LIFE05 ENV/F/000053
AMELIE

RELIABILITY AND INDUSTRIALISATION OF PROCESSES AND EQUIPMENT IN ELECTRONIC ASSEMBLY. COMPLIANCE WITH "WEEE" & "ROHS" EUROPEAN DIRECTIVES

LAYMAN'S REPORT

RoHS
2002/95/EC

Summary of project scope and objectives

An electronic board is the result of assembling components on a printed circuit board, using solder paste. The assembly is placed in an oven (reflow oven) where the solder paste is melted to form a metallic bond between the component and the circuit board. Analysis of boards shows that lead is present everywhere from the finish of the printed circuit board and the pins to the solder alloy. In some cases, the component itself contains lead. For a long time the eutectic alloy $Sn_{63}Pb_{37}$ has been the current solder used in assembling electronic components. It should be remembered that it has taken several decades for assembly processes using the eutectic alloy $Sn_{63}Pb_{37}$ to become reliable.

The RoHS and WEEE European directives have been set up to limit the content of some hazardous substances in electronic assembly:

- Lead (0.1%)
- Mercury (0.1%)
- Hexavalent Chromium (0.1%)
- Cadmium (0.01%)
- Polybrominated Biphenyls (PBB) (0.1%)
- Polybrominated Diphenyl Ethers (PBDE) (0.1%)

To meet RoHS and WEEE compliance, companies have until July, 2006 to remove these substances from the products they sell in Europe. Certain industries, such as medical and defence, are exempt from RoHS compliance by the July 2006 deadline up to 2010. Nevertheless these industries have to anticipate the switchover to lead-free products. The "lead-free assembly project" study carried out in 1999 in the USA by the NEMI (National Electronics Manufacturing Initiative) recommends use of the alloy $Sn_{95.5}Ag_{3,9}Cu_{0.6}$ for the solder re-flow method, the alloys $Sn_{99.3}Cu_{0.7}$ and $Sn_{96.5}Ag_{3.5}$ for wave soldering and Sn/Cu and Sn/Ag alloys for finishing components. Alloys therefore exist on the market today to replace $Sn_{63}Pb_{37}$. Many studies have been done throughout the world to demonstrate the feasibility and reliability of lead-free soldering but as yet there is neither "turnkey" solution nor feedback experience for highly reliable lead-free products. The alloys proposed all differ from the alloy $Sn_{63}Pb_{37}$ in their melting points, their mechanical properties, their wetting ability and their appearance. Most lead-free alloys have a melting point above 200°C, which is appreciably different from the melting point of the standard $Sn_{63}Pb_{37}$ alloy at 183°C. This difference requires a solder temperature range greater than that presently used. This is the case with ternary alloys (Sn/Ag/Cu) whose eutectic re-flow temperature is 217°C. The soldering temperature therefore needs to be raised by some 34°C. It will thus be necessary to study the impact of this temperature variation on the components and printed circuit boards. Similarly, it will be important to assess how far this substitution affects the present assembly processes (screen printing, re-flow soldering and wave soldering in particular). Finally, any solutions may have an impact on the waste treatment and recycling industries. In this context the main objectives of the AMELIE project were:

- to contribute to the design, the development and the validation of innovative lead-free industrial assembly lines and demonstrators integrating the whole electronic supply chain (printed circuit boards, passive components, plastic packaging, surface mounted devices assembly, wave soldering and manual soldering),

- to study the reliability of new lead-free alloys in compliance with the "Reduction of Hazardous Substances" (RoHS) and "Waste of Electrical and Electronic Equipment (WEEE) European Directives,
- to promote the dissemination of the knowledge from the AMELIE consortium to small and medium-sized companies and public institutions.

The added value of the AMELIE consortium is to bring together industrial partners from the whole electronic supply chain (including SME and large groups) to collaborate around the RoHS and WEE directives. In this context a global and common industrial approach will be used to tackle several assembly processes (from passive components, plastic connectors, printed circuit boards to functional demonstrators).

Description of the techniques/methodology implemented and the results achieved

The AMELIE project was implemented on a pilot and pre-industrial scale which permit evaluation of technical and economic viability of large scale introduction of high reliable products. Technical development and optimisation of test vehicles was the core of the project. The aim was to evaluate the reliability of lead-free materials and assembly processes put into play in the test vehicles and subjected to thermomechanical and/or climatic stresses for aeronautic environments. Industrial options have been taken on the choice and development of components and related finishing for future lead-free production. In terms of environmental benefits, all technical developments comply with the RoHS and WEEE directives.
The RoHS assembly process requires that none of the hazardous materials listed in the RoHS Directive are used in the printed circuit board, components or solder.

CHANGES REQUIRED

Printed Circuit Board: The substrate and board finish used on lead-free boards need to be different than for circuit boards using lead. Bare circuit boards used in the typical "leaded process" are often coated with a lead-tin finish, so the finish on the board must be modified significantly to be compliant with lead-free and RoHS standards. Lead-free processes also require that boards be assembled at higher temperatures—usually 30-50 degrees C higher. The higher temperature may require that the substrate of the circuit board be modified to withstand the higher temperatures in the oven.

In the frame of the project two dielectric materials have been studied: Polyimide (ARLON 35N) and FR4 High Tg. The major technical development was focused on the implementation and qualification of Immersion tin finish. The qualification process lasted more than one year. Many items have been checked:

- Qualification of the finish on several board technologies (different types of laminates, solder masks, design…).
- Qualification of the finish on current and lead-free assembly processes
- Impact of the process on waste treatment

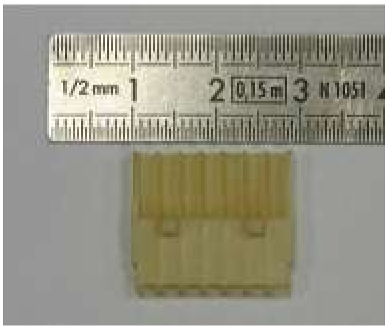
- Additional finishes have also been implemented and evaluated like Nickel/Gold coating and silver coating.

Equipment for Ni/Au finish cleaning located at SGCI (subsidiary of CIRE)

Components: Components have to meet RoHS standards and do not contain any of the banned substances. It is also more than just the lead and other banned substances. The components must also be able to withstand the higher temperatures required in manufacturing. Most standard components will be fine, but some will not be able to survive the extra 50 degrees C required in particular those using plastics like connectors. The terminations of components have also to be reconsidered as some terminations are not compatible with lead-free solder alloys.

Plastic for connectors

In the frame of the project plastic for connectors have been studied. The first part of the technical development was focused on the development of polymer mixtures as alternative materials but these materials do not show significant improvement in their thermo-mechanical behaviour. The second part of the technical development was focused on the use of crystalline Poly Ethylene Terephtalate (PET) because crystalline PET is an interesting way to substitute existing materials. Its cost is even lower than the material used today for connectors and recycled PET can be used. The crystallisation of PET requires specific injection conditions with a high mould temperature and technological development are required to manufacture connectors at the industrial scale. The PET specimens manufactured during the project have been shown to withstand the higher temperature required for lead-free soldering.



Plastic connector

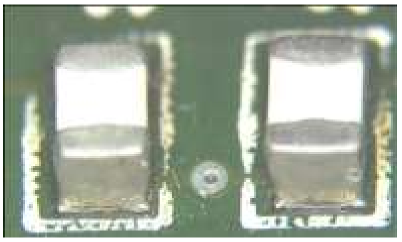
Passive components

Electrolytic process has been developed to produce passive components with tin terminations. The aim was to assess and compare the behaviour of these components with components non RoHS compliant (tin/lead terminations). The technical development consists of:

1) Qualification of the electrolytic plating process (tin bath)
2) Determination of the plating thicknesses in accordance with the increase of the Lead-Free reporting temperature.
3) Evaluation of the plating deposits
4) Qualification of the lead-free passive components

Electrolytic plating process line implemented at TEMEX CERAMICS

An electrolytic copper barrier termination has been developed to replace Silver/Palladium termination on passive components as it has been shown that this termination was not compatible with lead-free assembly processes.

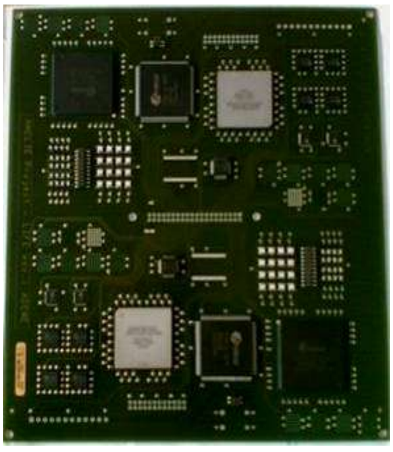


Ceramic capacitors

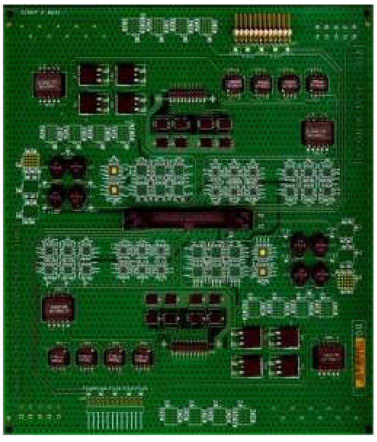
Solder: A lead-free compatible solder paste alloy has to be used.

The SAC305 (Sn3.0Ag0.5Cu) and SAC 405 (Sn4.0Ag0.5Cu) solder alloys have been used in surface mount technology, Wave Solder and Wire (Hand) soldering processes and compared with SnPb solder alloy.

Assembly process:
Two test vehicles have been defined taking into account the definitions and the identifications of the partners needs to study the reliability of lead-free assemblies. A total of 134 boards have been assembled. All boards have been produced for evaluation phase and introduced in thermal cycles, storage and humidity.



Test vehicle n°1



Test vehicle n°2

The Table 1 shows all the subjects dedicated to the test vehicle n°1:

Name	Finish	Solder paste alloy	Components	Solder wave alloy	Rework
VTP_SnPb_SnPb_WSnPb	SnPb reflowed	SnPb	None RoHS	SnPb	NO
VTP_Backward_WSnPb	SnPb reflowed	SnPb	RoHS	SnPb	NO
VTP_405_ENIG_W305	Ni/Au	SAC405	RoHS	SAC305	NO
VTP_405_Sn_W305	Sn chemical	SAC405	RoHS	SAC305	NO
VTP_405_ENIG_W305_R	Ni/Au	SAC405	RoHS	SAC305	YES
VTP_405_Sn_W305_R	Sn chemical	SAC405	RoHS	SAC305	YES
VTP_305_ENIG_W305	Ni/Au	SAC305	RoHS	SAC305	NO

Table 1 : VT-P subjects

The Table 2 shows all the subjects dedicated to the test vehicle n°2:

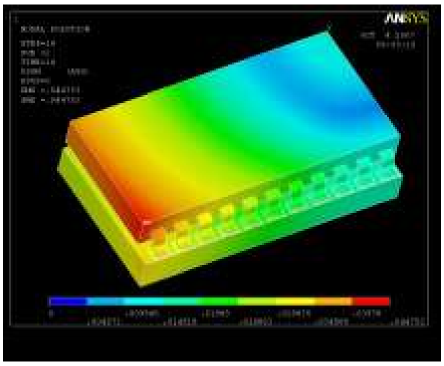
Name	Finish	Solder paste alloy	Components	Solder wave alloy	Rework
VTF_SnPb_ENIG_WSnPb	SnPb reflowed	SnPb	None RoHS	SnPb	NO
VTF_405_ENIG_W305	Ni/Au	SAC405	RoHS	SAC305	NO
VTF_405_Sn_W305	Sn chemical	SAC405	RoHS	SAC305	NO
VTF_305_ENIG_W305	Ni/Au	SAC305	RoHS	SAC305	NO

Table 2 : VT-F subjects

The main conclusions of the evaluation phase are:

- Standard components have been proved to withstand the standard validation according to end users requirements for devices used in military and aeronautic environment;
- For most of the configurations the reliability of lead-free assemblies is better than the reliability of leaded assemblies. Some caution should be considered as this tendency may be reversed in some cases due to a combined effect of different parameters: e.g. combination of dielectric material and stresses induced by thermal expansion;
- Backward assemblies and particularly mixed lead/lead-free solder joints are of high reliability when the assembly process is well mastered;
- The content of Silver in solder joint doesn't seem to affect the reliability of solder joint;
- The finishing of the printed circuit board (Nickel/Gold or Sn) has no influence on reliability;
- The process (reflow soldering or repair) has no influence on reliability;

Models for calculating the actual field lifetime of Pb-free solder joints on certain component types have been developed and validated using actual test data (from this project). These models are used to verify that electronics made with Pb-free solders will survive for the required lifetime in their use environments.



The accuracy of modelling depends strongly on the material properties knowledge. Mechanical tests have been performed to determine solder alloys properties. More than 150 samples of solder alloys have been produced for characterisation.

The next step was system-level demonstration/validation of promising lead-free solutions on functional aerospace and defence electronic demonstrators. This step validates the entire lead-free assemblies in an operational environment. Two functional lead-free demonstrators have been designed, manufactured and assembled in line with the chosen strategies. These demonstrators have undergone environmental testing specific to their respective fields of application, enabling qualification of the best technical concepts and chosen strategies. The demonstration took into account the whole electronic supply chain from purchasing activities to the implementation of a lead-free industrial assembly line and the management of the with/without lead mix.

GAIA CONVERTER demonstrator
(High reliability power converter)

THALES SA demonstrator
(Electronic board used in military aircraft)

To demonstrate the quality level and reliability of these two demonstrators that have unique application and are deployed into a harsh operating environment a customized test program that properly demonstrates and evaluates electronic components has been defined.

Tests carried out on GAIA CONVERTER demonstrators have shown that the RoHS assembly process is well controlled and is equivalent in term of reliability to the SnPb assembly process. Thermo mechanical stresses induced by thermal cycling revealed that ageing is more pronounced for RoHS assembly but there is no consequence on functional behaviour of demonstrators. Up to 1 500 cycles of thermal cycling functional behaviour is the same for RoHS and non RoHS demonstrators. This behaviour fulfils the more stringent customer acceptance level which is set at 1 000 cycles for this type of product.

THALES SA RoHS demonstrators have been qualified in term of robustness in mechanical conditions (vibration and shock). Thermo mechanical cycling has highlighted the weakness of a specific component and as a consequence the RoHS demonstrator does not pass the qualification threshold.

The lower reliability of the lead-free assemblies shown in some tests does not necessarily rule out the use of lead-free solder alloy on aerospace and defence electronics in some use environments. The results of this project should be used with other industry data as part of a comprehensive data set when considering lead-free solder process implementation.

Dissemination of project results

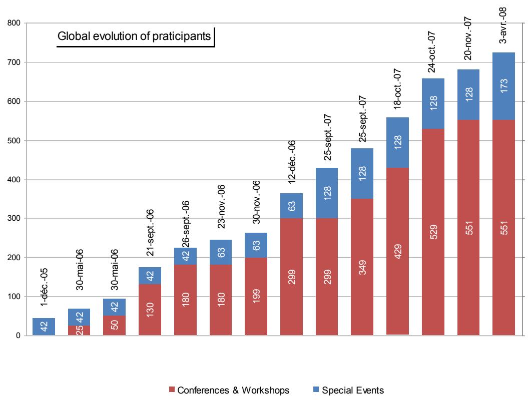
In the frame of dissemination activities a project website has been created and is available at the following address: www.life-amelie.info. The main deliverables of the project are available on this web site

Four special events have been organized by the AMELIE partners with a total of 173 attendees. The first Special Event took place on December 1, 2005 in Bordeaux in the frame of "Forum de l'Electronique Aquitain". The second special Event took place on November 23, 2006 in Bordeaux joining together a score of person in charge of electronic companies from Aquitaine Region. The third Special Event took place on September 25 to 27, 2007 in Paris in the frame of the "Forum de l'Electronique". The fourth Special Event took place on April 3, 2008 in Paris presenting the project results and conclusion (presentations may be downloaded from the website of the project: www.life-amelie.info).

Special event organised in Paris on April 3, 2008

✓ 10 articles have been published in newsletter, magazines with a total of more than 70 000 editions.

✓ 10 presentations of the project have been done during seminars or conferences. A total of more than 500 people were directly touched by this dissemination activity.



✓ Regional events

In the frame of the dissemination activities, CIRE group has organized at the beginning of the project 5 specific regional events. The dissemination during these events relate mainly to the existence of the AMELIE project, the role of the partners and the nature of work to be undertaken. These events were also organized to identify the latest market's requirements taking into account the RoHS directive. A total of 221 high skilled engineers and/or managers of the electronic sector representing 127 SMEs or large groups have attended these events.

Assessment of the environmental impact of the project, describing the environmental benefits

This high tech industry sector is sensitive to public concerns over possible health effects of lead use. Many companies are striving to reduce or eliminate lead where technically feasible.

The main environmental direct result is obviously the drastic reduction of lead in electronic assemblies. The reduction of lead use reduces air pollution with lead particulates and as a consequence potential risk of inhalation by workers. It also reduces the quantity of lead in landfills and as a consequence reduces concern that lead from electronic products in landfills might enter the soil or water.

The data below show the impact of the transition to lead-free process for three actors of the electronic supply chain (SOLECTRON : assembly processes; TEMEX CERAMICS : passive components manufacturer; CIRE : printed circuit board manufacturer)

- Impact on raw material consumption

		Lead-based process	Lead-free process
Raw material impact			
SOLECTRON	SnPb alloy (bar)	70 ton/year	0 ton/year
	SnPb solder paste	7,7 ton/year	0 ton/year
TEMEX CERAMICS	Treatment bath containing lead	290 L/year	0 L/year
CIRE	SnPb alloy	3.14 tons/year	0 ton/year

- Impacts on air and water quality:

		Lead-based process	Lead-free process
Air impact			
SOLECTRON	Lead discharge for one solder machine	100 g/day	0 g/day
TEMEX CERAMICS	Plating process	Lead-based vapors (not quantified)	0 g/year
CIRE	PCB finish process	Lead-based vapors < 170 g /year	0 g/year
Waste water			
SOLECTRON	Lead discharge	0,087 mg/L	0 mg/L
TEMEX CERAMICS	Lead in waste from surface treatment	3 220 l /year ([Pb]: 53 mg/l = 170 g per year)	1 000 l /year ([Pb]: 0.7 mg/l= 1.4 g per year)
CIRE	Water particle disposal	[Pb]: 1 kg/year	[Pb]: 0.42 kg/year

- Impact on waste produced

		Lead-based process	Lead-free process
Waste impact			
SOLECTRON	Solder paste (SnPB)	0,8 ton/year	0 ton/year
	Scoria	9 tons/year	Not significant
TEMEX CERAMICS	Lead in packaging waste	100 kg/year	0 kg/year
CIRE	Scoria	550 kg/year	0 kg/year

Cost-benefit discussion on the results

The switchover to lead-free is a critical issue for all electronic industry contracting/contractor partners (designers, printed circuit board manufacturers, component producers, assemblers, end-users) which should provide new cost effective lead-free solutions capable of meeting requirements of forthcoming calls for tenders.

In the military and aerospace high reliability sector the economic impact of the RoHS directive is overall negative. The development of processes compliant with the RoHS and WEEE directives has a high impact on costs and customers are not ready to pay these extra costs for lead-free products. It means that the manufacturers of lead-free components and electronic assembly have to support these costs. The impact on costs is divided in three categories:

- Increase in management costs (mainly during the transition period, stock management, technical data management, duplication of production processes, disposal and recycling)
- Non-recurring costs (investments, research and development, training, qualifications, commercial communication,…)
- Recurring costs (longer operating times, more expensive consumables, higher energy consumption, materials more expensive,…).

The fact that these new products are environmentally friendly is not an argument in this sector and the new lead-free "green" product introduction can not be used as a marketing driving force. The costs induced by the transition to lead-free products and the increase in product cost will therefore not be compensated. Furthermore alternative solders may increase recycling costs as multiple alternatives would require sorting, create impurity issues, decreasing economies of scale.

Nevertheless the knowledge acquired in the frame of the AMELIE project will help partners to implement competitive and time to market lead-free techniques and logistics in the future. The lead-free technology will certainly make possible new business opportunities in niche market.

Transferability of project results

The AMELIE project has been implemented on a pilot and pre-industrial scale which permit evaluation of technical and economic viability of large scale introduction of high reliable products. This validation was carried out by two demonstrators which have been defined by the specifications of the end-users (GAIA CONVERTER and THALES SA). The demonstration took into account the whole electronic supply chain from purchasing activities to the implementation of a lead-free industrial assembly line and the management of the with/without lead mix. The method can be easily transferred to other high reliability products and there are no significant obstacles for replicability. Transferability require the assistance of skilled experts in the field of assembly processes, supply chain, logistics, quality control, organization and/or investment strategy.

Transferability of project results has been achieved with 2 small and medium-sized companies located in the Aquitaine region. The transferability consists of assisting these companies step by step as they introduce lead-free manufacturing. They took place in a context of individual on-site assistance coached by an industrial partner from the AMELIE consortium.