PCB Materials Behaviours towards Humidity and Impact of the Design, Finishes, Baking and Assembly Processes on Assembly Quality and Solder Joint Reliability

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Abstract
As Electrostatic discharge, humidity can have a bad impact on assembly quality. It requires environmental conditions and process controls but also risks knowledge. To overcome humidity issue, parts (PCB or components) need to be baked to remove moisture. Baking drawback is the wettability issue especially with thermal sensitive PCB finishes. Can this wettability issue introduce reliability defects? Solectron has launched on this topic a project called Aquaboard. This project mainly deals with the PCB materials behaviours towards humidity, and the impact of different parameters such as baking on the solder joint reliability. The project took place in two steps. The part 1 is about PCB materials behaviours, mainly the baking and storage efficiency. Several curves have been drawn for most of the PCB materials (paper, E-glass, aramid, phenol, epoxy, BT, polyimide, hydrocarbon…): baking curves (from 80° to 120°C), absorption curves (ambient atmosphere, <5% RH, dry pack storage, 85°C-85%RH). The part 2 is a test vehicle to see the impact of baking, assembly process, PCB finish, atmosphere, design (DFR) on wettability, spreading, voiding, reliability, aluminium bonding…

Key words:
ENIG, OSP, HASL, Im Sn, Im Ag, lead free, clean, no clean, wettability, spreading, voiding, aluminium bonding, design for reliability, moisture, baking, Fick's law, PCB material, paper, E-glass, aramid, phenol, epoxy, BT, polyimide, hydrocarbon

Introduction
Solectron has launched a project called Aquaboard. It has taken place in two steps.

- The first step is dedicated to materials behaviours towards humidity. It is mainly based on weighting PCB during baking and storage. This second step is made of several studies:
    - The first study is to measure the efficiency of the baking. What is the impact of stacking PCB? What are the required times at different temperatures to have the same baking efficiency? This first study was performed mainly on E-glass epoxy and E-glass polyimide as they represent the major part of PCB materials assembled at Solectron. Seven PCB and five baking conditions (80°C, 90°C, 100°C, 110°C, 120°C) have been considered
    - The second study of this part is based on PCB storage. According to the storage conditions, how long does need the material to absorb water and how long is the allowed time prior reflow? Most of the PCB materials assembled at Solectron have been studied (paper, E-glass, aramid, ceramic, phenol, epoxy, BT, polyimide, hydrocarbon…). For each material the absorption curve has been drawn for the following storage conditions: dry pack (<2%RH), dry cabinet (<5%RH), ambient air (23+/-2°C, 45+/-5%RH), high humidity storage (85°C, 85%RH).
    - The third study of this part is to see the impact of humidity on assembly quality. Humidity can be the root cause of delamination, voids, and micro-balls... Unfortunately those defects can be caused by other parameters such as a bad lamination, an inappropriate reflow profile. Furthermore those defects are difficult to identify and occasional (PPM). Too much material investment was needed for this study so we only focused on delamination. PCB crammed with a controlled humidity amount went three times through reflow or wave soldering in order to see from which level of humidity, delamination is observed.
    - The forth study of this part is to finalise the baking conditions according to the percentage of copper in the PCB (ground layer), the PCB thickness, and the PCB finish (following the results of the third step of the study).
    - The fifth study is about the absorption curves during the assembly according to the process (no clean or clean).
- The second step of the project is a test vehicle to see the impact of different parameters on solder joint reliability. Daisy chain components such as 0.4 mm pitch QFP, 1.5 mm pitch BGA and 0.5 mm CSP have been assembled. Five PCB finishes (HASL, ENIG, Im Sn, Im Ag, OSP), four baking conditions (from 80°C to 120°C), three assembly processes

(SnPb clean, SnPb no clean, SnAgCu no clean), two reflow atmospheres (air, nitrogen) have been studied. The baking impact has only been performed on the SnPb no clean process under the air. Several tests have been carried out on the assembled boards: continuity test (daisy chain components) through thermal cycling (-55°C, +125°C) and mechanical shock, shear test, wetting balance, spreading test, hole filling (wave soldering), 3D X-rays, cross section & SEM, surface insulation resistance. In addition to this study, design for reliability has been carried out. On this test vehicle, several BGA design have been evaluated (1.5 mm pitch BGA and 0.5 mm pitch CSP): copper defined pad versus solder mask defined pad, dog bone versus microvia in pad design (centred, off-set and shifted), pad shape (round, oblong, square…). In the same way, designs for quality and reliability have been performed on chips: 0603 and 0805 packages, resistor and capacitor components. For each case, five PCB designs times five stencil apertures have been tested.

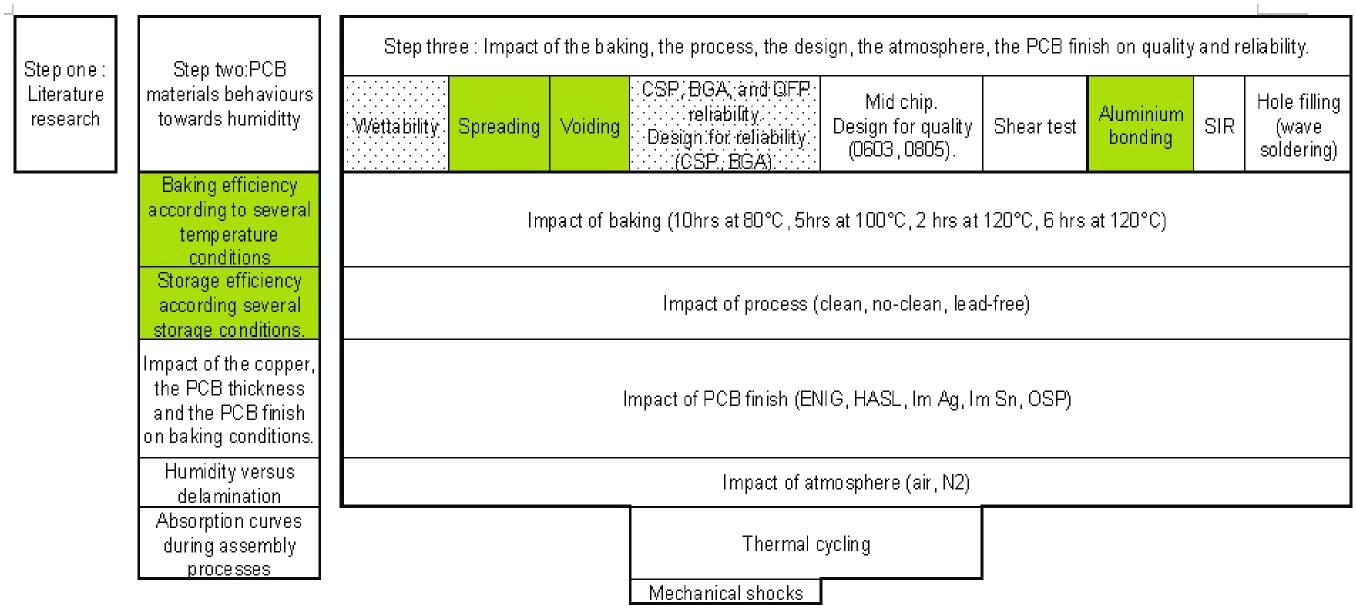


Figure 1 – Project Chart

The green cells (Figure 1) will be fully tackled is this paper. The hatched cells are partially tackled as they are still on going. Basically you will find in the paper the following parts of the project (see above for description):

<u>Step 2 of the project:</u>

- Baking efficiency
- PCB materials behaviours: baking & storage

<u>Step 3 of the project:</u>

- Wettability
- Voiding
- Spreading
- Aluminium bonding
- Thermal reliability

Concerning the 1.5 mm pitch BGA and 0.5 mm pitch CSP, the following design have been evaluated: copper defined pad versus solder mask defined pad, dog bone versus microvia in pad (MVP) design (centred, off-set and shifted), pad shape (round, oblong, square…). The following pictures (Figure 2) are showing some copper defined pad (NSMDP) designs.

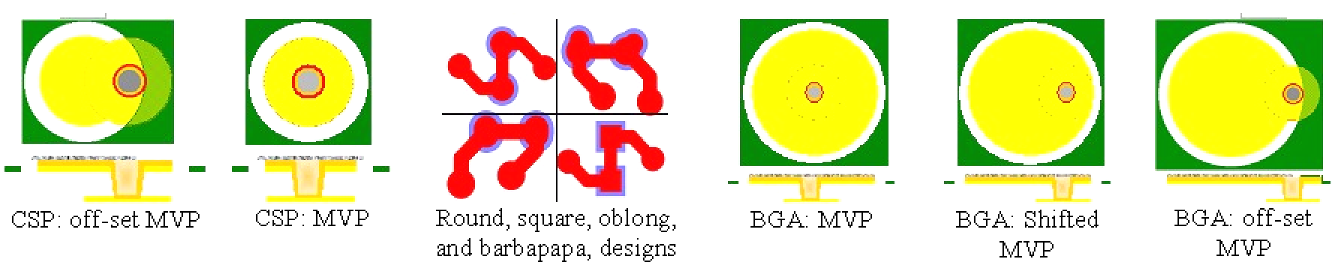


Figure 2 - NSMDP Designs

Step 2 of the Project
This part tackles the PCB materials behaviours towards humidity, meaning absorption and desorption behaviours. It is based on PCB weighting through baking and storage. The equipments used for this study are a Heraeus UT200 oven, Sartorius LP3200D accurate scales (mg), Secasi SLH34SP moisture oven.

Materials Behaviour Introduction[1-2]
Concerning the materials behaviours towards humidity, the literature research showed that a lot of data from PCB material suppliers are available. Unfortunately most of those data are about raw materials and not about the PCB itself. Obviously, it was easier to find documents about moisture sensitive PCB material such as polyimide than high frequency material that are usually not sensitive to moisture (i.e. PTFE). If we focus on polyimide material such as Polyimide/Thermount®, bake PCB for a minimum of 4 hours at 112°C, or a maximum of 6 hours at 136°C is mandatory. Thicker PCB or PCB with external copper planes should be baked for 6 hours at 136°C. In general, when a PCB contains over 50% of Thermount® reinforcement, the maximum allowable moisture regain by weight is 2800 PPM to assure reliable assembly. The following chart (Figure 3) shows the moisture amount removed from a ten layers PCB. Depending on the baking temperature, we can see on this chart that after 5 hours the baking is close to 65-80 % efficiency of the 25 hours baking. Forced absorption has also been studied. The following graph (Figure 4) compares E-Glass/FR-4 with Thermount® in an 85°C-85%RH environment. We can see that after 225 hours at 85°C/85%RH the Thermount® threshold is around 20000 PPM when the FR-4 threshold is close to 7000 PPM.

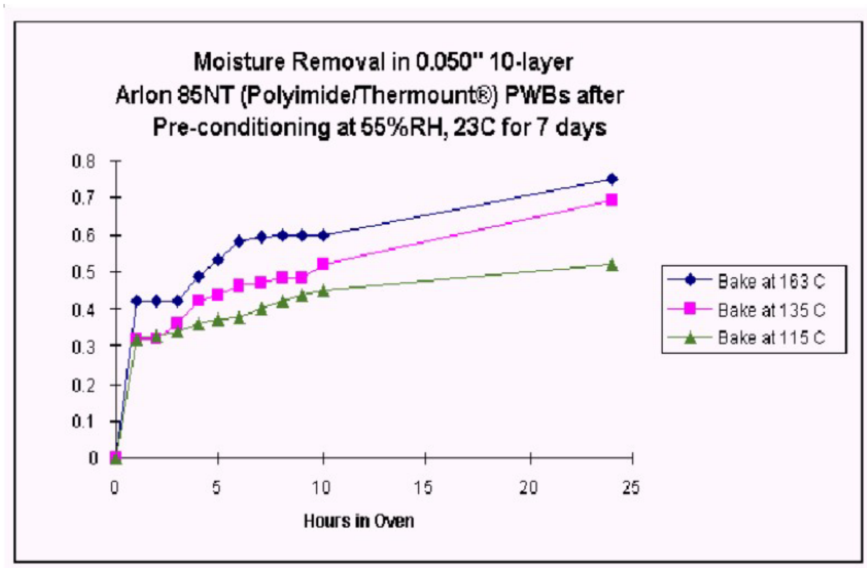


Figure 3 – Raw PCB Materials Baking

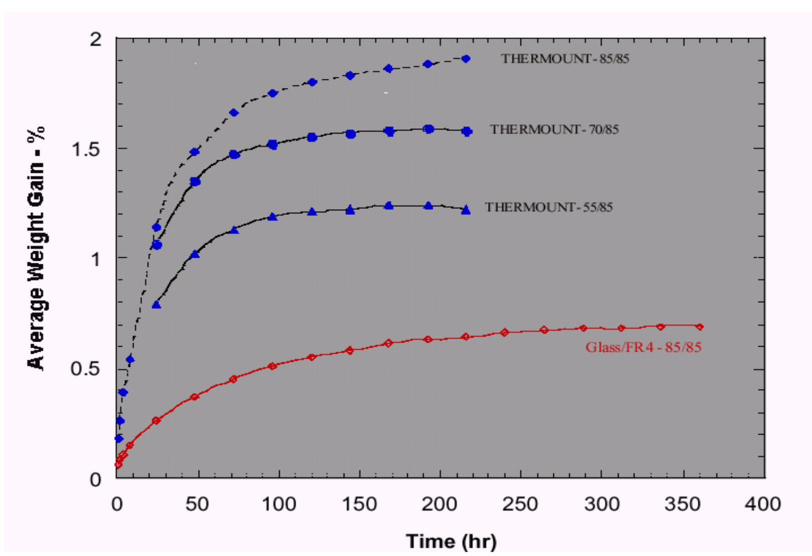


Figure 4 – Raw PCB Materials Moisture Absorption

Baking Efficiency

We have tried to figure out what are the required times at different temperatures to have the same baking efficiency. Seven PCB and five baking conditions have been studied. The PCBs have been baked 13 hours for each temperature condition. In order to better know the real dry weight of each PCB an additional baking at 120°C during 20 hours was performed. The seven PCB are representative of the PCB technology assembled at Solectron Bordeaux. The array on the left (Table 1) shows a light description of those PCB. For each PCB and for each baking condition several curves have been drawn.

Table 1 - Samples Description

	Materials	ANSI	Width (cm)	Length (cm)	Thickness (cm)
PCB I.1	E-glass + Epoxy	FR5/23	6	7,5	0,148
PCB I.2	E-glass + Polyimide	GPY/41	7,5	14,2	0,182
PCB I.3	E-glass + Epoxy	FR5/23	4,9	8,5	0,182
PCB I.4	E-glass + Epoxy	FR5/23	19,5	32,3	0,209
PCB I.5	E-glass + Epoxy	FR5/23	22	26,5	0,212
PCB I.6	E-glass + Epoxy	FR5/23	26	43	0,226
PCB I.7	E-glass + Epoxy	FR5/23	26,3	43,9	0,23

Desorption Curves

This graph (Figure 5) roughly describes the desorption rate (PPM) for each PCB. The weight after 13 hours of baking is not zero as the dry weight has been recorded after 20 additional hours of baking at 120°C. The 800 PPM line is the value found in the IPC handbook (IPC-HDBK-001) as the maximum value allowed for PCB assembly.

Humidity Amount Curves

This graph (Figure 6) shows raw data meaning what is the weight lost (mg) by each PCB through the baking. Obviously bigger is the PCB higher is the humidity amount lost during the baking. PCB I.6 and I.7 are the biggest (Table 1 - Samples Description), so they loose a lot of water (above 400 mg). PCB I.1 and I.3 are the smallest (Table 1 - Samples Description) so they loose less than 25 mg of moisture. One point that can be noticed is that the PCB I.2 looses three times more water than the PCB I.1 and I.3 with nearly the same dimension. It is due to the material type (E-glass/polyimide).

Humidity Amount versus Volume Curves

This graph (Figure 7) is based on the previous graph but the amount of moisture lost during baking has been calculated per volume unit. It is understandable that the PCB I.2 (E-glass/polyimide) is the PCB that looses more water per volume unit (4 mg.cm^3). The PCB I.7 seems to loose less moisture than the other FR-4 (2 mg.cm^{-3}). Basically, this PCB is full of copper (i.e. ground layers on layer 2 and n-1).

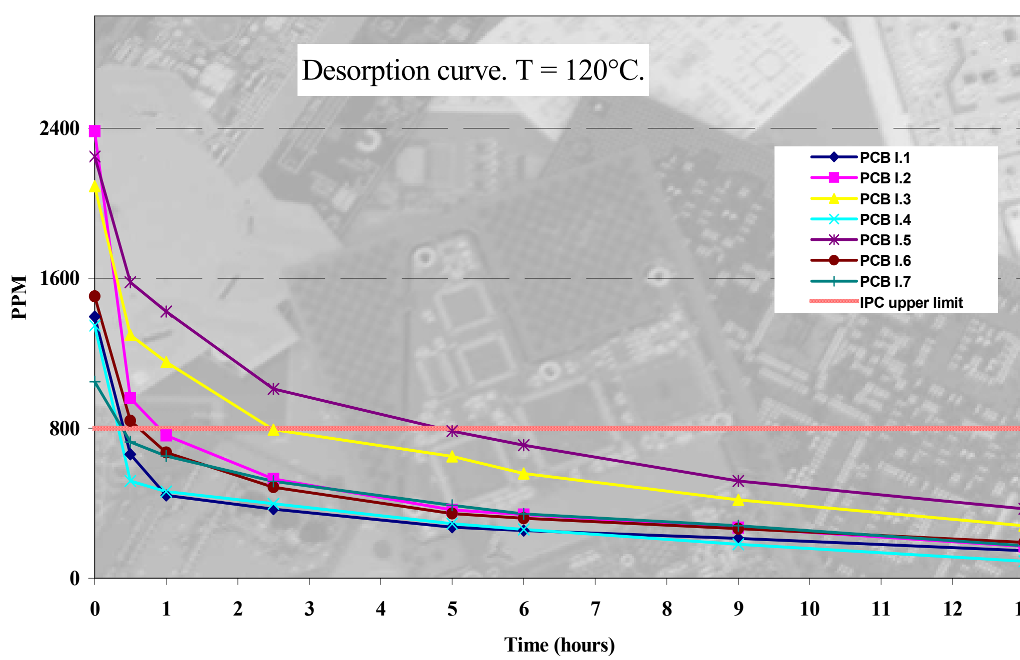


Figure 5 – Desorption Curves

Humidity Percentage Curves
This graph (Figure 8) exposes the humidity percentage lost during baking compared to the dry weight measured with 20 additional hours baking at 120°C. It is between 40-70% for the 80°C baking temperature after 13 hours.

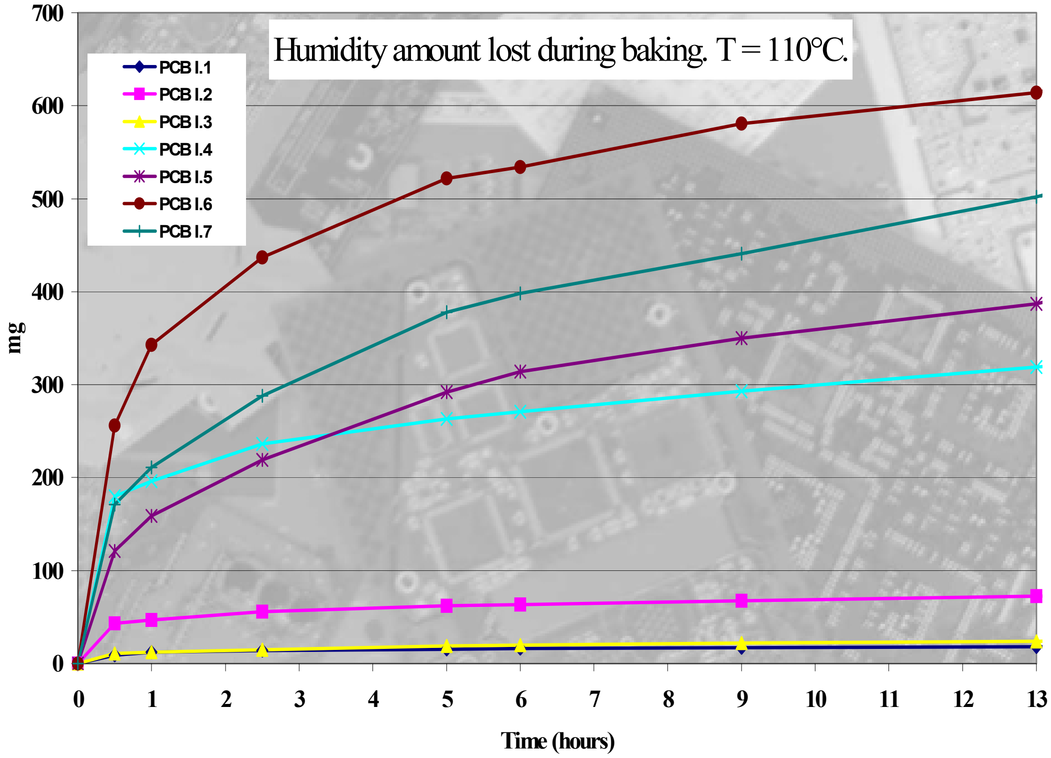


Figure 6 - Humidity Amount Lost During Baking

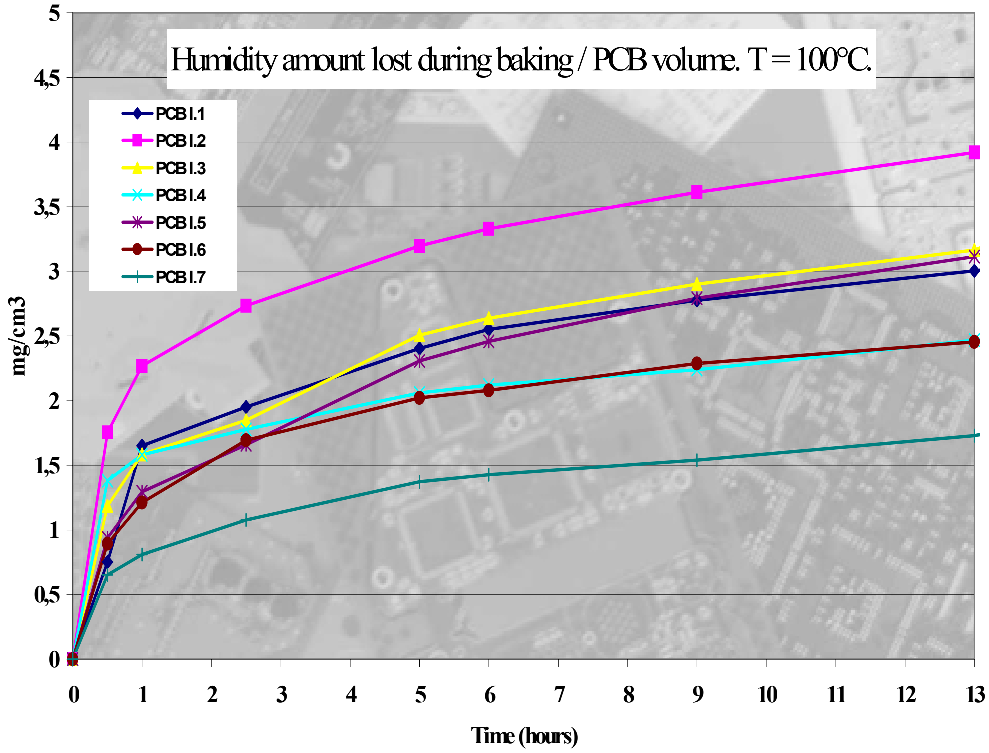


Figure 7 - Humidity Amount Lost During Baking/ PCB Volume

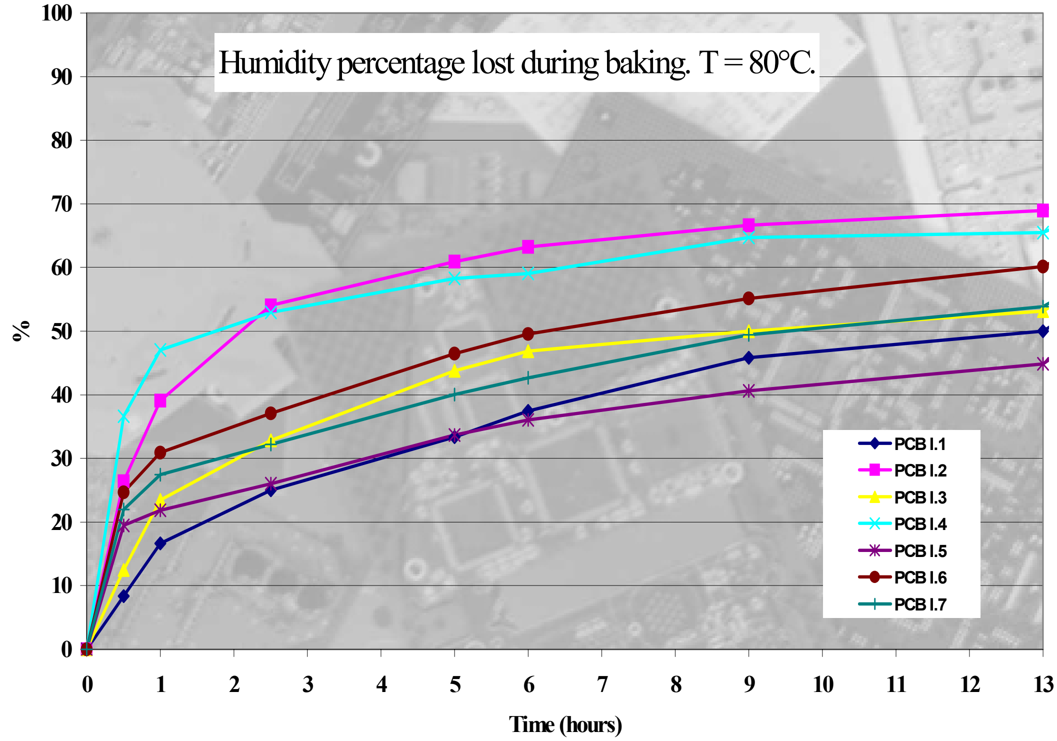


Figure 8 - Humidity Percentage Lost During Baking

The initial question was what are the required times at different temperatures to have the same baking efficiency? In order to answer this question, we drew for each PCB the relative desorption curves. Relative desorption means simply that the initial weight was considered to be equal to one for each test. This allows it to have the same starting point (0, 1). Then we made the average of all the relative desorption curves and drew the inverse. The relative desorption average inverse points are making lines (Figure 5). Thanks to this average, the red curve showing the 800 PPM has been added for information.

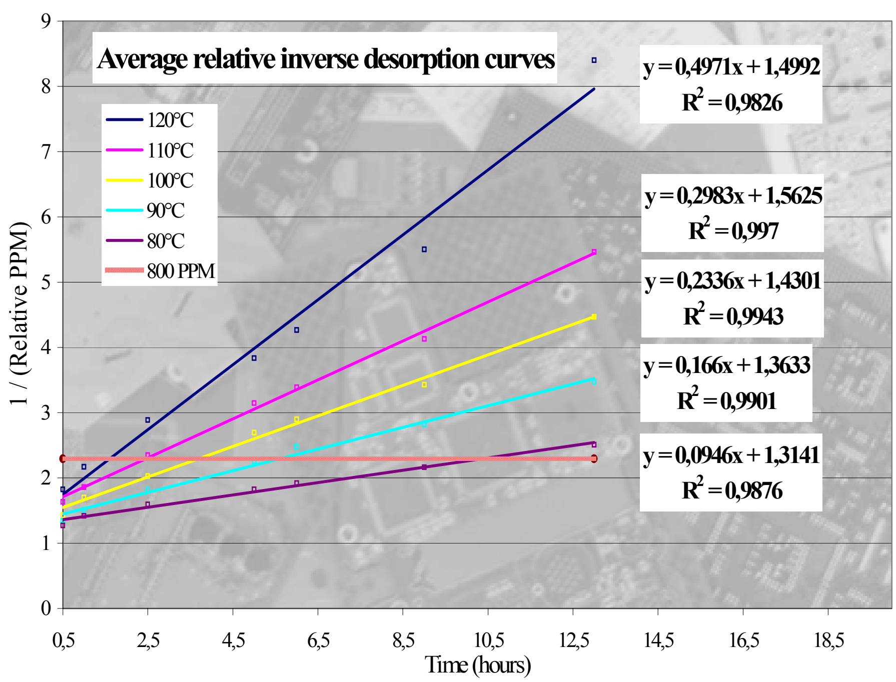


Figure 9 – Average Relative Inverse Desorption Curves

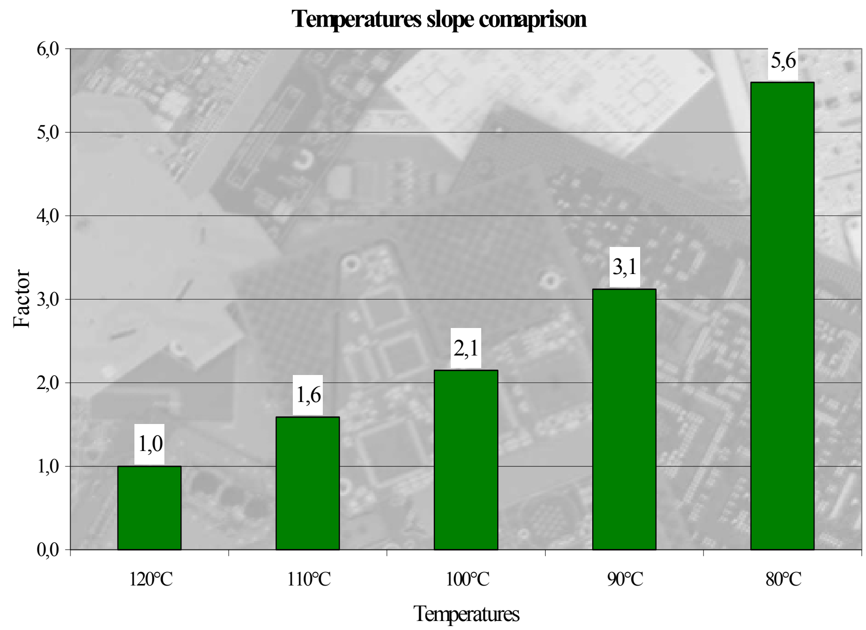


Figure 10 – Temperatures Slopes Comparison

If we compare the baking slope (Figure 2), we can say what are the required times at different temperatures to have the same baking efficiency. Those points have an exponential shape. If we consider at this stage of the study that 4 hours at 120°C is enough to dry the parts below 800PPM, we can deduce an equation (Equation 1) that gives the required time according to the baking temperature:

$$t\ (hrs) = 1.92 \times 10^{-6} \times e^{5726/T}$$ T in Kelvin

Equation 1 – Required Baking Time (hrs) According to the Baking Temperature (K)

It is important to notice that the equation has been establish for a baking range from 80°C to 120°C on a PCB population described above and mainly composed of E-glass/Epoxy PCB.

Materials Behaviors towards Humidity

Most of the PCB materials assembled at Solectron Bordeaux have been studied. The following array (Table 2) shows the different materials available on the market. The one that are with a coloured square have been included in this study.

Table 2 – PCB Materials Classification

Reinforcement	Resin	
Cellulose paper	Phenol	■
	Epoxy	■
E-glass Unidirectional or Woven Surface or full	Polyester/Vinyl ester	
	Epoxy	■
	Epoxy/Phenolic	
	Epoxy/PPO	
	Epoxy/Triazine	
	BT/Epoxy	■
	Polyimide	■
	APPE	■
	Cyanate ester	
	Polyimide/Epoxy	■
	PTFE	■
Aramid Unidirectional or non woven paper or woven	Epoxy	■
	Cyanate ester	
	Polyimide	
	Polyimide/Epoxy	
Woven quartz fiber	Polyimide	
Woven S-2 glass	Cyanate ester	
Ceramic Pure or woven glass reinforced	Hydrocarbon	■
	PTFE	■
Expended PTFE	BT	
None	Polyimide	■

The PCBs have been divided into three groups:

The group 1: PCB that have absorbed less 4000 PPM in moist conditions (28 days at 85°C, 85%RH).

Group 1	
II.3: E-glass/Epoxy//Ceramic/Hydrocarbon	II.15: FR-4 full copper (L1 & Ln)
II.9: Ceramic/PTFE	II.20: FR-4 full copper (L1 & Ln)
II.10: E-glass/APPE	IB7: FR-4 Full copper (L1 & Ln)
II.12: E-glass/PTFE	

The group 2: PCB that have absorbed between 4000 and 9000 PPM in moist conditions (28 days at 85°C, 85%RH).

Group 2	
II.4: E-glass/Epoxy/BT	II.19: FR-4
II.11: Aramid/Epoxy	IB1: FR-4
II.16: FR-4	IB3: FR-4
II.17: FR-4	IB4: FR-4
II.18: FR-4	IB6: FR-4

The group 3: PCB that have absorbed more than 9000 PPM in moist conditions (28 days at 85°C, 85%RH).

Group 3	
II.1: None/Polyimide	II.7: Paper/E-glass/Epoxy
II.2: E-glass/Polyimide	II.8: Paper/E-glass/Phenol/Epoxy
II.5: Eglass/Epoxy//None/Polyimide	II.2: E-glass/Polyimide
II.6: Paper/Phenol	IB5: FR-4

Figure 11 – PCB materials groups

Baking

The following graph (Figure 4) is simply showing the baking curves of the group 2 at 110°C during 13 hours. The dry weight was measured with 20 additional hours at 120°C. Prior baking the PCB were left on shelves at 50%RH and 23°C. The PCB II.12 is a very thin E-glass/PTFE PCB. It probably suffered a lot during the baking. It turned from white to yellow. Its behaviour is the opposite of the other materials. It absorbed moisture during baking. We can see a difference between the groups even at T0. Most of the PCB of group 1 is below 800PPM at T0, meaning the baking was not necessary. The PCB of the group 2 is between 800PPM and 3400PPM with an average around 1700PPM. The PCB of the group 3 is between 1400PPM and 4400PPM with an average around 2400PPM.

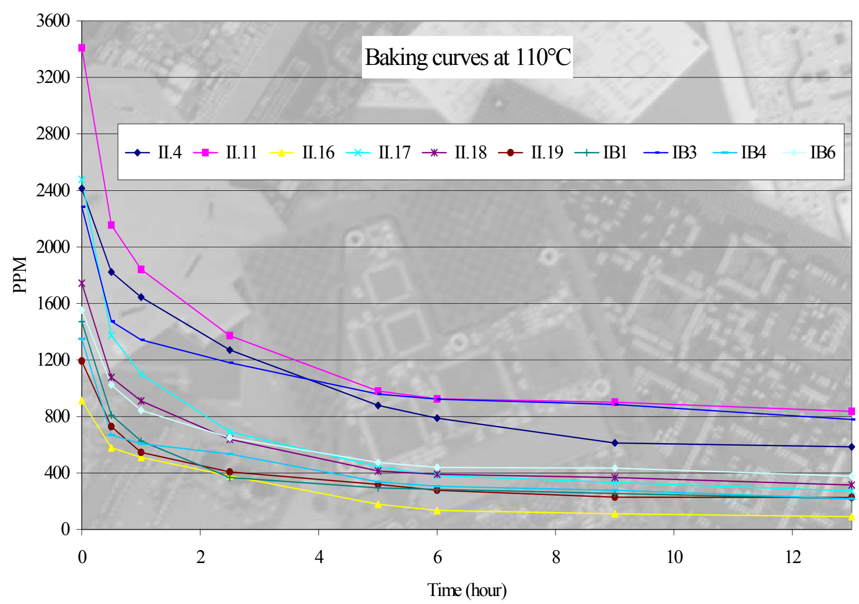


Figure 12 – Baking Curves at 110°C

Storage Comparison

This part aims to check the storage efficiency. First PCBs have been baked 33 hours at 120°C and then they have been stored through different ways:

- Dry pack: PCB is sealed under vacuum with a desiccant. The storage conditions can be estimated below 2%RH.
- Dry cabinet: PCB is stored in a dry atmosphere. The dry air coming from the inlet pipe is around 2%RH and 23+/-2°C.

We can consider with such dry air inlet that the RH in the cabinet is below 5%. The dry cabinet has been used for production; this means that the door was opened several times during the day. Each time the door is opened the moisture percentage increases to 15-20%RH and it takes around one hour to decrease below 5%RH.
That is to say that we took a real production environment to test the dry cabinet storage efficiency.
- Ambient atmosphere: PCB was left on a shelf. The standard storage conditions are 50+/-10%RH and 20+5/-0°C. During the experiment the observed storage conditions were closer to 45+/-5%RH and 23+/-2°C.
- Moist atmosphere: PCB were placed in moist conditions 85%RH and 85°C. Of course measurements disturb measurements.

For example each time we made a measurement it took around one hour before the moist conditions (85%RH) become stable back. This phenomenon has not been taken into account.

The following graph (Figure 13 is showing the materials behaviour of the group 2 through the different storages.

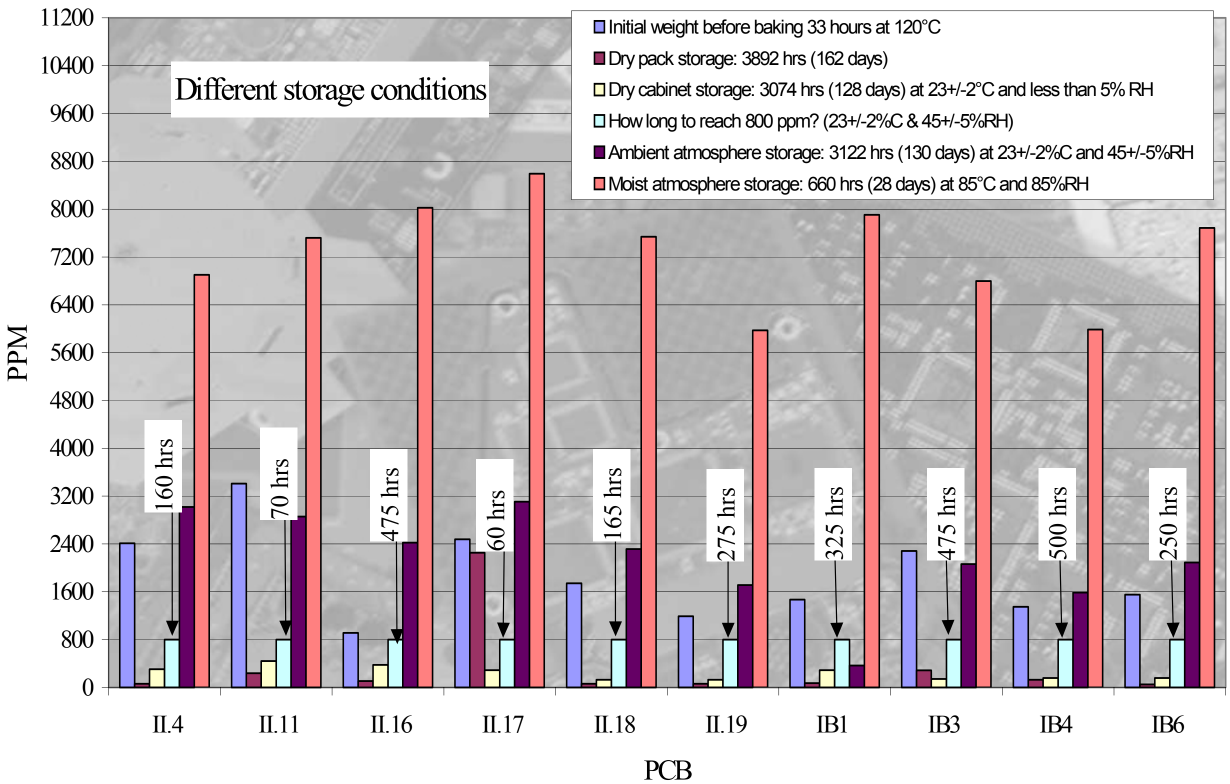


Figure 13 – Group2: Different Storage Conditions

First of all, it is important to notice that no PCB has reached up the 800PPM after 162 days storage under dry pack or 128 days storage under dry cabinet. As mentioned above, after 28 days under moist atmosphere, the group 1 absorbs less than 4000PPM, the group 2 absorbs between 4000 and 9000PPM, and the group 3 absorbs more than 9000PPM with a paper PCB above 20000PPM. Under ambient air, the group 1 needs more than 1000 hr to reach 800PPM, except the PCB II.10 (E-glass/APPE) that needs only 50 hours to absorb such a moisture quantity. The group 2, under ambient air, needs between 100 and 500 hours to reach 800PMM except the PCB II.11 (Aramid/Epoxy) that needs 70 hours and the PCB II.17 (FR4) that needs 60 hours. The group 3, under ambient air, needs less than 100 hours to reach 800 PPM, except the PCB II.5 (E-glass/Epoxy/None/Polyimide) that needs 425 hours and the PCB II.7 (Paper/E-glass/Epoxy) that needs 275 hours. After 130 days under ambient atmosphere, the group 1 absorbs less than 1600PPM, the group 2 absorbs between 1600 and 3200PPM, and the group 3 absorbs more than 3200PPM with paper PCB above 16000PPM, except the PCB II.5 (E-glass/Epoxy/None/Polyimide) that is around 1600PPM.

Absorption Comparison

The PCBs have been baked during 33 hours at 120°C, and then they were left at 45+/-5%RH and 23+/-2°C. A first weight was performed after 96 hours and an other after 3120 hours. After these 3122 hours, the PCB have been baked 4 hours at 120°C and weighted. Again, they were left at 45+/-5%RH and 23+/-2°C and a first weight was performed after 96 hours and an other after 650 hours. Finally, the PCB was baked 8 hours at 120°C. The following graph (Figure 14) represents these measurements for the group 2. When the PCB are left 3120 hours 45+/-5%RH and 23+/-2°C, if they are baked 4 hours at 120°C they need only 650 hours to reach again the same moisture level. This point is verified whatever the group. After 3120 hours at 45+/-5%RH and 23+/-2°C, the group 1 absorbs less than 1600PPM, the group 2 absorbs between 1600 and 3200PPM, and the group 3 absorbs more than 3200PPM with paper PCB above 16000PPM, except the PCB II.5 (E-glass/Epoxy/None/Polyimide) that is around 1600PPM. When the PCB are baked 4 hours at 120°C after they were stored 3120 hours at 45+/-5%RH and 23+/-2°C, some of them are not dried down below 800PPM. The group 1 is dried below 800PMM, the group 2 is dried down between 600 and 1600PPM, and the group 3 is still above 1600PMM. If we bake those same PCB 8 hours at 120°C instead of 4 hours at 120°C, the group 1 and 2 are dried down below 800PPM while the group 3 is only dried down 1600PPM. One exception for the group 2, the PCB II.16, there is not a significant difference between 8 hours at 120°C and 4 hours at 120°C.

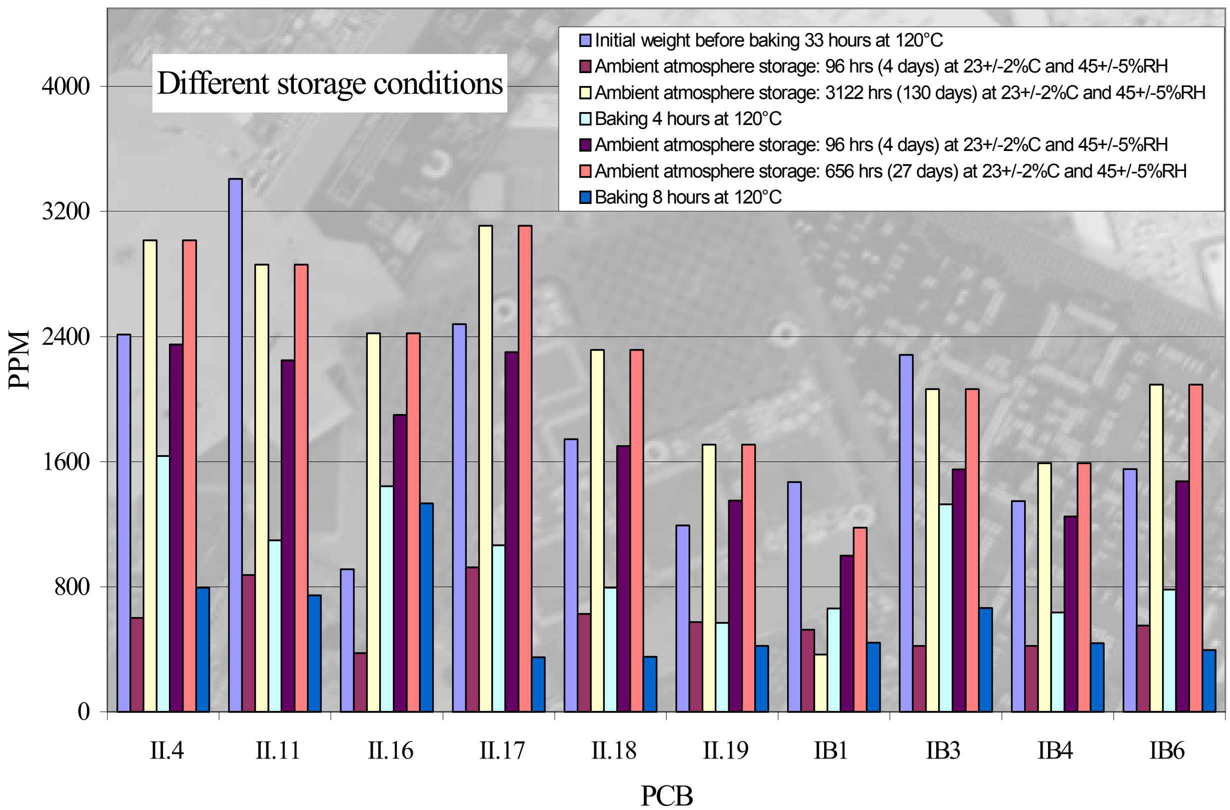


Figure 14 – Group2: Different Storage and Baking Conditions

Materials Comparison

We can compare, how much and how fast do the different materials absorb moisture? The first graph (Figure 15) is the amount of moisture per volume unit absorbed after 3122 hours at 23+/-°C and 45+/-5%RH. Of course, we find on the left the PCB belonging to the group one and the PCB on the right are belonging to the group three. The second graph (Figure 16) shows how many days does it take for each PCB to reach 800 PPM after 33 hours of baking at 120°C. Again, we can roughly find the group three on the left and the group one on the right.

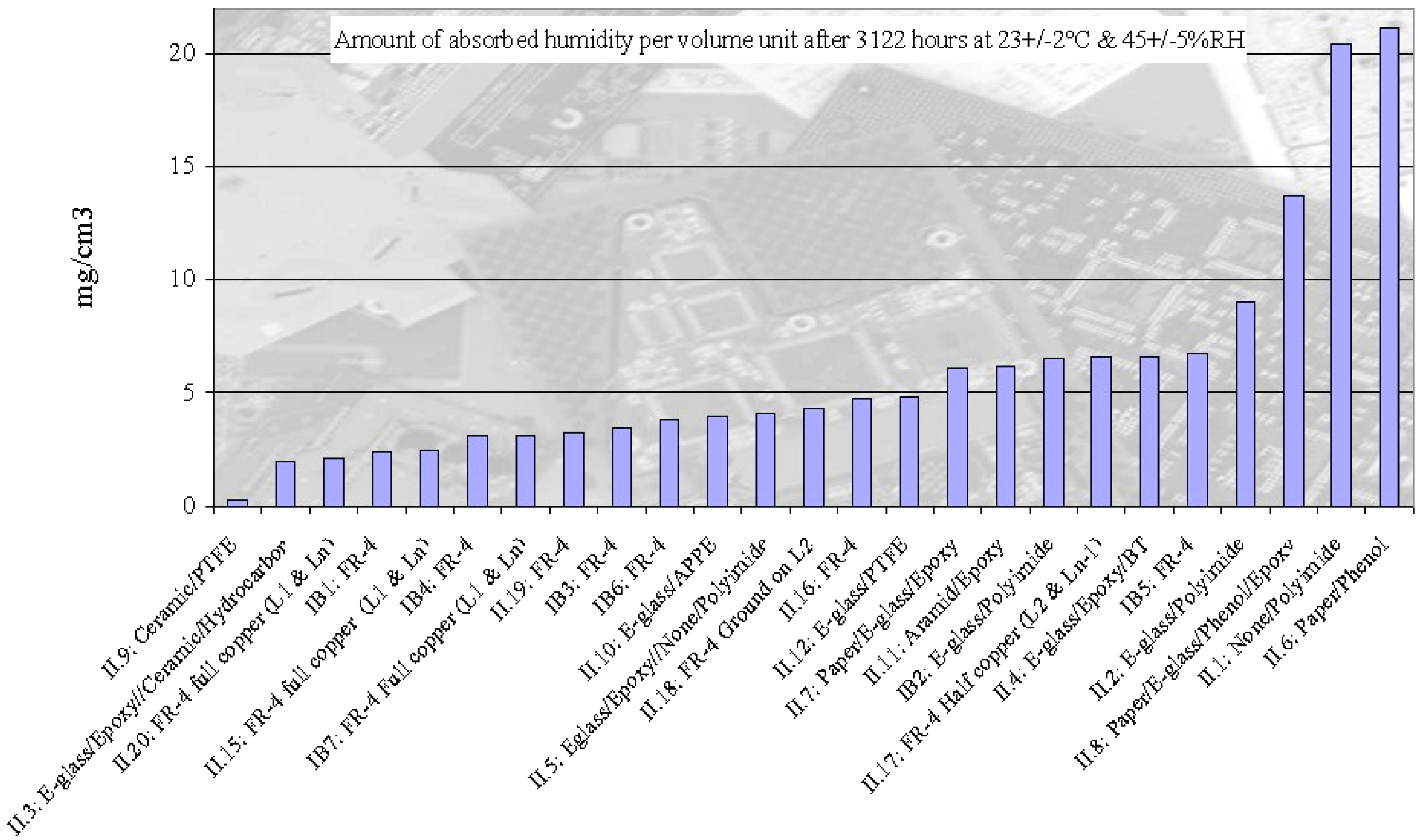


Figure 15 – Group1: Different Storage and Baking Conditions

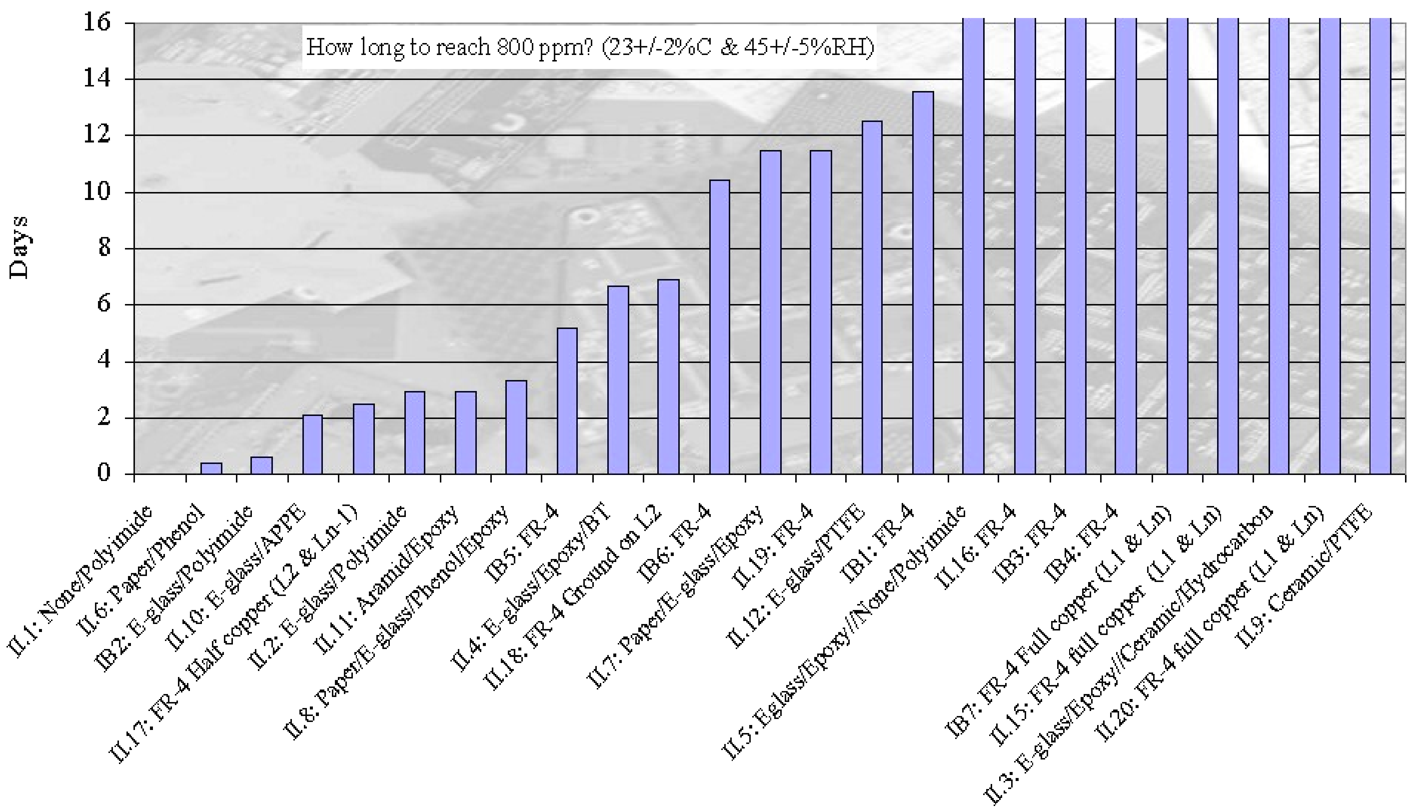


Figure 16 – Group1: Different Storage and Baking Conditions

Fick's Law [11-14]

Assuming a rectangular plate is taken to be infinitely long in the y- and z- directions, the moisture content inside the plate varies only in the x-axis. Initially the moisture concentration c_i inside the plate is uniform. The plate is suddenly exposed to a moist environment and the exposed faces instantaneously reach the equilibrium moisture concentration c_a, which remains constant. The moisture uptake through the thickness of an infinite plate is given by the simple model Fick relationship (Equation 2). The solution of this Fick equation can be calculated if the initial concentration and the space limits are known (Equation 3). This solution gives a Gauss shape curve showing the moisture concentration diffusing through the x-axis at a given time (Figure 17). At temperatures well below the Tg of the conditioned material, water absorption of most polymers correlates with Fick's laws. The diffusion coefficient, independent of time and moisture concentration can be calculated from the Fickian diffusion curve. The Fickian diffusion curve is the percentage uptake of water by weight in function of square root of time (Equation 4). The diffusion coefficient D is determined from the initial linear region of the Fickian diffusion curve using the last equation (Equation 5). Where M∞ is the equilibrium moisture concentration, M_1 is the moisture uptake after time t_1, M_2 is the moisture uptake after time t_2 and h is the thickness.

$$\frac{\partial c}{\partial t} = D_x \frac{\partial^2 c}{\partial x^2}$$

Equation 2

$$\frac{W - W_{Dry}}{W_{Dry}} = f(\sqrt{t})$$

Equation 4

$$c(x,t) = \frac{c_0 e^{-x^2/4Dt}}{2\sqrt{\pi D t}}$$

Equation 3

$$D = \frac{\pi}{16}\left(\frac{h(M_2 - M_1)}{M_\infty\left(\sqrt{t_2} - \sqrt{t_1}\right)}\right)^2$$

Equation 5

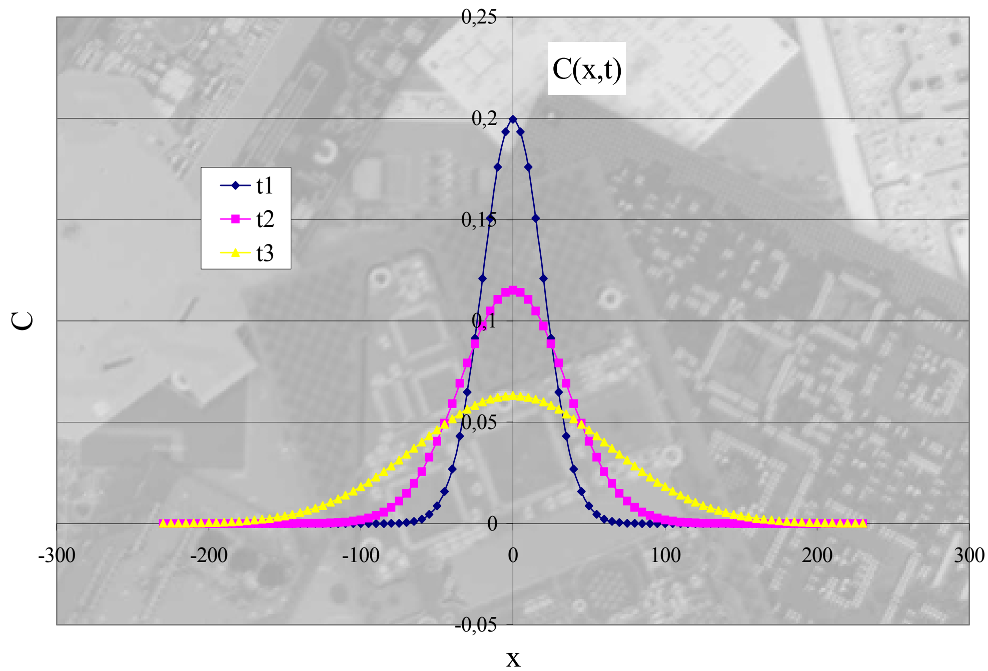


Figure 17 – Gauss Shape Curve

The moisture equilibrium concentration corresponds to the final asymptotic value on the diffusion curve. The rate of moisture uptake by a composite laminate is dependent on the temperature and relative humidity of the environment. The equilibrium moisture concentration (saturation concentration in the material) is assumed to be independent of temperature, depending only on the moisture content or relative humidity of the environment. We can transform the different absorption curves in Fickian model. The graph on the left (Figure 18), is showing the absorption curves of the PCB II.4 during the first 525 hours for each atmosphere. The graph on the right (Figure 19) is showing the Fickian curves for the PCB II.10 for the ambient and moist conditions.

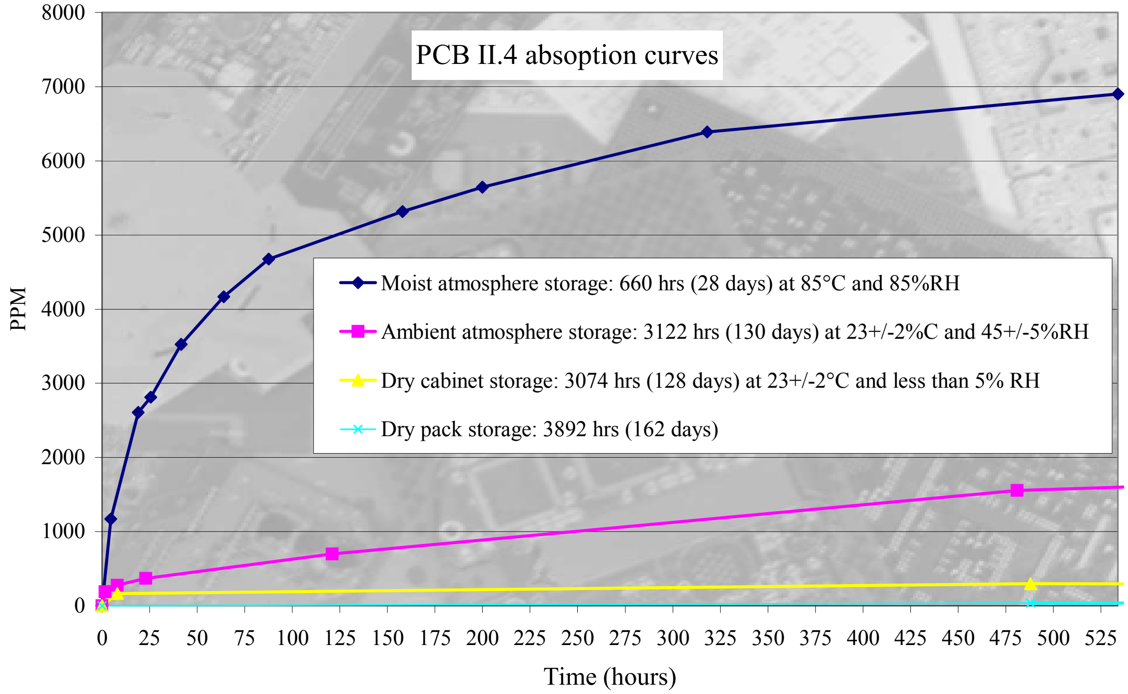


Figure 18 –Absorption Curves of the PCB II.4

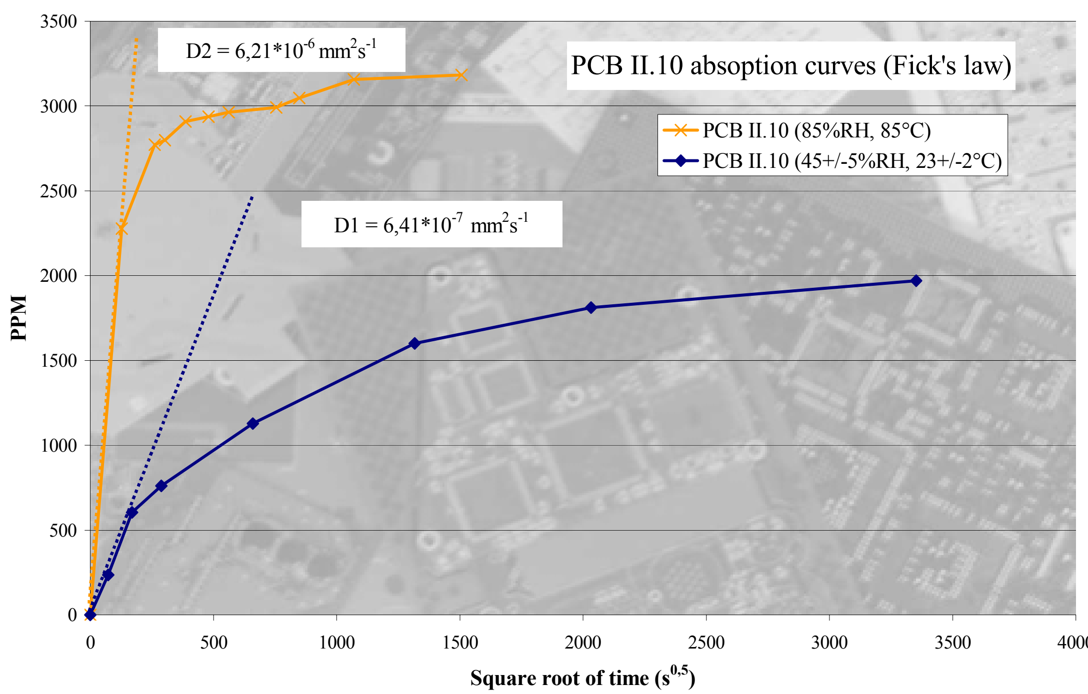


Figure 19 – Fickian Behaviour PCB II.10

Some values can be compared to the moisture/water diffusion coefficient of pure resin found in literature. The polyimide diffusion coefficient was found to be nearly constant with reaction temperatures ranging from 160°C to 240°C around 2.2 to 4.8 x 10^{-7} mm^2s^{-1}. Moisture diffuses through polyimide at room temperature with a diffusion coefficient of 5 x 10^{-7} mm^2s^{-1}. In comparison we found for E-glass/Polyimide 1.02-8.29 x 10^{-7} mm^2s^{-1} depending on ambient or moist conditions. The epoxy diffusion coefficient was found in literature to be around 13 × 10^{-7} mm^2s^{-1}. The distilled water diffusion coefficient through epoxy was found to be 0.53 x 10^{-7} mm^2s^{-1} at 22°C and 13.6 x 10^{-7} mm^2s^{-1}at 60°C. In comparison we found for E-glass/Epoxy 2.21-8.14 x 10^{-7} mm^2s^{-1}depending on ambient or moist conditions.

Conclusion

The aim of this part was to better know the PCB materials behaviours. Concerning the baking, a first equation (Equation 1) has been given to calculate the required time according to the baking temperature. Following the study on the three PCB materials groups, the equation can be adjusted (Equation 6). “A” is a correction coefficient (Table 3) according to the storage, the material and the required moisture level.

$$t\ (hrs) = A \times 1.92 \times 10^{-6} \times e^{5726/T} \qquad \text{T in Kelvin.}$$

Equation 6 - Corrected Baking Equation

Table 3 – Correction Coefficient (A) values

Storage	Storage < 3 months			Storage > 3 months		
Required moisture level	800PPM	1600PPM	2400PPM	800PPM	1600PPM	2400PPM
Group 1	0	0	0	1	0,25	0
Group 2	1	0,25	0	2	1	0,25
Group 3	2	0,5	0,25	3	2	1

The storage conditions (Table 3) are 50+/-10%RH and 23+/-2°C. Basically, the group 1 is composed of HF materials and PCB with full ground copper on external or not external but one layers. The group 2 is mainly composed of epoxy material (FR-4, E-glass/BT, Aramid/Epoxy…). The group 3 is composed of moisture sensitive resins such as phenol or polyimide (CEM1, CEM3, flexible, rigid-flexible, polyimide rigid…). See Figure 11

.

Concerning the storage, how long is the average time for each group to reach the required moisture level. We take into account the ambient air (Table 5) and dry cabinet (Table 4) storages. If we consider that the PCB are dried only 200PPM under the required moisture level, the two following arrays (Table 4, Table 5) are given the maximum average time allowed to gain again those 200PPM. It is important to notice that all those storage and baking data are given for PCB with a thickness below 2.6 mm. The ambient air conditions (Table 5) are 50+/-10%RH and 23+/-2°C. The dry cabinet (Table 4) conditions are RH below 5% at 23+/-2°C.

Table 4 - Maximum Allowed Storage Prior Assembly in a Dry Cabinet

Required moisture level	800PPM	1600PPM	2400PPM
Group 1	/	/	/
Group 2	2976 hrs (124 days)	/	/
Group 3	1488 hrs (62 days)	2976 hrs (124 days)	/

Table 5 - Maximum Allowed Storage Prior Assembly at the Ambient Air

Required moisture level	800PPM	1600PPM	2400PPM
Group 1	720 hrs (30 days)	/	/
Group 2	72 hrs (3 days)	288 hrs (12 days)	480 hrs (20 days)
Group 3	24 hrs (1 day)	60 hrs (2,5 days)	120 hrs (5 days)

Two exceptions have to be noticed concerning the storage. The first one is the PCB II.10 (E-glass/APPE) that belongs to the group 1 concerning the moisture level absorption properties but it has an absorption velocity close to the PCB materials belonging to the group 3. The second one is the PCB II.1 (None/Polyimide), that is a thin flexible product (100µm). Full polyimide, very thin thickness means that this product absorbs the 800 PPM in less than half an hour. Two PCB behaviours have also to be discussed. Both PCB II.11 (Aramid/Epoxy) and PCB II.17 (FR-4) are belonging to the group 2 and they absorb 800PPM within 70 hours. The PCB II.11 behaviour is due to the aramid. Whereas the PCB II.17 behaviour can be explained by two reasons: the panelisation and copper density. The PCB is a card panelised by five so quite a lot routing. It is a 1.3 mm thick four layers. It is possible to see through as the copper density is not high.

Finally, it has to be noticed that the IPC recommendation is 800 PPM maximum moisture in the PCB prior reflow. It can be found in the literature, PCB material suppliers recommending around 2800 PPM maximum prior assembly. We also performed delamination test on PCB materials, no delamination was found below 2400 PPM. The test consisted in 3 successive hot standard reflow or 3 successive wave soldering.

Step Three of the Project

***PCB immersion finishes*[3-7]**

HASL, OSP and ENIG are famous PCB finishes as they represented more than 80% of the world market in 2001. Then we will focus on immersion finishes and discuss briefly about manufacturing, cost, intermetallics, drawbacks and wettability/spreading.

Manufacturing
The electromotive potential between silver and copper is 0.456V, so the reaction is instantaneous. Unfortunately, tin's potential relative to copper is -0.480V, so the reaction is not spontaneous. A strong complex or, typically thiourea, is introduced into the tin solution to act as a selective complexing agent for the cuprous cation. Additional chemicals are used to improve the finish quality. Organic compounds are added to the silver bath to inhibit tarnish and to prevent electromigration. Organic surface modifiers, inorganic grain modifiers or inorganic barrier layers are added into tin baths. Silver and tin form a thin surface coating due to environmental exposure to sulphides and chlorides. These tarnishes are visible and may concern incoming inspection. Silver oxide is not stable, and tin oxide is not readily visible. Immersion metal chemicals systems have been formulated to contain organic materials, resulting in a protective film on the metal surface or within the metal deposit. The degree of protection offered by the film depends on such parameters as porosity, uniformity and solubility.

Cost
The cost associated with PCB finish depends on the cost of the metal itself, the thickness of the metal, the cost of the chemicals in plating bath, the cost of other chemistry and equipment before and after metal deposition. One cost benefit of immersion deposit is due to galvanic displacement which is a self limiting reaction that will usually result in a thickness of less than 0.5µm. Finally, immersion deposits are generally less expensive than electroless deposits because of the relative simplicity of the immersion baths and overall processes. The electroless nickel process cost nearly 30 times more than the nickel metal itself and immersion silver process is at least 10 times faster than electroless nickel. The cost of immersion processes is about the same than HASL, and 3 times less expensive than electroless nickel.

Intermetallics
When solder becomes molten the immersion metals instantly dissolve into the solder. At 232.2°C, gold dissolves at a rate $3\mu ms^{-1}$ and silver dissolves at $1.11\mu ms^{-1}$. Once copper circuitry is exposed, thin and copper begin to form an intermetallic phase that joins the metals. Then the copper-tin intermetallic interface is the same than the one formed with HASL and OSP finishes.

Drawbacks
Reliability drawbacks are well documented, while ENIG is well known to form nickel-tin intermetallic when black line nickel does not act as a killjoy, silver forms water soluble salts when exposed to condensing moisture (electrical bias), and tin is prone to whiskering. The tendency for pure silver to migrate increases with increasing thickness, while lower thickness is more likely to whisker. This explains the standard thickness of silver below 0.5µm and that of tin at about 1.0µm. Finally tin copper intermetallic is formed at room temperature so sufficient tin thickness is necessary to guarantee efficient storage.

Wettability/Spreading
Silver is one of the most wettable metals with eutectic Sn/Pb soldering due to mainly the quick dissolution of silver at soldering temperature. Wetting balance studies with Sn/Pb alloy seemed to show that silver remains efficient towards baking while immersion tin suffers from thermal degradation. Spreading studies seemed to be more profitable for ENIG. Immersion tin and immersion silver have nearly the same spreading properties. Solderability of immersion silver is relatively insensitive to storage at 85°C/85%RH conditions but depending on the type and thickness of the immersion silver.
Wettability and spreading with Sn/Ag/Cu alloy are also well documented and trends to show that immersion tin and ENIG surfaces provided the best wetting results on fresh boards follow by immersion silver and OSP. While immersion silver can withstand multiple lead free reflow, immersion tin cannot withstand multiple lead free reflow without significant degradation.

Wettability Test
Only the impact of the baking on the wettability is tackled in this paper as the study is still on progress. Hopefully, the full results will be presented at the APEX. For each finish and for each baking condition, the wettability test has been performed after baking, after first reflow and after second reflow. The IPC test coupon and the recommended flux have been used. According to the finish, we can roughly represent the different wettability curves as follow (Figure 20). Immersion silver and immersion tin reach a threshold, ENIG, OSP, HASL don't. ENIG, HASL and immersion silver cross over the corrected zero, immersion tin reaches with difficulties the corrected zero, OSP never crosses the corrected zero.

According to the IPC test method it can be measured two results (Figure 21): the wetting time (Tw) and the wetting force (Fmax). We have taken the highest Fmax and fixed it at 20, the smallest Fmax was fixed to nil and then we were able to give marks to the other Fmax between nil to 20. As for Fmax, we have taken the fastest Tw and fixed it at 20, the test duration was fixed as the slowest Tw means fixed to nil and then we were able to give marks to the other Tw between zero to 20. Unfortunately when the Tw could not be measured (mainly OSP) because of the wettability curve shape, we had taken into account the remaining negative Fmax at the latest point on the curve. The negative values are not representative of Tw, they simply indicate if the curve was far from cross over again the corrected zero.

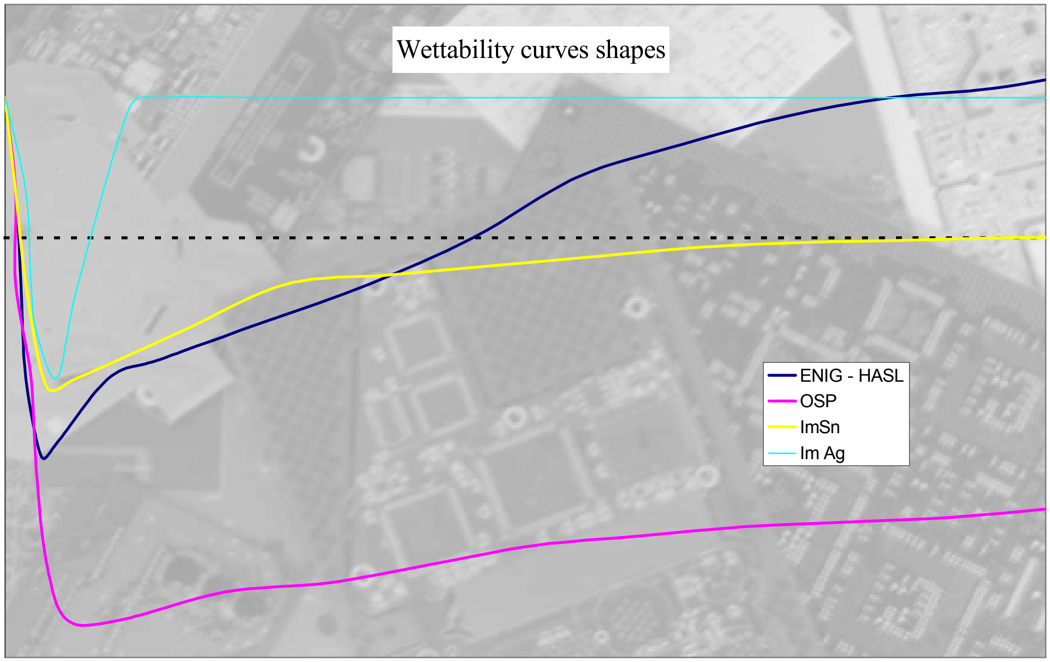


Figure 20 – Wettability Curves

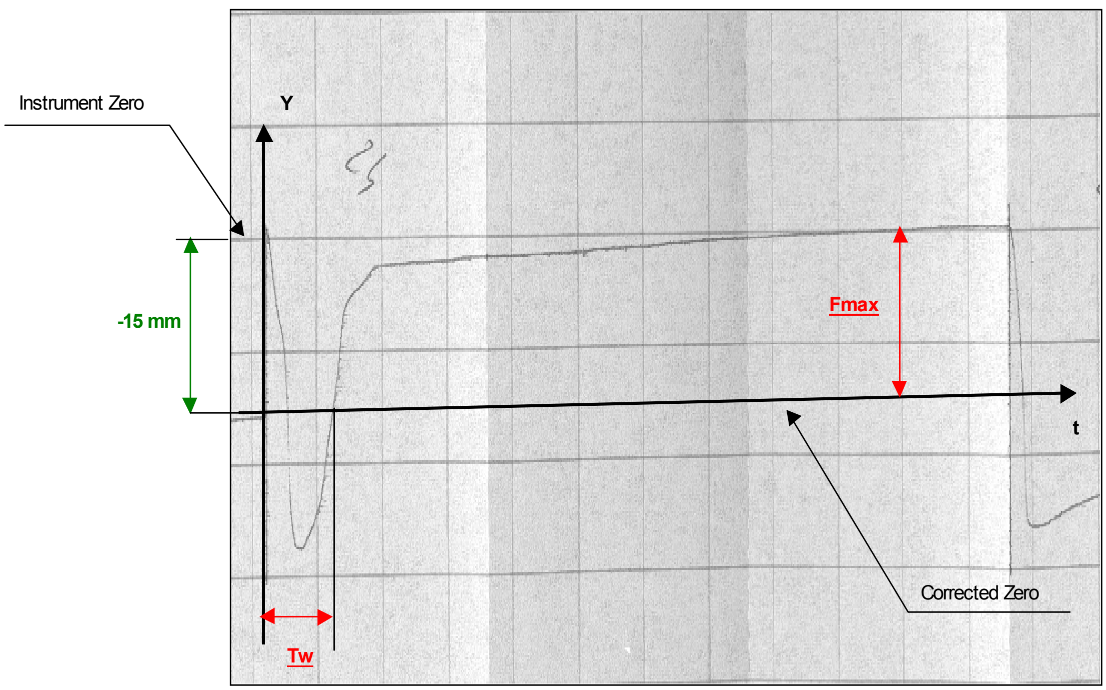


Figure 21 – Tw and Fmax

Concerning Fmax (Figure 22), only ENIG, HASL and immersion silver are above 15. OSP is below 5 and immersion tin is around 14. ENIG seems to be slightly impacted with baking conditions when immersion silver remains good whatever the baking condition. HASL is the only finish that improves slightly its Fmax when baking conditions are becoming more severe. Concerning the Tw (Figure 23), OSP never crossed again the corrected zero meaning very poor wettability. Immersion tin has irregular results and faced difficulties to cross over the corrected zero. Baking conditions seem to have a slight impact on ENIG, immersion silver and HASL. Immersion silver and HASL are the only finishes above 13. We can make an average whatever the baking conditions and whatever the Tw or Fmax. Then, the immersion silver has the best results, followed by HASL. ENIG is only third because of poor Tw results due to the wettability curve shape. Immersion tin is a bit behind while OSP is far from good results.

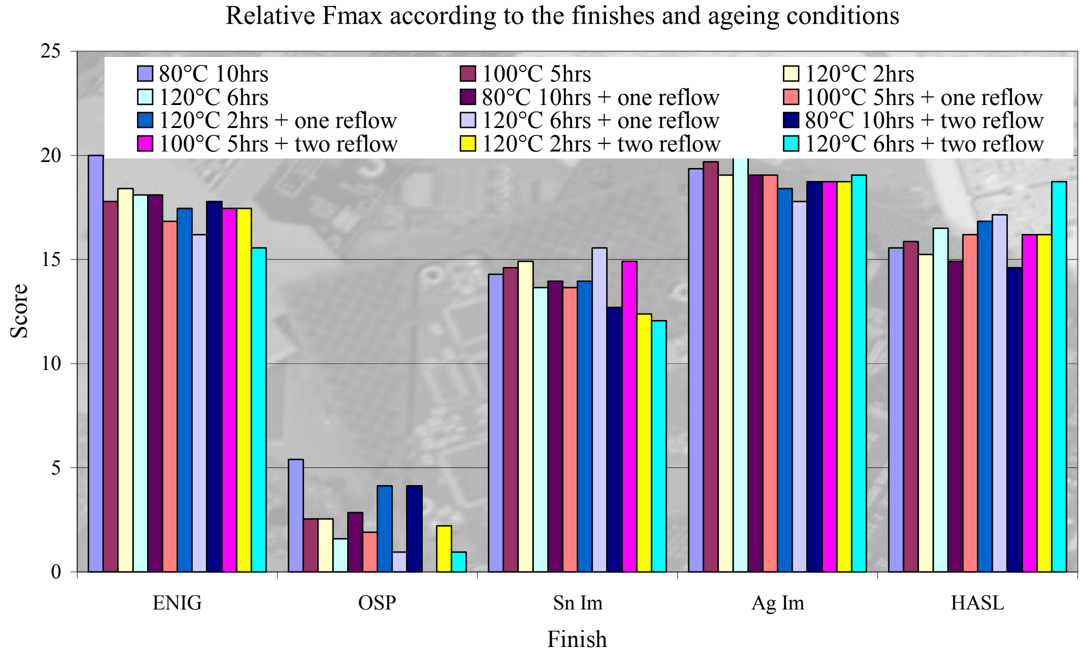


Figure 22 – Baking Impact on Fmax

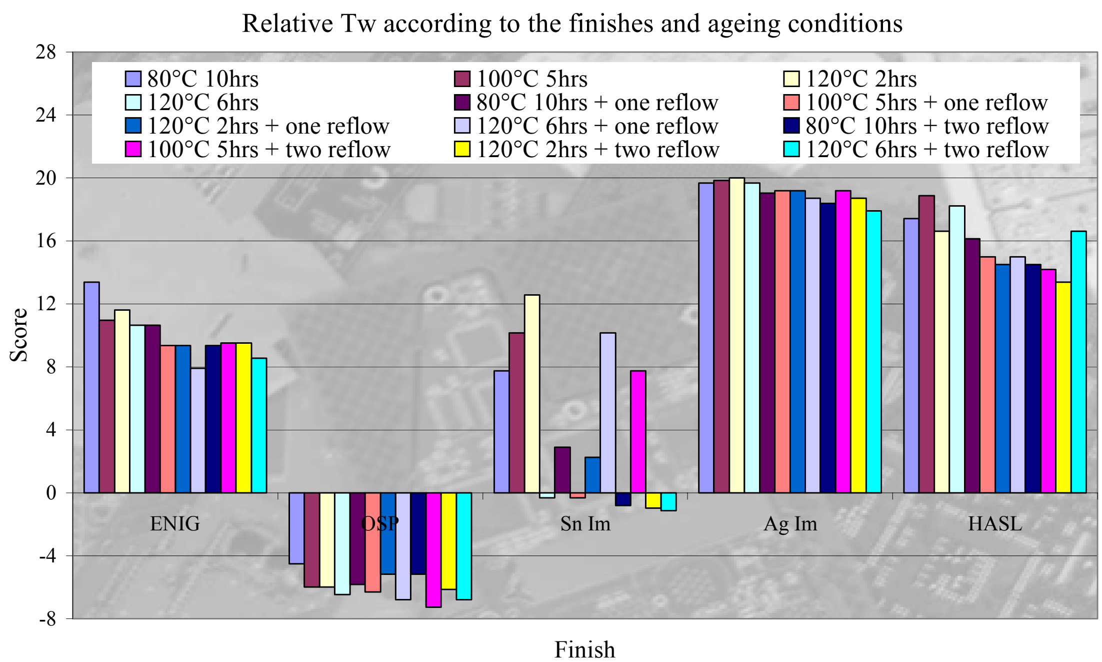


Figure 23 – Baking impact on Tw

CSP and BGA Voiding

The assembly line for the test vehicle was composed of a Dek 265, a Fuji CP65E, a Fuji IP3, and Paragon P150. The stencil was a 150µm laser cut for the bottom and a 110µm electroformed for the top side. The solder paste characteristics used for the assembly are described in the array below (Table 6) thermal profil monitored for each solder paste are shown on the following graph (Figure 24). Concerning the PCB finishes thickness. ENIG (Ni 5-7µm, Au 0.05-0.075µm), Im Sn (1.1µm), Im Ag (0.1µm), HASL (2µm).

Table 6 – Solder Paste Characteristics

	Alloy	Flux (JSTD004)	Tackiness (g)	Viscosity (poise)
Clean	Sn63Pb37	ORM0	43	1800
No celan	Sn63Pb37	ROL0	40	1250
Lead free	Sn95,5Ag3,8Cu0,7	ROL0	38	1950

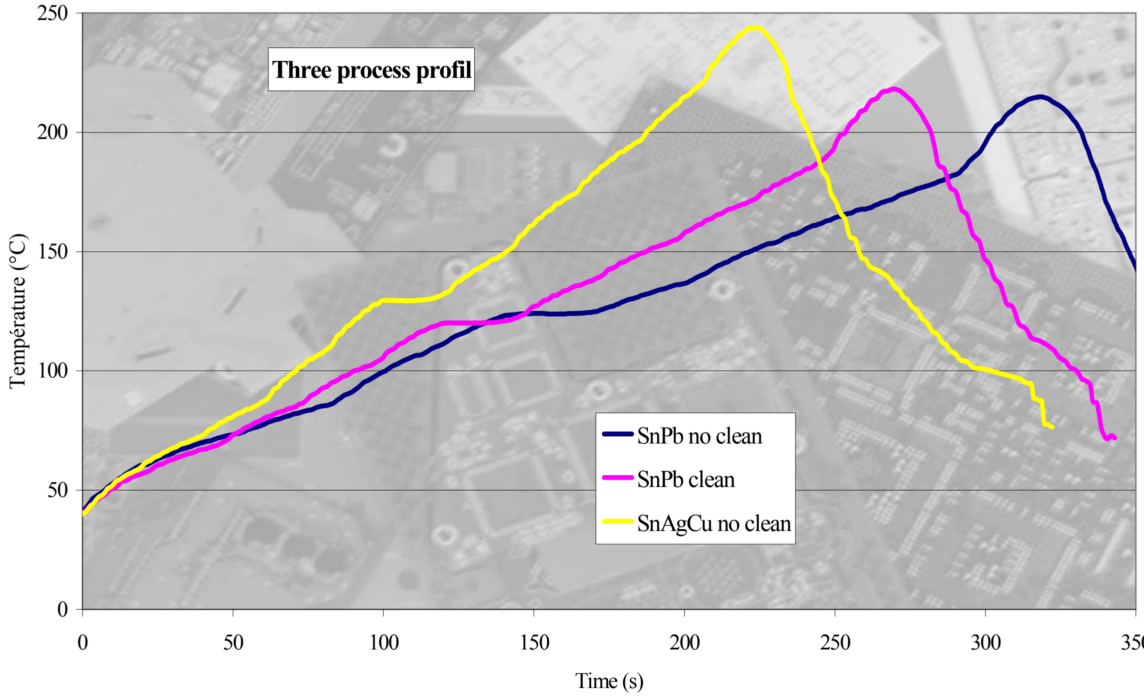
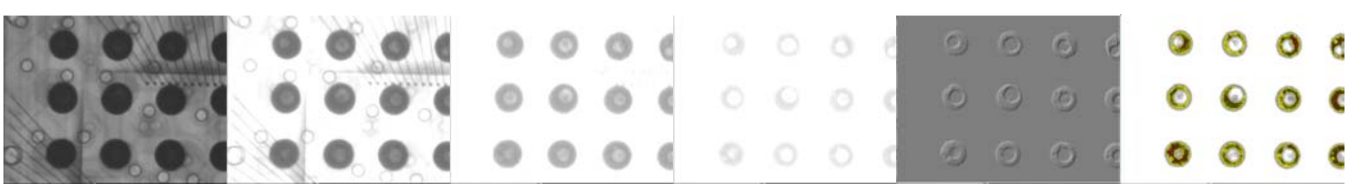


Figure 24 – Reflow Profil According to the Process

Voids in BGA/CSP ball bring sometimes an endless discussion between quality engineers. Some says voids increase reliability as they act as chock absorbers. Some say they are the root cause of the BGA defects. Anyway IPC standard has to play a key role for decision. The new draft document (IPC-7095A, March 2003) seems to give more details concerning the acceptance criteria. Basically this draft divides the BGA ball in three areas: one at the package interface, one at the PCB interface and one in the middle of the ball. This draft gives, as acceptable conditions that at the package or PCB interface the void diameter should be inferior at 50% of the pad diameter for the class 1, 35% of the pad diameter for the class 2, and 20% of the pad diameter for the class 3. We took these values as a rule in our study to compare the impact of the different parameter. We only measured the void diameter without taking into account where was located the void within the BGA balls. Furthermore, in the IPC, it is also about a maximum allowed percentage of the impacted balls. This parameter has not been taken into account. In addition X-rays power should be monitored to measure a void. Meaning, higher is the voltage; more the x-ray beam goes through the material (Sn/Pb or SnAgCu in our case). As the void has usually a sphere shape it is hardly possible to see where the voids ends as the picture is made of a grey colour gradient. Higher is the voltage; more the light grey becomes white. Anyway, as we only compare results we only need to take care that the X-rays parameters remained the same through the all study. The following pictures (Figure 25) are the same location with different X-ray parameters (I remaining at 1.5 A). We took the parameters of the right hand picture to measure all the voids. Those measurements have been performed on more than 6,000 balls.



Grey, V = 50kV Grey, V = 62kV Grey, V = 70kV Grey, V = 78kV P3D, V = 78kV Colour, V = 76kV

Figure 25 – X-rays Picture with Different Parameters (voltage, colour…)

Regardless microvia in pad, generally voids are caused by the outgassing of entrapped flux in the sandwiched solder during reflow. The voiding is mainly dictated by the solderability. Voiding increases with decreasing solderability of metallization, decreasing flux activity, increasing metal load of powder, and increasing coverage area under the lead of the joint. Decrease solder particle size causes only a slight increase on voiding. Voiding is also a function of the timing between the coalescing of solder powder and the elimination of immobile metallization oxide.

The sooner the paste coalescing occurs, the worse the voiding will be. Increase in voiding usually is accompanied by an increasing fraction of large voids, suggesting factors causing voiding will have an even greater impact on the large void and then on the joint reliability. Concerning the assembly parameters (Figure 26), here are some comments: higher is the maximum peak temperature, more chance to have voids. Higher is the soaking zone, more chance to have voids. Fluxes chemistry has definitely the major impact on voids. Clean process increases the wettabillity and so decreases the voids. Regarding the assembly of the test vehicle boards we firstly performed a kind of reflow DOE to be sure that the reflow profil was optimised to reduce the voiding. For each solder processes (SnPb clean; SnPb no clean, SnAgCu no clean), it appears that longer is the profil less voiding occurs (Figure 27). We took the worse case (microvia in pad design) to define the most appropriate profil that reduce voiding effect. The three pictures have been performed with the same settings (Figure 28).

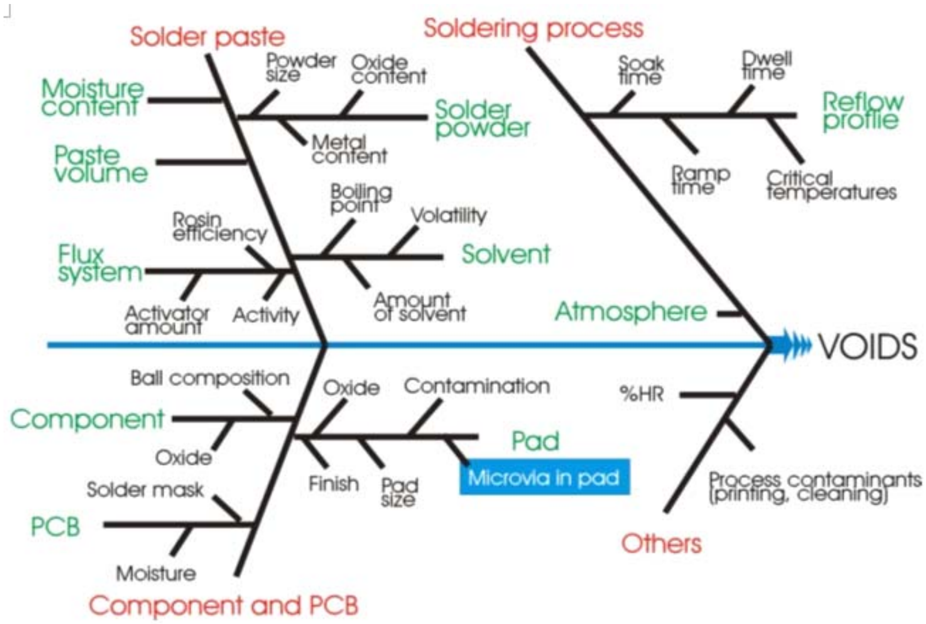


Figure 26 - Voiding Fish Bone

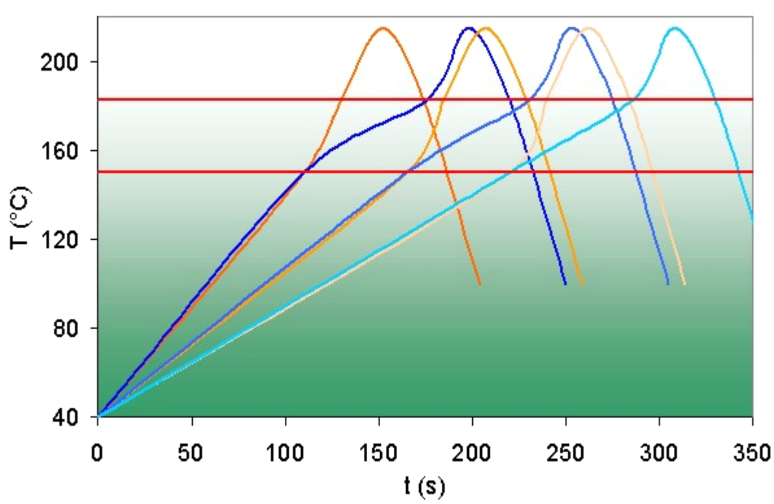


Figure 27 – Reflow Profils DOE

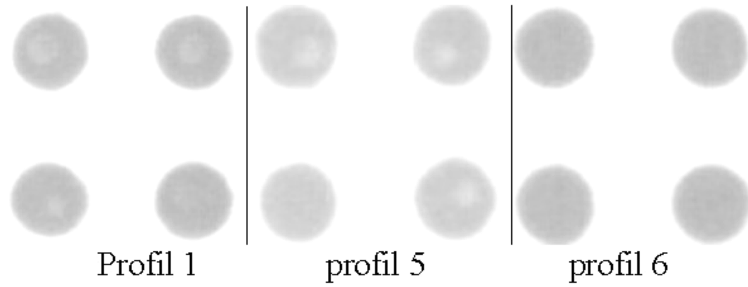


Figure 28 – Different X-rays Picture According to the Reflow Profil

Among the voiding fish bone (Figure 26), we have chosen, in the Aquaboard project, to see the impact of the following parameters: the baking, the process, the finish, the atmosphere and the design. See the introduction for the details. The following graphs are resuming the different performed tests. It can be noticed that **if we consider** that all the voids are located at either the package interface or the PCB interface the percentage of the CSP balls within class 3 criteria is the percentage described by the red column. Each graph takes into account only the studied parameters. For example the graph showing the impact of the atmosphere does not take into account the solder, the design, or the finish.

All the designs for the CSP (Figure 29), except the microvia in pad design have more than 65% of the balls free of void and 90% of the balls with a void below 20% of the pad diameter. The MVP design has more than 25% of the balls free of void and 60% of the balls with a void below 20% of the pad diameter. The graph on BGA voiding (Figure 30) is only about the copper defined pad. The round dog bone design and the off-set MVP design have more than 99.5%of the balls with a void below 20% of the pad. It is important to notice that the microvia diameter is about 100µm for both CSP and BGA whereas the BGA pad is much bigger than the CSP one. 640µm pad diameter for the BGA and 280µm pad diameter for the CSP. This mean that a void with a diameter around 120µm is classified within the class 3 for the BGA (<20% of the pad diameter), whereas this void is out of the class 3 and class 2 specifications for the CSP (>35% and <50% of the pad diameter). For the BGA there is no significant difference between the MVP design and the shifted MVP design. The shifted MVP design tends to reduce lightly the voiding phenomenon. The MVP design for the BGA has 95% of the balls with a void below 20% of the pad diameter while the MVP design for the CSP has only 60% of the balls with a void below 20% of the pad diameter.

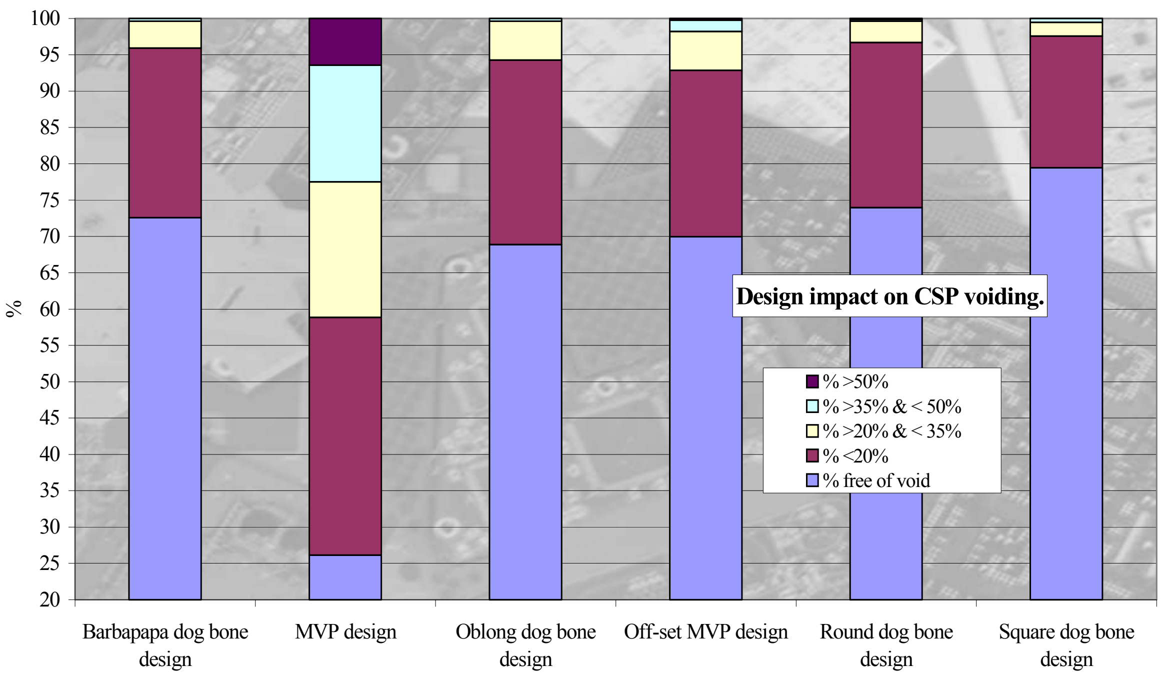


Figure 29 – Design Impact on CSP Voiding

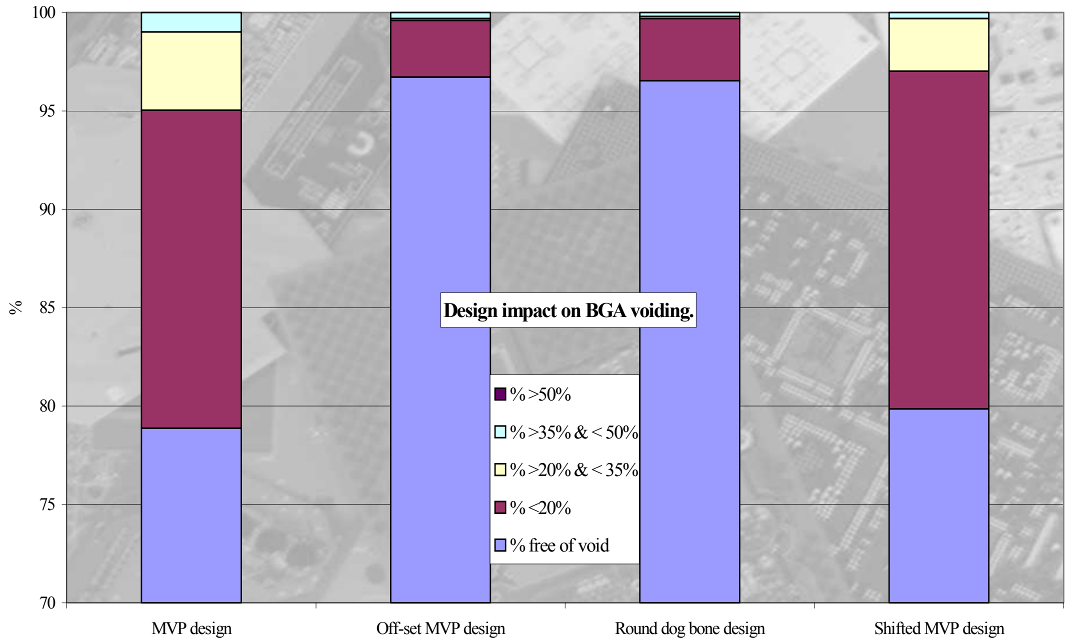


Figure 30 – Design Impact on BGA Voiding

The nitrogen (Figure 31) tends to reduce slightly the voids. With an air atmosphere, around 62% of the balls are free of void and 87% of the balls have voids below 20% of the pad diameter. With nitrogen atmosphere, around 68% of the balls are free of void and 92% of the balls have voids below 20% of the pad diameter. Concerning the PCB finish (Figure 32) HASL (72%, 92%) and Im Ag (73%, 89%) seem to be ahead, OSP (60%, 86%) and Im Sn (59%, 91%) seem to be behind and ENIG (64%, 91%) is between.

The SnPb clean (Figure 33) process (71%, 93%) is a bit better than the SnAgCu no clean process (73%, 89%). The SnPb no clean process is worse (54%, 85%). On the baking graph (Figure 34), we cannot say that baking has an impact on voiding. Once again this graph is an average whatever the finish. This average minimizes the effect of the baking (i.e. hard baking on OSP assembled with no clean process under air atmosphere). We can go deeper in the analysis. For example we can compare the microvia in pad design versus the dog bone design according to the other parameters. The two following graphs (Figure 35, Figure 36) compare the microvia in pad design versus the dog bone design according to the finish whatever the solder, the atmosphere, the pad definition (solder mask defined pad or copper defined pad).

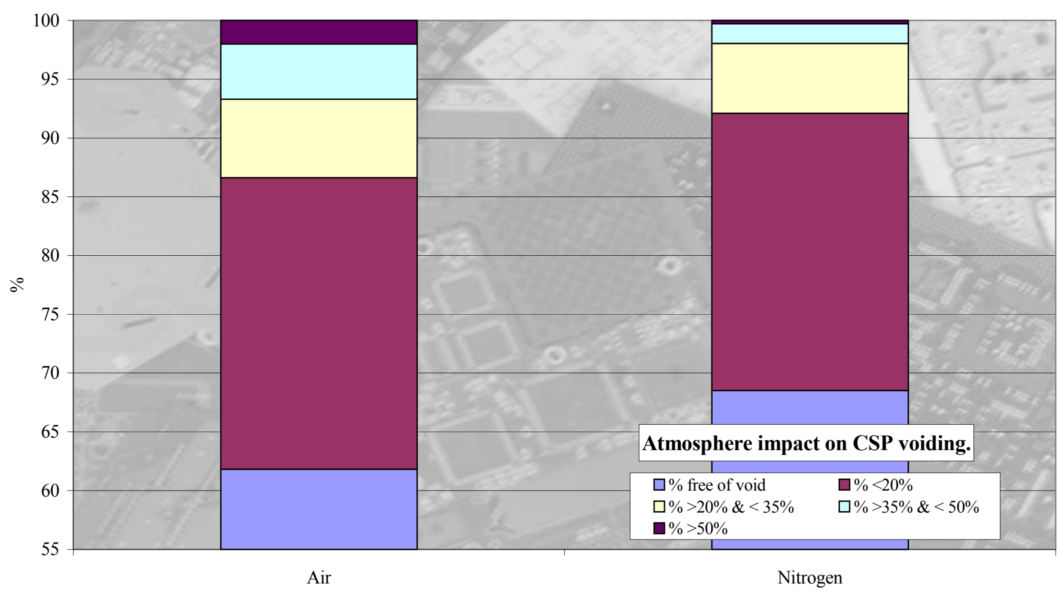


Figure 31 – Atmosphere Impact on CSP Voiding

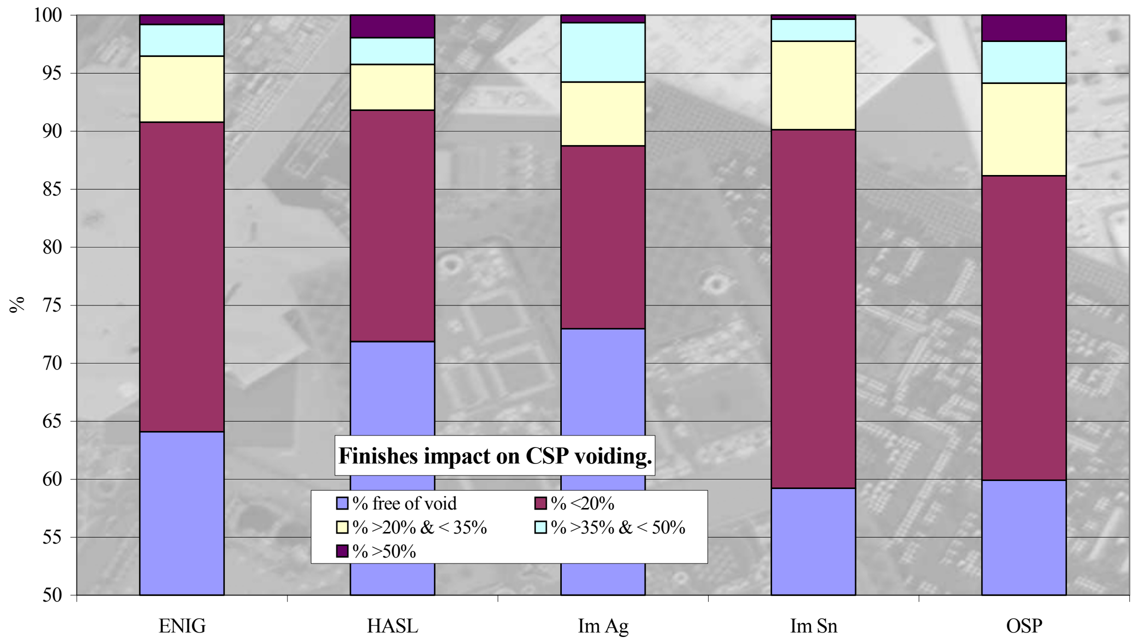


Figure 32 – Finishes Impact on CSP Voiding

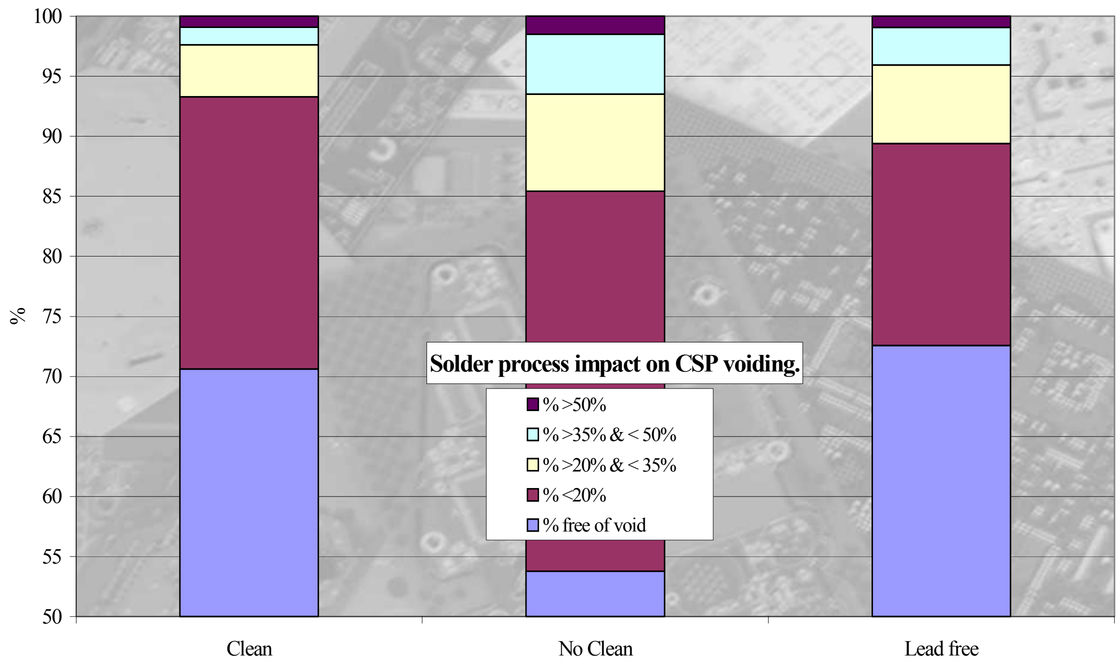


Figure 33 – Solder Processes Impact on CSP Voiding

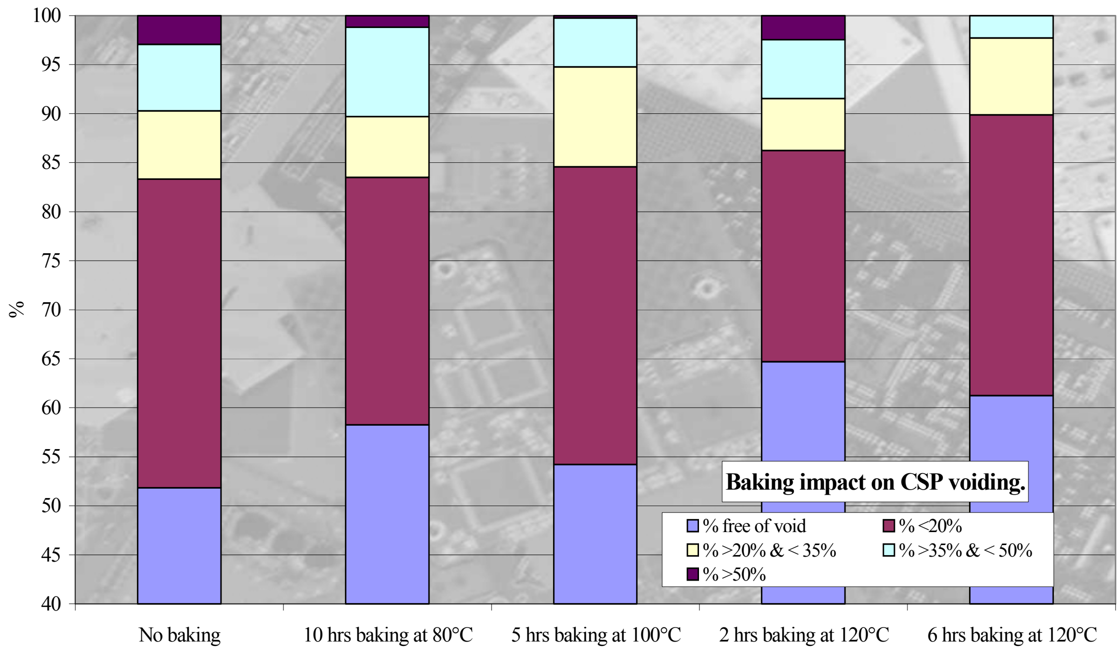


Figure 34 – Baking Impact on CSP Voiding

On dog bone designs (Figure 35), if we consider only balls free of void, Im Ag is first with 85% followed by HASL 78%, ENIG 72%, Im Sn (67%), OSP (67%). If we consider balls with a void diameter below 20% of the pad diameter, all the finish are above 90%. HASL (97%), Im Ag (97%), ENIG (96%), Im Sn (95%), and OSP (93%). On microvia in pad design (Figure 36), Im Ag is the most impacted by the MVP design compared to the dog bone design. HASL (48%, 68%), ENIG (29%, 65%), Im Sn (19%, 64%), Im Ag (20%, 49%), OSP (21%, 52%). HASL might decrease the voiding on MVP design, as the microvia hole may be full of solder. But when a void occurs, it is bigger (%>50%). The two following graphs (Figure 36, Figure 37) compare the microvia in pad design versus the dog bone design according to the pad definition (solder mask defined pad or copper defined pad) whatever the finish, the atmosphere, the solder.

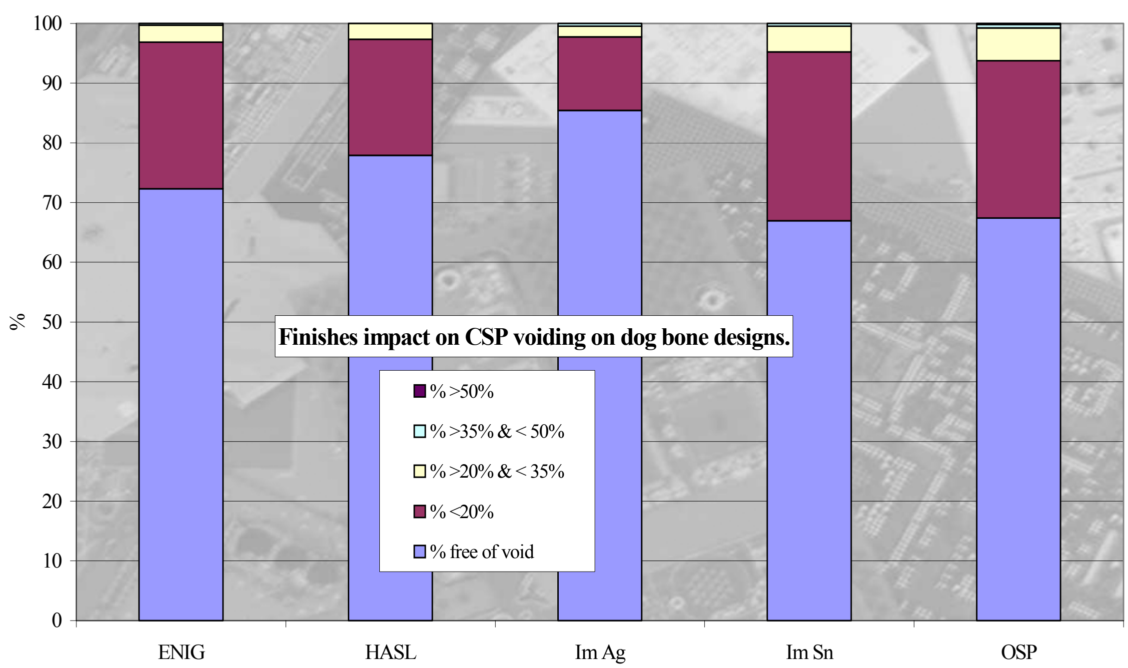


Figure 35 – Finishes Impact on CSP Voiding on Dog Bone Designs

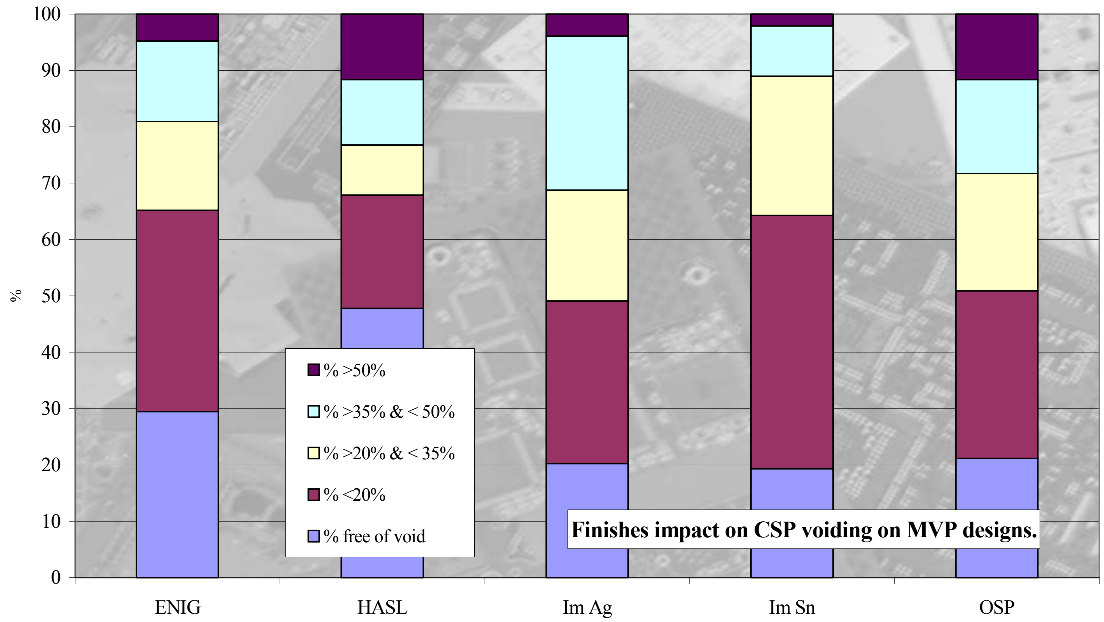


Figure 36 – Finishes Impact on CSP Voiding on MVP Designs

There is a significant difference between the dog bone shapes (Figure 37). The NSMDP designs have around 80% of the balls free of void and 99% of the balls with a void below 20% of the pad diameter. While the SMDP designs have around 60% of the balls free of void and 93% of the balls with a void below 20% of the pad diameter. This means that SMDP design creates small voids. There is no significant difference between the SMDP design and the NSMDP design for microvia in pad design (Figure 38) as the microvia in centered in the pad. Concerning the off-set MVP design. There is less void with the NSMDP. This might be due to that the solder mask border crosses the middle of the microvia hole. It does not protect against voiding as half of the hole is still open, and does not help the solder to fill properly the microvia as half of the hole is closed. Furthermore, the main voiding root cause for the MVP design is the centered microvia hole and not the solder mask. Whereas for the other designs, the microvia is not the key factor of voiding, the solder mask becomes the major contributor of the voiding. The two following graphs (Figure 39, Figure 40) compare the microvia in pad design versus the dog bone design according to the solder and the atmosphere whatever the finish, the pad definition (solder mask defined pad or copper defined pad).

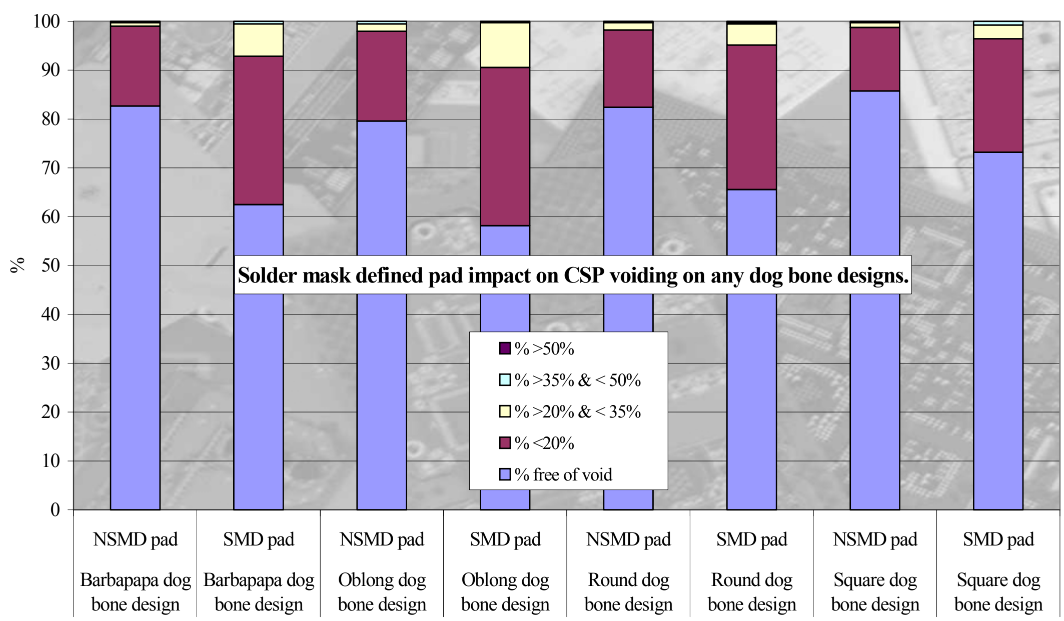


Figure 37 – Solder Mask Defined Pad Impact on CSP Voiding on any Dog Bone Designs

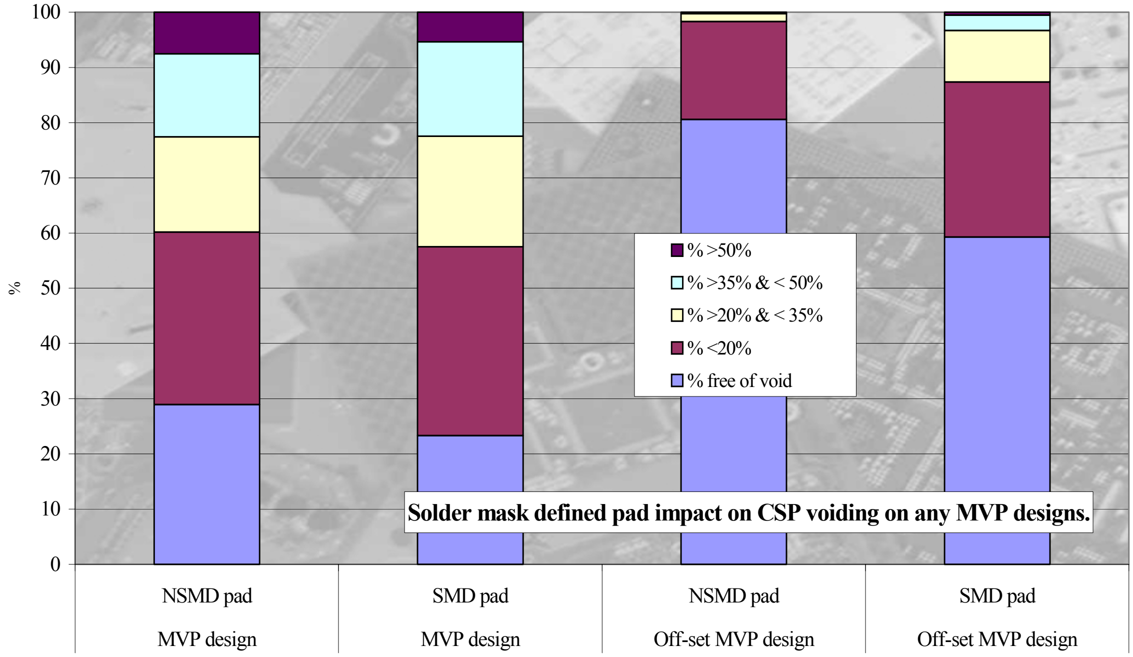


Figure 38 – Solder Mask Defined Pad Impact on CSP Voiding on any MVP Designs

On dog bone design (Figure 39), it seems that nitrogen does not change the voiding effect on SnPb no clean process (from "62%, 95%" to "64%, 94%"). It decreases the voiding effect for the SnPb clean process (from "68%,96%" to "84%,100%") and increases the voiding effect for the SnAgCu no clean process (from "89%,97%" to "80%,95%"). On MVP design (Figure 40), nitrogen decreases the voiding effect. SnPb clean process (from "28%,58%" to "53%,85%"). SnPb no clean process (from "4%, 28%" to "24%, 60%"). SnAgCu no clean process (from "19%, 47%" to "29%, 77%"). The two following graphs (Figure 41, Figure 42) compare the microvia in pad design versus the dog bone design according to the solder and the finish whatever the atmosphere, the pad definition (solder mask defined pad or copper defined pad).

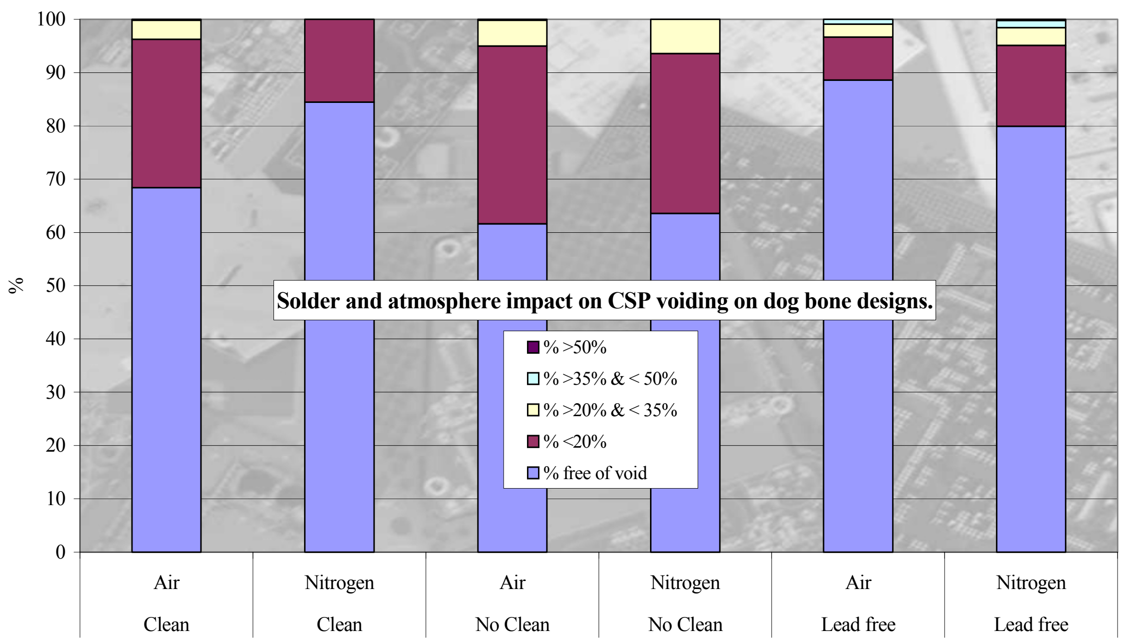


Figure 39 – Solder and Atmosphere Impact on CSP Voiding on any Dog Bone Designs

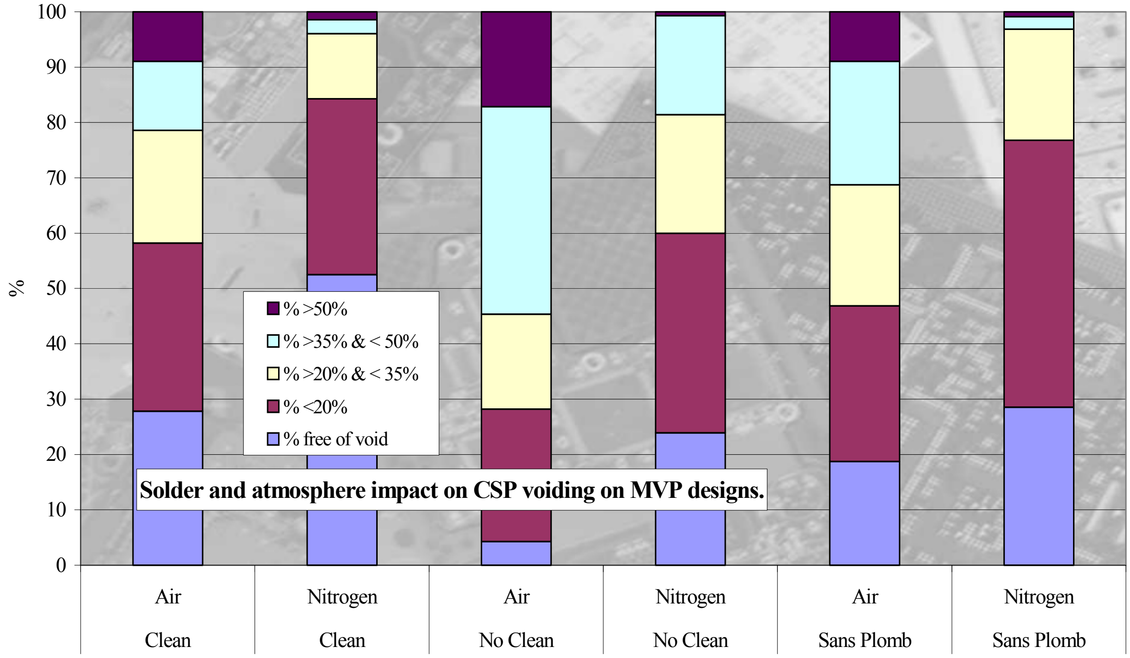


Figure 40 – Solder and Atmosphere Impact on CSP Voiding on any MVP Designs

On dog bone designs (Figure 41), for the SnPb clean solder, only HASL and Im Ag are above 80% for the balls free of void and all the finishes are above 96% for the balls with a void below 20% of the pad diameter. For the SnPb no clean solder, only Im Ag is above 80% for the balls free of void and all the finishes are above 94% for the balls with a void below 20% of the pad diameter. For the SnAgCu no clean solder all the finishes are above 80% for the balls free of void and all the finishes are also above 90% for the balls with a void below 20% of the pad diameter. Im Ag finish is the most impacted by the MVP (Figure 42). This confirms the first above conclusion. For the balls free of void, the Im Ag drops down from 88% to 1 % for the SnAgCu no clean solder, from 83% to 35% SnPb clean solder, from 85% to 25% for the SnPb no clean solder. Except for SnAgCu no clean solder (from 86% to 52%), OSP is also impacted by the MVP design, from 41% to 0% for SnPb no clean solder, from 67 to 12% for the SnPb clean solder. Only ENIG with SnPb clean solder, HASL with SnPb clean solder, and OSP with SnAgCu no clean solder are above 50% for the balls free of void and also above 75% for the balls with a void below 20% of the pad diameter. The following X-rays pictures (from Figure 43 to Figure 50) aim to compare some of the parameters and try to localize the void within the CSP balls.

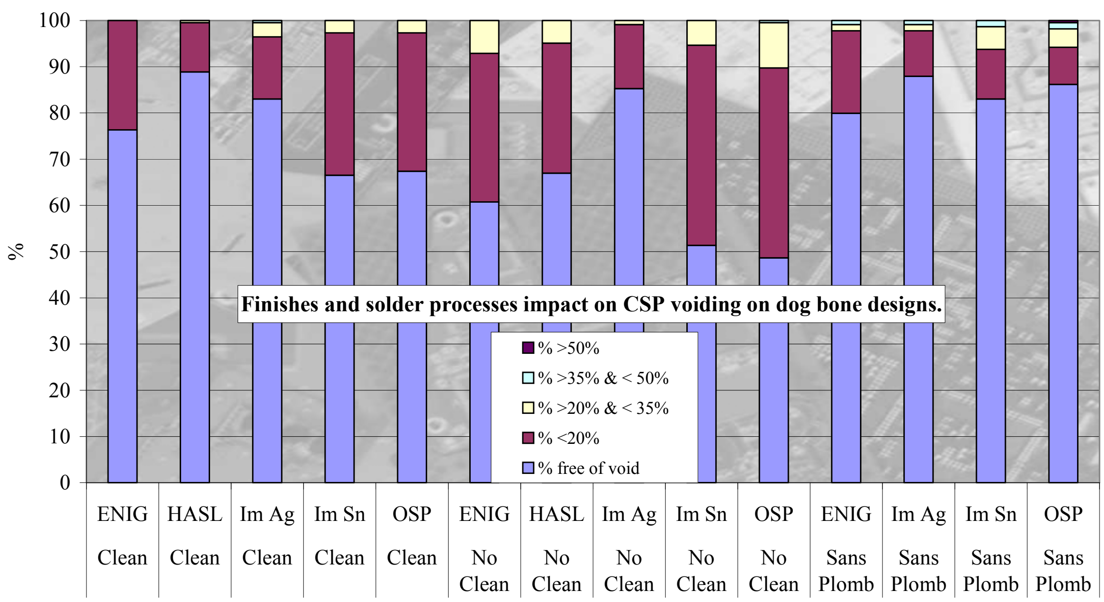


Figure 41 – Finishes and Solder Processes Impact on CSP Voiding on Dog Bone Designs

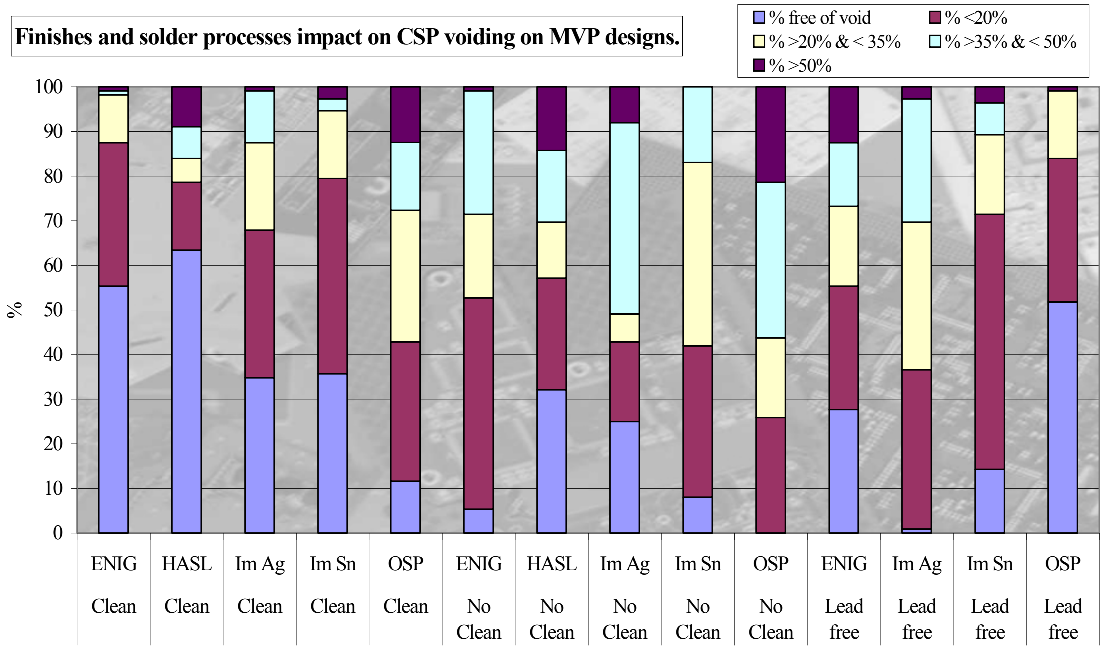


Figure 42 – Finishes and Solder Processes Impact on CSP Voiding on MVP Designs

On the left pictures Figure 43, Figure 44), it is exactly the same process as the two components are on the same board. Only the design has been changed. The benefit of the off-set MVP design on 0.5 mm pitch CSP is obvious on those two pictures. The two pictures on the right (Figure 45, Figure 46) are clearly showing that the voids are located at the PCB interface when a MVP design is used. The PCB interface is on the top of the CSP ball.

Those two pictures on the left (Figure 47, Figure 48) are showing the benefit of the nitrogen on the MVP design for the 0.5mm pitch CSP. Nitrogen reduces considerably the voids size. On the right pictures (Figure 49, Figure 50), the square pads show that the balls are not round. This detail can be useful to see the open as long as the reliability is not impacted by such a design. Voids in CSP ball on MVP pad were sometimes found in the middle of the ball or on the CSP interface. It has been mainly found on Im Ag finish boards.

Figure 43 - MVP Design

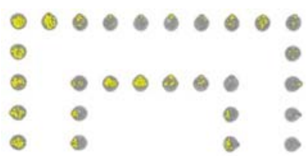


Figure 44 - Off–set MVP Design

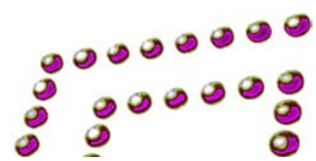


Figure 45 - 3D X-rays with Big Voids at the MVP Interface

Figure 46 - 3D X-rays with Small Voids at the MVP Interface

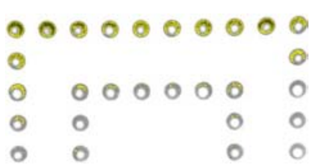


Figure 47 - MVP Design, SnPb no Clean, Air

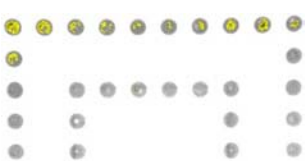


Figure 48 - MVP Design, SnPb no Clean, N2

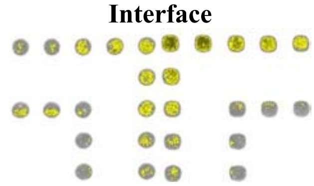


Figure 49 - Round & Square Dog Bone Design

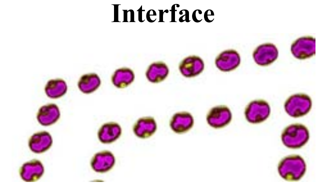


Figure 50 - Voids Inside the Balls or at the Package Interface

Spreading Test

We have performed two different spreading tests. One is a standard test with rectangular apertures; the other is based on archery target. Those two tests are present on the two board sides in order to see the impact of the first reflow.

Finally the standard test is present twice on the top side to see the impact of sweat on spreading. All the boards were manipulated and assembled with appropriate gloves except this second area where people were allowed to add their finger print prior baking or assembly. The pictures on the left hand (Figure 51) are showing the stencil apertures designs, a circular pad after screen printing prior reflow and the same pad after reflow for OSP and ENIG finish.

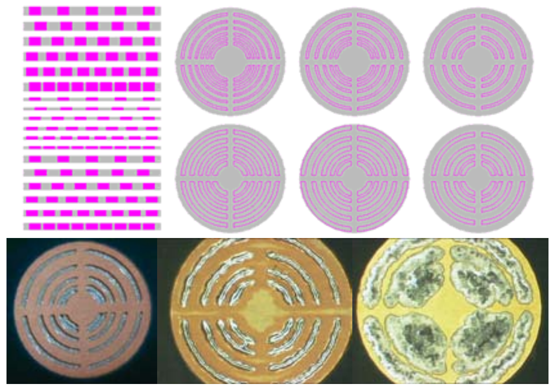


Figure 51 – Stencil Aperture, Screen Printed and Reflowed Pads

We have chosen, in the Aquaboard project, to see the impact on spreading of the following parameters: the baking, the process, the finish, and the atmosphere. See the introduction for the details. It was given to each test a mark. Higher is the mark less area on the pad is free of solder paste. The maximum mark means full pad covered with reflowed solder paste. The maximum mark is 20. The following graphs are resuming the different performed tests. Each graph takes into account only the studied parameter. For example the graphs showing the impact of the PCB finish on spreading does not take into account the solder, the atmosphere, and the type of test.

ENIG and HASL (Figure 52) show the best spreading capabilities. OSP is last. Im Sn and Im Ag are between. SnPb no clean (Figure 53) has the best spreading capabilities, followed by SnPb clean and the last process is SnAgCu no clean.

The impact of baking is not obvious on this graph (Figure 54). It seems that the baking tends to slightly decrease the spreading. SnPb clean process is the most impacted by the atmosphere. N_2 nearly double the spreading capabilities of SnPb clean process (Figure 55). N_2 has a light positive impact on SnPb no clean and SnAgCu no clean processes.

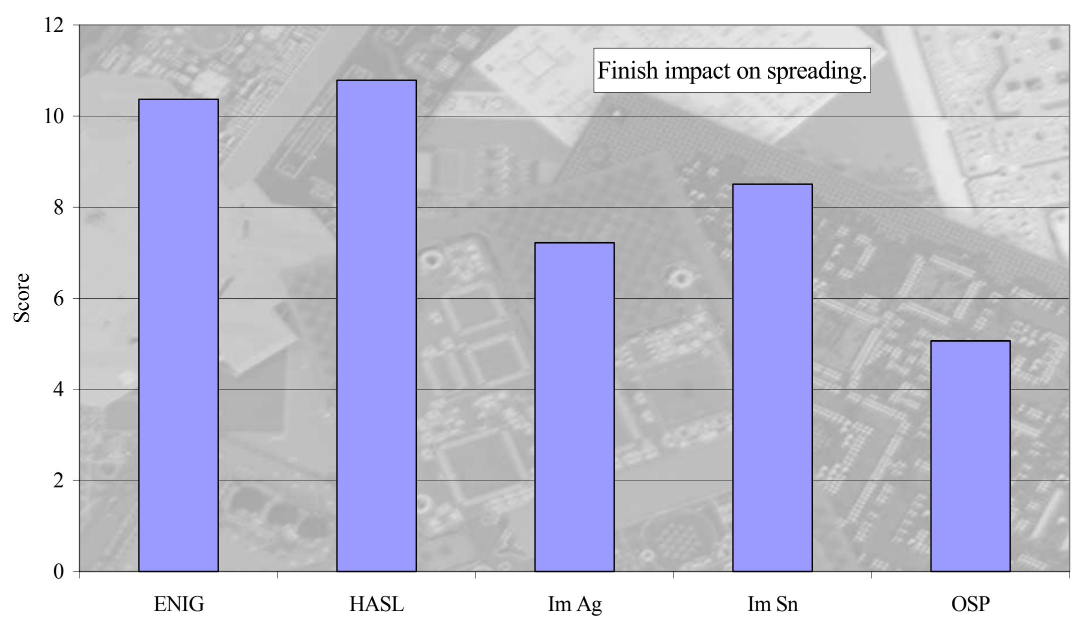


Figure 52 – Finish Impact on Spreading

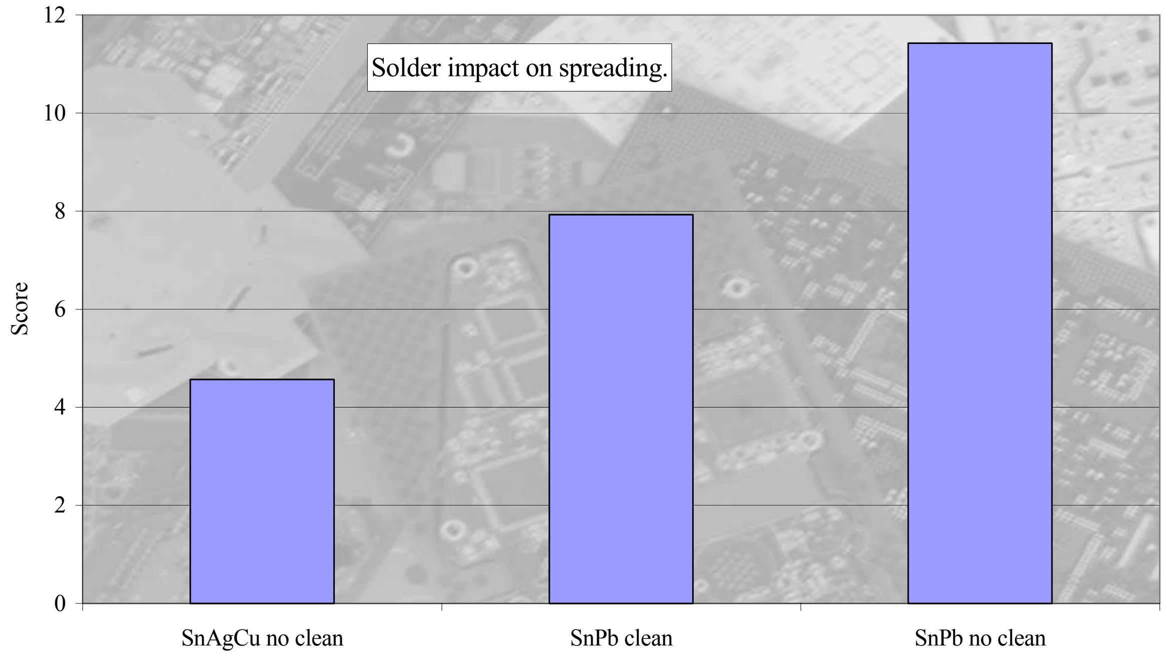


Figure 53 – Solder Impact on Spreading

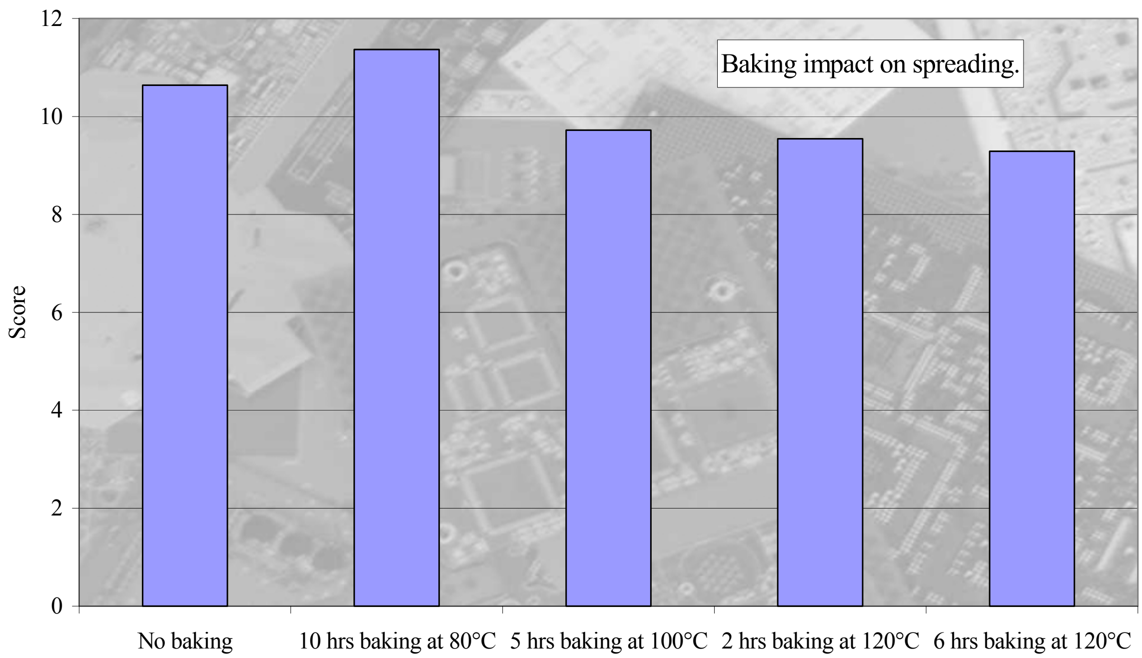


Figure 54 – Baking Impact on Spreading

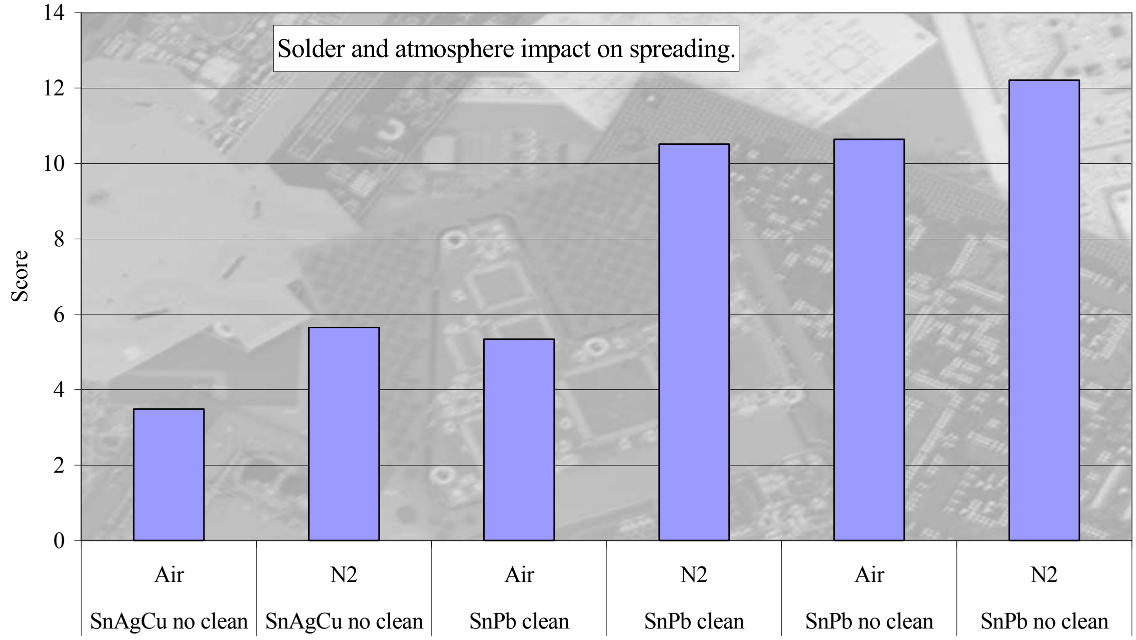


Figure 55 – Solder and Atmosphere Impact on Spreading

On the TOP side (Figure 56), Im Ag and OSP are the finishes that are the most damaged by sweat. Meaning they really need to be manipulated with appropriate care. Obviously on the TOP side (Figure 57), the rectangular test has been fatal for SnAgCu no clean. SnPb no clean seems to be the process that suffered the most of sweat contamination.

ENIG, Im Ag and Im Sn improves significantly the spreading capabilities under nitrogen (Figure 58). HASL and OSP are lightly positive impacted. For SnAgCu no clean (Figure 59), the OSP finish is the worse. The other finishes seem to give the same spreading capabilities to this alloy. For SnPb clean, the ENIG is the best, the OSP is the worse, HASL, Im Ag, Im Sn are between and close together. For the SnPb no clean, it is nearly the same than the SnPb clean process but with tighter differences meaning the ENIG is less ahead and OSP less behind.

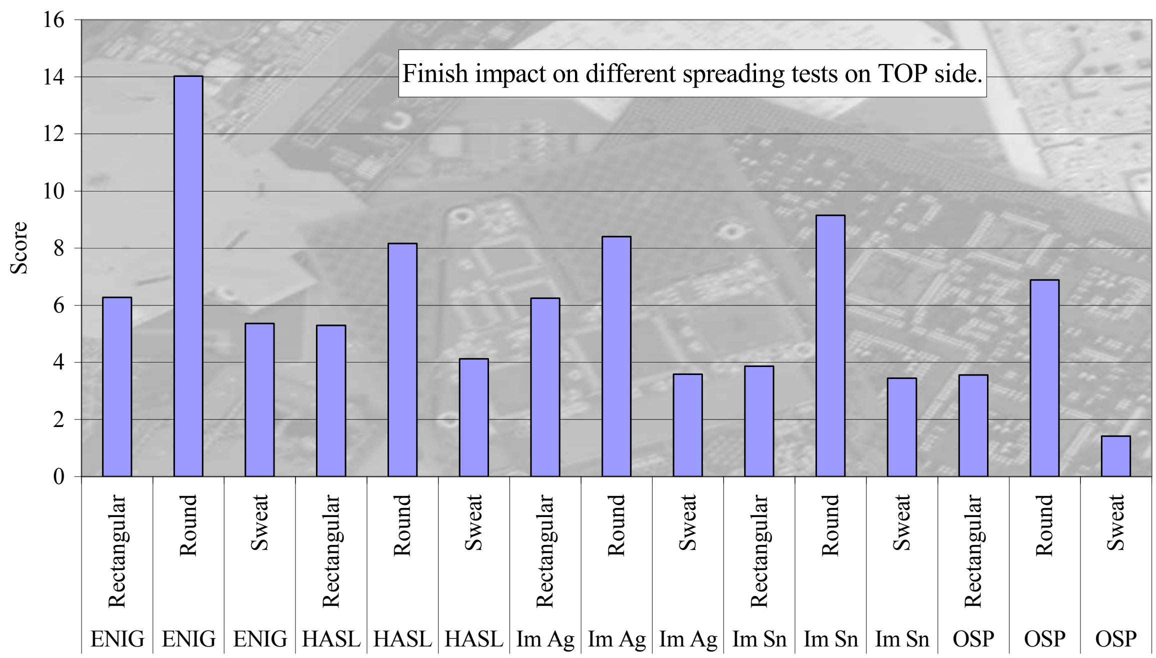


Figure 56 – Finish impact on different spreading test

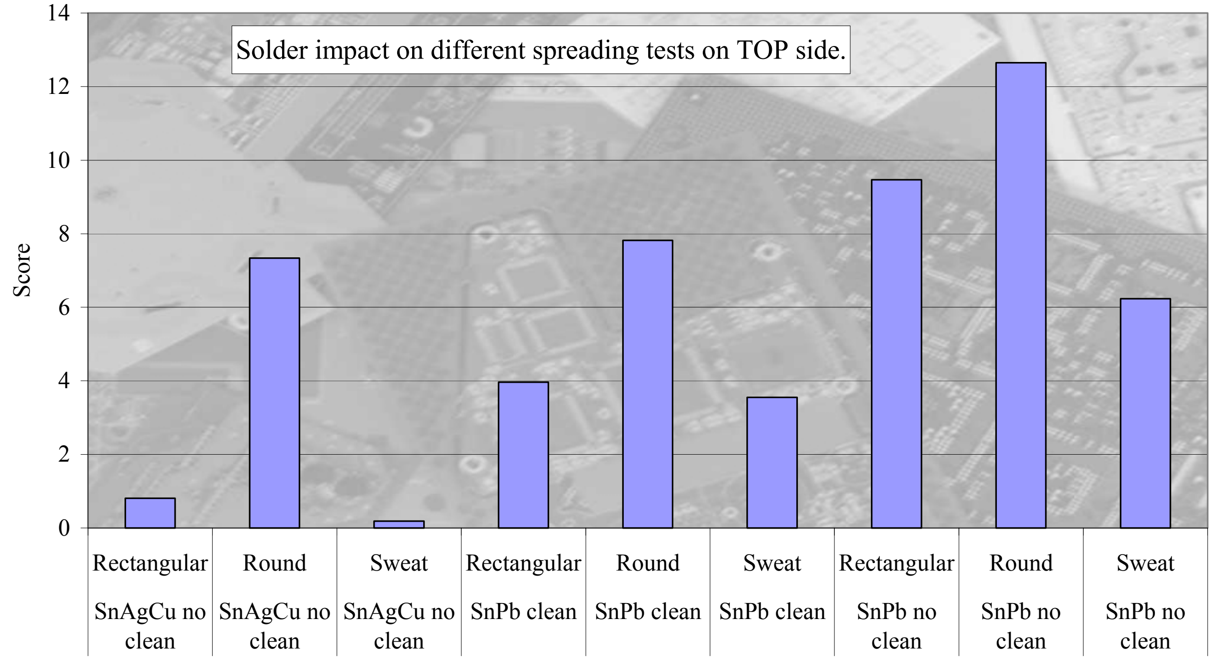


Figure 57 – Solder Impact on Different Spreading Test

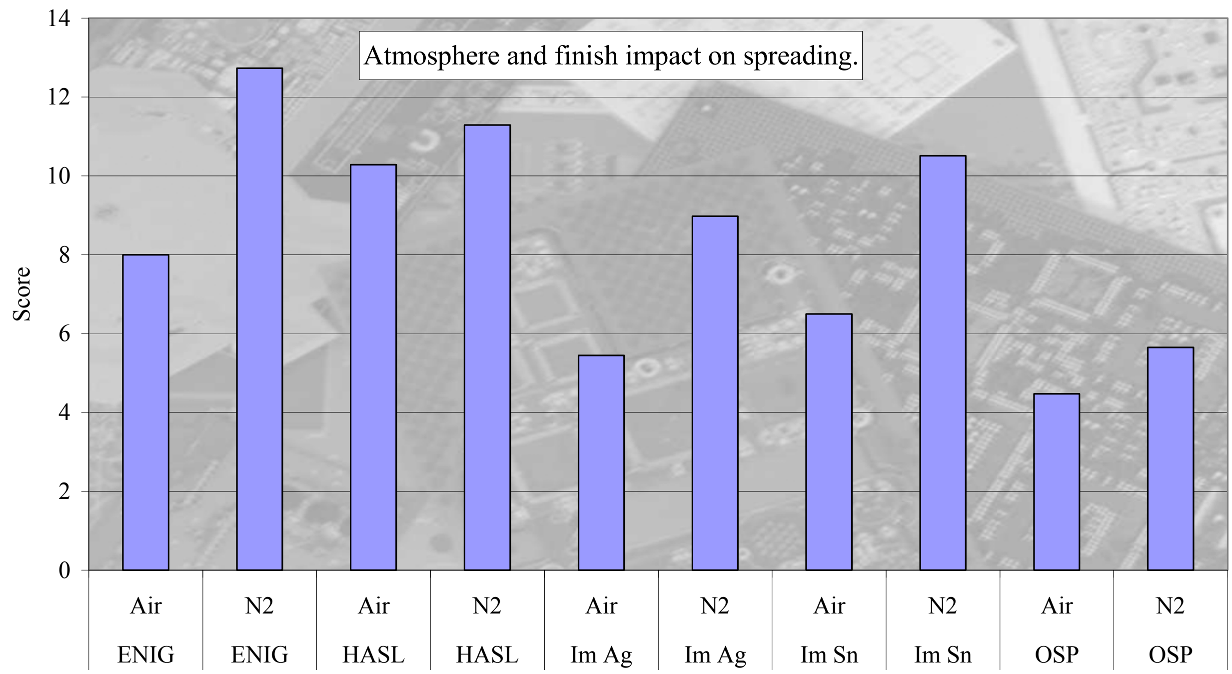


Figure 58 – Atmosphere and Finish Impact on Spreading

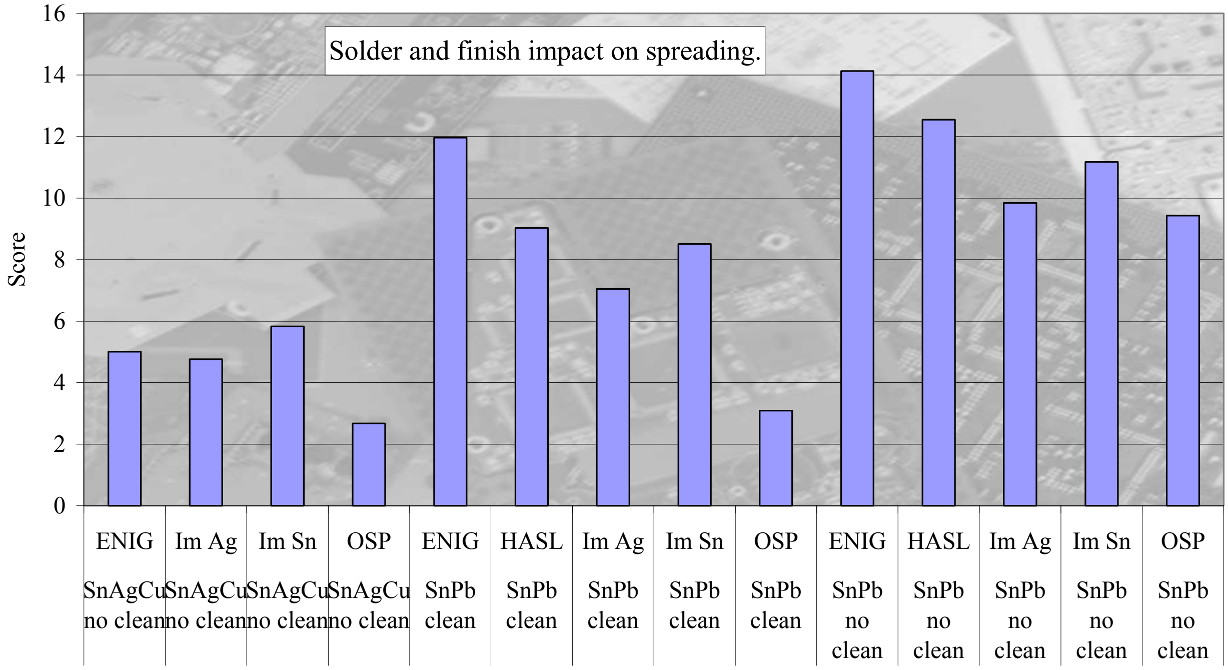


Figure 59 – Solder and Finish Impact on Spreading

SnPb clean process is the most impacted by the two reflows (Figure 60). It is important to notice that the boards are water cleaned prior the second reflow. This water cleaning obviously impacts the spreading. HASL and Im Sn are the finish where the results are significantly different between the BOT and TOP side (Figure 61). The spreading test is much better on the bottom side which is assembled first compare to the top side that undergoes one additional reflow prior assembly. In fact, this result is not better because the finish of the top side is destroyed during the first reflow but because the solder paste on the bottom side has two reflows to spread. The spreading tests on the bottom side gave nearly the same result than the one on the top side prior the second reflow.

Only OSP (Figure 62) and Im Sn seem to be impacted by the baking. The rectangular test (Figure 63) is more severe than the circular one (Figure 62). All the finishes are impacted by the baking (Figure 63). OSP and Im Sn are the most impacted. Im Ag is the less impacted.

The circular test is not so severe (Figure 64); we can say that the results are better for ENIG on BOT side, ENIG on TOP side and Im Sn on BOT side. The rectangular test is much severe and so it emphasizes the difference between the process and the PCB finishes (Figure 65). Several points can be noticed. First, obviously the results are better under nitrogen than air. Second the SnPb clean air process on TOP side is closed to null score on every finish except Im Sn and Im Ag. It can be noticed the difference between BOT and TOP side on HASL and ENIG for this SnPb clean process.

On ENIG and Im Sn finishes, the SnPb clean process under nitrogen has better results than the SnPb no clean process under nitrogen. For OSP, Im Ag, and HASL it is the opposite. Only SnPb no clean process under air or nitrogen and SnPb clean process under nitrogen have no null result. SnAgCu no clean process has very bad result on ENIG and OSP. Im Sn on BOT side under nitrogen has the best results for the three processes. On TOP side, Im Ag seems to have the best average result.

Notes:
Once again, the previous graphs are taking into account only the studied parameters. Several times the previous graphs showed better spreading results for the SnPb no clean process compare to the SnPb clean process.

It is mainly due to because the results of the SnPb clean process under air are very bad. Then, the results under the air badly decrease the average mark of the process. If we detail the marks (Table 7), we can see that 4 out of 6 of the best marks are from SnPb clean process under nitrogen and 3 out six of the worse results are from SnPb clean process under the air. Concerning the HASL results, as for the wettability tests, the spreading test are not good as expected as tin lead alloy shall spread easier on tin lead alloy than other metallic or organic finishes. One critical point that needs to be said is that 0.4 mm QFP and 0.5 mm CSP pitch are assembled on the board. Furthermore 100µm SIR is also on the outer layer. This means that hard hot air knives were used to have a flat and regular HASL finish resulting in a thin and weak finish (less than 2µm).

Figure 60 – Solder and Side Impact on Spreading

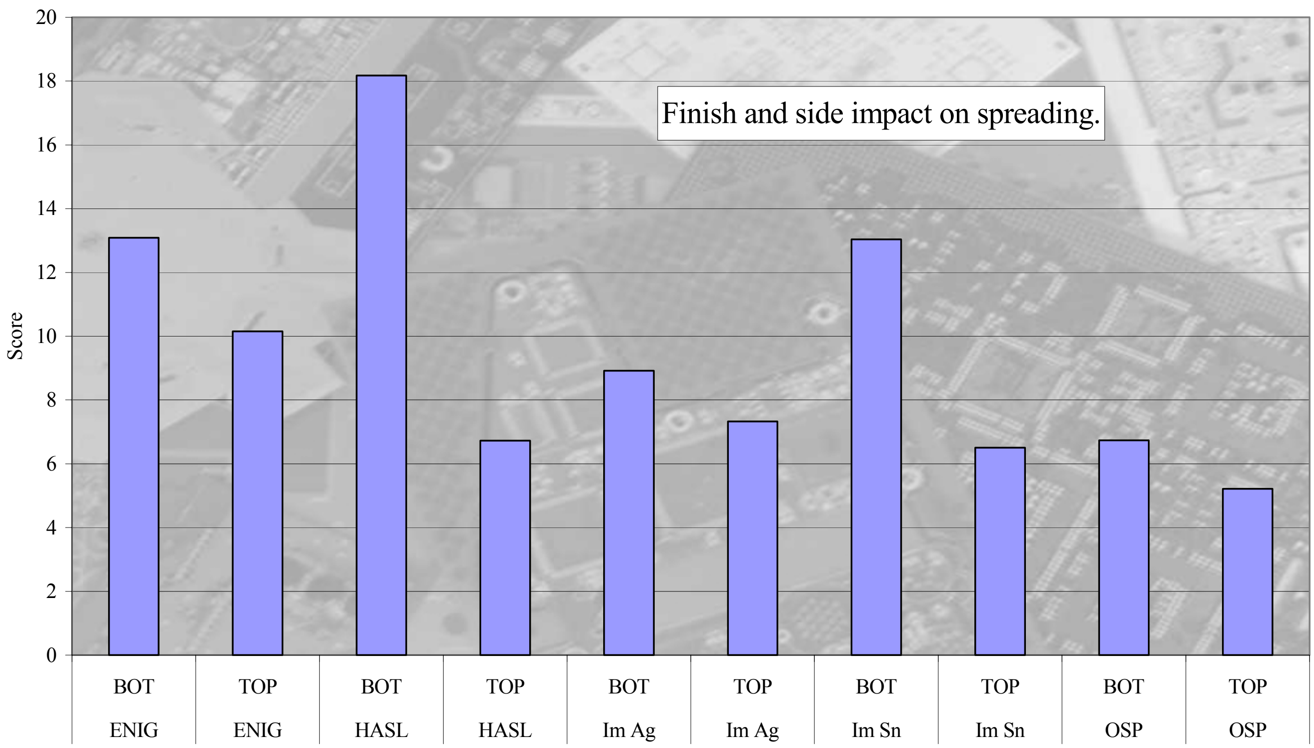


Figure 61 – Finish and Side Impact on Spreading

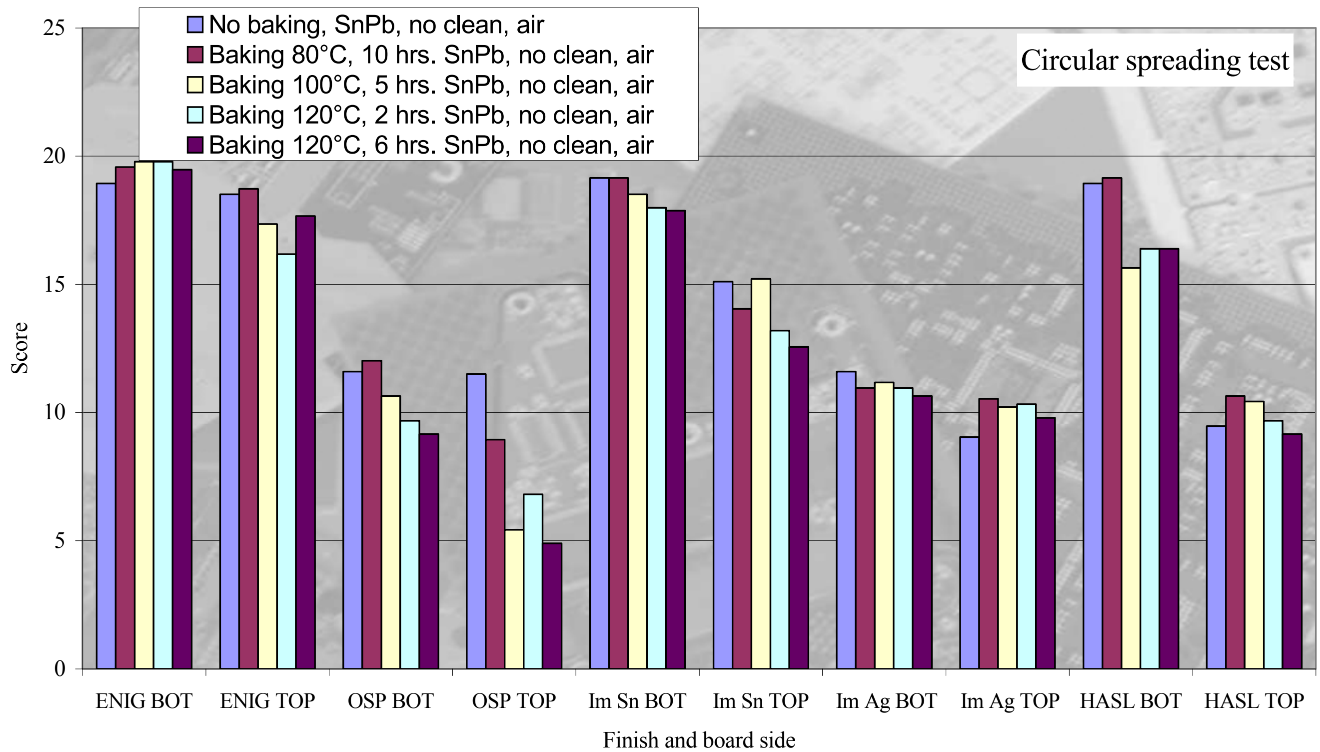


Figure 62 – Impact of Baking on Circular Tests

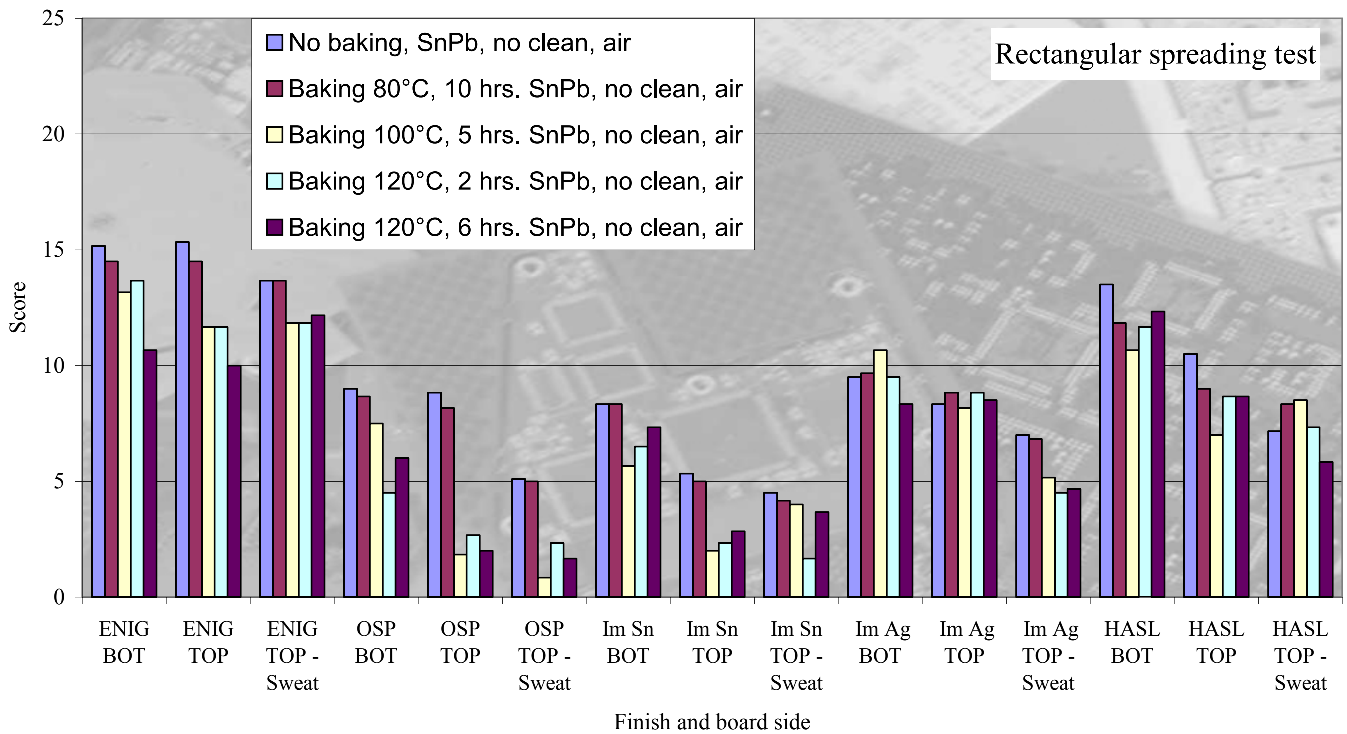


Figure 63 – Impact of Baking on Rectangular Tests

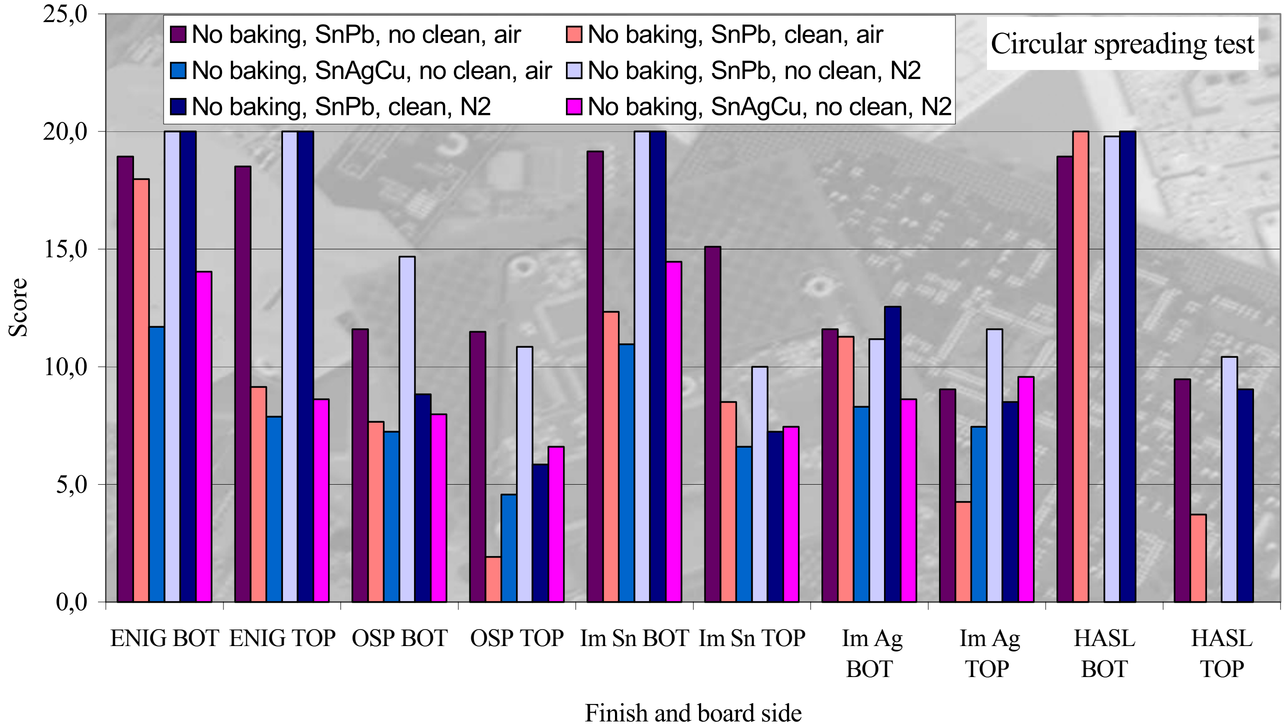


Figure 64 – Impact of Process on Circular Test

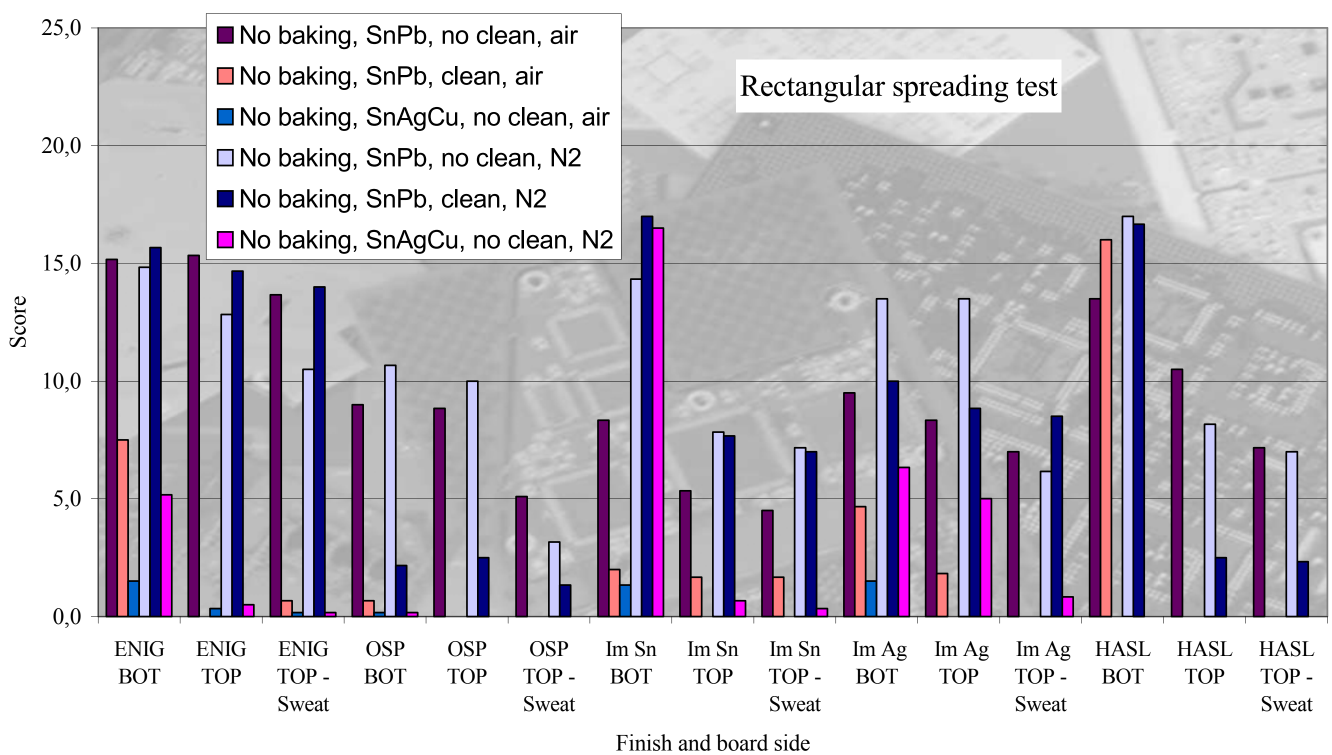


Figure 65 – Impact of Process on Rectangular Test

Table 7 – Marks Classification

Solder	Atmosphere	Mark	Side	Finish
SnPb clean	N2	18,5	BOT	Im Sn
SnPb no clean	N2	18,39361702	BOT	HASL
SnPb clean	N2	18,33333333	BOT	HASL
SnPb clean	Air	18	BOT	HASL
SnPb no clean	Air	17,96808511	BOT	HASL
SnPb clean	N2	17,83333333	BOT	ENIG
…	…	…	…	…
SnAgCu no clean	N2	2,19858156	TOP	OSP
SnAgCu no clean	Air	2,19858156	TOP	Im Sn
SnPb clean	Air	2,029550827	TOP	Im Ag
SnAgCu no clean	Air	1,524822695	TOP	OSP
SnPb clean	Air	1,241134752	TOP	HASL
SnPb clean	Air	0,638297872	TOP	OSP

Aluminum Bonding

Only two finishes give positive results for the aluminum bonding ENIG and Im Ag. The two following graphs are showing the impact of the baking and the process on the pull test force. First of all, the bonding parameters on each PCB finish have been adjusted on fresh finish.

On the left graph (Figure 66), for Im Ag, we can see that neither the process nor the atmosphere has a significant impact on the pull test force. For ENIG the process has not an impact on the pull test force. We can say that the results are slightly better with SnPb no clean process. On the other hand, the atmosphere has a real impact on the pull test force for ENIG (whatever the process SnPb no clean, SnPb clean, or SnAgCu no clean). Concerning the baking (Figure 67), no impact on Im Ag, but significant impact on ENIG whatever the baking conditions. It is important to notice that the absolute values are different. Around 4 gF for the process impact chart, around 8gF for the baking impact chart. This point is still under investigation. As the baking impact has only been performed on the standard SnPb no clean process under the air, the value should close to the “SnPb, no clean, air” chart. Otherwise this means that prior assembly, baking the PCB will help to aluminum bond the parts after reflow, which has no sense.

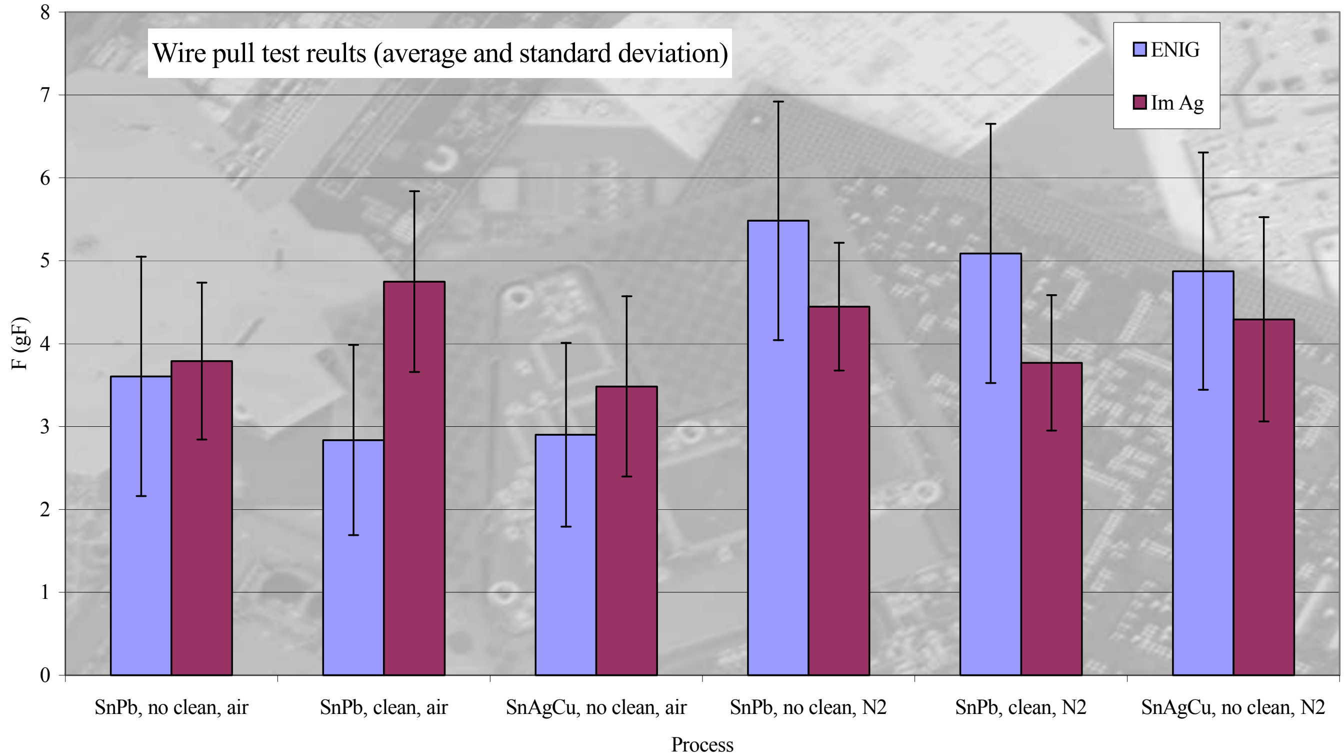


Figure 66 – Impact of the Process on Pull Test Force

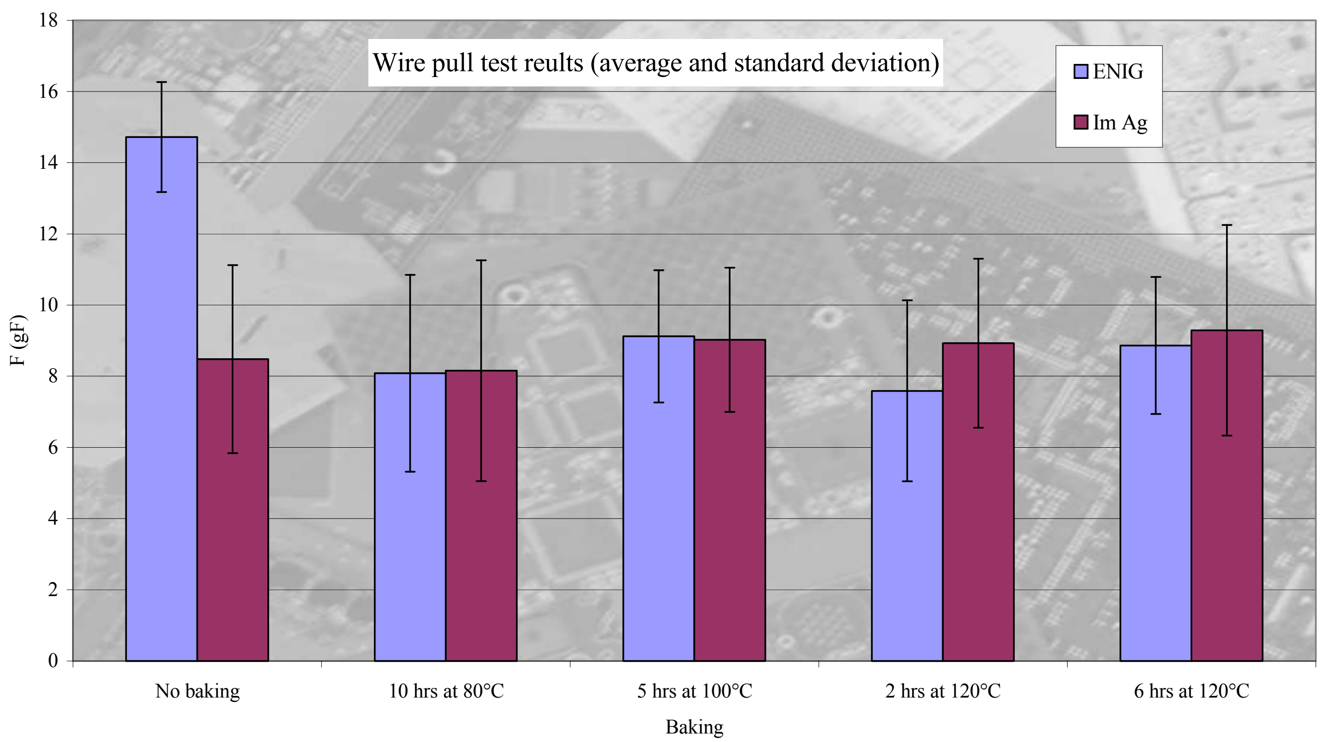


Figure 67 – Impact of the Baking on Pull Test Force

Thermal Reliability

The boards have gone through thermal cycling. The conditions are –55/+125°C, 15°Cmin^{-1} slope, 20 mins stage. At that time, the boards have undergone only 400 cycles. It can be noticed that 15 balls out of 8092 are opened. 8 balls out of these 15 balls were already open after 50 cycles. 14 out of the 15 defects are observed on boards assembled under the air. 8 out of the

15 defects are observed on boards assembled with the SnAgCu alloy. 7 out of the 15 defects are observed on boards assembled with HASL. No defect on Im Ag boards. Concerning the DFR, 10 out of the 11 defects observed on CSP are with a NSMDP design. 7 out of the 11 defects observed on CSP are with a MVP or off-set MVP designs. The impact of the baking on the reliability has not been observed yet (400 cycles). Hopefully, more results will be given in February at the APEX.

Conclusion

- Highlights of the parts conclusion are given below. In the second step of the project, the PCB materials study allowed us to calculate the Fick's coefficient for each material. It also allowed to establish an equation that gives the required baking time according to the temperature (from 80°C to 120°C), the PCB material (3 groups, see Figure 11), the storage time (below and above 3 months), and the required moisture level (800, 1600, and 2400PPM). This second step, also gave the maximum time allowed after baking prior reflow according to the storage conditions (ambient air or dry cabinet), the PCB materials, and the required moisture level.
  In the third step of the project, the wettability, the voiding, the spreading, and the wire bonding have been studied.
- Concerning the impact of the finish and the baking on the wettability (Tw + Fmax), the immersion silver has the best average results, followed by HASL. ENIG is only third because of poor Tw results due to the wettability curve shape. Immersion tin is a bit behind while OSP is far from good results. Im Ag is the finish less impacted by the baking, while ENIG is a bit impacted and OSP or Im Sn is badly impacted especially on the wetting time.
- The impact of the design, the atmosphere, the PCB finish, and the solder on CSP and BGA voiding has been studied. All the designs for the CSP, except the microvia in pad design have more than 90% of the balls with a void below 20% of the pad diameter, while the microvia in pad design has only 60% of the balls with a void below 20% of the pad diameter. For comparison, the MVP design for the BGA has 95% of the balls with a void below 20% of the pad diameter and the others designs have more than 99.5% of the balls with a void below 20% of the pad. It has to be noticed that a void with a diameter around 120µm is classified within the class 3 for our BGA (<20% of the pad diameter), whereas this void is out of the class 3 and class 2 specifications for our CSP (>35% and <50% of the pad diameter). The NSMDP designs have around 80% of the balls free of void, while the SMDP designs have only 60% of the balls free of void. The baking has no significant impact on voiding for the SnPb no clean under the air process. The SnAgCu no clean process has the same capabilities than the SnPb clean process to reduce voiding compare to the SnPb no clean process. But the SnAgCu is the process that is the most impacted by the MVP design. On dog bone designs, Im Ag is the finish that mostly minimizes the voiding but it is also the finish that is the most impacted by the MVP design. If we take the Im Ag and the SnAgCu there are 88% of the balls free of voids on dog bone designs while there are only 1% of the balls free of voids on MVP design. On dog bone designs, its seems that nitrogen does not change the voiding effect on SnPb no clean process, it well decreases the voiding effect for the SnPb clean process, and increases the voiding effect for the SnAgCu no clean process. Whereas on MVP design, nitrogen decreases significantly the voiding for the three processes.
- Concerning the impact of the atmosphere, the PCB finish, the baking and the solder on spreading. Only Im Ag is not impacted by the baking. OSP and Im Sn are the most impacted by the baking. The nitrogen increases the spreading especially for the SnPb clean process. Im Ag and OSP finish are the most impacted by sweat contamination. SnAgCu no clean is the process that provides less spreading on the TOP side.
- Concerning the impact of the atmosphere, the process, and the baking on the aluminum wire bonding. For Im Ag, neither the process nor the atmosphere has a significant impact on the pull test force. For ENIG, the process has not an impact on the pull test force. We might say that the results are slightly better with SnPb no clean process. On the other hand, the atmosphere has a real impact on the pull test force for ENIG. Concerning the baking, no impact on Im Ag, but significant impact on ENIG whatever the baking conditions.
- Concerning the thermal reliability, as that time 400 cycles are not enough to give first significant results. Anyway it can be noticed that 15 balls out of 8092 are opened. 8 balls out of these 15 balls were already open after 50 cycles. 14 out of the 15 defects are observed on boards assembled under the air. 8 out of the 15 defects are observed on boards assembled with the SnAgCu alloy. No defect on Im Ag boards. 7 out of the 11 defects observed on CSP are with a MVP or off-set MVP designs.

Acknowledgment

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