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Investigation on thermal fatigue of SnAgCu, Sn100C, and SnPbAg solder joints in varying temperature environments

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ABSTRACT

Thermal cycling tests have been performed for a range of electronic components intended for avionic applications, assembled with SAC305, SN100C and SnPbAg solder alloys. Two temperature profiles have been used, the first ranging between −20 °C and +80 °C (TC1), and the second between −55 °C and +125 °C (TC2). High level of detail is provided for the solder alloy composition and the component package dimensions, and statistical analysis, partially supported by FE modeling, is reported. The test results confirm the feasibility of SAC305 as a replacement for SnPbAg under relatively benign thermomechanical loads. Furthermore, the test results serve as a starting point for estimation of damage accumulation in a critical solder joint in field conditions, with increased accuracy by avoiding data reduction. A computationally efficient method that was earlier introduced by the authors and tested on relatively mild temperature environments has been significantly improved to become applicable on extended temperature range, and it has been applied to a PBGA256 component with SAC305 solder in TC1 conditions. The method, which utilizes interpolated response surfaces generated by finite element modeling, extends the range of techniques that can be employed in the design phase to predict thermal fatigue of solder joints under field temperature conditions.

1. Introduction

The RoHS directive [1] limits the use of lead in the manufacture of various types of electrical and electronic equipment. The transition to lead-free electronics will shortly propagate also to manufacturers of electronic equipment for harsh environments, such as avionics, that are currently exempt from the RoHS directive. This is partly explained by the decreasing availability of standard tin–lead components on the market.

Facing the transition to Pb-free electronics, the avionics industry now needs to know that all packages – not only new packages – can be qualified for field usage with sufficient reliability. In the research community, large effort has been put on determining whether lead-free solder can replace the well-proven tin–lead solder with regards to thermal fatigue life [2–6]. This process is however difficult to complete, due to the large number of lead-free solder alloys that exist on the market, variation of the alloy composition of a specific solder alloy between different suppliers, and high dependence of initial microstructure, and thus reliability, on manufacturing parameters.

During product development for avionic applications, the electronic packages must be qualified for field conditions that vary depending on the specific location of the equipment (i.e. in zones with controlled or uncontrolled environment in an aircraft). In qualification of a certain package for different thermal environments, accelerated testing is the predominating method. Research on thermal cycling reliability of Pb-free solders and constitutive laws for thermal fatigue can be found in literature [5–9]. However, validated constitutive laws that describe thermal fatigue both for accelerated test conditions and field temperature conditions are still missing, due to lack of field data. Nevertheless, the industry is encouraged to employ finite element (FE) prediction of accumulated creep strain energy density (SEDcr) to transfer the accelerated test results to field conditions, via lifetime prediction models that are fitted to accelerated test data [10–13]. The latter assumes reduction of field conditions to cyclic loading, which might result in reduced accuracy of the predicted damage. Evaluation of damage accumulation in solder joints for field conditions

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Table 1
Composition of tested solder alloys, as provided from component supplier, and SAC305 composition measured after the reflow process.

	Sn (%)	Ag (%)	Cu (%)	Sb (%)	Pb (%)	Bi (%)	Zn (%)	Fe (%)
SAC305	Bal.	2.8–3.2	0.4–0.6	⩽0.12	⩽0.09	⩽0.1	⩽0.002	⩽0.02
SAC305 measured	94.9	3.3	1.8					
SN100C	99.3		0.7					
SnPbAg	62	2			36			

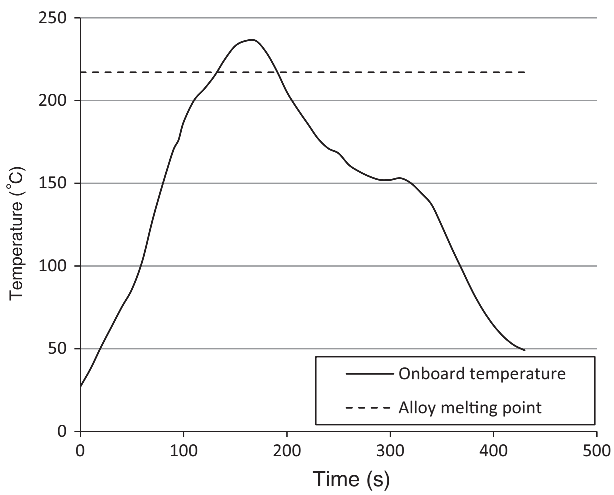

Fig. 1. Reflow soldering temperature profile for the lead-free test boards (°C), monitored near the center solder balls on one of the BGA1152 components.

without data reduction is a task that still poses a large challenge for full-scale FE analysis, in terms of computational resources.

When experiments or FE simulation is considered too time consuming for practical utilization, and the dependency of one or more response variables on one or more design variables is not possible to express analytically, measures such as model reduction methods or surrogate modeling can be applied. Model reduction methods that take into account nonlinear response have been demonstrated, for example on advanced calculations of crack propagation in elastic–plastic media [14]. While these methods assume computationally efficient reduced FE modeling in the calculations, surrogate modeling takes one step further in that more simple methods are utilized for the response evaluation. One way to create a surrogate model for design space approximation is to design a response surface by interpolating the values of the response variables between the results of a limited number of experiments with design variables set to cover the design space. Different interpolation schemes can then be applied to estimate the response in between the data points included in the experiments [15].

The present article copes with the following needs in the product development process for avionic applications: further thermal cycle test data to help in qualification of certain packages and lead-free solder alloys, and quick evaluation in the design phase of the damage accumulation in solder joints under harsh, non-cyclic field temperature conditions.

First, analysis is provided of the results from an in-house large-scale thermal cycling experiment with −20 °C to +80 °C (TC1), and −55 °C to +125 °C (TC2) thermal cycling. A range of surface-mount electronic component packages that could be considered for avionic applications have been tested with SAC305, SN100C, and Sn62Pb36Ag2 solder alloys. The composition of each tested solder alloy is provided, as well as detailed manufacturing parameters and dimensions of each electronic package. Based on the experimental results and FEA assisted interpretation thereof, engineering guidelines have been generated regarding selection of packages and solder alloys for avionic applications.

Next, recent advances are presented on an efficient method for SEDcr computation that has been introduced in [16], which utilizes interpolated response surfaces generated by short FE simulations. Substantial improvements have been implemented, which enable computation of damage accumulation for an extended temperature range. The accuracy of the computations has been evaluated

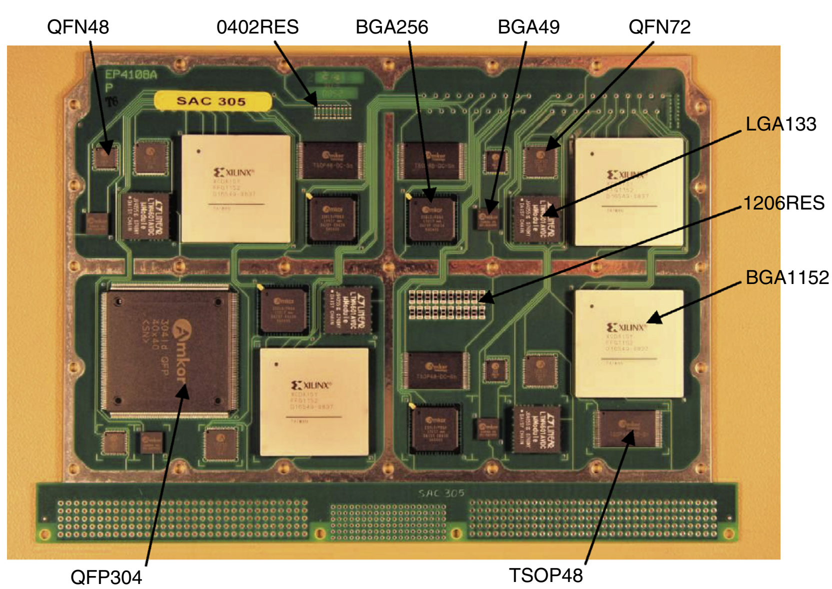

Fig. 2. Populated test board.