Study and Recommendation for Increasing PCB Surface Finish Shelf Life

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Abstract
Storage time allowed between bare printed circuit board manufacturing and assembly is quite limited. Based on an interpretation of IPC standards, shelf-life of the surface finish is the limiting factor. A lot of boards are scrapped worldwide because they have exceeded their shelf-life. Size of manufacturing lots is limited due to the risk of overpassing shelf-life of stored PCB[1]. A three-year study involving PCB manufacturers, EMS[2] and OEMs[3] has been conducted to evaluate the possibility to extend the shelf-life. Details of the study will be described in this paper. More than five thousand samples with different finishes coming from different PCB suppliers have been aged in normal and accelerated conditions with or without additional packaging (none, anticorrosion paper, dry pack). Following ageing, solder ability has been evaluated by two methods. Solder spread test have been realized by an EMS involved in automotive market on its production line. Wetting balance test have been realized by an independent laboratory. Results summarized in this paper clearly indicate that actual limitations are very conservative, and that shelf-life in normal ambient conditions can be at least doubled, whatever the packaging conditions. New recommendations for storage conditions and limitation will be issued from this study. They will contribute to significant improvement of the worldwide electronic industry efficiency and costs.

Introduction
The main function of a printed circuit board (PCB) is normally to interconnect electronic components. A PCB is made by a PCB maker, and components are later soldered onto the PCB surfaces by an Electronic Manufacturing Services company (EMS). External layers of the PCB thus have to be suitable for the component soldering process, which occurs a certain time after the end of PCB manufacture. This time duration is considered as the shelf life, and in conjunction with storage conditions it has an impact on soldering quality. The primary function of a PCB surface finish is to provide a solderable surface that has extensive shelf life and that is suitable for surface mount and/or through-hole assembly applications.

A lot of OEMs specify shelf life according to IPC recommendations to ensure solderability. For instance, when a PCB is ENIG[4] surface finished, 12 months is the maximum shelf life, between PCB end of manufacture and board assembly. Another example: when a PCB receives a chemical tin surface finishing with 6 months maximum shelf life.

To remain compliant with OEM specifications and lead-time expectations, the EMS needs to take an additional time margin, typically from 3 to 6 months, which reduces the maximum shelf life allowed between end of PCB manufacture and board assembly. As a result, a certain amount of PCBs produced around the world wait on a shelf too long for being compliant with IPC recommendations for storage time. This is especially true in the high-end/low volume supply-chain. These PCBs are either scrapped or require costly requalification tests. In any case, the whole supply-chain has to support this inconvenience and associated costs.

This paper presents the method, tests, results obtained, and finally concludes that it seems reasonable to propose to increase significantly the maximum shelf life, without major risks for the overall assembly yields and product performance.

Current situation
In May 1995, IPC's Technical Activities Executive Committee (TAEC) adopted Principles of Standardization as a guiding principle of IPC's standardization efforts. Among other valuable principals, this guide states that:

Standards should:

Show relationship to Design for Manufacturing (DFM) and Design for the Environment (DFE)
Minimize time to market
Contain simple (simplified) language
Just include spec information
Focus on end product performance
Include a feedback system on use and problems for future improvement

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[1] Printed Circuit Board
[2] Electronic Manufacturing Services
[3] Original Equipment Manufacturers
[4] Electroless Nickel/Immersion Gold

Standards should not:

- Inhibit innovation
- Increase time-to-market
- Keep people out
- Increase cycle time
- Tell you how to make something
- Contain anything that cannot be defended with data

For a long time, most OEMs, EMS, PCB manufacturers around the world consider IPC standards to design, specify, manufacture, qualify their products, and this is true for one key characteristic of printed circuit boards: surface finish.

What is surface finish?

PCB conductors are made of copper, which naturally oxidizes. Unprotected copper is therefore not suitable for soldering processes. The primary function of a PCB surface finish is to provide a solderable surface that has extensive shelf life and that is suitable for surface mount and/or through-hole assembly applications.

Depending on the application, copper surfaces can be protected with different techniques. The surface finish choice is a significant aspect of PCB specifications, and an important decision from designers. Many questions have to be answered to make this choice.

This paper does not intend to list precisely all surface finishes available around the world, or to rank them in terms of performances or costs, but it seems important to remind the reader what are the most used. The oldest PCB finishes were 63Sn/37Pb solder (containing lead) and OSP[5]. Later, RoHS[6] resulted in development and deployment of lead-free solders (e.g. SnAgCu) and lead-free surface finish for the PCBs (except for some applications, most notably military). On a higher end of the market, ENIG, ENEPIG[7], EPIG[8] have some other advantages (flatter surface, longer shelf life, wire-bondable…). Figure 1 below gives an idea of the relative cost of these quite common PCB surface finishes. Obviously, surface finish costs are impacted by precious metals content.

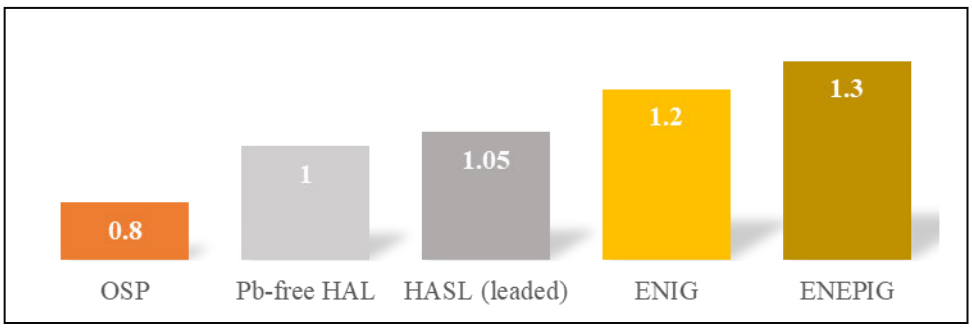

Fig. 1: Relative costs of different surface finishes

What about shelf-life

Shelf-life is normally defined as the period during which solderability must be guaranteed by a PCB maker. It aims globally at ensuring a good PCB assembly process yield.

ENIG is a good candidate to explain how shelf-life is interpreted on the market, as it is a very popular surface finish for high-end application for quite a long time now. Fifteen years ago, one question raised about ENIG in IPC-4552 was: "How much gold is needed for a minimum shelf life of one year?"

Tests reported in IPC-4552 Appendix 5 "Standard Development Efforts of Electroless Nickel Immersion Gold" concluded at that time that 2 micro inches (0,0508 µm) would easily guarantee a one-year shelf life. One year became the theoretical standard value for ENIG shelf-life.

[5] Organic Surface Protection

[6] Restriction on Hazardous Substances

[7] Electroless Nickel Electroless Palladium Immersion Gold

[8] Electroless Palladium Immersion Gold

Over time, notably for operational reasons, PCB End-users have built their own specifications in terms of shelf-life. For instance, in the case of ENIG, while some EMS or OEMs accept up to 24 months shelf-life, others ask for 9, 6 or even down to 2 months maximum shelf life. This causes problems to the entire supply chain: at least time-to-market and costs are not optimized. Moreover, for PCB makers, managing different shelf lives for the same surface finish but different customers become a logistic nightmare. As an example, Figure 2 below shows the typical situation in terms of ENIG surface finish maximum shelf life specified by a significant panel of 41 PCB end-users, either EMS or OEMs, applying IPC standards.

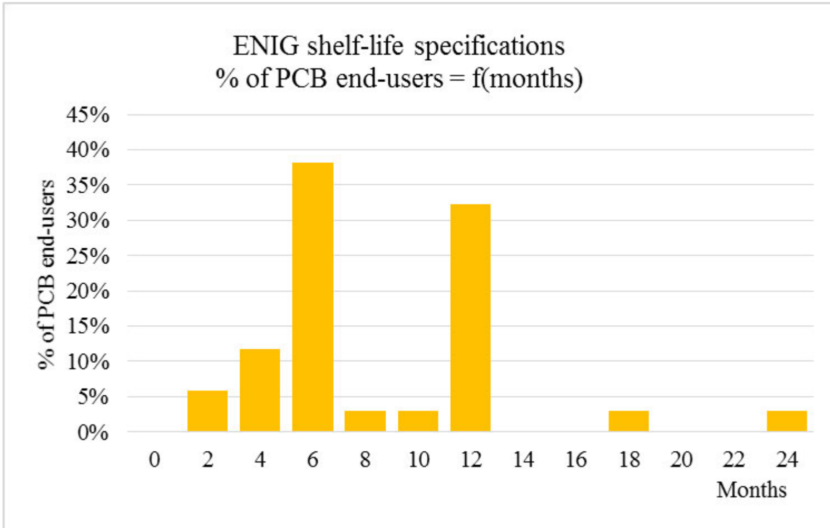

Fig. 2: Example of ENIG shelf-life, as specified by a panel of PCB end-users

These data are extracted from actual specifications received by a PCB maker from its end-users: aero-mil market with small to medium series, high level of expectations and long product life cycle. As seen above, approximately 60% of this PCB's end-users ask for less than 12 months shelf-life, 32% ask for 12 months (IPC 4552 recommendation), and 8% more than 12 months. As a summary, these PCB end-users ask for a significantly shorter shelf-life than twelve months, while on this market segment, bare PCBs can actually be stored for a much longer time on a shelf before going to component assembly.

At the same time, a majority of end-users consider that ENIG plated boards can be assembled much later than 12 months after PCB fabrication without any impact on assembly process - provided that the PCB surface finish is conforming at time zero. This feeling comes usually from a long history, either because "expired PCBs" go through the assembly process without any problems, or because requalification tests conducted on these "expired PCBs" (for instance according to IPC J-STD-003C) show no solderability degradation.

For other surface finishes, a similar situation exists on the market. For instance, the same end-users ask for shelf-lives from 2 to 12 months for chemical tin finished PCBs (Figure 3).

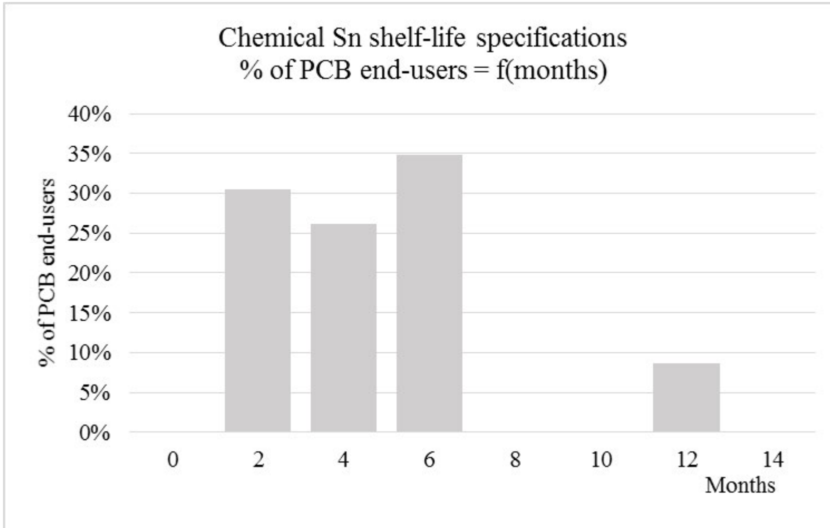

Fig. 3: Example of Chemical Sn shelf-life, as specified by a panel of PCB end-users

As a summary, a majority of end-users take an additional margin of several months, whatever the surface finish. The resulting maximum shelf-life allowed becomes extremely short, leading to unplanned costs and time to market delays.

What happens if the shelf-life is expired?

When shelf-life has expired, bare PCBs are either simply scrapped or requalified through specific solderability tests. Requalification tests can be done by PCB makers, end-users or specific laboratories. Usually, these tests are conducted according or closely to IPC's J-STD-003C "S*olderability Tests for Printed Boards*" on either a board, or a representative part of the printed circuit board (test coupon). There are no statistics about the percentage of expired PCBs not being qualified after reactivation. However, most stakeholders agree to consider this percentage to be negligible or even zero.

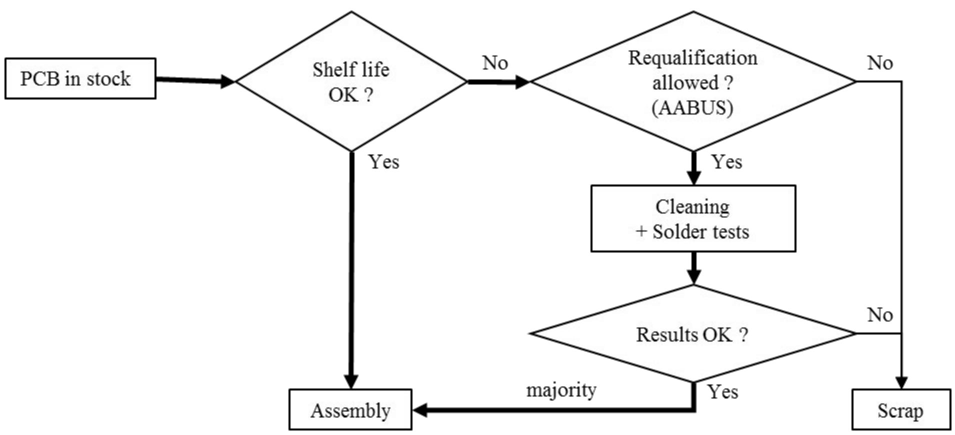

Fig. 4 : PCB use flow-chart versus shelf-life, theoretical

In reality, a lot of bare PCBs are often stored longer than the end-user allowed shelf-life before going to the assembly process. Some programs of projects can be very long (compared to the PCB shelf-life). It is difficult to collect accurate data and have exact figures, because PCBs can be stored at different locations, but the proportion of expired shelf-lives can be quite high in certain market segments.

The existing situation has 2 detrimental effects on the supply-chain:

- A lot of good boards are scrapped worldwide, or costly complementary solderability tests are realized to requalified boards for a limited time
- Only small batches of boards are ordered to be sure that shelf-life will not be passed. This is detrimental in terms of cost and quality. Larger volume batches provide higher quality thanks to higher stability of chemical bathes.

This is especially true for military or avionic products which are small to middle volume production, but with a very high reliability requirement. When complementary tests are realized according to IPC J-STD-003C, results are most of time good. This trends to show that shelf life required in standard or customers' specifications is very conservative. Provided the finish is well realized, storage in normal condition is not a major problem. This is true in particular for ENIG and ENEPIG for which many companies have learned that except problems like black pad or brittle fracture, usually detected very early in the manufacturing process, very few problems occur.

Answers

A group of PCB manufacturers, EMS and OEMs in France decided at the end of 2013 to work together to look to address the shelf life question, for various surface finishes: fused SnPb, HASL[9], ENIG, and chemical tin. In the frame of a large collaborative project, this consortium evaluated the actual risks on assembly process yield, when storage time is increased, taking into account different production sites, different packaging conditions (from no specific packaging, to high-end packaging) and different ageing conditions (accelerated / not accelerated).

A large study (more than 5000 tests) has been realized to procure data to try to establish new recommendations. The purpose of the test realized was not to qualify a new finish or a new supplier for these finishes, but to assess the real shelf-life of normal production. Samples have been produced by several qualified manufacturers, operating qualified chemistries in good process conditions. Solderability of the supplied printed boards are considered as good at time zero, as PCBs that are produced daily by these manufacturers, with these surface finishing processes, without any noticeable problems. The goal of the tests was to quantify solderability changes depending of different ageing conditions.

Methodology

Sample production

For information, a total of 13 different surface finish types were evaluated in the whole project. All samples have been produced in normal process conditions, by 7 different PCB manufacturing sites in France, having different surface finishes, sometimes from different chemistry suppliers. Among all these 13 different types of surface finish evaluated in the project, this paper focusses only on 5 popular surface finish types, for which the project consortium considers that shelf-life extension can have a significant positive impact on the supply-chain:

- Fused SnPb
- HASL
- ENIG
- ENEPIG
- Chemical Sn[10]

Table 1 below summarizes how many PCB makers produced which type of the 5 different surface finish, depending on their own installed capabilities. ENIG and chemical tin are usually available and strongly represented, while chemical tin, fused SnPb and HASL are a little bit less common.

Table 1: Sample production table

Surface finish	Number of different PCB manufacturers
Fused SnPb	**1**
HASL	**1**
ENIG	**4**
ENEPIG	**1**
Chemical Sn	**3**

Packaging

PCBs are usually packed when delivered and stored. To represent the actual situation on the field, all these PCB samples were packed in 3 types of popular packaging: no specific packaging, anticorrosion paper, vacuum sealed bag with aluminum barrier.

[9] Hot Air Solder Levelling – lead-free Hot Air Solders Levelling

[10] Also called "Immersion tin", or "electroless tin"

Note: Taking into account the further tests, with intermediate solderability evaluations at different times over more than two years, batches of samples were packed individually (either in corrosion inhibition paper or vacuum sealed bags) in as many packs as tests to be performed. This allowed to open only the selected samples for solderability tests when they had to occur, leaving untouched all the other samples in their own packaging.

Failure modes to be tested

It is considered that the solderability degradation of a printed board final finish can result from three main fundamental root causes:

- Final finish oxidation
- Intermetallic formation (diffusion of base metal layer through the final finish and subsequent oxide interactions)
- External contamination

Thus, to assess the solderability of printed board surface finishes, accelerated ageing conditions must address the three main failure modes. Taking into account existing literature and the project consortium experience, it was decided that these modes are addressed by the following ageing conditions:

- Humidity accelerated tests at 85°C and 85% relative humidity: 6 hours, 12 hours, 24 hours
- High temperature storage at 155°C : 6 hours, 12 hours
- Reflow simulations (actual temperature profile, but no solder paste) on an actual SMT assembly line, 2 reflows, 4 reflows
- Multi-gas chamber tests 1 day, 2 days, 3 days, where 1 day in a (SO_2, H_2S, H_2O, Cl_2) mixture represent 1 year in the field
- Natural ageing in standard room storage condition[11] (2 years), with tests every 6 months

All samples were prepared according to these ageing conditions, as described in Table 2 below.

Table 2 : sample preparation

	Surface finish =>	Fused SnPb			HASL			ENIG			ENEPIG			Chemical Sn		
	Packaging =>	No[12]	AP[13]	VSB[14]	No	AP	VSB	No	AP	VSB	No	AP	VSB	No	AP	VSB
Natural ageing	Initial time (T0)															
	6 months															
	9 months															
	12 months															
	18 months															
	24 months															
Multi-gas	1 day															
	2 days															
	3 days															
High temperature Storage	6 hrs @155°C															
	12 hrs @155°C															
Humidity accelerated test	6 hrs @85°C/85RH															
	12 hrs @85°C/85RH															
	24 hrs @85°C/85RH															
Reflow simulation	2 reflows															
	4 reflows															

[11] Standard room conditions : Temperature : (20±5)°C, Relative Humidity : (50±20) %RH

[12] No specific packaging

[13] Anticorrosion paper

[14] Vacuum Sealed Bag

Measurements
Solderability is the key performance of surface finish. Two types of tests were made: wettability measurement through the wetting balance tests, and solderability assessment through a solder spread test sample passed on an actual assembly line and inspected.
Wetting balance measurement were done with both 63/37 tin lead solder and lead-free solder: SAC305[15], always with a low activated flux ROL0.
Solder spread tests were done only with SAC305, also with ROL0 flux (no clean).

Note about the flux
When assessing solderability, fluxing conditions impact wetting angle measurement. To be consistent with high-reliability PCB end users' requirements, it was decided to use a low activated flux: "ROL0" type for solderability tests (less than 0,05% Halide by weight). Indeed, for high-reliability PCB markets, low activated rosin flux #1 (ROL1, less than 0,5% Halide in weight) as specified in IPC-J-STD-003C standard is not allowed and not used anymore.

With a low activated flux ROL0, wetting angle absolute values are expected to be higher (i.e. worse) than in IPC J-STD-003C standard. But the absolute value itself is not the most important indicator to analyze here. The interesting aspect is the **evolution** of wetting angle as a function of ageing conditions, for each couple {surface finish; packing conditions}.

Solder spread tests
The test specimens are processed on an EMS assembly line (lead-free solder paste stencil printing + reflow oven). Solder paste is printed (stencil printing), reflowed, and after reflow the way the solder spreads (coverage of solder and the quality) is visually inspected as an indicator of solderability.

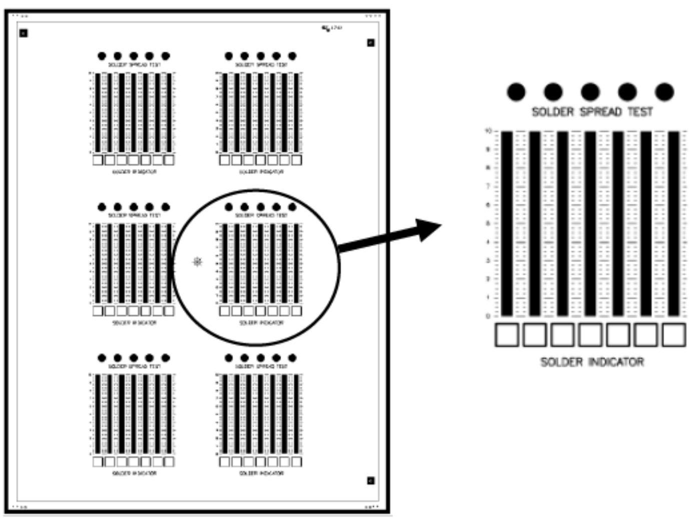

Fig. 5 : Solder spread test panel (left) containing 6 solder spread test specimens (right).

Samples having passed appropriate ageing conditions were sent all along the DoE[16] (more than 2 years) to an EMS specialized in high volume, high quality boards for the automotive industry. SAC 305 solder paste was used. The standard production process was used. Solder spread quality was assessed on 5 samples of each, by trained and confirmed technicians. More details about the complete test conditions are available upon request from the authors.

Note: "Reflow simulation" ageing conditions described before were performed at the same EMS facility, on the same production equipment (reflow oven), but without solder paste deposition. Two successive reflow temperature profiles simulated component assembly on 1 side, then on the other side. 4 successive reflows simulate the same both side assembly + repair operations.

Wetting balance tests
This test is done on equipment measuring the solder weight remaining on a test specimen after fluxing and dipping into solder. It allows to determine comparative wetting angle values. Wetting angles measured are then sorted by categories with a quality index defined by the project team, as described in Table 3 below.

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[15] Sn Ag Cu, lead free solder alloy, containing typically 96.5% of Sn, 3% of Ag and 0.5% of Cu.
[16] Design of Experiment

Wetting angle	Quality	Quality index
≤30	Outstanding	1
30< Θ ≤40	Very good	2
40< Θ ≤55	Good	3
55< Θ ≤80	Acceptable	4
>80	Not acceptable	5

Table 3: Small angles measured indicate a good wettability.
Due to ROL0 flux, the absolute quality index is different from IPC J-STD-003C

Test specimens were designed and produced with 99 individual wetting balance test specimens implemented in a PCB production panel.

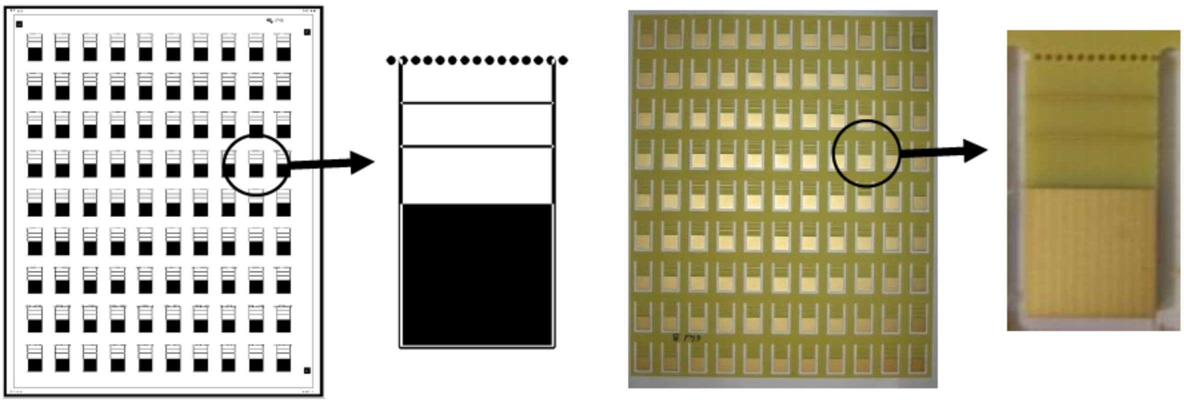

Fig. 6 : Wetting balance test specimen, and example of ENIG plated panel

Each panel produced received the appropriate surface finish and was packed according to the determined conditions (no specific packaging, anticorrosion paper, vacuum sealed bag). Then ageing conditions have been deployed, and all along the DoE (more than 2 years) samples have been regularly taken out of their packaging and sent to an independent and certified laboratory to perform wetting balance tests. Both SnPb 63/37 and SAC 305 wetting balance tests were done, by confirmed technicians. To assess wetting angle for each configuration, 5 coupons were used, and the average value recorded.
More details about the complete test conditions and specimen used are available upon request from the authors.

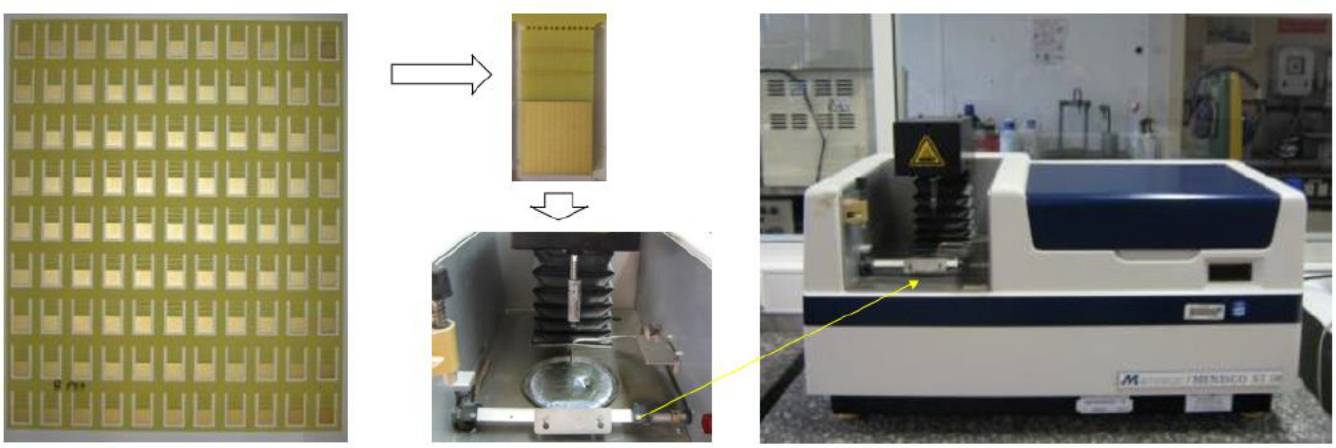

Fig. 7 : Representation of the wetting balance test

Results overview

More than 5000 measurements were performed all along this study. To give an acceptable overview and not too many numbers and tables, the next pages summarize the results organized in graphs. Wetting angle quality index is rated from 1 (Outstanding) to 5 (not acceptable), see

Table 3: Small angles measured indicate a good wettability.

Solderability assessed by solder spread tests (on the assembly line) are rated in terms of yield, from 100% (outstanding) to 0% (not acceptable). The first graphs try to give an overview of the results. They represent the average observed solderability by wetting angle method, for SAC305 and SnPb solders, all ageing conditions together, reported by surface finish and packaging type. They do not give any indication on solderability evolution, but just an overall picture of what is the average solderability observed after 24 months and all ageing tests together.

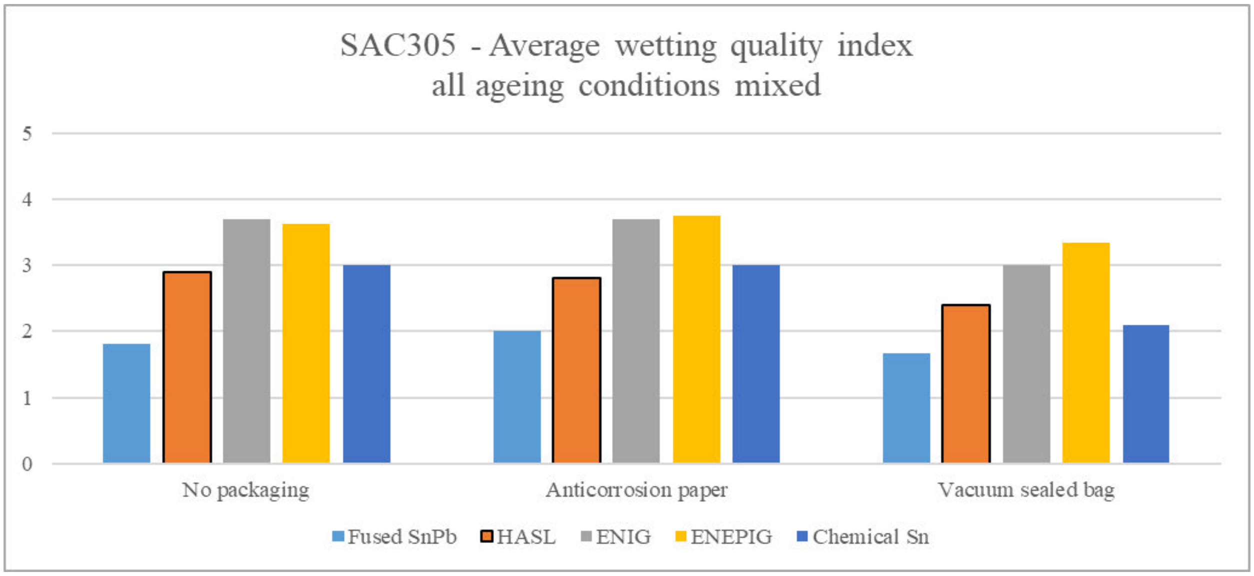

Fig. 8: SnAgCu results - wetting angle quality index is rated from 1 (Outstanding) to 5 (not acceptable)

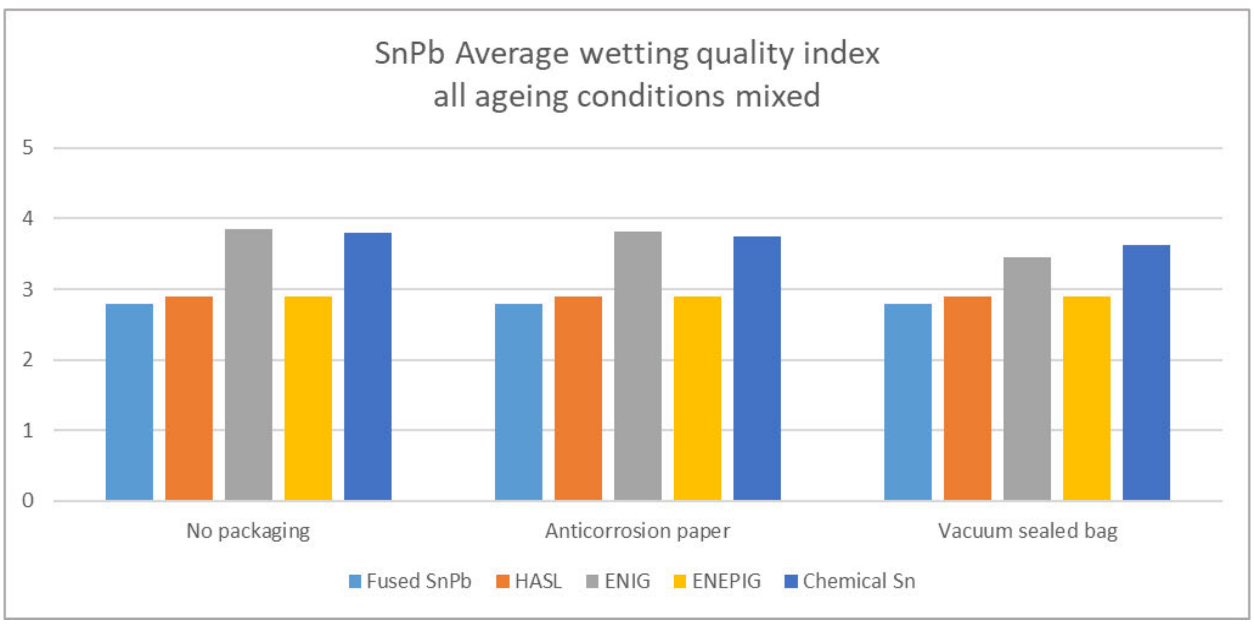

Fig. 9: SnPb results - wetting angle quality index is rated from 1 (Outstanding) to 5 (not acceptable)

With SAC305 solder, after 24 months of various ageing conditions, wetting balance results are good, whatever the PCB packaging. On average, chemical tin seems good, but in reality, high temperature storage is degrading this surface finish. With SnPb solder, after 24 months of various ageing conditions, wetting balance results are good, whatever the PCB packaging.

Solder spread test

Figure 10 below represents the average observed solderability observed after the lead-free assembly process at the EMS facility, after all ageing conditions over 24 months, by surface finish and packaging type. It does not give an indication on solderability evolution, but just an overall picture of what is the average solderability observed for all surface finishes, in a standard industrial lead-free reflow process after 24 months and all ageing tests together.

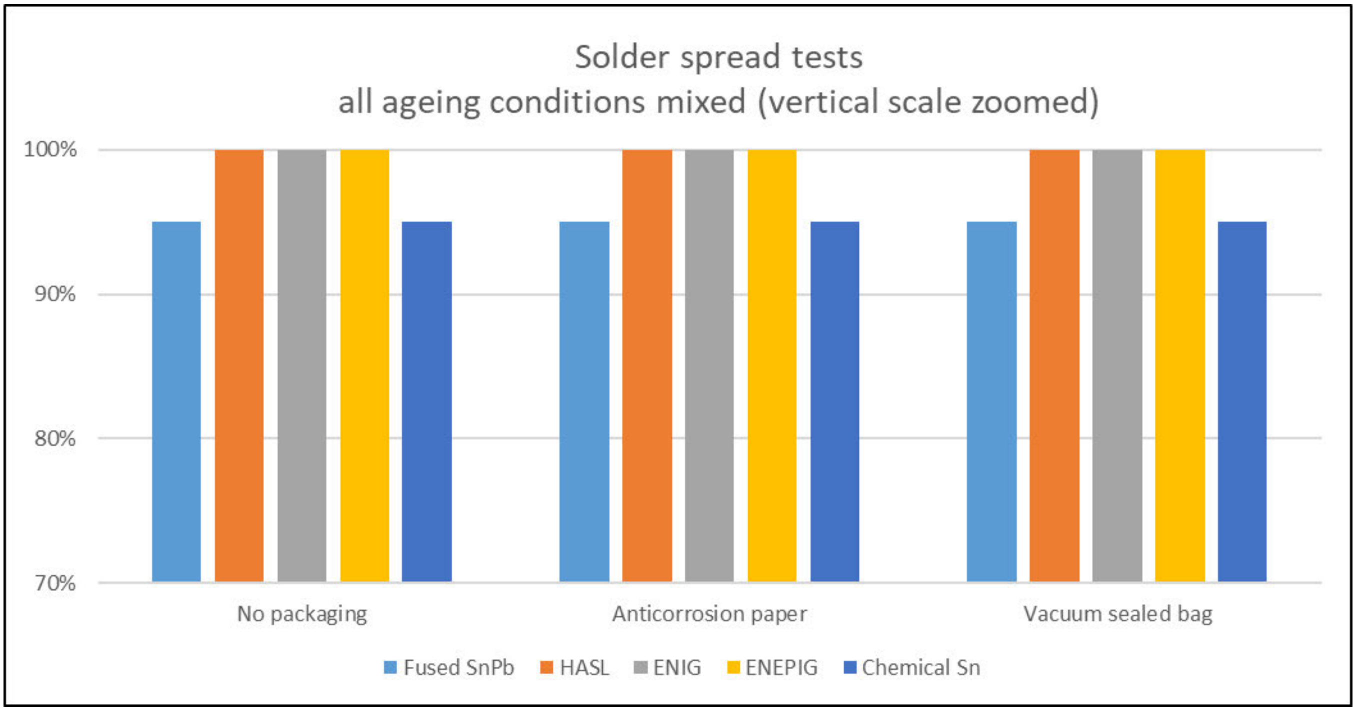

Fig. 10: After 24 months and various ageing conditions, solder spread tests results are good for HASL, ENIG and ENEPIG, whatever the packaging. Chemical Sn and fused SnPb are still acceptable even if a little bit less good, but this is known, and these finishes can be reactivated easily.

Conclusions

This study is the fruit of a collaboration between a significant panel of PCB manufacturers, EMS and OEMs. A large number of dedicated test vehicles were produced, and solderability was tested against various packaging and ageing conditions. The results collected demonstrate that IPC recommended shelf-life of some surface finishes can be at least doubled. To complete the data presented in this paper, complementary test after 36 months storage is currently being conducted, including correlation with ROL1 flux conditions.

If minimum surface finish thicknesses specified in IPC standards are respected, according to the three main failure modes analyzed extensively in this study, there is currently more than a sufficient margin for solderability degradation in storage, whatever the packaging conditions and the PCB manufacturer, to double shelf life.

Extra safety can normally be procured by reinforcing the packaging, for instance vacuum sealed bags with aluminum barrier. This kind of packaging appears to be efficient on average for humidity and corrosion protection. For high reliability applications, extra-costs of such packaging solutions are counterbalanced by the safety margin they procure.

Taking into account the results of this design of experiment, major PCB suppliers in France and Europe are starting to progressively agree to guarantee solderability of their boards according to this new proposal. Major French PCB end-users for high reliability applications have accepted 24 months shelf-life specification for fused SnPb, HASL, ENIG and ENEPIG, and 12 months for chemical tin. The entire supply-chain will benefit from these new conditions. Discussions are currently ongoing with IPC in a blue-ribbon committee on this work.

APPENDIX, Detailed results

Some wetting quality index graphs are given hereafter (Figures 11 to 15), organized by packaging type, SnPb or SAC305 solder, and ageing conditions, and show solderability evolution over time.

Notes: Low values are better solderability, T_0 is the initial time for the samples (PCB end of fabrication date).

No packaging, examples of graphs obtained

Fig. 11 : No packaging results (Natural ageing and Multi-gas tests). Low values are better solderability. (To= Initial time)

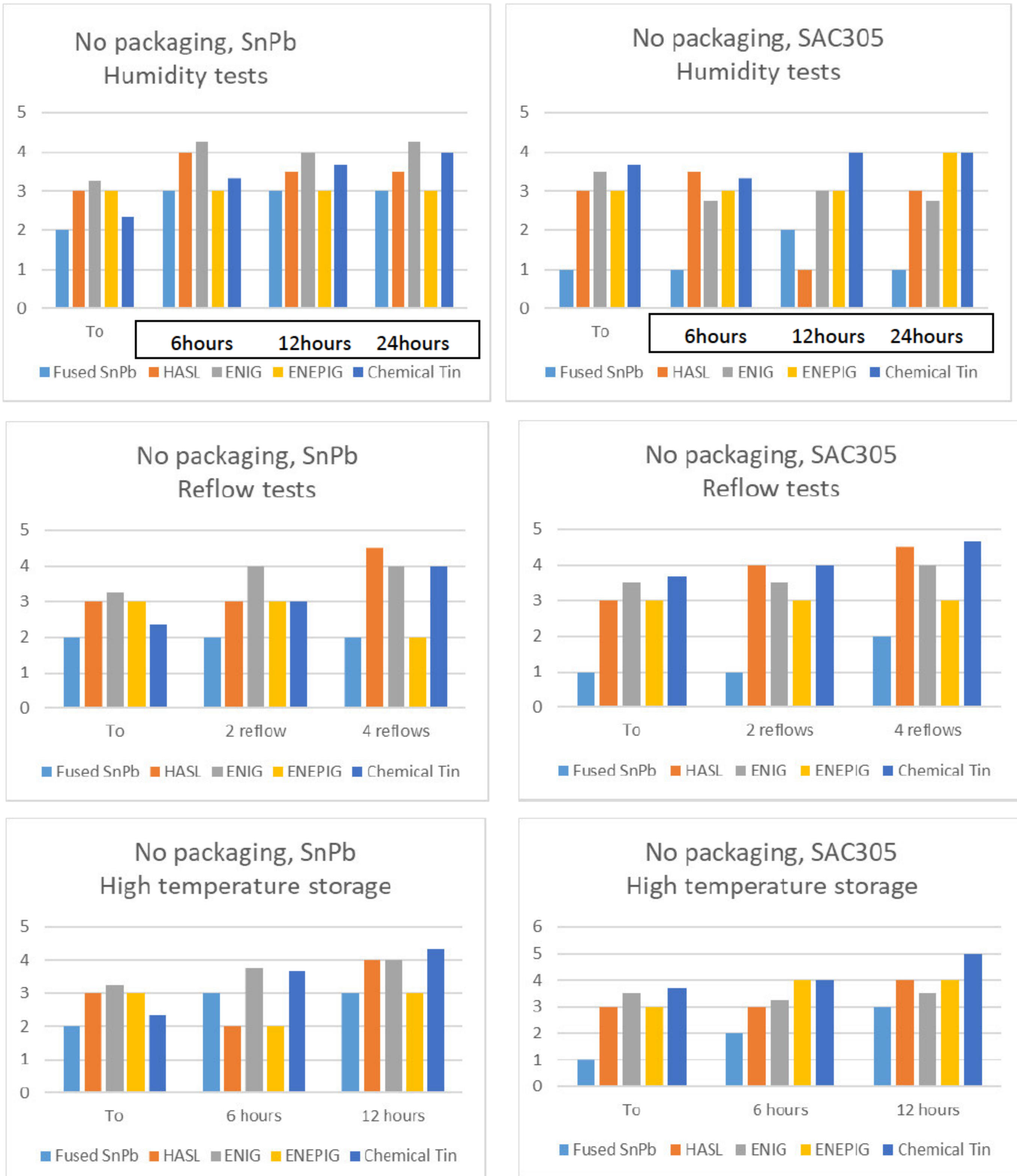

Fig. 12: No packaging results (Humidity, Reflow and High temperature storage tests). Low values are better solderability. (To= Initial time)

Anticorrosion paper, example of graphs obtained

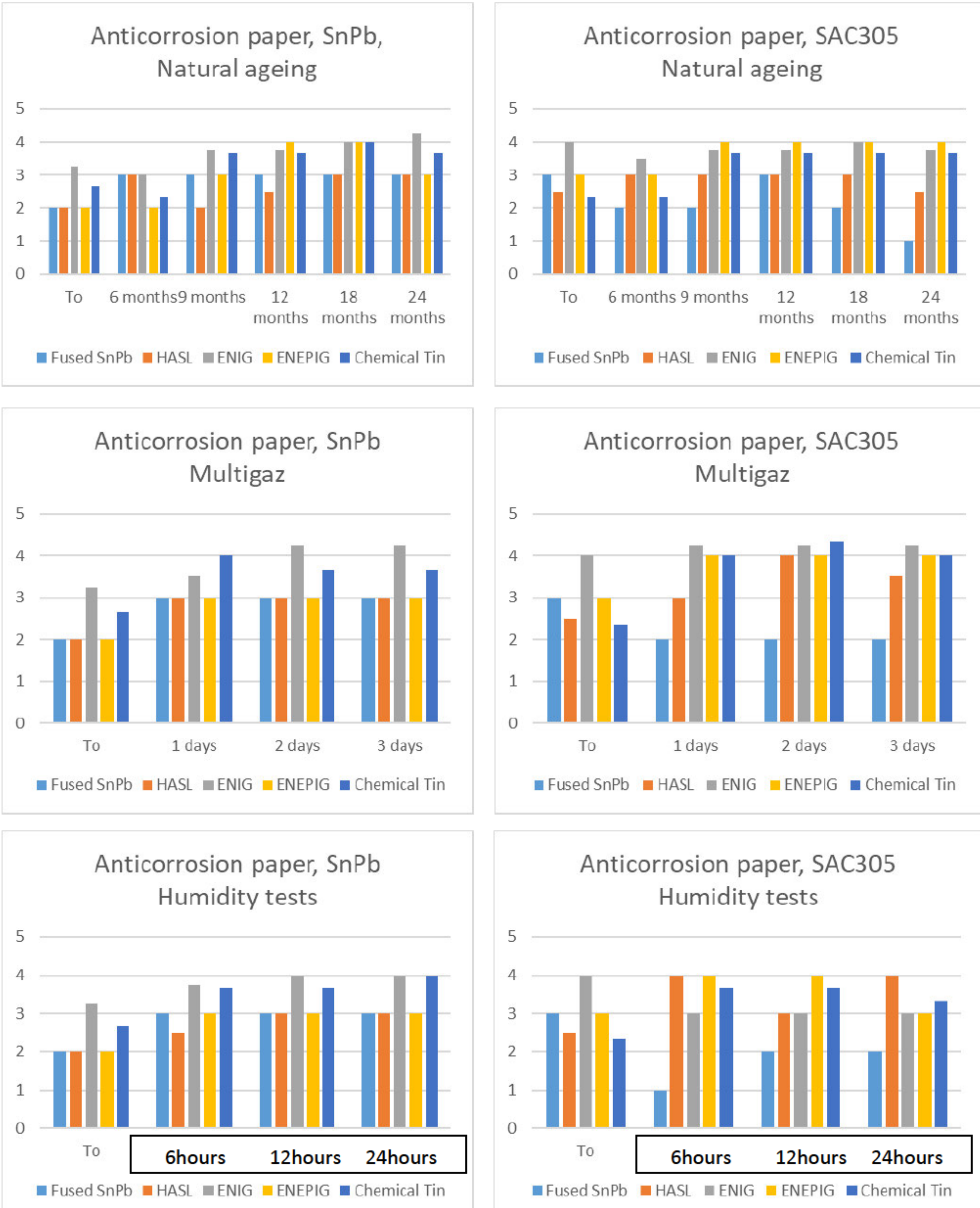

Fig. 13: Anti-corrosion paper results (Natural ageing, Multi-gas and Humidity tests). Low values are better solderability. (To= Initial time)

Vacuum sealed bags, example of graphs obtained.

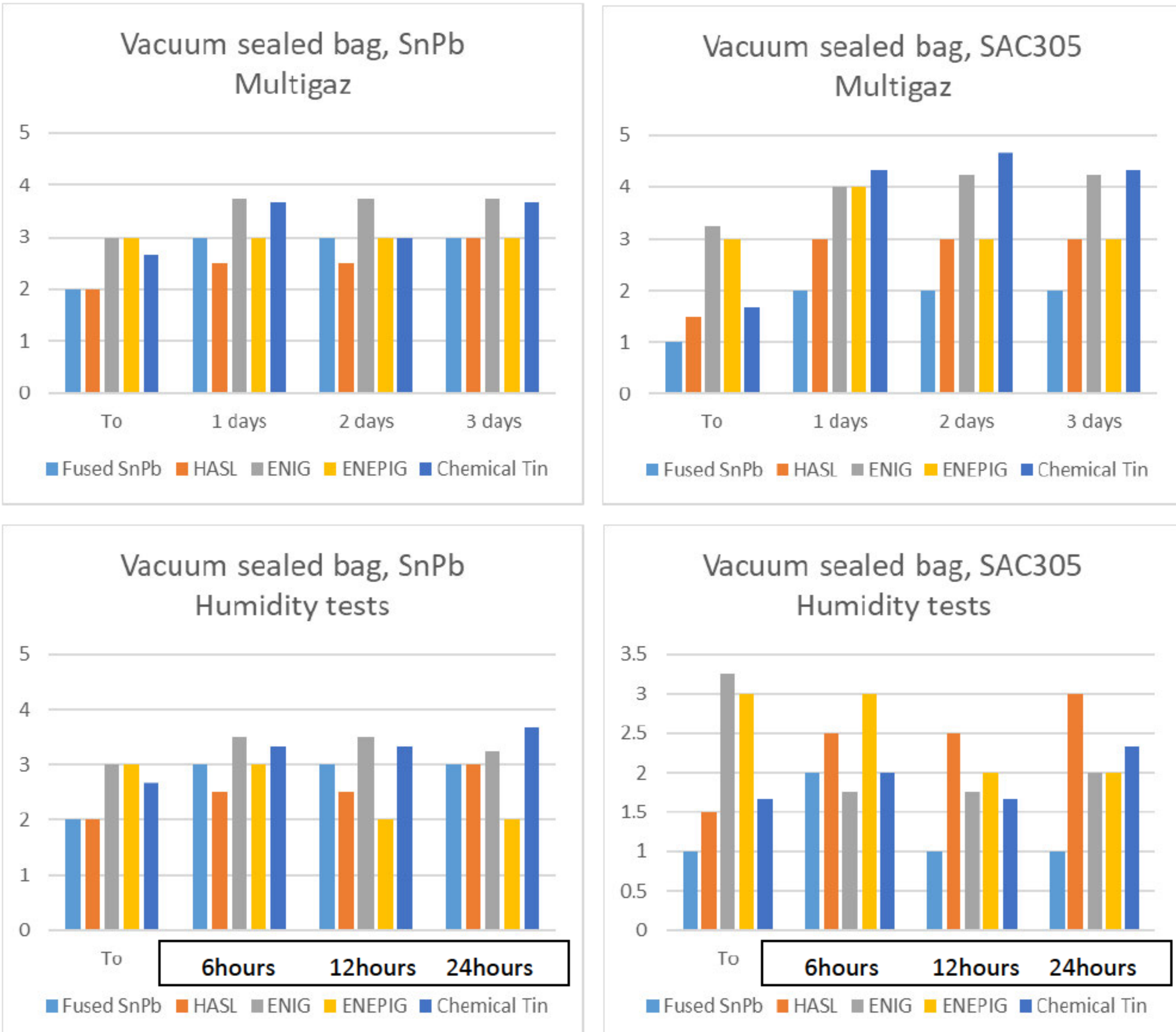

Fig. 14: Vacuum sealed bag results (Multi-gas and Humidity tests). Low values are better solderability. (To= Initial time)

Packaging types

Solderability tests on an industrial assembly line by ageing conditions for each surface finish type.

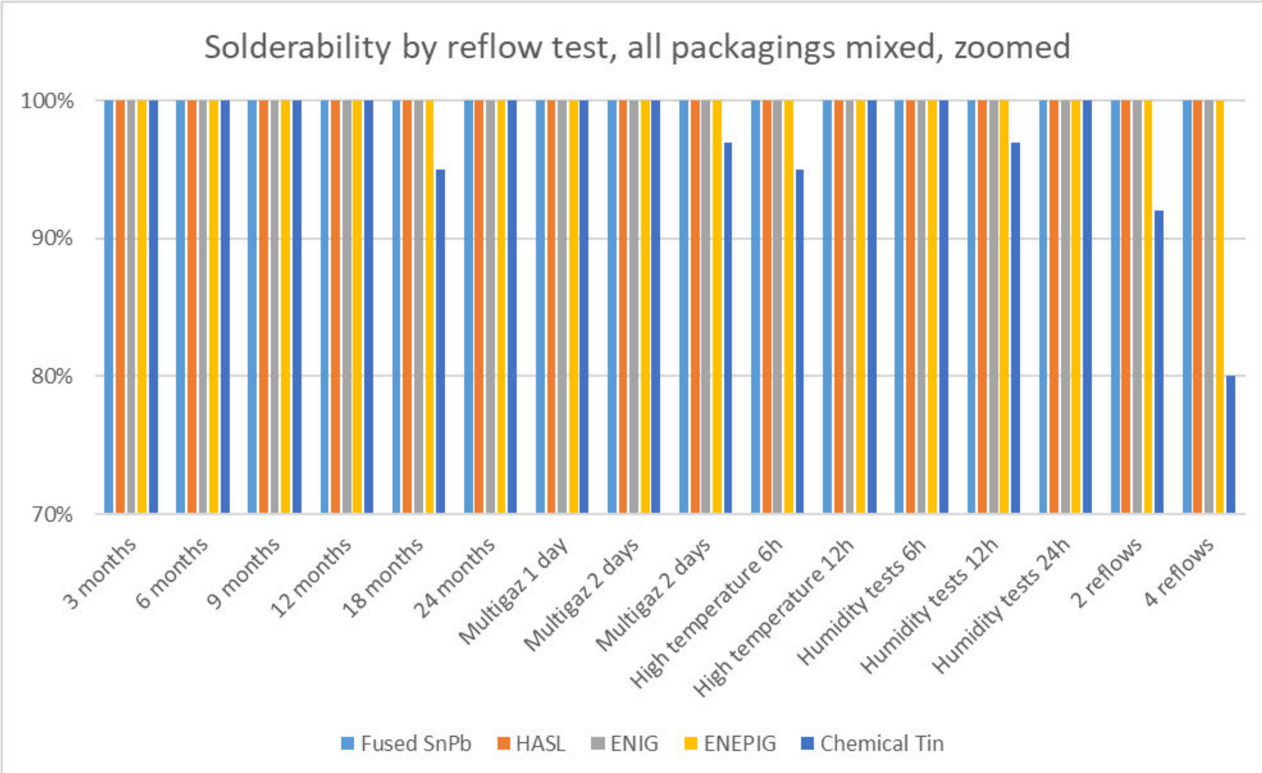

Fig. 15: Solderability tests on an industrial assembly line by ageing conditions (Natural ageing, Multi-gas, High Temperature, Humidity, Reflow) for each surface finish type. Low values are better solderability.

Study and Recommendation for Increasing PCB Surface Finishing Shelf Life

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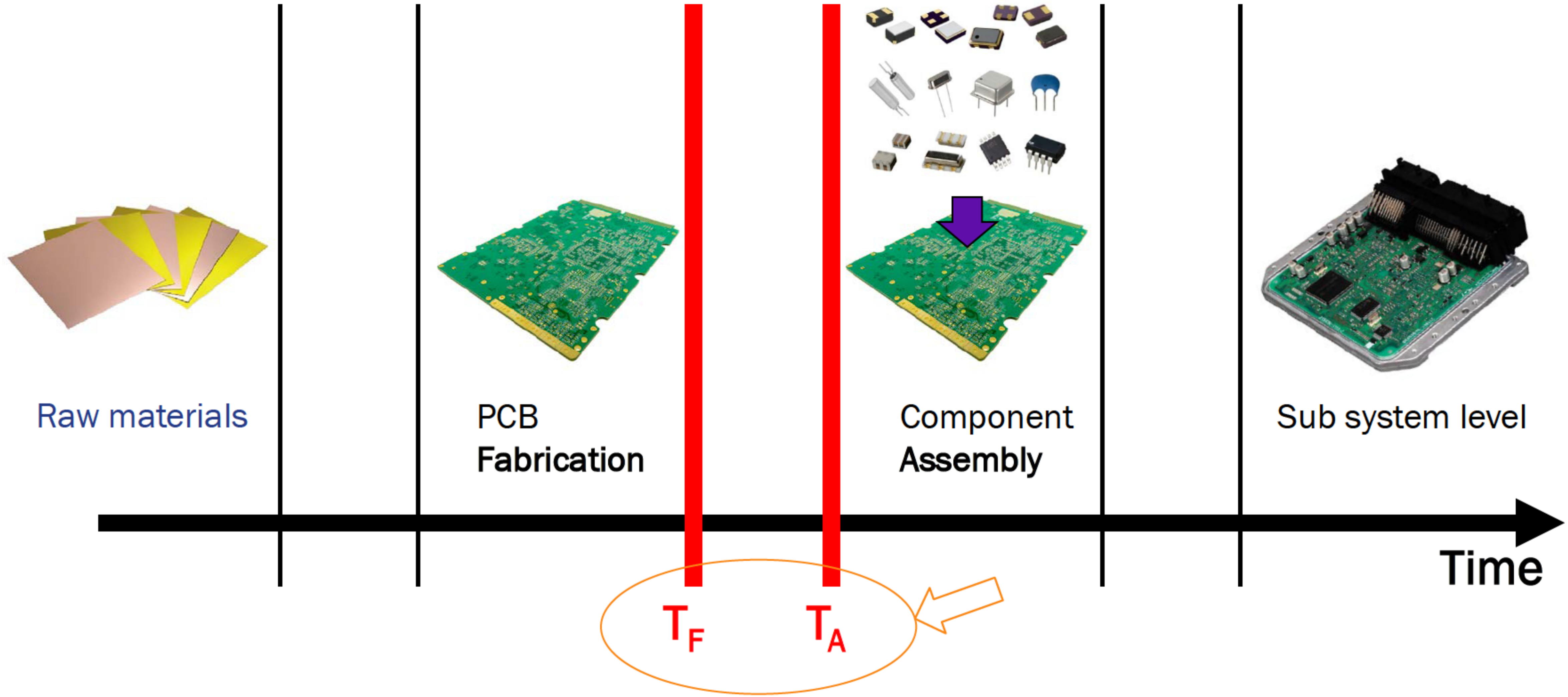
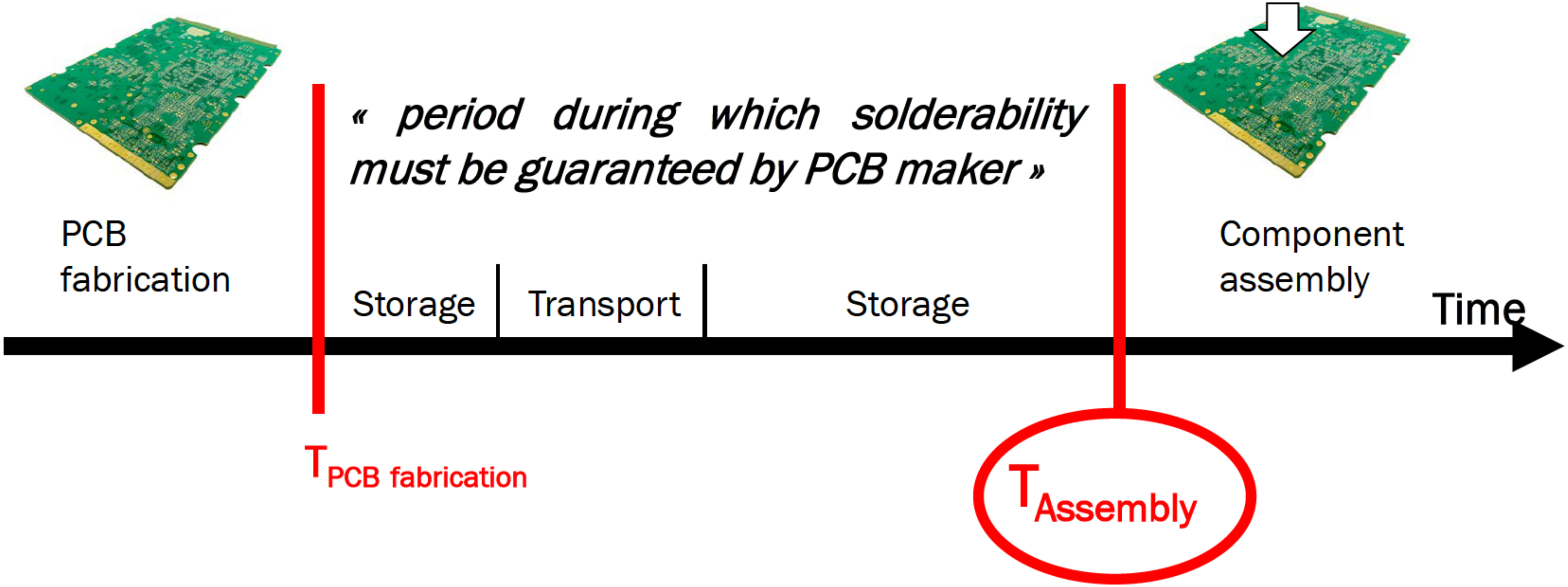
Chronology

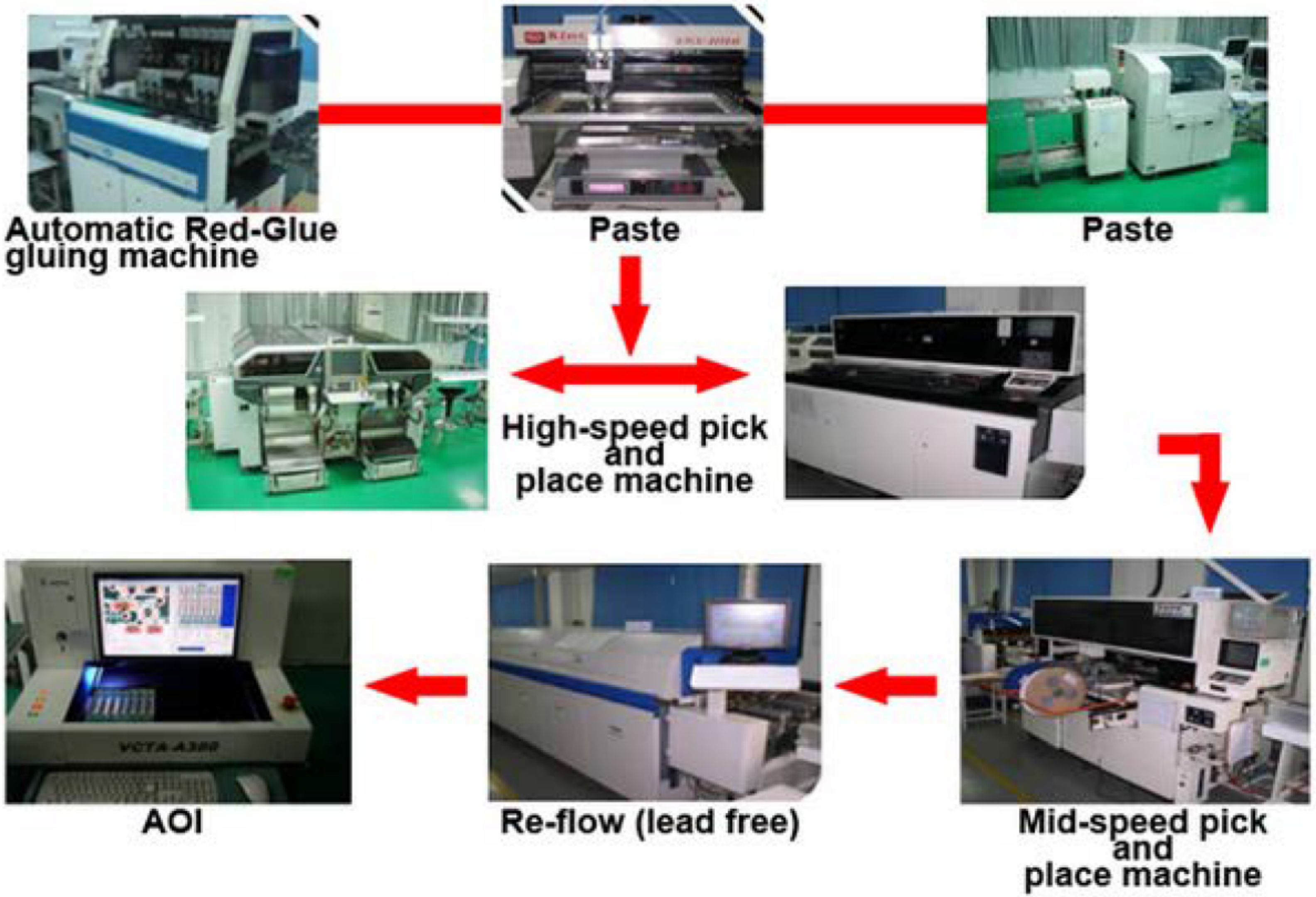

Raw materials
PCB
Fabrication
Component
Assembly
Sub system level
Time
T_F
T_A

Shelf-life


« period during which solderability must be guaranteed by PCB maker »
PCB fabrication
Storage
Transport
Storage
Component assembly
Time
T PCB fabrication
T Assembly

What happens at $T_{Assembly}$?

Components are usually soldered onto the PCB external surface



PCB fabrication

PCB can be very complex structures, but usually only a top and bottom surface (external layers) to mount components

Conductors and pads are made of copper

Exposed to the environment, copper is not stable in time : it oxidizes

PCB surface finishing is designed to provide stable enough properties over time

PCB surface finishing must be adapted to component assembly process

NB : Component pads are also metal with a surface finish…

PCB surface finishing

There are a lot of different surface finishing possibilities, designed to provide a good yield at component assembly

- Non metallic
  - *Organic Solderability Preservative*
- Metallic
  - *Electroless deposition : NiAu, Sn, Ag, NiPdAu …*
  - *Electrolytic deposition : NiAu, Au, Ag, SnPb …*
  - *Hot Air levelling : Leadfree, SnPb …*

Time does not spare us, it does not spare surface finishes either…

Current situation about shelf-life

IPC driven tests concluded 15 years ago that 2 micro inches (0,0508 µm) of gold would “**easily**” guarantee a one year shelf life for ENIG : **One year** became the theoretical standard value for ENIG shelf-life…

Over time, PCB users have built their own shelf-life specifications

in the case of ENIG, some EMS or OEMs accept up to 24 months shelf-life, others ask for 9, 6 or even down to 2 months maximum shelf life – Safety margin ?

This causes problems to the entire supply chain: time-to-market and costs are not optimized

For the same surface finish each customer asks for a different shelf life. At least a logistics nightmare…

Current situation about shelf life – ENIG case

From actual customer specifications

Aero-mil market with small to medium series

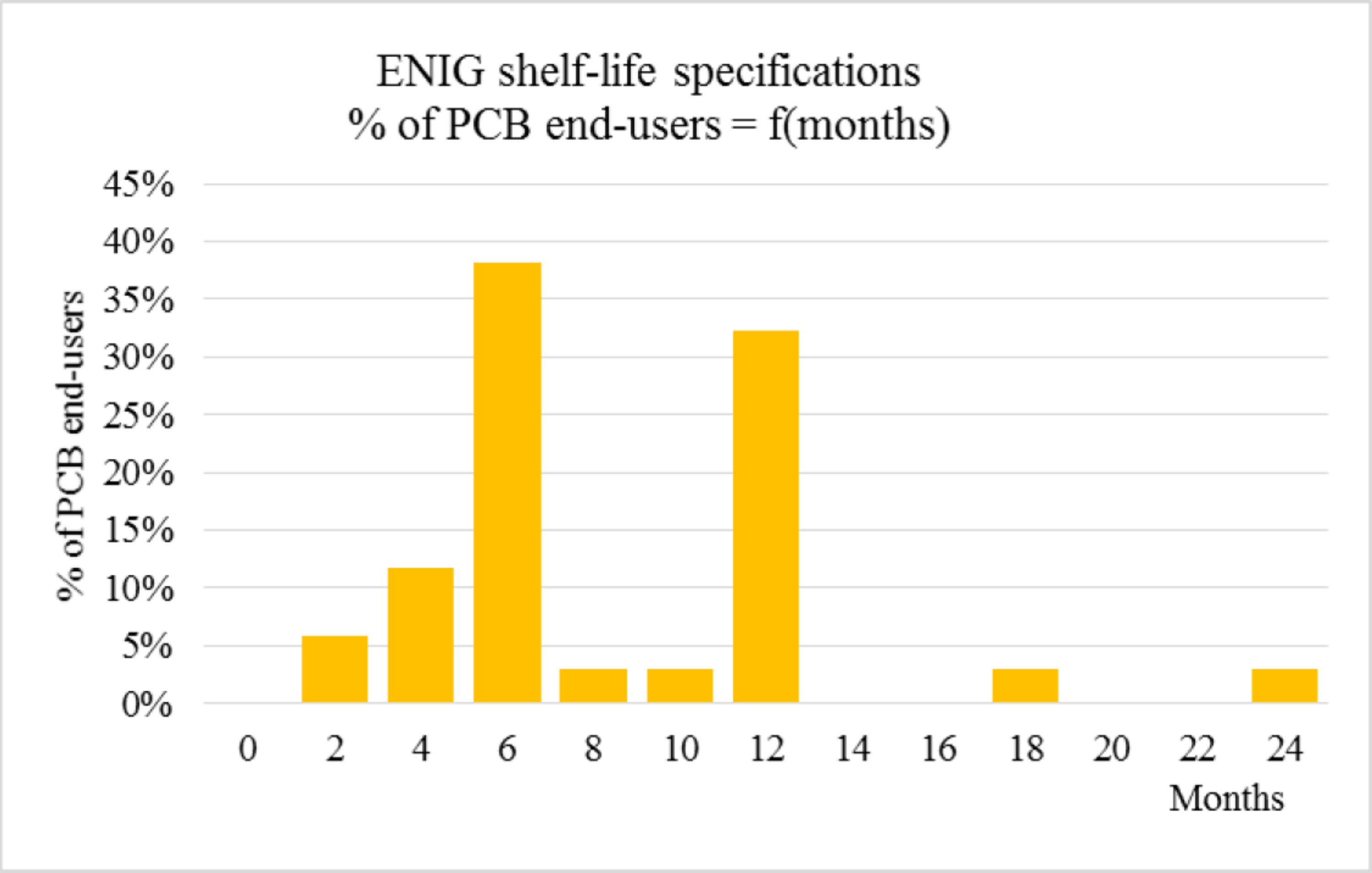
High level of expectations and long product life cycle

ENIG

32% customers apply IPC4552 recommendations (12 months)

60% customers ask for less than 12 months

8% accept more than 12 months



Current situation about shelf life – Sn case

From actual customer specifications

Aero-mil market with small to medium series

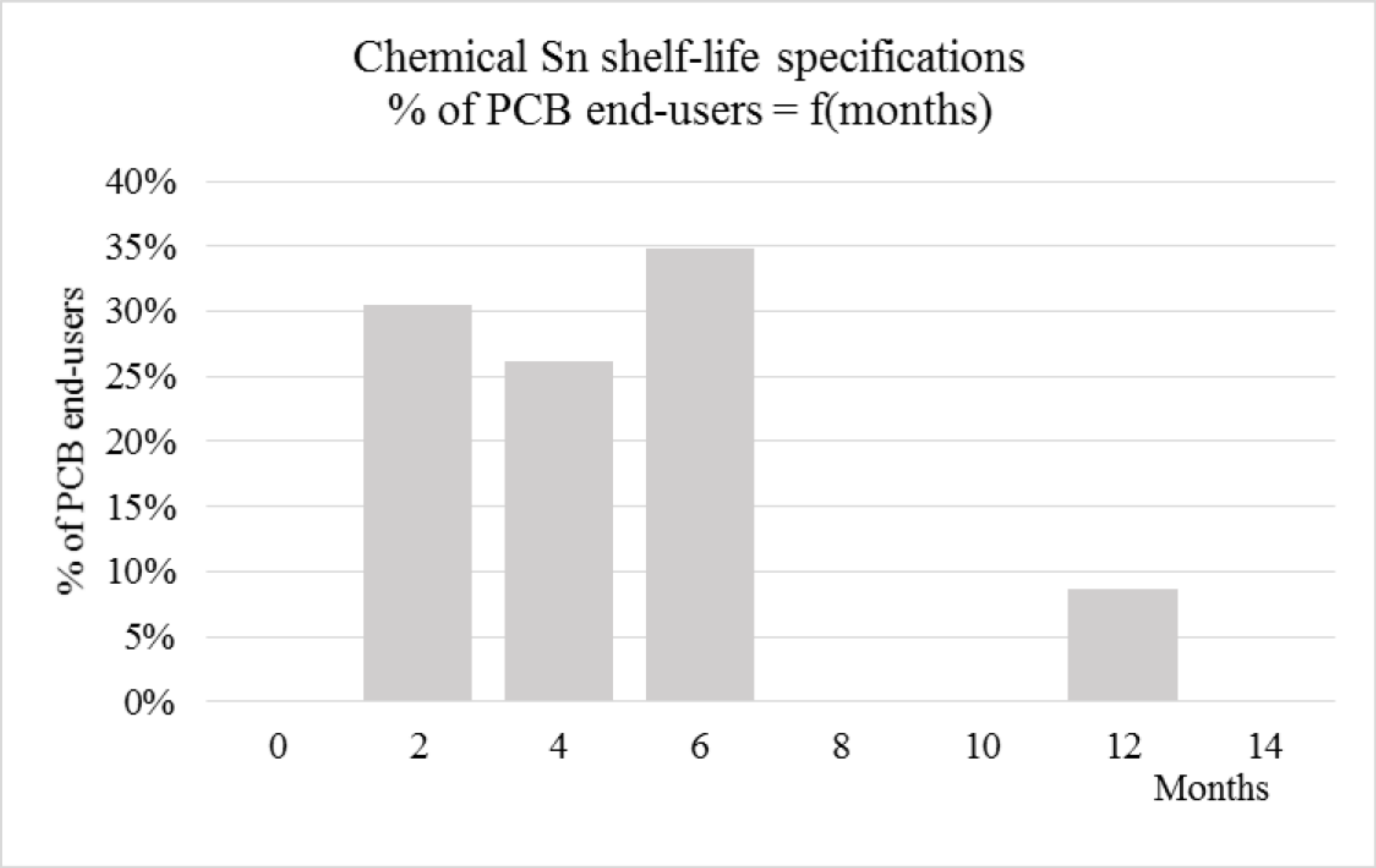
High level of expectations and long product life cycle

Sn

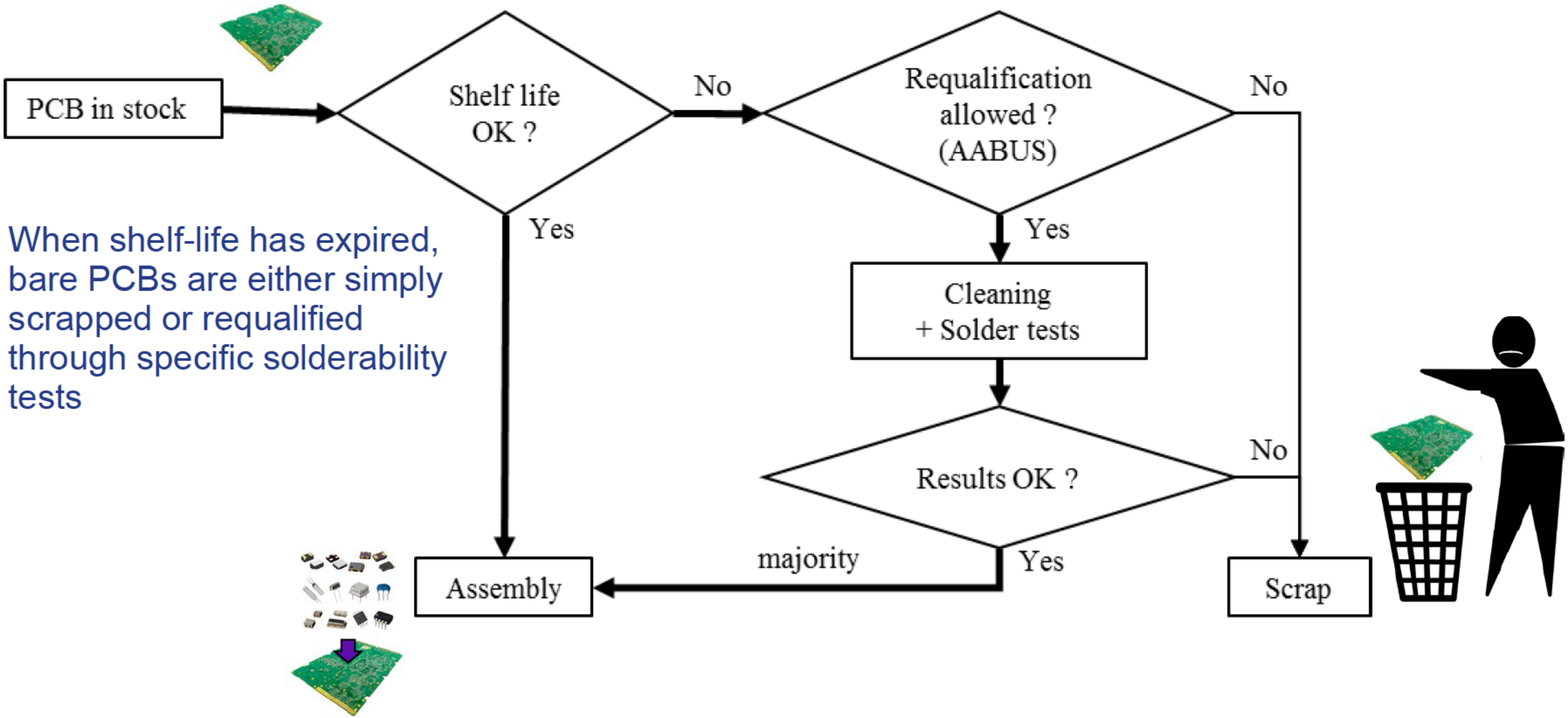
35% customers less than 6 months

56% customers ask for 6 months

8% accept more than 6 months



What happens if shelf life expired ?



When shelf-life has expired, bare PCBs are either simply scrapped or requalified through specific solderability tests

Some programs/project can be very long (compared to the PCB shelf-life)

The proportion of expired shelf-lives can be quite high in certain market segments

Impact

This has two significant detrimental effects :

•A lot of good boards are scrapped worldwide, or costly complementary solderability tests are realized to requalify boards for a limited time

•Only small batches of boards are ordered to be sure that shelf-life will not be overpassed.

Cost, quality and time to market are currently not optimized

Some answers…

A group of PCB manufacturers, EMS and OEMs in France decided at the end of 2013 to work together around the shelf life question, for various surface finishes: fused SnPb, HASL , ENIG, and chemical tin

In the frame of a large collaborative project, this consortium evaluated the actual risks on assembly process yield, when storage time is increased, taking into account different production sites, different packaging conditions (from no specific packaging, to high-end packaging) and different ageing conditions (accelerated / not accelerated)

This large study (more than 5000 tests) has been realized to provide data to establish new recommendations. The purpose was to assess the real shelf-life of normal production

Methodology

Test samples have been produced by several qualified manufacturers operating qualified chemistries in good process conditions.

Solderability of the supplied printed boards is considered as good at initial time, as PCBs are produced daily by these manufacturers, with these surface finishing processes, without any noticeable problems

Solderability **change** has been assessed as a function of ageing conditions

$$\Delta = \boxed{\text{After ageing Solderability}} - \boxed{\text{Initial Solderability}}$$

Methodology – surface finishing studied

Sample production
Different surface finish types were evaluated in the whole project. All samples have been produced in normal process conditions, by 7 different PCB manufacturing sites in France, having different surface finish offerings, sometimes from different chemistry suppliers

5 most popular surface finish types analyzed, for which the project consortium considers that shelf-life extension can have a significant positive impact on the supply-chain:

Surface finish	Number of different PCB manufacturers
Fused SnPb	1
HASL	1
ENIG	4
ENEPIG	1
Chemical Sn	3

Methodology – packaging conditions

PCBs are usually packed when delivered and stored. To represent the actual situation on the field, all these PCB samples were packed in **3** types of popular packaging:

Packaging type
No packaging
Anticorrosion paper
Vacuum sealed bag with Aluminum barrier

Methodology : failure modes to address

It is considered that the solderability degradation of a printed board final finish can result from 3 main fundamental root causes:

- Final finish oxidation
- Intermetallic formation (diffusion of base metal layer through the final finish and subsequent oxide interactions)
- External contamination

These failure modes are addressed by the following <u>ageing</u> conditions:

- Humidity accelerated tests at 85° C and 85% relative humidity : 6 hours, 12 hours, 24 hours
- High temperature storage at 155° C : 12 hours, 24 hours
- Reflow simulations (actual temperature profile, but no solder paste), 2 reflows, 4 reflows
- Multigaz chamber tests: 1, 2, 3 days, where 1 day in a (SO_2, H_2S, H_2O, Cl_2) mixture represents 1 year
- Natural ageing in standard room storage condition (2 years), with tests every 6 months

Methodology : measurements

Solderability is the key performance of the surface finish.

Two types of tests were made: wettability measurement through **wetting balance tests**, and solderability assessment through a **solder spread tests**

Wetting balance measurement were done with both 63/37 tin lead solder and lead-free solder: SAC305 , always with a low activated flux ROL0

Solder spread tests were done on an assembly line, with SAC305 and ROL0 flux (no clean)

*With a low activated flux ROL0, wetting angle absolute values are expected to be higher (i.e. worse) than in IPC J-STD-003C standard. But the interesting aspect here is the **change** of wetting angle as a function of ageing conditions*

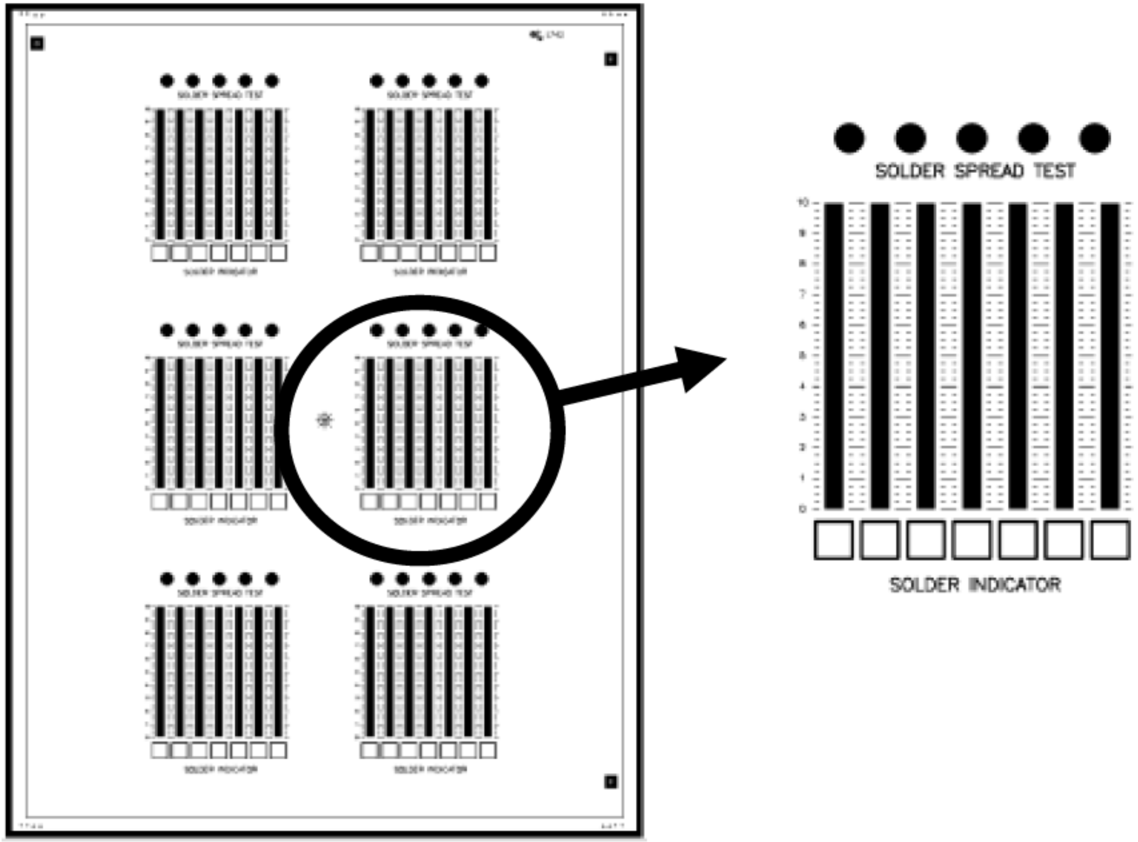
Δ = After ageing Solderability - Initial Solderability

Methodology : Solder spread test

A specific design has been produced to make solder spread test on assembly line

The way the solder spreads is judged by trained technicians

(Even after the worse ageing conditions, results were too good to use the scale on the test vehicle design)



Methodology : Solder spread test

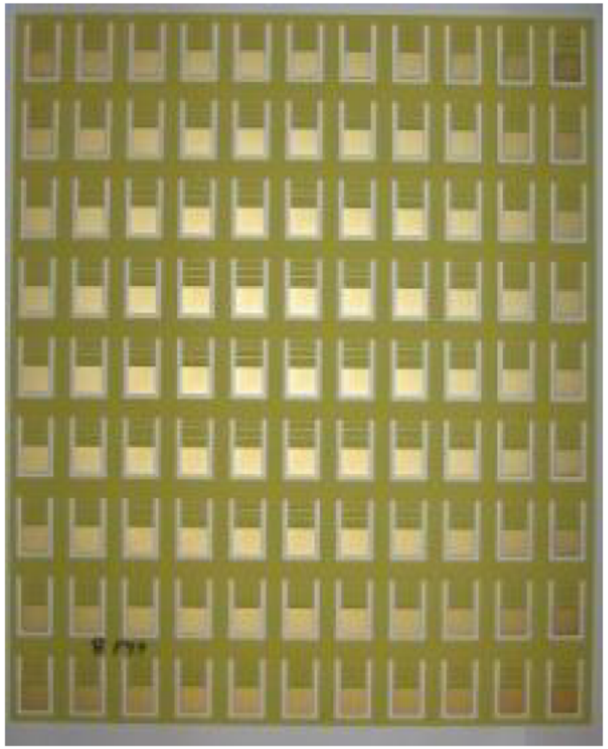
Samples having passed appropriate ageing conditions have been sent all along the DoE (more than 3 years) to an EMS specialized in high volume, high quality boards for automotive industry

SAC 305 solder paste was used. The standard production process was used. Solder spread quality was assessed on 5 samples of each, by trained and confirmed technicians

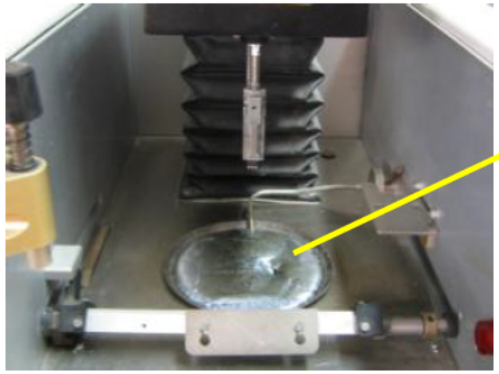
EMS : Electronic Manufacturing Services
SAC305 : Sn Ag Cu, lead free solder alloy, containing typically 96.5% of Sn, 3% of Ag and 0.5% of Cu.

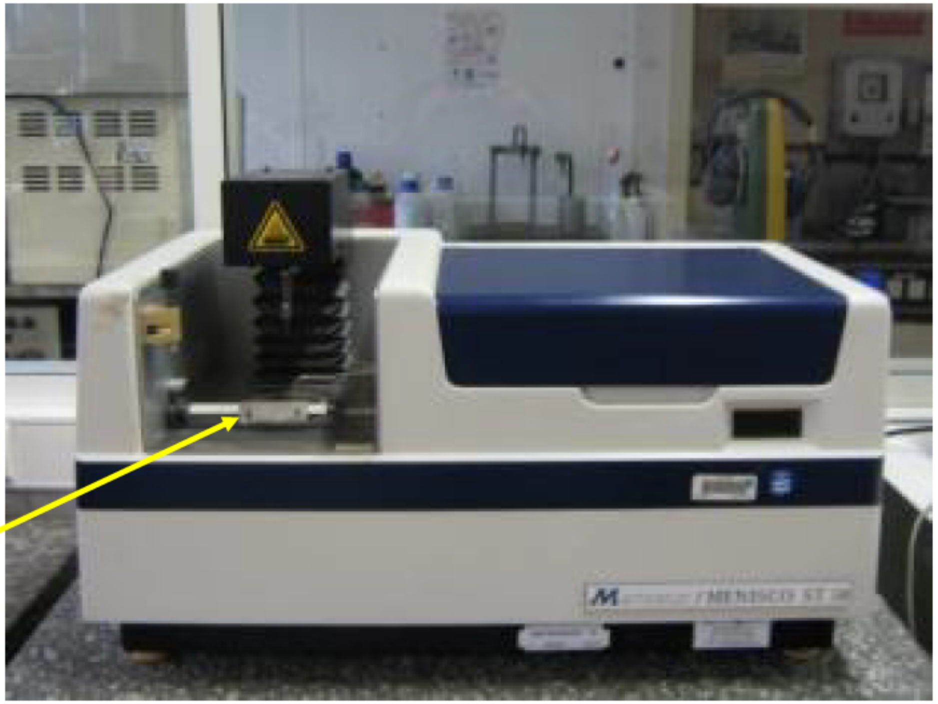
Methodology: Wetting balance

This test is done on an equipment measuring the solder weight remaining on a test specimen after fluxing and dipping into solder. It allows to determine comparative wetting angle values

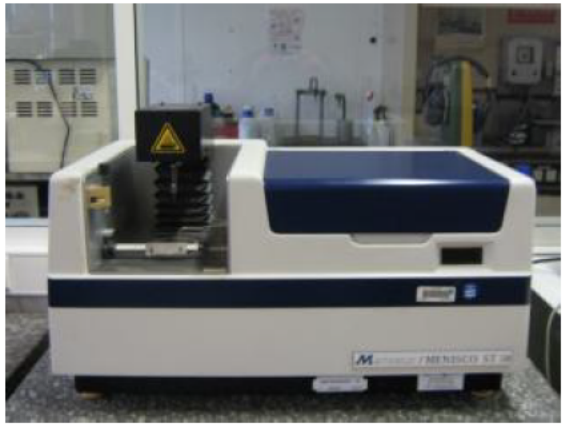


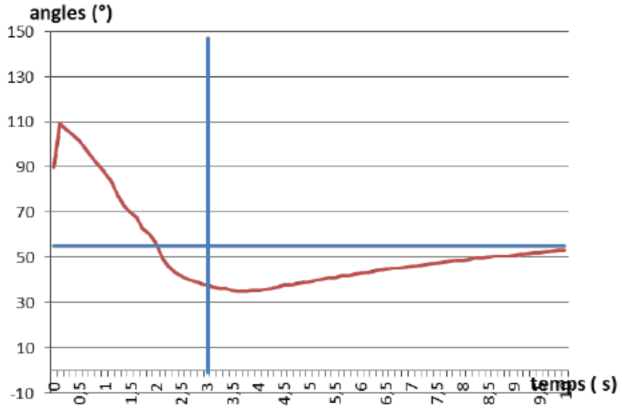
Test coupon





Methodology – Wetting angle





For each sample, quality index is recorded

Small angles measured indicate a good wettability.

Wetting angle	Quality	Quality index
≤30	Outstanding	1
30< ϴ ≤40	Very good	2
40< ϴ ≤55	Good	3
55< ϴ ≤80	Acceptable	4
>80	Not acceptable	5

Due to ROL0 flux, absolute quality index is different from IPC J-STD-003C

Methodology: all sample preparation

		For each surface finishing		
Ageing conditions		No Packaging	Anticorrosion Paper (AP)	Vacuum Sealed Bag (VSB)
Natural ageing	Initial time (T0)			
	6 months			
	9 months			
	12 months			
	18 months			
	24 months			
Multigaz	1 day			
	2 days			
	3 days			
High temperature storage	6 hrs @155°C			
	12 hrs @155°C			
Humidity accelerated test	6 hrs @85°C/85RH			
	12 hrs @85°C/85RH			
	24 hrs @85°C/85RH			
Reflow simulation	2 reflows			
	4 reflows			

5 wetting balance test coupons
5 solder spread tests coupons
for each configuration

Summary

3 years study

5 different surface finishes analyzed

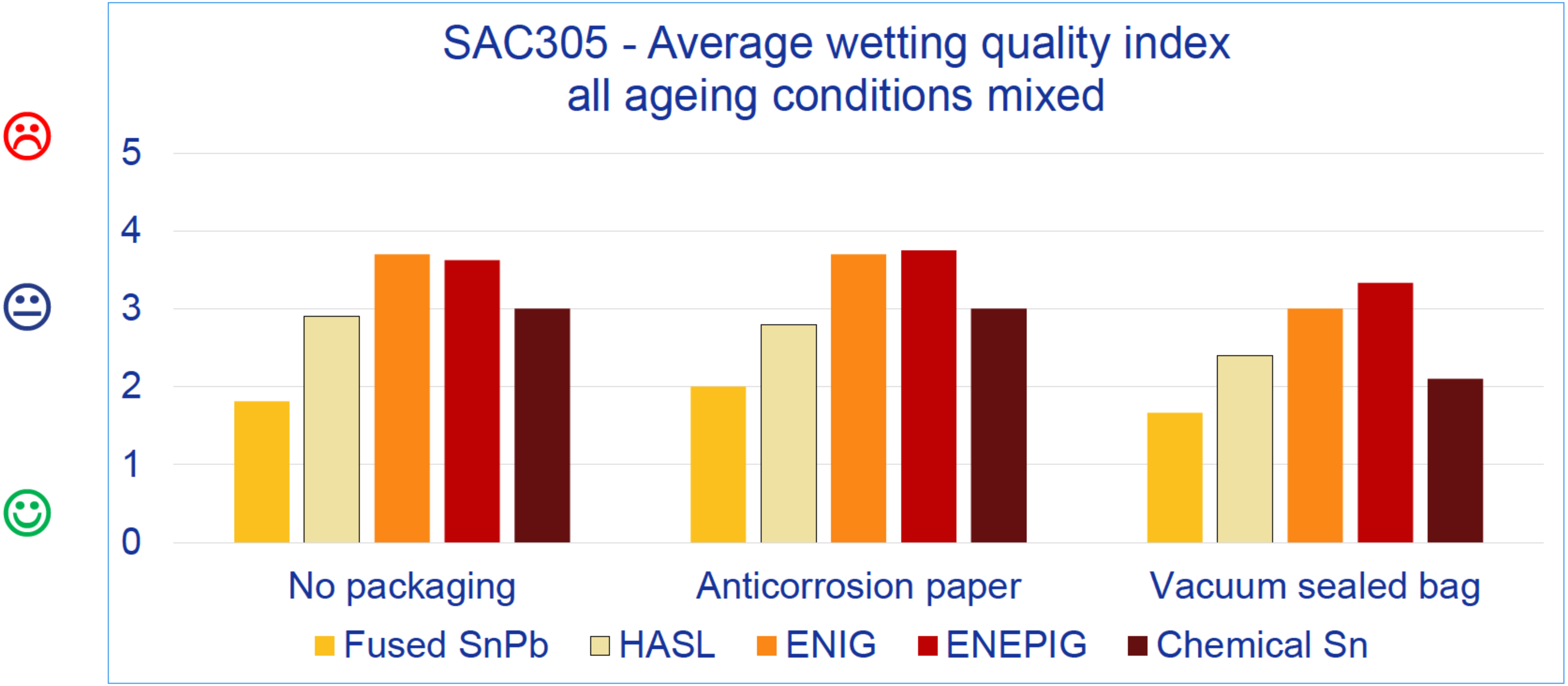
7 different manufacturers

Qualified labs and professional EMS involved

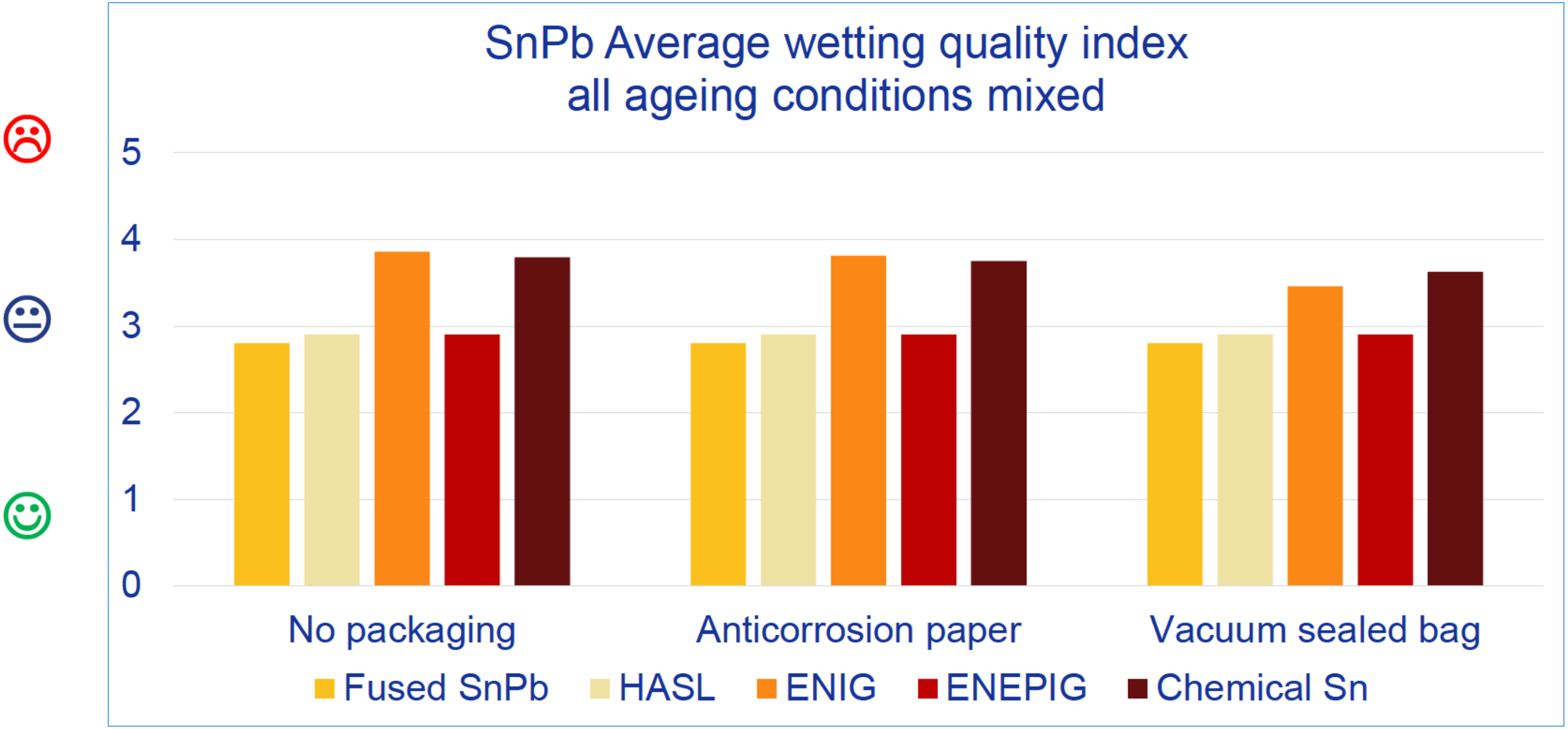
More than 5000 measurements were performed all along this study

Solderability assessed by solder spread tests and wetting angle measurement

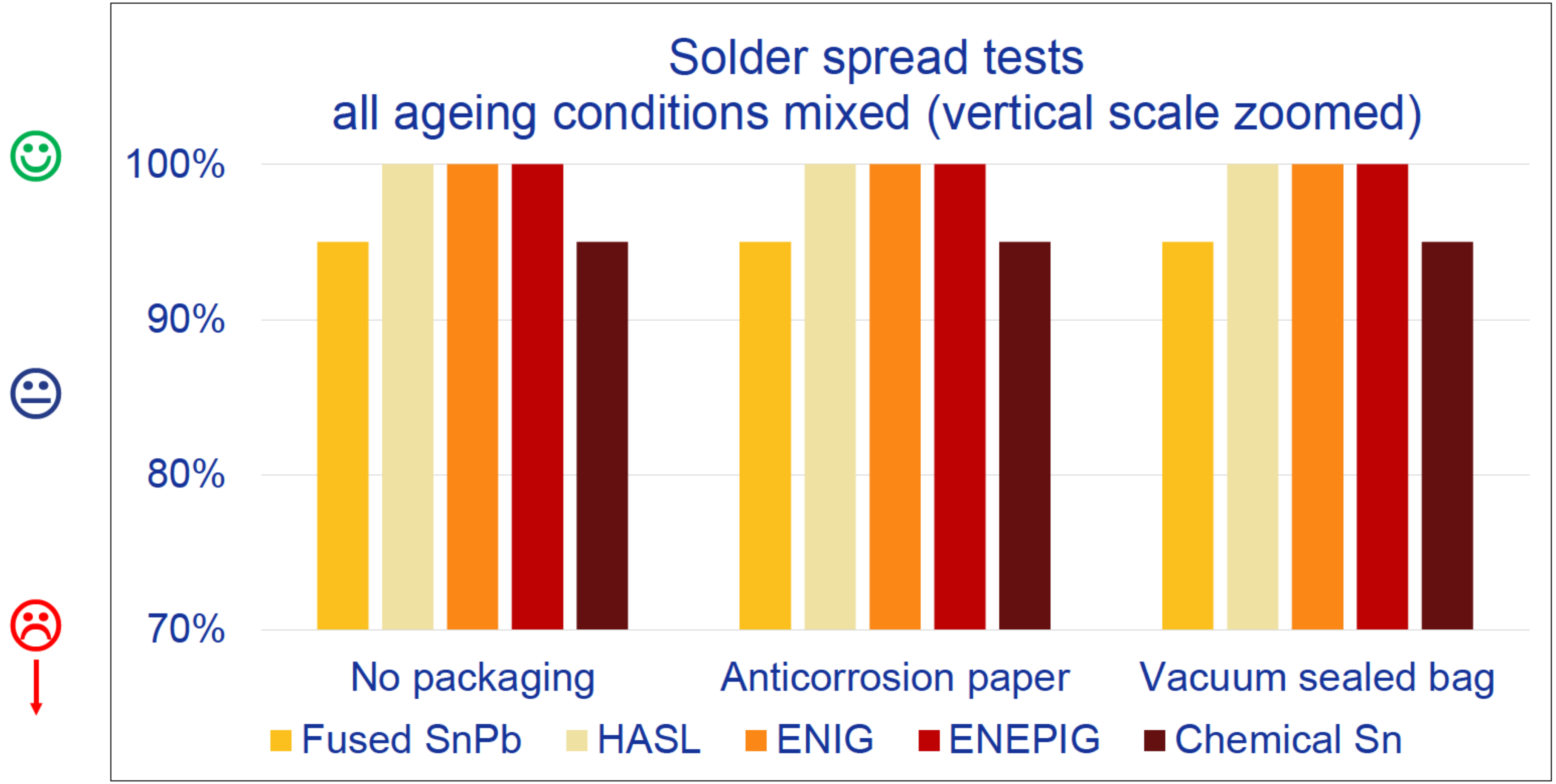
Results

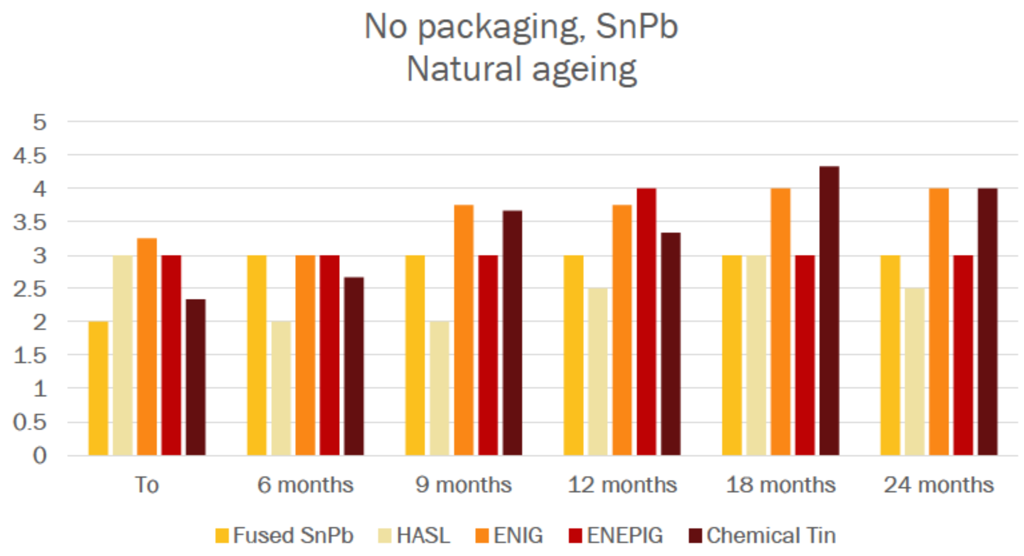

SAC305 - Average wetting quality index
all ageing conditions mixed
5
4
3
2
1
0
No packaging
Anticorrosion paper
Vacuum sealed bag
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Sn

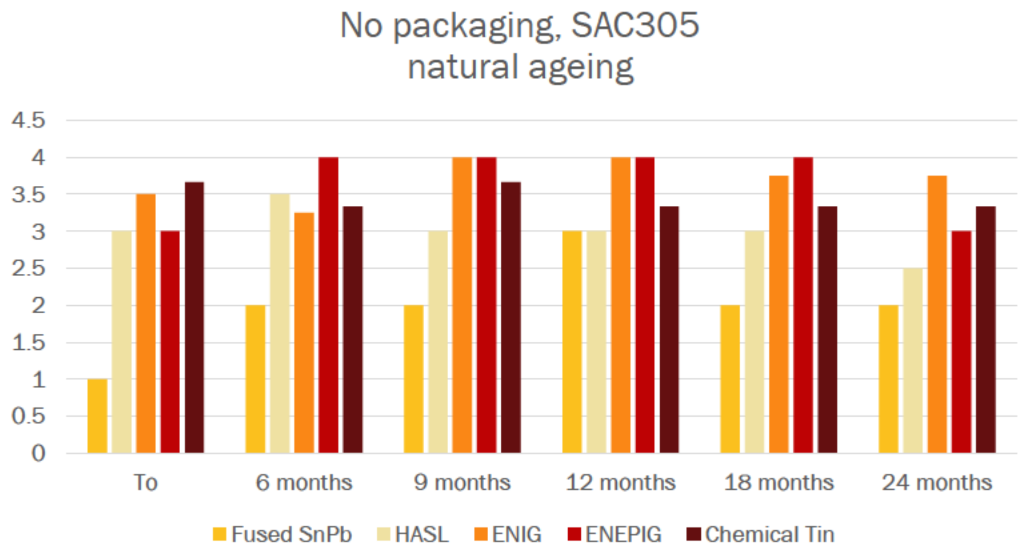
Results

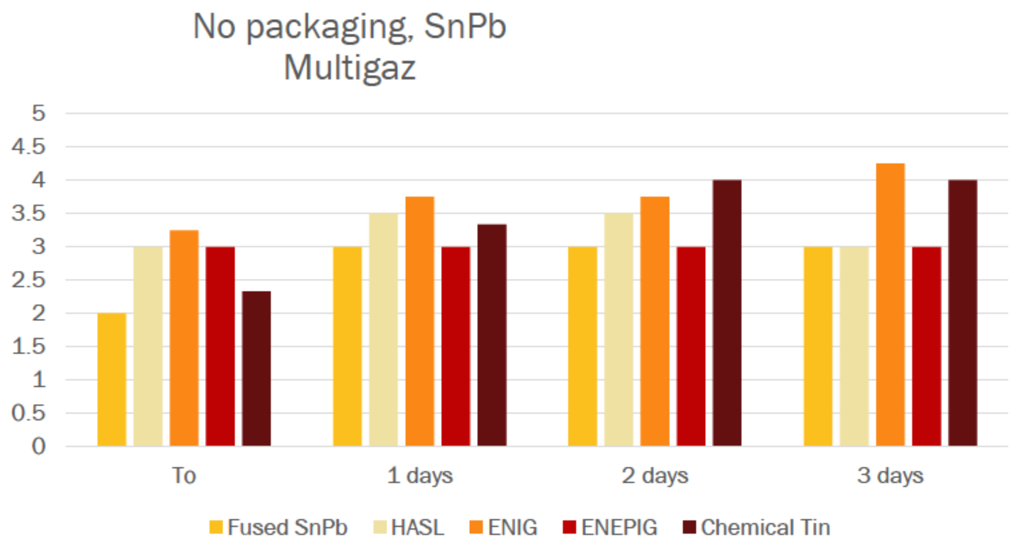

SnPb Average wetting quality index
all ageing conditions mixed
5
4
3
2
1
0
No packaging
Anticorrosion paper
Vacuum sealed bag
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Sn

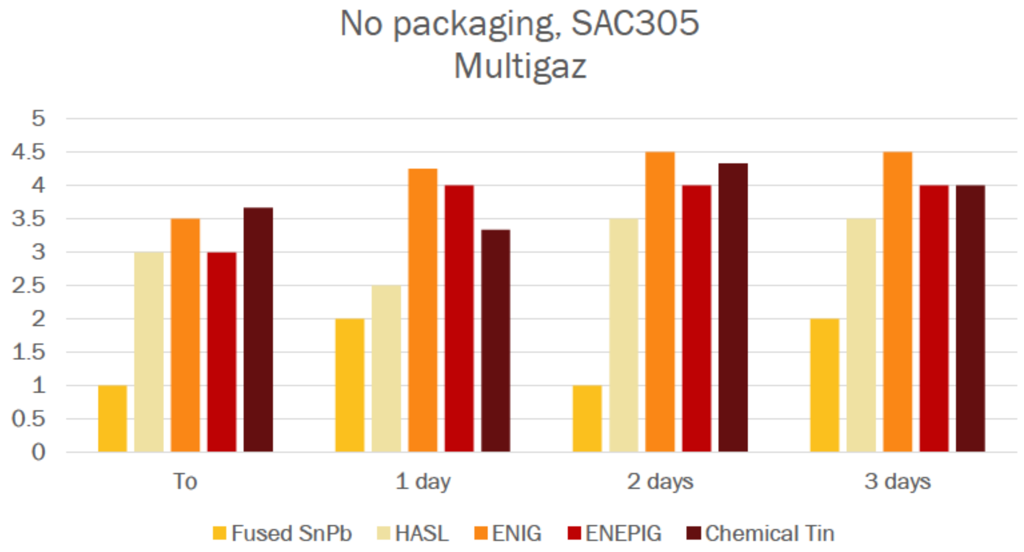
Results

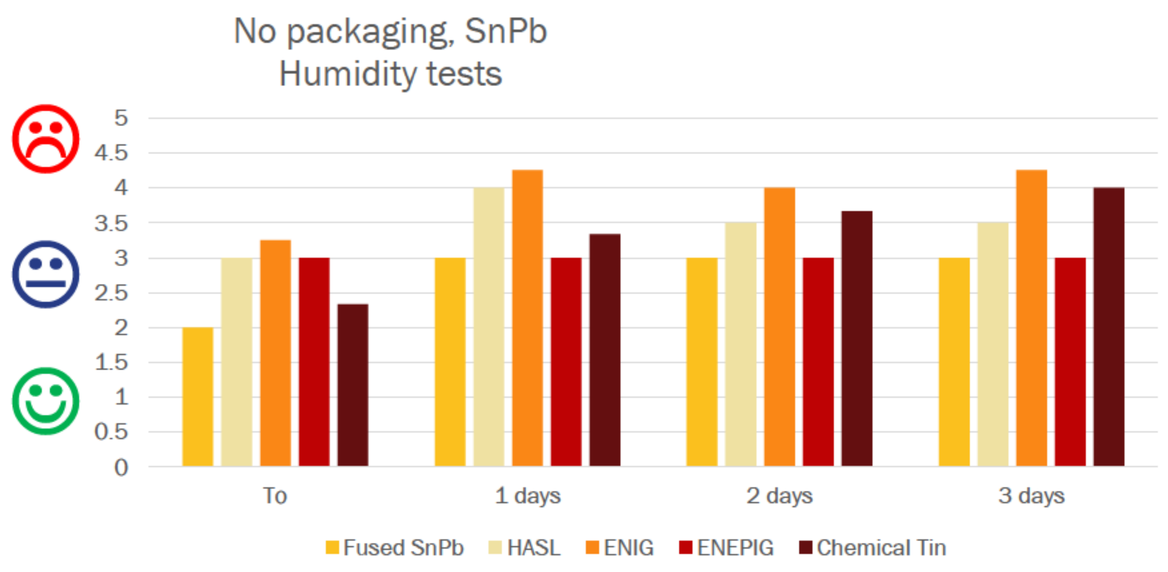

Solder spread tests
all ageing conditions mixed (vertical scale zoomed)
100%
90%
80%
70%
No packaging
Anticorrosion paper
Vacuum sealed bag
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Sn

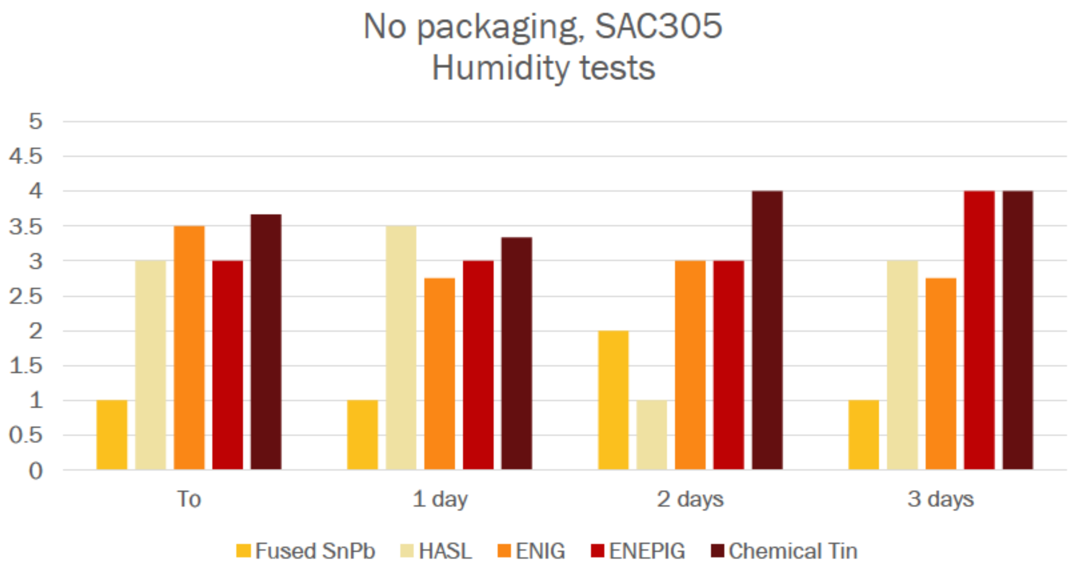

No packaging, SnPb
Natural ageing
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
6 months
9 months
12 months
18 months
24 months
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

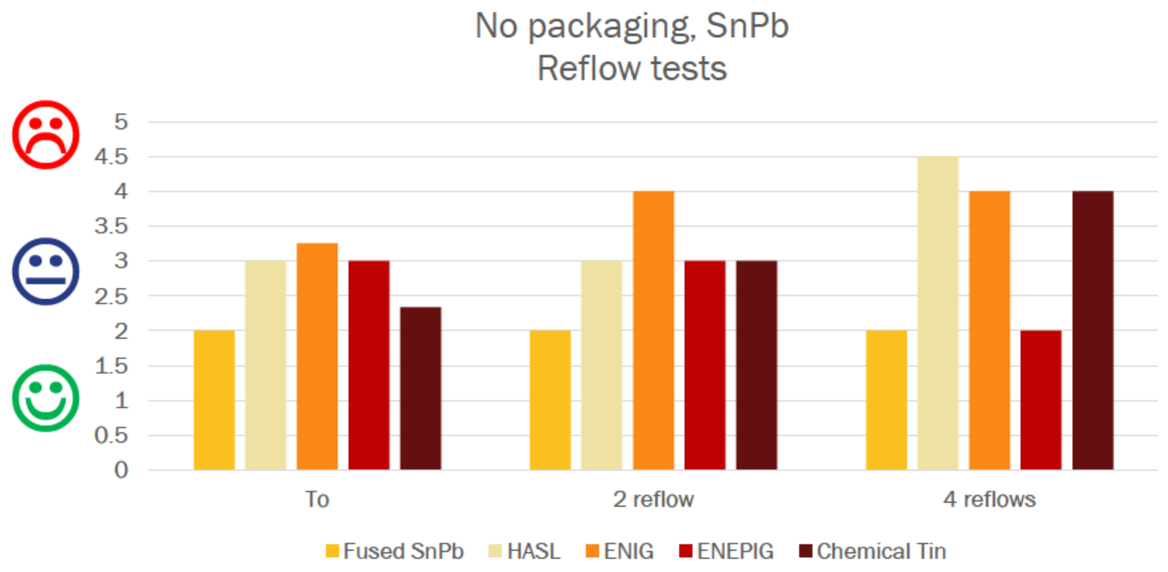

No packaging, SAC305
natural ageing
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
To
6 months
9 months
12 months
18 months
24 months
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

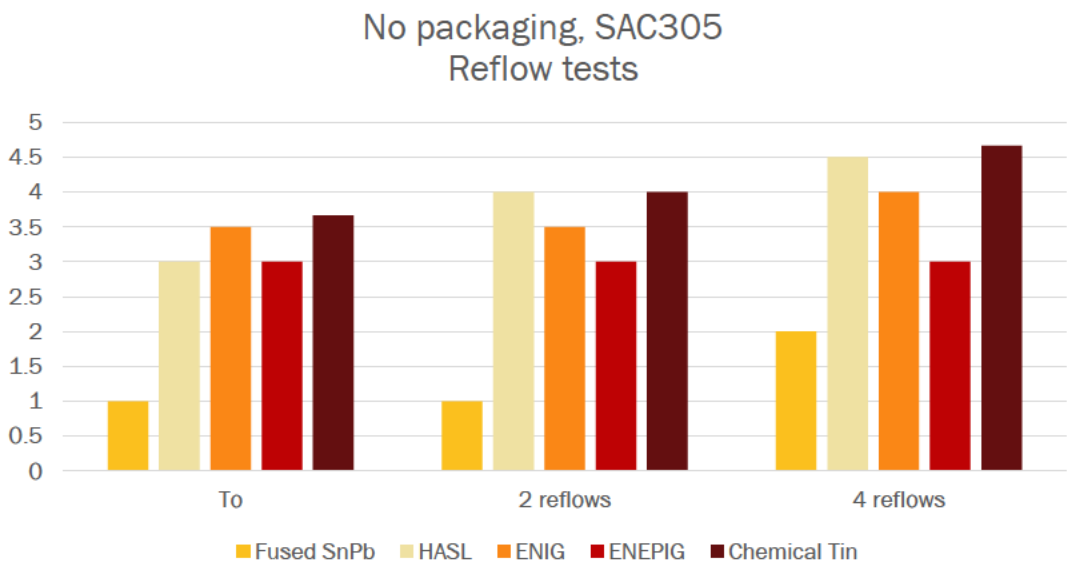

No packaging, SnPb
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

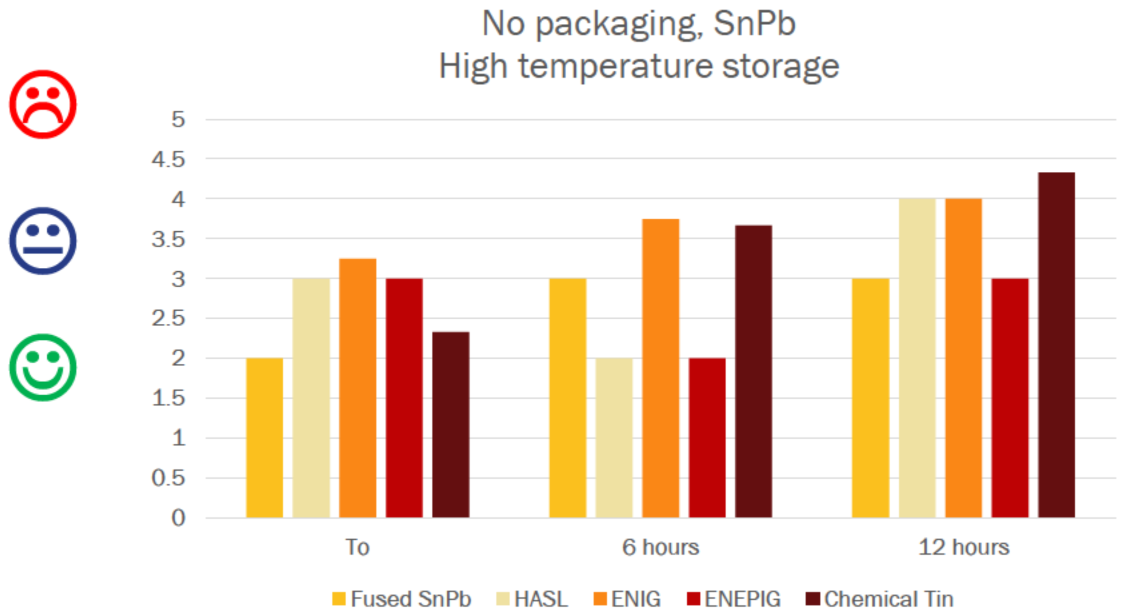

No packaging, SAC305
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 day
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

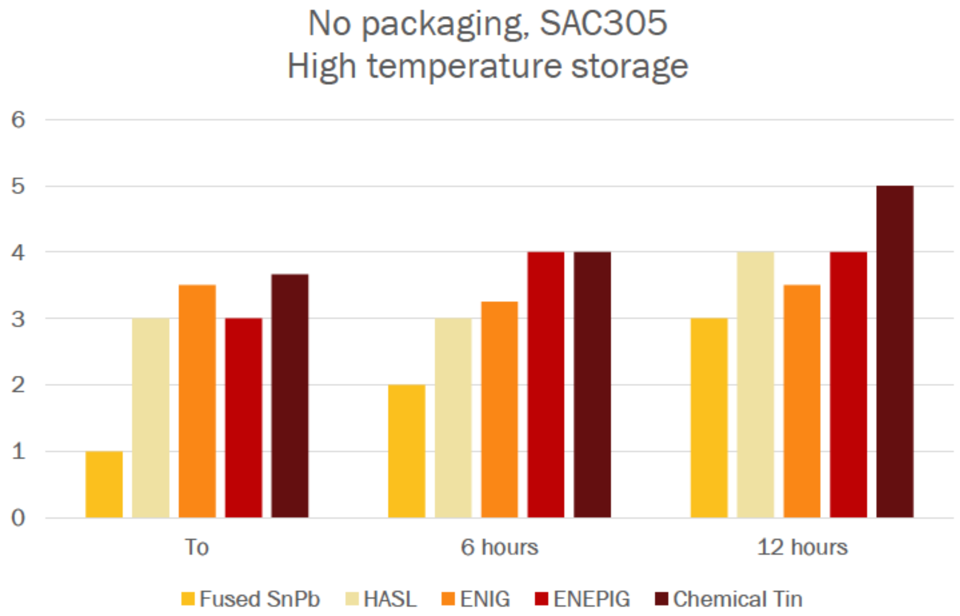

No packaging, SnPb
Humidity tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

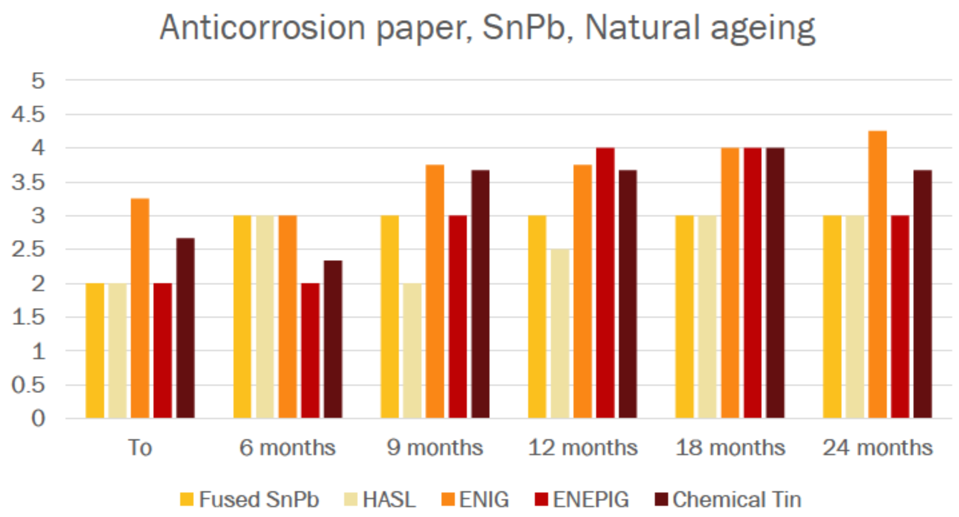

No packaging, SAC305
Humidity tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
1 day
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

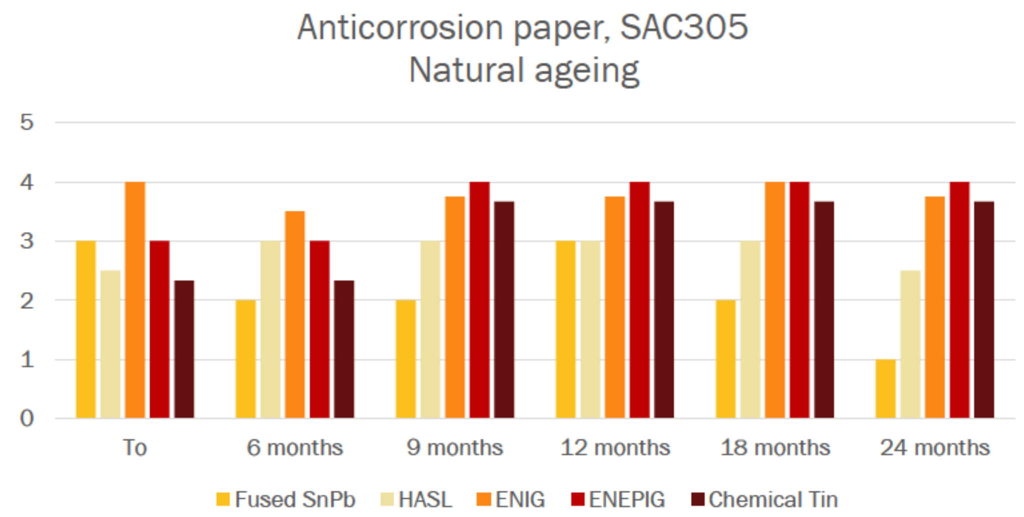

No packaging, SnPb
Reflow tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
2 reflow
4 reflows
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

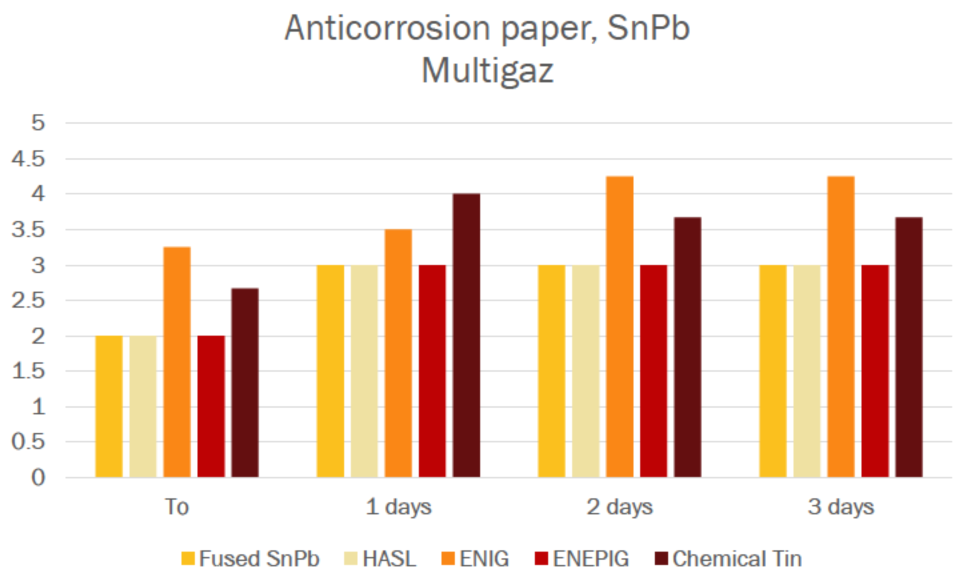

No packaging, SAC305
Reflow tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
2 reflows
4 reflows
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

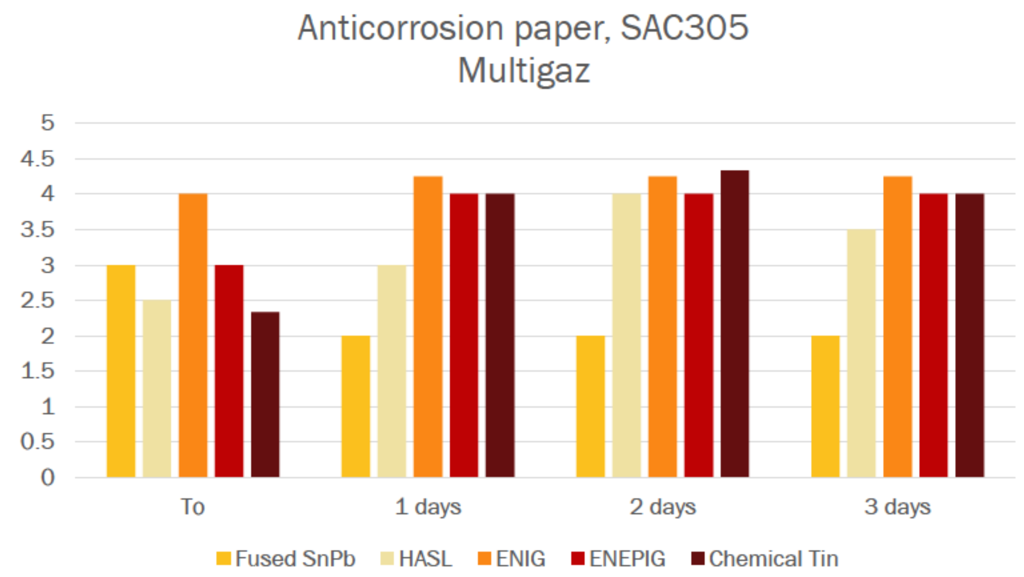

No packaging, SnPb
High temperature storage
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
6 hours
12 hours
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

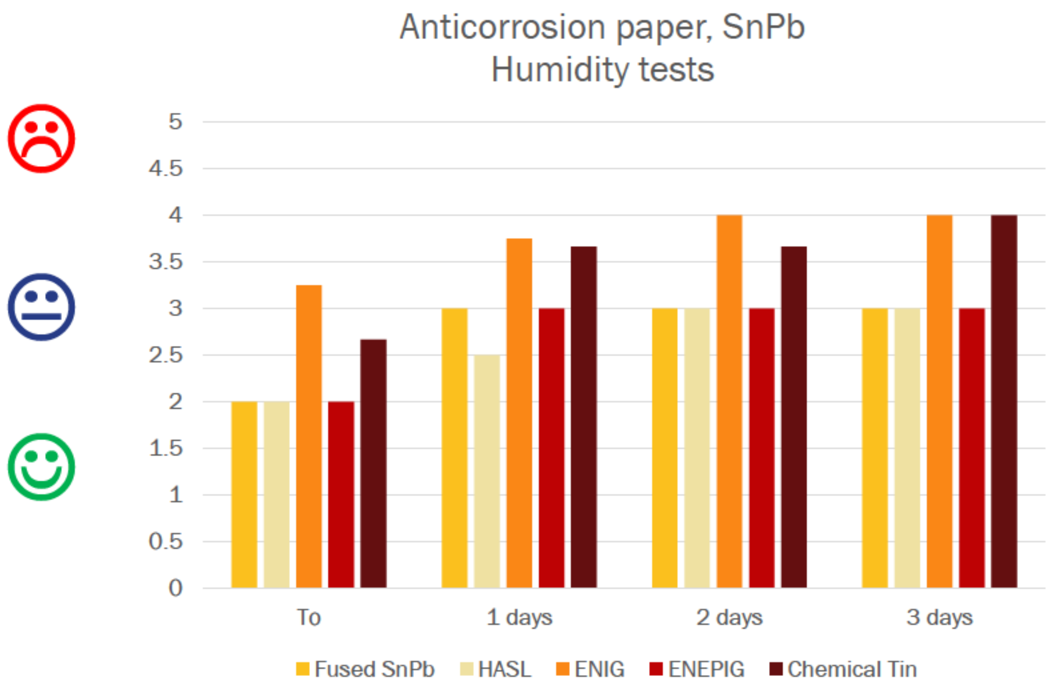

No packaging, SAC305
High temperature storage
6
5
4
3
2
1
0
To
6 hours
12 hours
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

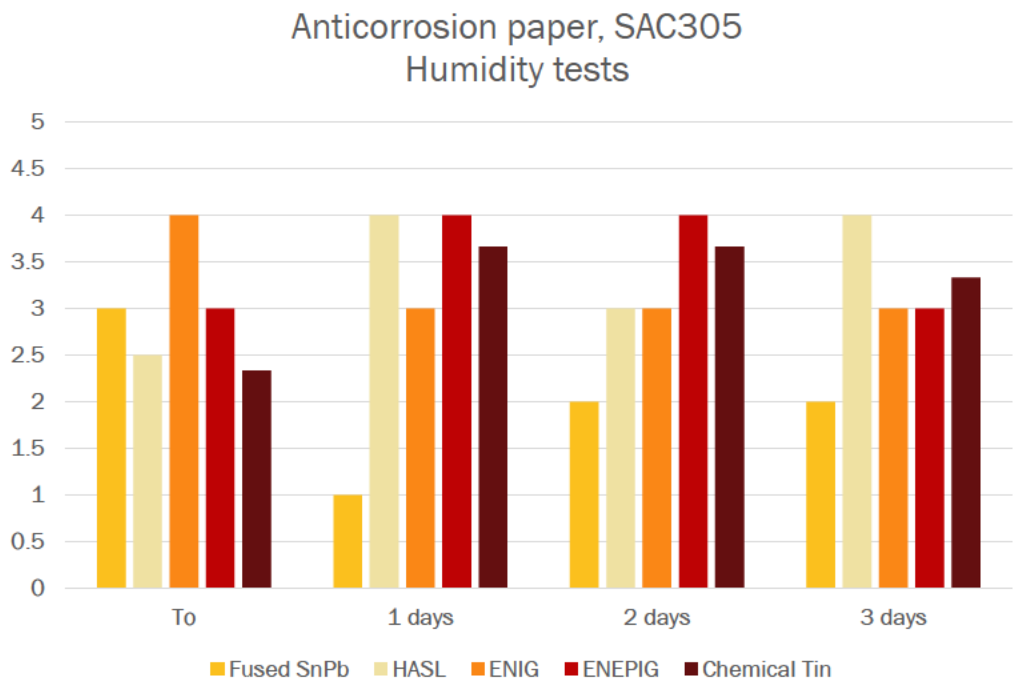

Anticorrosion paper, SnPb, Natural ageing
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
6 months
9 months
12 months
18 months
24 months
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

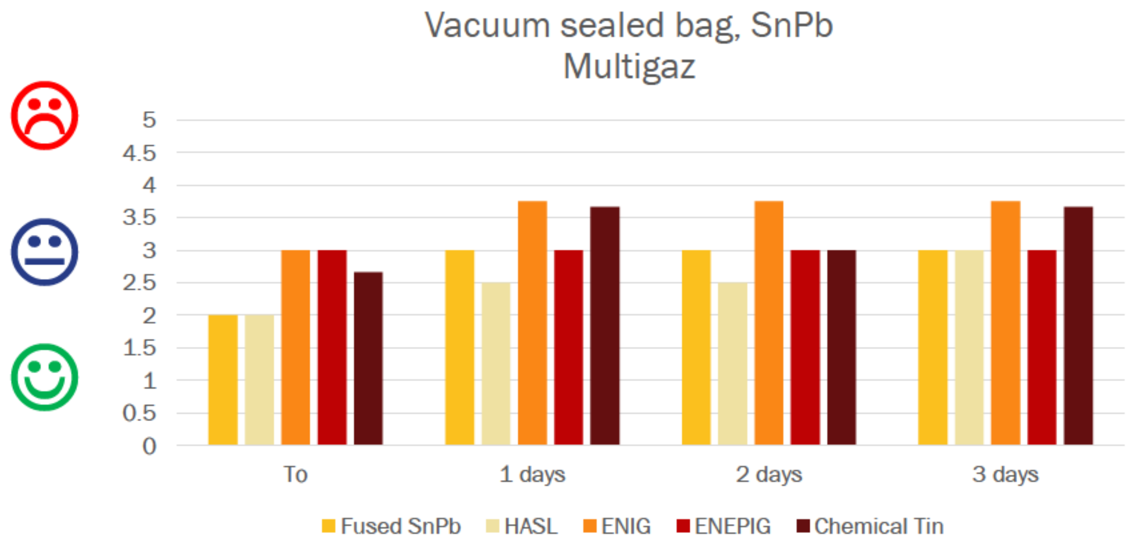

Anticorrosion paper, SAC305
Natural ageing
0
1
2
3
4
5
To
6 months
9 months
12 months
18 months
24 months
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

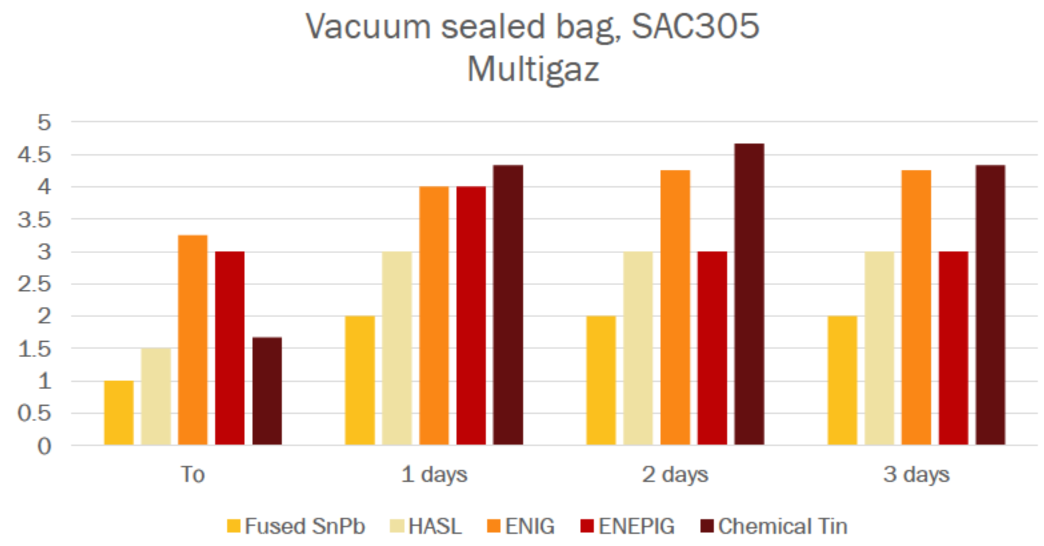

Anticorrosion paper, SnPb
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

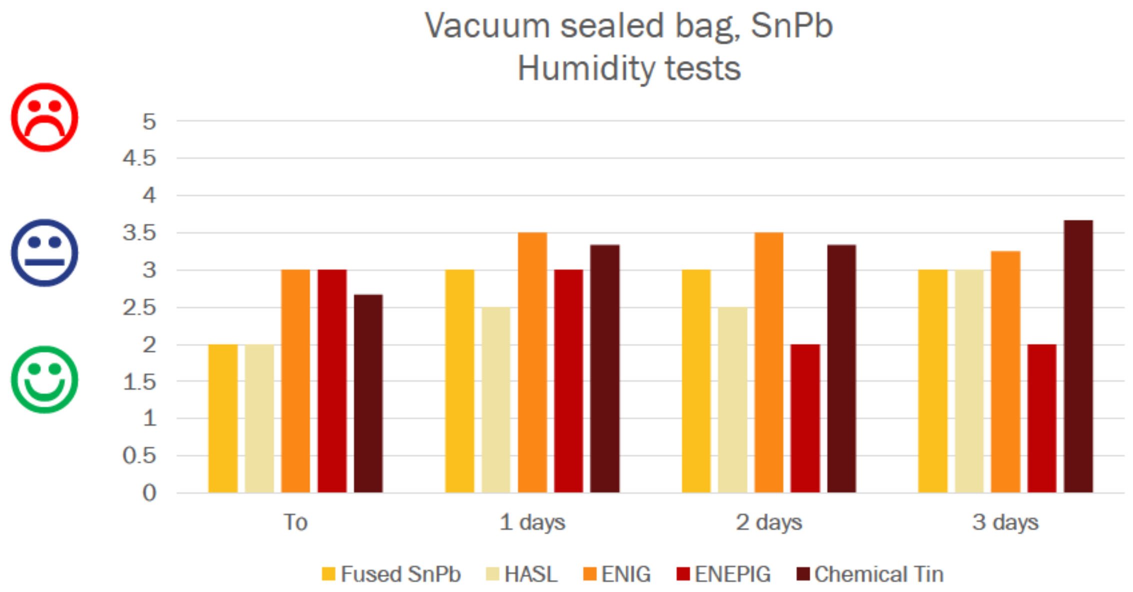

Anticorrosion paper, SAC305
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

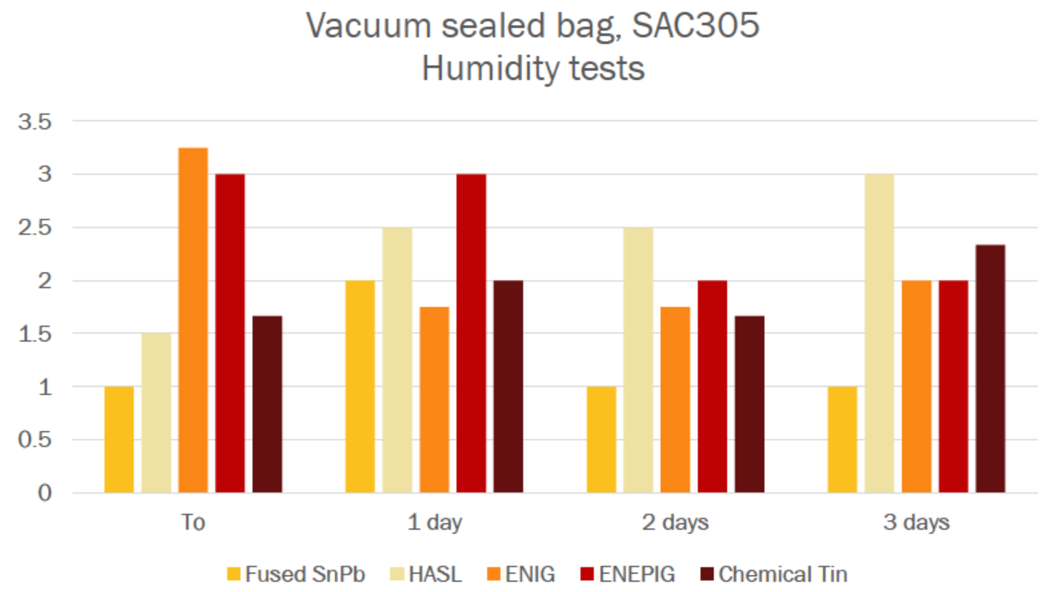

Anticorrosion paper, SnPb
Humidity tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin


Anticorrosion paper, SAC305
Humidity tests
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

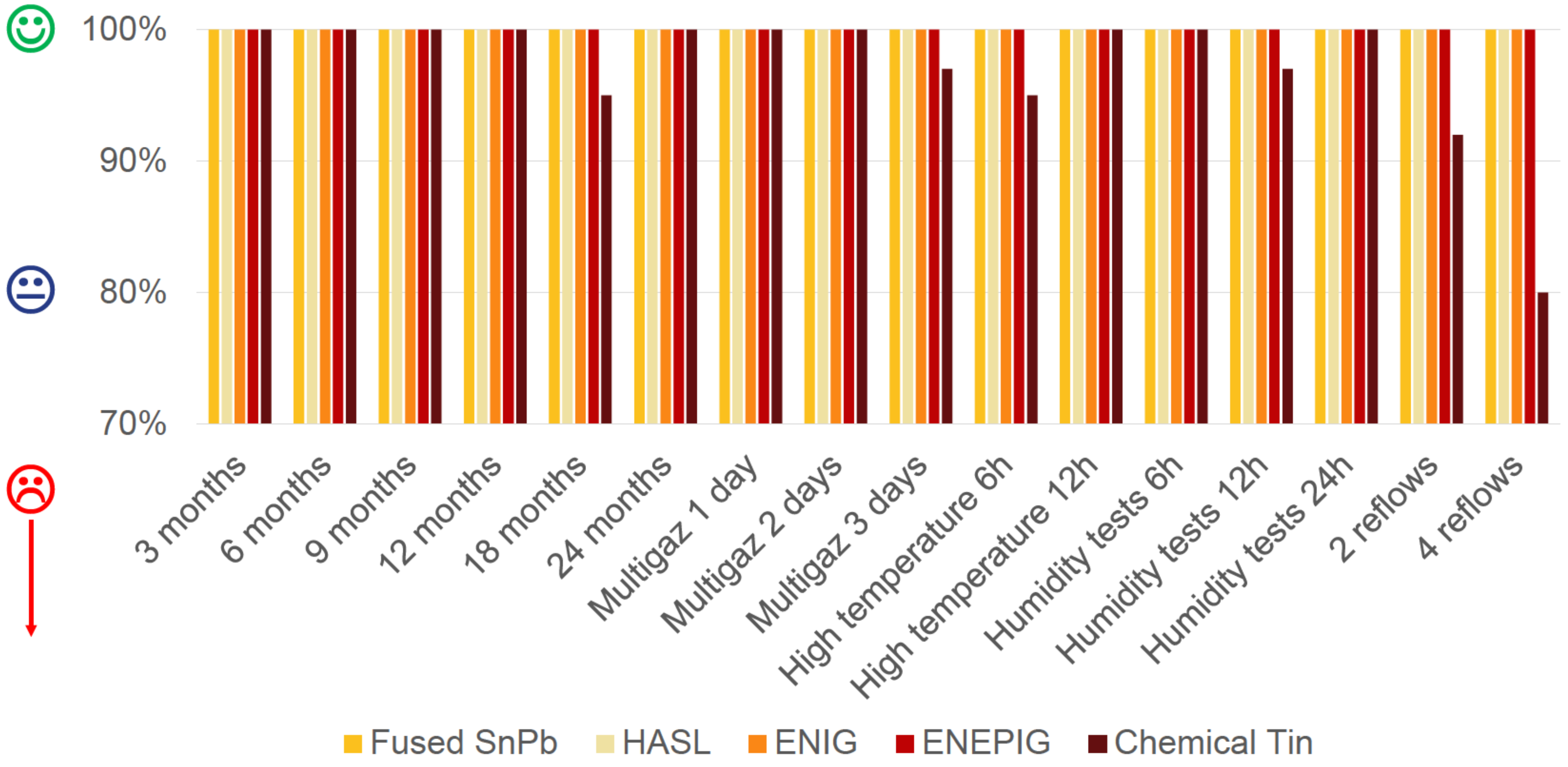

Vacuum sealed bag, SnPb
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin


Vacuum sealed bag, SAC305
Multigaz
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin


Vacuum sealed bag, SnPb
Humidity tests
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
To
1 days
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin


Vacuum sealed bag, SAC305
Humidity tests
0
0.5
1
1.5
2
2.5
3
3.5
To
1 day
2 days
3 days
Fused SnPb
HASL
ENIG
ENEPIG
Chemical Tin

Solderability assessed by reflow on assembly line
All packaging mixed, (Y axis zoomed)



Note about the flux used

J-STD 003 recommends to use ROL1 flux for wettability measurement.

This study was intentionally conducted with ROL0 flux (no clean), which is supposed to give worse results than ROL1

To confirm, a correlation has been carried out between ROL0 and ROL1 flux (more active), on two surface finishes : Chemical tin (Sn) and ENIG, after 38 months ambient storage.

Wetting balance tests were made with

SnPb solder + flux ROL0 (Flux A)

SnPb solder + flux ROL1 (Flux B)

No significant difference

Conclusions

This study is the fruition of a collaboration between a significant panel of PCB manufacturers, EMS and OEMs

A large number of dedicated test vehicles were produced, and solderability was tested against various packaging and ageing conditions

If minimum surface finish thicknesses specified in IPC standards are respected, according to the three main failure modes extensively analyzed in this study, there is currently more than a sufficient margin to **double** shelf life**,** whatever the packaging conditions, in normal storage conditions, typically : (50±20)% relative humidity, (20±5)°C temperature

Conclusions

Taking into account the results of this design of experiment

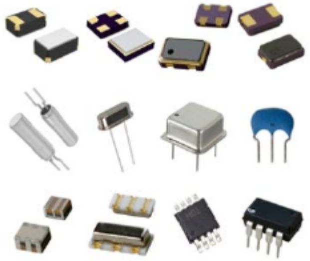
Major PCB suppliers in France and Europe agree to guaranty solderability of their boards

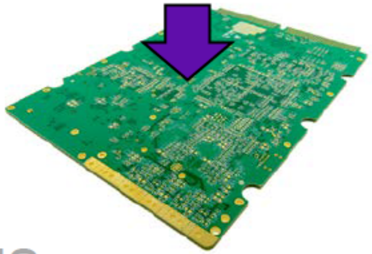
- **24** months shelf-life specification for fused SnPb, HASL, ENIG and ENEPIG
- **12** months for chemical tin

Major PCB end-users in France for high reliability applications have accepted this proposal

The entire supply-chain will benefit from these new conditions

Discussions are currently ongoing with IPC in a blue ribbon committee





Previous situation

PCB manufacturer

Shelf-life
ENIG : 12 months
Sn : 6 months

EMS

New situation

PCB manufacturer

Shelf-life
ENIG : 24 months
Sn : 12 months

EMS

Thank you

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