

Reliability Testing and Damage Analysis of Lead-Free Solder Joints: New Assessment Criteria for Laboratory Methods

Antje Steller, Axel Zimmermann and Stephan Eisenberg
Laboratory Metals, Volkswagen AG

Klaus-Juergen Wolter
Electronic Packaging Laboratory, Dresden University of Technology

Petrik Lange
Technology Development, Hella KGaA Hueck & Co.

Copyright © 2009 SAE International

ABSTRACT

Driven by legislation in the European Union (ELV directive 2000/53/EC [1]) and international industry activities for the use of environment-friendly technologies, automotive suppliers and OEMs are faced with the demand to substitute lead-containing solders in electronic assemblies. Compared to consumer electronics, for which lead-containing technologies had to be phased out by July 2006, automotive applications have to meet considerably higher requirements concerning lifetime and environmental loading conditions, which mainly result from superimposed vibrations and temperature cycling. Therefore, advanced reliability testing and damage analysis techniques are needed to ensure a reliable use of lead-free solders.

This paper presents the results of reliability tests that aimed at assessing the capabilities of different analysis tools to characterize solder joints for quality assurance and damage analysis. Detailed electric and mechanical testing as well as metallographic cross-section analysis of differently aged specimens soldered with standard SnPb and lead-free SnAgCu-solder revealed advantages and disadvantages of commonly used examination methods. The gained experiences are used to develop an approach for a new test series. The goal is to develop quantitative measures for damage analysis of solder joints via new testing methods and more elaborate examinations of common methods. On the basis of

these measures a more distinct correlation of failure modes to loading conditions shall be possible.

INTRODUCTION

With the decision of the European Commission to speak out a ban of lead in solders for electronic components for all vehicles type approved after December 31st 2010 [1], automotive OEMs now need to consider implementation steps for the change to lead-free electronics. The revaluation of the manufacturing processes is a task that the supplying industry has to carry out. Automotive OEMs though have to find a reasonable way for qualification of new and re-qualification of carry-over parts. The two major concerns include the following questions:

- The change to lead-free electronics implies something like a "mentality - change". In the era of SnPb-solder, one material combination was the solution to almost every question, including whisker in surface finishes and reliability of component-to-board joints. For lead-free devices the great diversity of different solders and surface finishes and combinations thereof poses the question of which material combination represents the best solution for automotive requirements. How can OEMs, that often treat electronic devices as "Black Box parts", decide in the qualification process, if a material combination

proposed by a supplier is suitable to be used for a specific requirement profile?

- Over the past decade lots of projects have been carried out to investigate the processability and reliability of lead-free solders. Results have been published e.g. in [2, 3, 4]. The processability has been proven to be comparable to that of SnPb. An exemption applies to the narrower process latitude that is caused by the higher melting points of most lead-free solders. Of greater concern is the question of long-term reliability: there is only little field data available for automotive devices soldered lead-free. The results of laboratory reliability tests are treated carefully because there still exists uncertainty about the comparability of testing conditions to real operating conditions and the resulting damage mechanisms.

Lots of data about the characteristics of different material combinations are available in the literature, e.g. in [2-6]. Yet the uncertainty about reliability issues remains. The reason lies in the type of data that is available: The results of reliability tests generally have a describing character. For example, when conducting a temperature cycling test on a printed circuit board (PCB), the results obtained would describe the damage after a certain number of cycles. The description of microstructural changes for example includes the comparing interpretation of thickness and growth of intermetallic compounds as a function of solder material and aging time. A similar approach is chosen for the interpretation of joint strengths. Quantitative properties for reliability estimation of an as-soldered joint or damage analysis within in a joint are not available. Only quantifiable properties though can be used to obtain universally valid evaluation criteria.

Hence the Volkswagen laboratory is not only evaluating the properties of solder joints, but also the methods that are used to gain those properties. In the following sections a review of commonly used analysing tools is presented. The results were collected in reliability tests including temperature cycling and vibration tests of differently soldered PCBs. The drawbacks of the applied methods are intentionally pointed out to illustrate the approach for a new testing series proposed at the end of this paper.

RESULTS OF PREEXAMINATIONS

OUTLINE OF EXPERIMENTS - In general reliability tests include the exposure of a device of interest to a loading profile similar to that under operating conditions. A "reliable" product should be able to perform the desired functions for a defined period of aging time.

The goal of the preexaminations was to gain experiences with the behavior of lead-free solders compared to the standard SnPb. Therefore a PCB once soldered with SnPb37 and once with SnAg3.0Cu0.5 was stressed via temperature cycling and vibration which resemble the most critical loads for solder connections in automotive applications. The loading profiles were taken from the Volkswagen testing standard VW 80101 [8] and are shown in figures 1 and 2. Temperature tests included up to 1900 cycles between -40 and +125°C. Mechanical loading included vibrating new parts and already temperature-cycled parts under sinusoidal or random vibration profiles for 48 hours each. Specimens were taken to be analyzed after different loading durations.

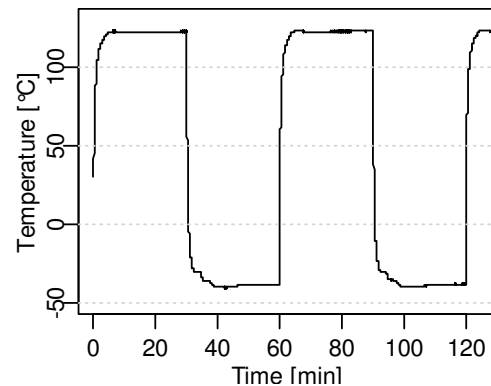


Figure 1 Temperature cycling profile: $T_{min}=-40^{\circ}\text{C}$, $T_{max}=+125^{\circ}\text{C}$

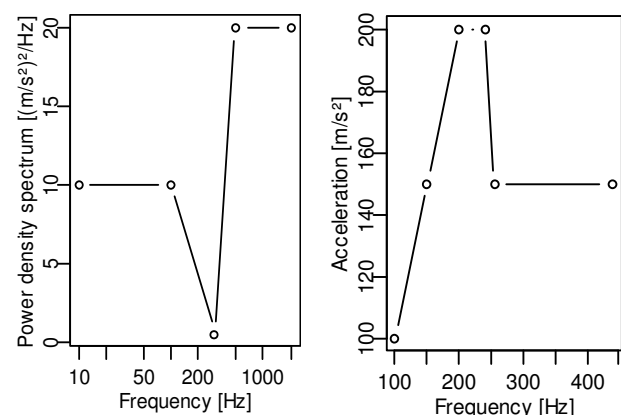


Figure 2 wide-band random vibration profile (left) and sinusoidal vibration profile (right)

ANALYSIS TECHNIQUES AND RESULTS

Electrical Testing - In-Circuit tests and functional tests were performed after 300, 600, 1400 and 1900 temperature cycles and after vibration tests. Although subsequent cross section analysis revealed quite an amount of cracks after the final testing duration, as exemplified in figure 3, no electrical failures or significant changes in electrical properties could be detected. Consequently it can be stated that electrical measurements cannot be used to observe the initiation and growth of damage in a solder joint. Only complete electrical interruptions would be detectable.

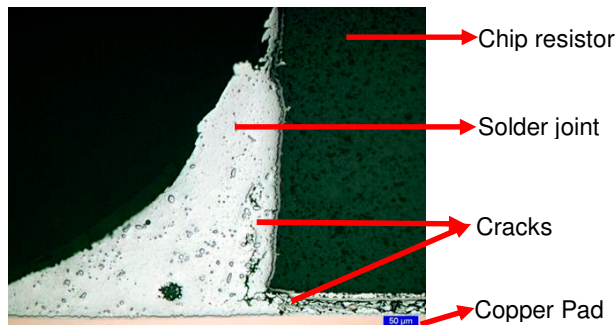


Figure 3 Cross-section of a 1206-chip resistor: After 1400 temperature cycles cracks could be detected, but the resistor didn't show a significant change in electrical properties

Shear Testing - In shear tests a force is applied onto an electronic component, figure 4. The force is increased till a rupture of the joint between the component and the PCB occurs. The shear force is the maximum force that is determined at time of rupture and it offers a measure for the mechanical strength of the joint. Additionally, the type of fracture can be evaluated. Figure 5 shows as an example a tear-off of component metallization. In such a case the measured force cannot directly be used as a parameter characterizing the solder. The location of the fracture in this case tells us that the solder connection is stronger than the connection of the metallization to the capacitor.

The interpretation of shear test results is commonly done by comparing shear force and fracture types of different solder materials or after different aging conditions. In the

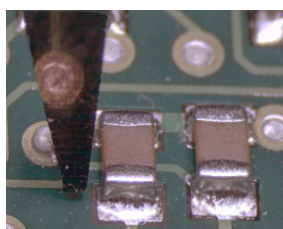


Figure 4 Shear tool about to apply force F onto a chip capacitor

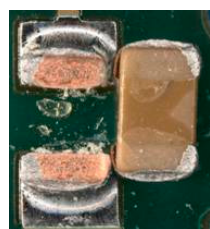


Figure 5 Possible type of fracture of a chip component: tear-off of metallization

following a few examples from the preexaminations are presented.

In Figure 6 the shear strength as a function of package size, solder material and aging condition is compared. As expected the shear force depends on the size of a component. 1206 and 0805-resistors only slightly vary in their shear strength. The packages are of different sizes and therefore the microstructure varies due to different cooling conditions, but the sizes of the solder joints are very similar which leads to similar joint strengths. The 0201-resistors are significantly smaller in package and joint size and, accordingly, the strength is a lot smaller compared to R1206 and R0805. Comparing the two different solders it can be stated that in the as-soldered state the lead-free solder has a slightly greater strength than SnPb, but the differences are not statistically significant. For statistical significance the confidence intervals of different measurement series should not overlap.

Figure 7 demonstrates a different way of interpreting the data shown in figure 6. After temperature cycling remaining shear strengths are compared as a function of component size and solder material. The remaining shear strength is determined by calculating percentages of the force after 1900 temperature cycles compared to the initial shear force. Aging of solders causes a gradual reduction of shear force. In the case of chip resistors the larger components experienced a greater reduction which is due to differing strains caused by the unequal coefficients of thermal expansion of resistors and board and varying pad sizes of different components. These results correspond to differing crack lengths in chip components of unequal sizes. The larger components experienced stronger crack growth compared to components of same package style but smaller dimensions.

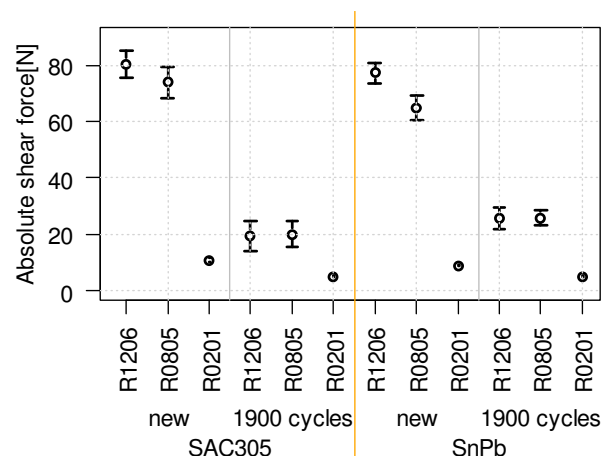


Figure 6 Absolute shear forces of different chip resistors, once soldered with SnAg3.0Cu0.5 and once with SnPb37, no aging