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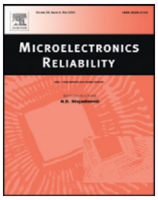

Verification of empirical warp-based design criteria of space electronic boards

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ABSTRACT

Space electronics are subjected to severe vibration environment. The present paper examines empirical warp-based design rules of electronic boards, i.e., criteria verifying that the ratio of maximum board warp to its length remains below a threshold percentage. An analytical approach assessed that peak stress of the board stems better from its curvature than its warp. The same applies to the adhesive peak stress by investigating a finite element model of an adhesively bonded component. Alternatively, a modified formulation based on board curvature is proposed and a threshold curvature is assessed.

1. Introduction

Before their use, space electronics need to undergo series of qualification tests to check out their reliability towards real environmental conditions. For the purpose of alleviating duration and cost of the design, early verifications should be performed during the pre-design. In that phase, engineers numerically simulate devices through validated finite element (FE) models [1,2,3]. The static and dynamic mechanical integrity of a given device can be, also, verified via empirical design rules [4]. These criteria emanate from experimental strain, displacement or stress correlations with damage. For instance, Gu et al. [5] established correlation between strains in the back side of a printed circuit board (PCB) and strains in solder joints. Amy et al. [6] and Lau et al. [7] justified the accuracy of PCB strains in predicting damage of electronic components. In [8], the maximum PCB principal strain was revealed dependent on tensile and shear loads inside solder balls of a flip-chip ball grid array component. Authors pointed out that radial strain conveniently matches with solder stress regardless the deformed shape of the PCB. Obviously, failure of electronic components relies on curvature or strain of their board. Nowadays, generic design rules based upon these metrics are scarce. This is due in part to the unpublished heritage and to hidden or unreferenced industrial rules of thumb. Perhaps, most referenced and known criteria of design are ones stipulating that the ratio of maximum warp of the board to its length remains below a threshold value. A first citation is found in a specification published by the European cooperation for space standardization (ECSS) [9]: a rigid PCB with thickness over 1.6 mm should verify

$$\frac{Z}{L} < 0.011. \tag{1}$$

Z is the maximum deflection of the PCB and L its length. In contrast to criteria based on PCB curvature or strain, Eq. ((1)) is based on a dimensionless metric, Z/B, denoted by ‘warp ratio’. A similar formulation is found in [10]: electronic components can survive 10 or 20 million stress reversals under respective sinusoidal or random vibration as soon as the respective peak single-amplitude or 3-σ displacement of the PCB verifies

$$Z < \frac{0.00022L}{Ch_p r\sqrt{L_c}} \quad \text{or equivalently} \quad \frac{Z}{L} < \frac{0.00022}{Ch_p r\sqrt{L_c}} = R_S \tag{2}$$

with h_p the PCB thickness and L_c the length of the attached electronic component, both originally expressed in inch. r is at most equal to 1 when the component is placed at the PCB center. C ranges from 1 to 2.25 depending on type of the component. The main concern of Eqs. (1) and (2) is not their application field (constant, random or sine loads) but their physical consistency. Objectives of this work can be summarized in the following points.

- Ensure that the warp ratio reflects stress state not only in the PCB but also in interconnections such as solder or adhesive joints.
- Establish confidence in threshold values of warp-based criteria (Eqs. (1) and (2).
- Correct, if necessary, the formulations of warp-based criteria.

  To do so, a first section of this work is devoted to verify qualitatively the physical consistency of warp-based criteria. At this level, a

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simple analytical beam-model intends to reveal which warp-based ratio better correlates with PCB peak stress. Next, a finite element model is developed for an adhesively bonded component. Interest to this packaging technique is increasing as it permits to consolidate surface mount chips and to attach heavy components (>3 g [10]). The numerical model helps to select among warp ratio and PCB curvature, the candidate that better correlates with peak adhesive stress. Meanwhile, the state of the art dealing with adhesive modelling is discussed. This prepares to express, in a third section, a threshold curvature in function of most influential parameters of the bonded assembly. Finally, PCB warp ratio and curvature criteria are compared from their conservatism and precision. This work is done within the framework of a basic assumption that of materials of space devices strictly working in their elastic range [10].

2. Qualitative study of the Steinberg deflection criterion

Steinberg [10] represented the PCB by an equivalent beam so that the Euler–Bernoulli theory can be used. For a simply supported beam subject to a constant vertical acceleration field $\vec{G}$, the deflection appears proportional to the acceleration magnitude G and to L^4

$$Z \propto GL^4. \tag{3}$$

The maximum bending stress, σ_p, depends on the same parameters as follows

$$\sigma_p \propto GL^2. \tag{4}$$

It comes out from Eqs. (3) and (4) that σ_p is related to the maximum deflection by

$$\sigma_p \propto \frac{Z}{L^2}. \tag{5}$$

In parallel, the geometric model illustrated in Fig. 1 permits to express the curvature radius of the beam in bending, R, as follows

$$R^2 = (R-Z)^2 + L^2/4. \tag{6}$$

By assuming Z small compared to L and R, the curvature radius comes down to

$$R \simeq \frac{L^2}{8Z}. \tag{7}$$

Eqs. (4) and (7) bring out

$$\sigma_p \mu \frac{1}{R}. \tag{8}$$

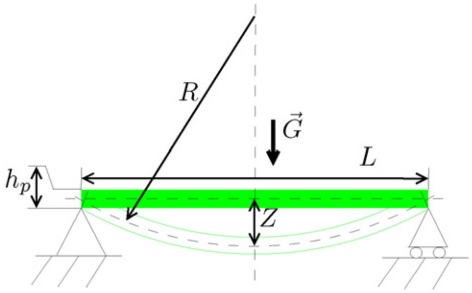

Fig. 1. Geometry and boundary conditions of the equivalent beam model.

Given that σ_p is proportional to the curvature, it should not be related to the warp ratio. A corrected form of the warp-based criterion is, therefore, better updated in term of curvature such as

$$\frac{Z}{L^2} \le C_c \tag{9}$$

where C_c is a threshold curvature to determine further. Z can be measured experimentally in different ways (linear variable differential transformer, laser velocimeter, etc.).

3. Finite element modelling of a total adhesively bonded electronic component

3.1. Objective

The previous section illustrated the correlation between the PCB peak stress and its curvature. This is, however, not sufficient to transform the curvature metric into a design rule. As most failures occur at interconnections such as solder or adhesive joints, the dependence between PCB curvature and stress in these interconnections has still to be addressed.

3.2. Modelling assumptions

This paper is interested in the case study of an adhesively bonded electronic component. Existing adhesive distributions underneath the component have been studied in [1] which reveals that adhesive coverage of 80% of the underside of a ceramic quad flat package component with glue on its corners contributes, compared to other adhesive distributions, to further reduce stress in solder joints and to increase their fatigue lifetime. In seek of simpler modelling, the latter adhesive distribution is merely replaced by total bond of the component underside.

Given the symmetry about (XZ) and (YZ) planes, only quarter of the assembly is simulated through a 3D FE model under ABAQUS v6.10 [13] (Fig. 2). Mechanical and geometric properties of the simulated model are reported in Table 1. The assembly is subjected to a constant transverse acceleration field. For information, constant acceleration occurs during the launch phase and is used, inter alia, to quantify the level of random vibration. In [14], an error lower than 7% between experimental and numerical adhesive stress peaks is obtained among different bond configurations of thin-walled joined beam structure. Hence, assembly of the model is achieved by use of ABAQUS tie interactions at interfaces.

3.3. Mesh of the adhesive layer

In fracture mechanics, the adhesive is modelled through fictitious cohesive elements in order to compute stress and predict crack

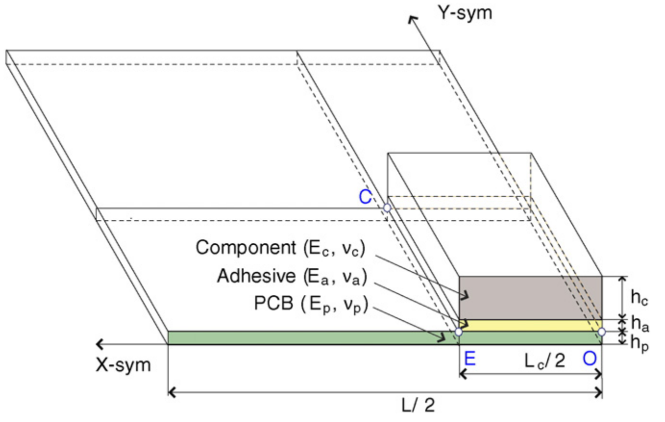

Fig. 2. Annotated 3-D view of the simulated quarter assembly.