17

IMPLEMENTATION OF LEAD-FREE SOLDERING TECHNOLOGY

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1. Introduction

Lead is the toxic heavy metal which is well-know form the antiquity. The typical lead characteristics are very low melting point (327.5 °C), good forgaability and stainless property. Metallic lead does occur in nature, but it is rare. Lead is usually found in ore with zinc, silver and cooper, and is extracted together with these metals. Lead is ranked as one of the seventeen most hazardous chemical elements. Lead is a poisonous metal that can damage nervous system, especially in the case of young children.

Worldwide production and consumption of lead is increasing. Total annual production is about 8 million tonnes. About half is produced from recycled scrap. The USA is the leader in its production, with the 20 % of primary volume [1]. The lead is extensively used in car batteries, ammunition, high voltage power cables, etc.

2. Lead-free Soldering in Automotive Application

Although the automotive electronic industry is exempted from the RoHS directive, the effort towards lead using reduction is noticeable. There are number of reasons why to introduce lead-free technology into an automotive manufacturing process. Certainly the exemptions will fall in the future. Demand on "green product" steam from the customer requirements, which result from the worldwide environmental policy.

However, the most important reason is that the electronics industry supply chain has already specialized in the lead-free technology. Only "green" components are available from the suppliers in many cases. In despite of the considerable difficulties the change to the lead-free solder technology is unavoidable. Over 80 % of components are already lead-free and at the beginning of 2008, 90 – 95 % of all packaged devices will be "green" [2]. Extensive lead-free technology investigation and collection of information is necessary before serial production. The experimental time frame should be longer than for standard electronic devices.

Legislation

The electronics industry in Europe was faced with the implementation of lead-free technology in July 2006. From this date onwards, no new products on the market may contain lead in any quantity. However, this legislation does not cover automotive applications. The ban of lead was determined by the EU Directive 2002/95/EC RoHS (Restriction on Hazardous Substances) [3].

The automotive application is exempts from these regulations and has a regulation of its own. The relevant restriction is according to EU Directive is 2000/53/EC (End of Life Vehicle). The several exceptions from the ban of lead required by this EU Directive are listed in the Annex II 2005/673/EC. The exceptions are lead in soldering alloys, soldering finishes, lead in ceramics, etc. The limit of 60 g of lead for all the electronic components in every car may not be exceeded [4].

Technical Requirements

The particular technical requirements are the main differences between standard electronics and automotive applications. The demands on electronic equipment in cars are much higher. The electronics in a car are responsible for life saving function, e. g. airbag deployment. The need to guarantee these functions is very strong.

Additionally, the operating environment of the automotive applications is different. The temperature interval is from the minimum -40 °C to the maximum of +85 °C [5]. The continuous vibration has considerable impact on the reliability of the electronics equipment as well. The typical life time expectation of the automobile applications is 20 years.

3. Introduction of Lead-free Technology into Project

Project management is concerned with organizing and managing resources with respect to define scope, process quality, time and cost limitation. These constraints limit the project. It is not possible to affect one item without impact the other two ones.

Introduction of lead-free technology into project includes risks. Risk management is used for risks determination. Risk can be positive or negative. Positive risk is opportunity. It can leads to a profit in terms of money or technology know-how.

Risk Management for Lead-free Technology

Risk management is complex of coordinated and repeating activities to direct and control project with regard to risk. Risk management is concerned to reduce the probability of occurrence of particular risks or decrease of its influence on project.

The risk management is a process done intuitively by which an objective value is assigned to subjective risk factor. The process of risk evaluation has been standardized. Consecution of particular steps is complied. Risk action list is the outcome.

The management decision is mandatory for the red risks. These risks can include additionally investment, technology modification, customer notification or project stop. Risk action list contains 13 % of general red risks relevant to implementation of the lead-free technology.

Summary

High technical and financial risks have been found in the field of the through-hole technology. This indication leads to tendency to eliminate THT. SMT is the only one technology desired to be used. The application of purely surface mount technology allows focus on issues which are relevant to SMT.

Several types of components are available only for THT, e. g. connectors. The proper method which allows soldering of THT components on SMT line has to be established. Tests of the selected method are essential.

4. Lead-free Technology in Manufacturing

Lead-free technology for SMT can be challenging, however this challenge can be reduced if the basic changes associated with this transition are clearly understood. Both solder paste and reflow process will need to be tested and prepared for minimalization of the issues. Selection of the suitable lead-free alloy is one of the main tasks in case of implementation of lead-free technology.

Properties of SAC Alloys

As a basis for our testing results of tests, which were carried out on SAC solder alloys, have been taken. The SAC alloys differ from a lead-content alloys in numerous ways. Liquidus temperature of SAC alloys is 217 °C – 220 °C. This is about 34 °C above the melting point of eutectic Sn63Pb37 alloy. This higher melting range requires peak temperatures to achieve sufficient wetting in the range 235 °C – 245 °C. A new solder pastes flux chemistries are essential by reason of higher reflow temperature profile. Solder paste flux accounts for nearly 11.5 % of the solder paste volume [6].

Manufacturing Equipment

All samples were made on manufactured line, released for surface mount technology. Every PCB is marked by laser in the first instance due to specification of the particular PCB. Laser marking machine is not a part of SMT line. The SMT line consists of three process machines, two automatic optical inspection (AOI) equipments and one 3D control machine (Figure 1). Transport of PCB is provided by conveyors.

Figure 1 Manufacturing line for surface mounted technology

Pin-in-Paste Method

On grounds of the results, which can be gained from previous chapter, it is very profitable to avoid through-hole technology. Pin-in-paste method is combination of surface mount and through hole technology. Whole process using only the line for surface mounts technology. In the first step, the stencil for solder paste printing is applied. After that follows solder paste printing by squeegee. This is made in solder paste printing machine. Component placing by pick and place machine and reflow process by reflow soldering oven are following steps. Paste printing on pads for surface mounted components, their placing and reflow, are done during these steps too. In the end of this process, PCB is fully assembled and TH process is not required [7].

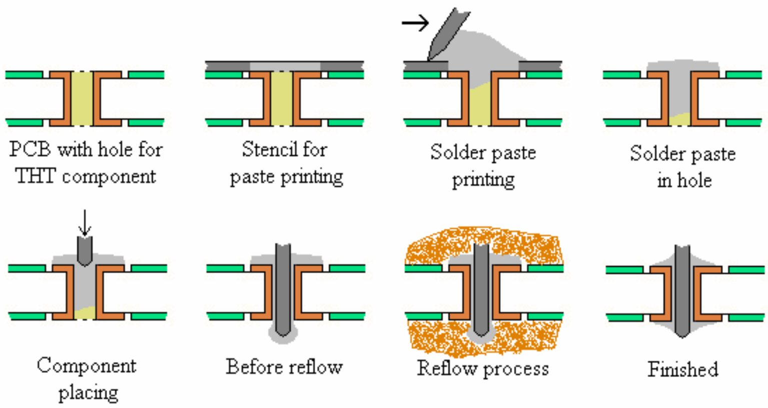

Figure 2 Pin-in-paste process

5. Experimental Investigation of Lead-free Soldering

This chapter includes quality evaluation tests of two selected lead-free solder alloys. The tests results were compared with the used lead-content solder alloy Sn62.6Pb36.8Ag0.4Sb0.2. The chemistry of the lead-free solder alloys is:

SAC A	SnAg3Cu0.5
SAC B	SnAg3.5Cu0.75

Au over Ni surface finish is compatible with the lead-free solder alloys as well as compatible with the lead-content solder alloys. The temperature profile was according to the lead-free soldering requirements. Nitrogen atmosphere was used during reflow soldering. It was measured 400 ppm of residual oxygen during atmosphere verification.

The tests evaluation was mostly based on the IPC – A – 610D standard [8]. This standard is concerned with the acceptability of electronic assemblies. This experimental investigation of the lead-free solder alloys was realized for the Class 3 products. The Class 3 includes products, where continued high performance is critical. Equipment downtime cannot be tolerated and the equipment must function when required, such as life support or other critical systems.

Visual Control

Wetting, surface characteristics and reflectiveness of the solder joints were analysed in the first control step. The spread of the flux around the lead-free solder joint is evident at the first sight. Residues are not spread uniformly, which could be caused by a too short preheating. The flux residues are at the sides of the component, which means, that the pad was not heated enough to allow the uniform spreading of the flux. The flux content of the lead-free solder alloys is 11.5 % and the flux content of the lead-content is 10 %.

Temperature Shock Test

Lead-free solder alloys typically have a higher melting temperature than eutectic SnPb. This consequent higher soldering temperature inevitably may induce some thermal damage to the components or boards. The solder joint reliability was tested by the temperature shock test. Reliability assurance after 1000 cycles is the general requirement for automotive industry. Definition of one cycle:

Temperature interval	-40 °C / +125 °C
Dwell time	30 minutes
Ramp time	10 seconds

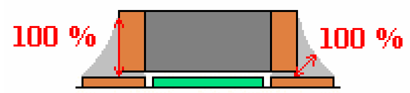

Figure 3 Solder joint crack length

Cross section and microscope analysis was used for the reliability evaluation. No complete solder joint crack is allowed to occur. Length of a solder joint crack has to be smaller than 50 % of the solder joint width.

Nearly all components showed good lead-free solder joints. The most of the solder joints fulfil the standard reliability criteria after 1000 temperature cycles. They were released to be used within a lead-free process. Three components have not matched the solder joints reliability requirements.

Voiding

Poor voiding is another shortcoming noticed by the quality evaluative tests of lead-free solder pastes. The acceptable level for class 3 is 25 % or less voiding in the solder joints, according to the IPC standard. The solder joints in the following pictures are practically comparable with the lead-content solder joints.

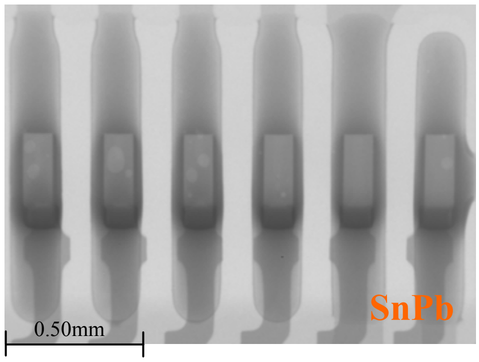

Figure 4 Voiding of the lead-content solder joints

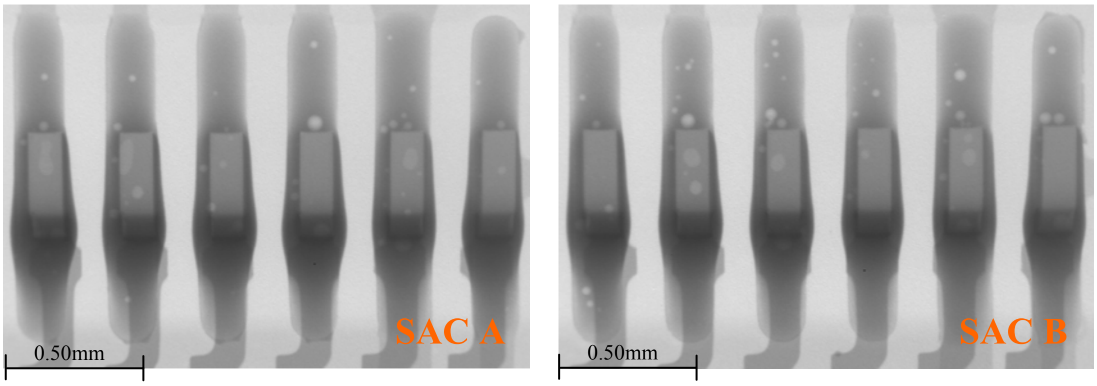

Figure 5 Voiding of the lead-free solder joints (IC)

Cross Section

The cross section is used for quality evaluation of the solder joints. It can be applied for analysis of the wetting angle, solder joint crack, fillet lifting, etc. Following figures show the cross sections of the THT components. This test was realized due to evaluation of the pin-in-paste method. The quality of the solder joints is acceptable for both lead-free solder pastes.

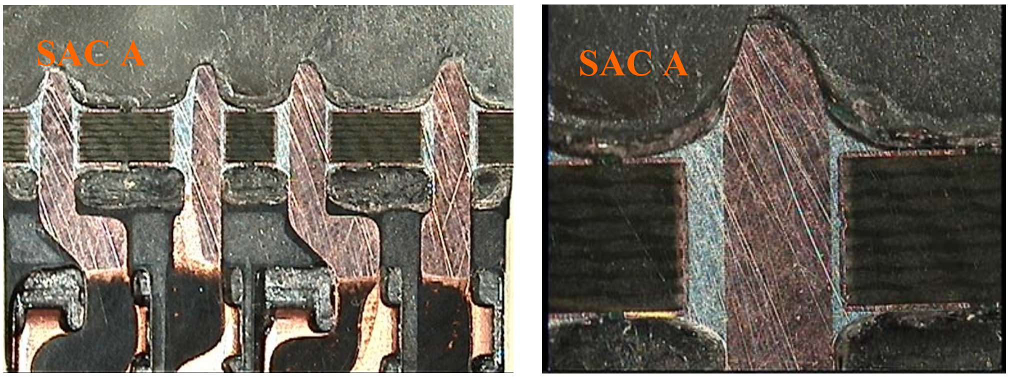

Figure 6 Lead-free solder joints (Relay – solder alloy A)

Self-Alignment

One of the finest attributes of the SMT process is its self-alignment capability arising from the high-surface-tension forces of solders. The self-alignment characteristics of the lead-free solder alloys are acceptable. The worst results were reached for the heavier components e. g. capacitor. It is necessary to design the PCB pads with respect to this property. The pads for these components have to be bigger.

Surface and Chemical Analysis

The surface and chemical analysis were made for detailed evaluation of the solder joint surface characteristics and for chemistry analyses of the solder joints.

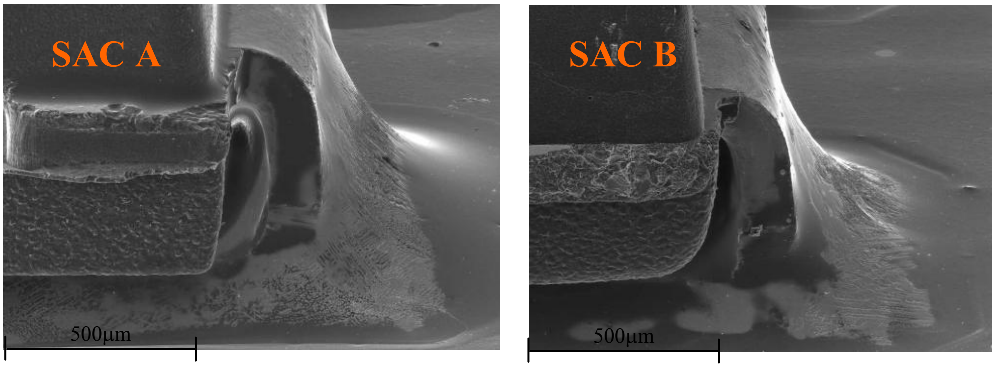

Figure 7 Detail of the wetting angle

6. Conclusion and Future Recommendations

This thesis has presented problems and solutions joined with implementation of lead-free soldering in process of electronics assembly. Main consideration gave attention to the special requirements of the automotive industry. Worldwide, no effective legal restrictions exist today, that claim the ban of lead for automotive electronics. But the change can be expected in the future.

Generally, the lead-free soldering technology is used by customer request only. Worldwide effort to environment friendly electronics exerts pressure on the automotive manufacturers too. It results in more frequent lead-free soldering technology implementation in this branch. For new projects, the consequences of a lead-free design have to be discussed and harmonized with the customer in a careful manner. The switch to lead-free technology causes additional expenses and additional quality risks.

Experimental investigation of lead-free soldering is fundamental. The reliability of the solder joints and manufacturing capability can be evaluated by the carefully selected set of the tests in accordance with standards. Obviously, it is not easy to replace the know-how collected in more than 80 years of real life soldering experience with lead-content electronic circuits.

In the case of the self-alignment test it is possible to declare, that the lead-free solder alloys showed identical characteristics as the lead-content solder alloy. The solder joint chemical analyses are according to the technical specification. In the case of the lead-free solder joints, there is considerable occurrence of the dendrite surface structure.

As a future recommendation concerning the experiments I would state the necessary of following temperature shock test of the unsatisfactory components and the second solder alloy. Additionally, it is recommended to focus on the influence of the temperature profile setting in the case of the surface solder joints quality. The following function tests will point out the issues, which cannot be detected by the quality tests.

It is necessary to pay attention to the defects, which are detected during the samples manufacturing. Careful causation analysis should prevent from the issues. These experiences would answer to future questions, which will appear with the following manufacturing expansion.

7. References

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