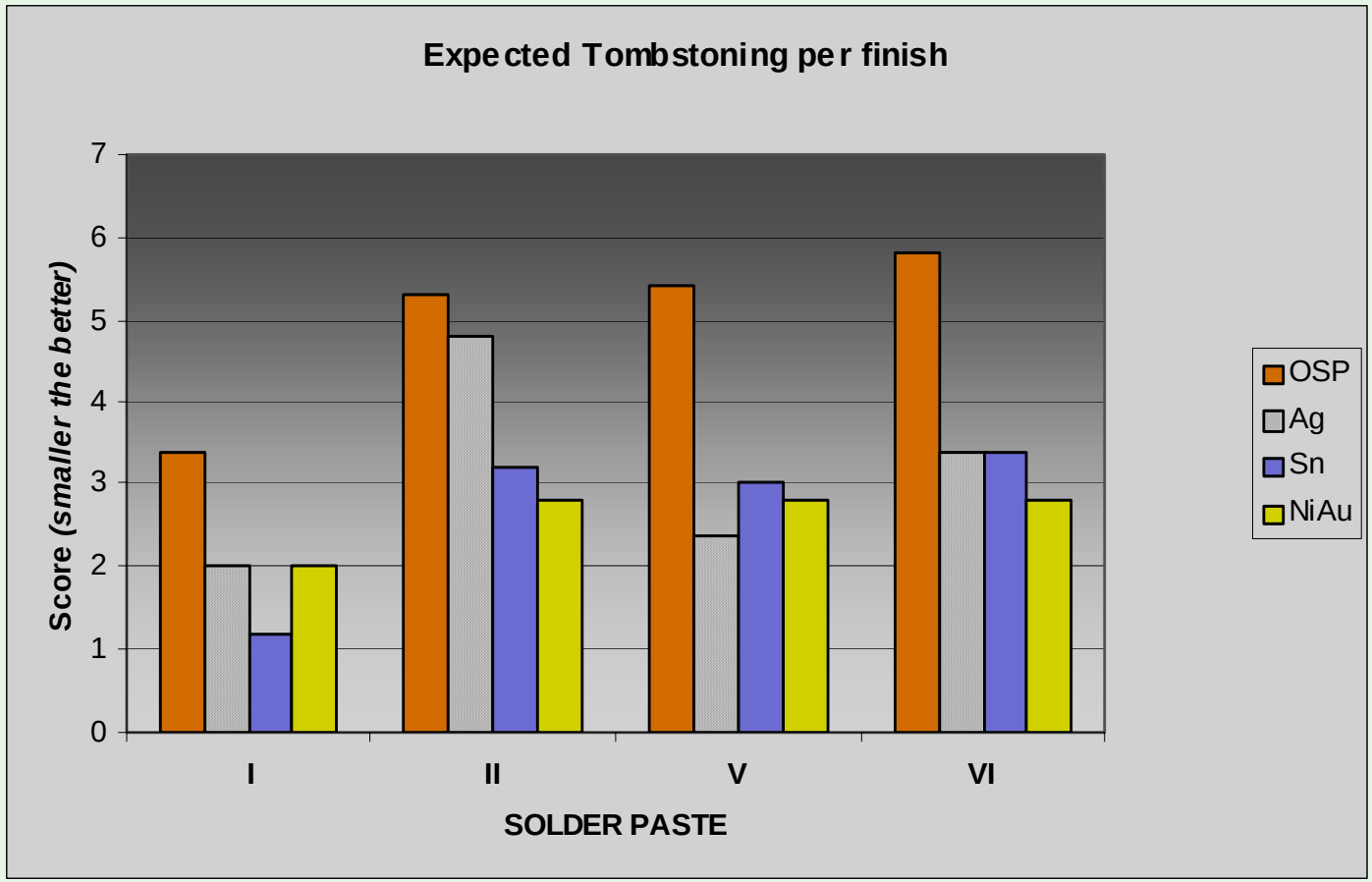
Note: this score is the smaller the better !



Expected Tombstoning

Different Board Finishes

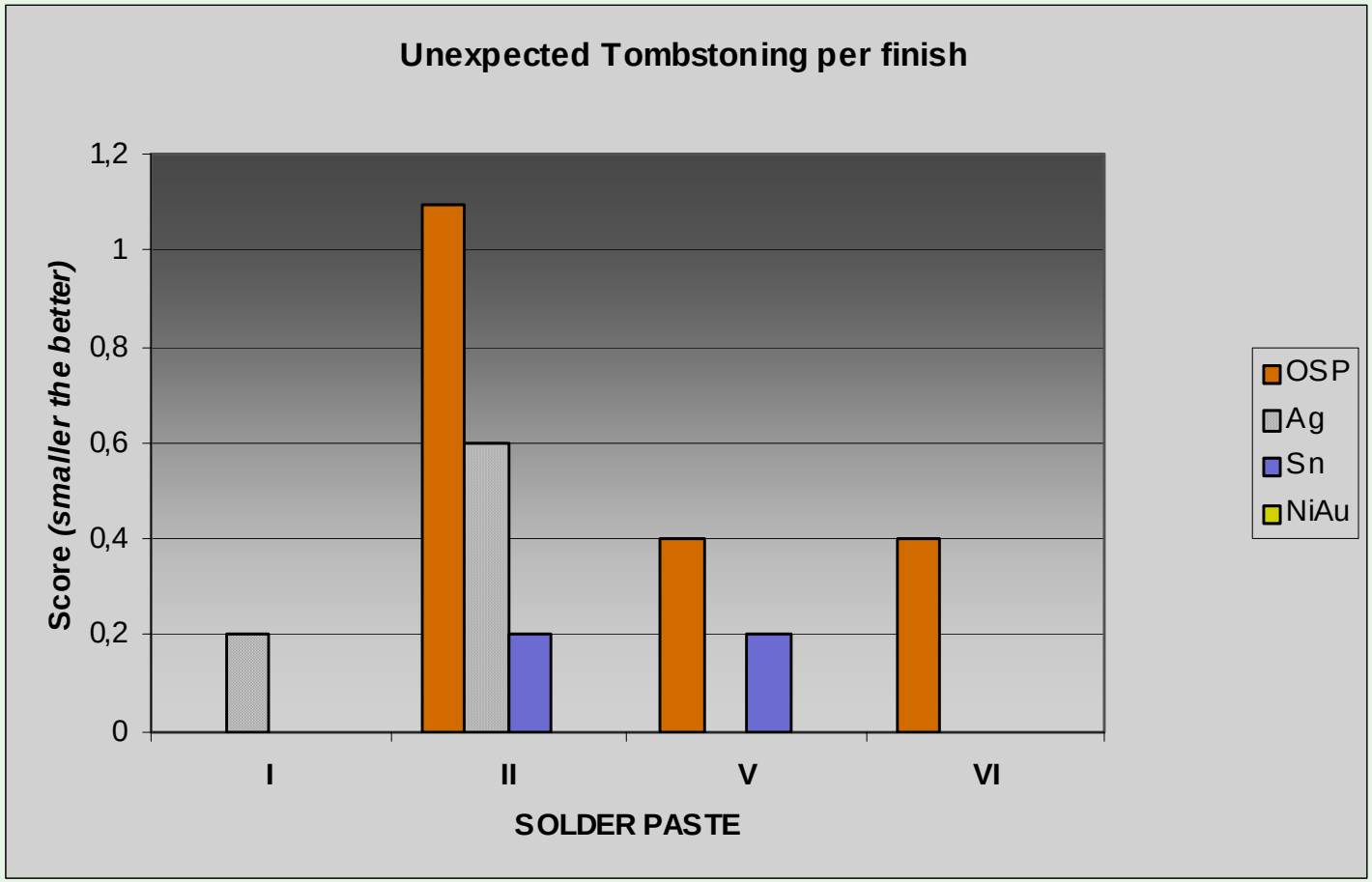
ImSn and ENIG proved to be the best.



Unexpected Tombstoning

Different Board Finishes

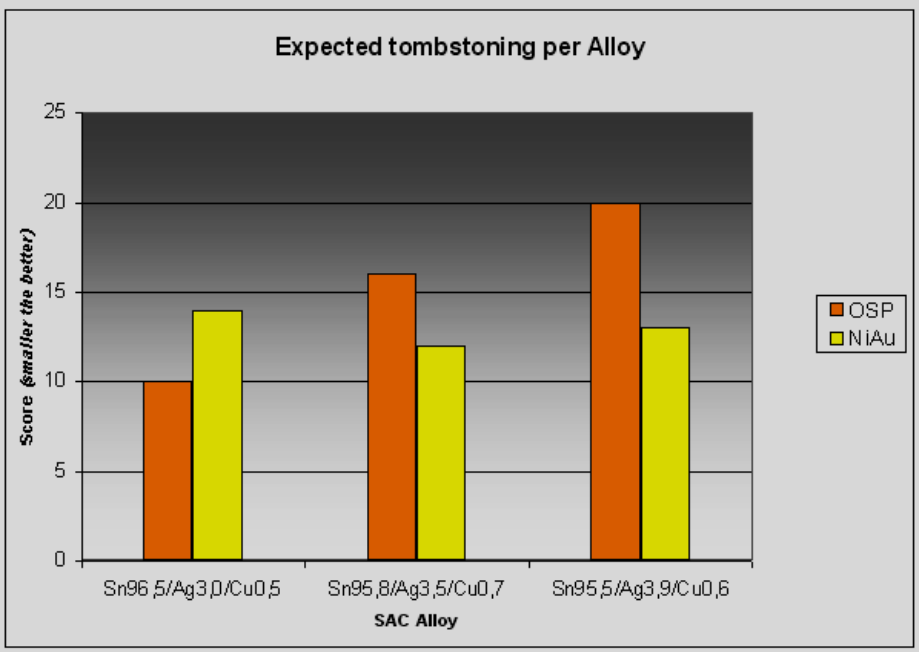
Unexpected tombstoning proved worse with OSP
Paste I showed the best performance.

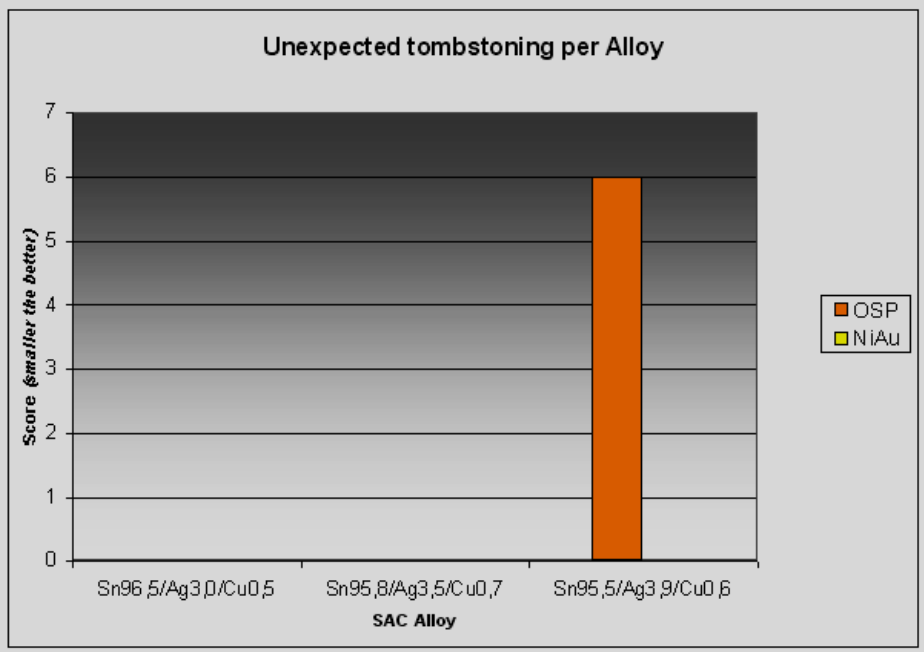


Tombstoning per pcb-finish

Different Board Finishes

To check the degree of tombstoning with different SnAgCu alloys on OSP





Less Ag causes less tombstoning.
Low silver SAC alloys have a melting range, where high silver SAC alloys are almost eutectic.

Conclusion

Selecting the best overall solder paste

By ranking and weighing the solder paste for basic quality criterion, the solder paste with overall best performance becomes clear.

		Rank Score			
	PASTE	I	II	V	VI
Quality Criterion	Weight				
Screenprinting	4	3	2	4	2
Soldering	3	3	0	1	3
Pin testing	1	4	1	3	2
	Total Score	25	9	22	19

Conclusion

Selecting the best overall solder paste

Graph view

Future Work

The three production companies will continue final testing.
From this experiment 3 lead-free solder pastes can be used as a starting point of the transition to lead-free soldering.
Some quality criteria are not examined yet like:

- **X-ray voiding**
- **CSP, BGA and Flip Chip Assembly**
- **solder paste batch to batch consistency**
- **reliability tests**

Also test have to be conducted to find an alternative for SnPb HASL finished boards. This also depends on the product design and on the equipment used in production.

Each company has to test one or more solder pastes in the actual products and find the best paste that fits into their production.
Choice of lead-free board finish and the use of nitrogen during reflow must be made.

This way more information can be gathered and shared.

Thank you for your attention !

Any questions ?