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Four-point bending cycling: The alternative for thermal cycling solder fatigue testing of electronic components

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ABSTRACT

This paper deals with an alternative testing approach for quantifying the life time of board level solder joint reliability of components. This approach consists of applying a relative shear displacement between component and Printed Circuit Board (PCB) through cyclic board bending. During the cycling, the temperature is kept constant, preferably at elevated temperature in order to accelerate the creep deformation of the solder joint. This is done in a four-point bending setup which allows to apply an equal loading on all components lying between the inner bars. The scope of the paper is, firstly, to evaluate if the four point bending testing generates the same fatigue fracture as in thermal cycling; secondly, that the measured life times can be also predicted through finite element simulations; and thirdly if the technique can finally accelerate the cycling frequency to reduce the testing time.

1. Introduction to alternative testing for thermal cycling

Thermal cycling testing is a widely spread method for analyzing the board level thermal cycling performance of printed board assemblies. Thermal cycling testing is part of many qualification standards.

However, thermal cycling testing for analyzing the second level solder joint reliability is a time consuming experiment. Acceleration of the test in order to obtain fast failures is only possible through an increase of the temperature swing. This is done either through increasing the maximum temperature closer to the melt, or decreasing the minimum temperature close to or below the homologous temperature where creep seizes to occur and making the solder more brittle. Both too high or too low temperature can lead to new failure modes which may not be relevant for the operational conditions the system has to work.

In order to cope with these limitations, an alternative testing approach has been developed and evaluated in this work. The method is based on applying four-point bending to the PCB. The bending causes an absolute displacement at the top/bottom fiber of the PCB and as such applies a displacement mismatch with the component which is similar to what is seen during temperature cycling. The bending system is installed in a climatic chamber which allows to combine bending and thermal cycling. This new test method decouples the fatigue failure inducing cyclic mechanical load on the solder joint from the imposed temperature creating an additional degree of freedom the accelerate the test. Additionally, one can now fully explore and exploit the temperature dependence of the material properties especially the increased creep rate at high temperature. In first instance, we kept the temperature constant during the mechanical cycling.

JEDEC provides a standard for Board Level Cyclic Bend Test Method for Interconnect Reliability Characterization of Components for Handheld Electronic Products [1]. It is mentioned that the test procedure is presently more appropriate for relative component performance than for use as a pass/fail criterion. It is also not meant for life time estimations nor for assembly qualifications.

2. Analytical equations relating the applied bending parameters to the local strain on the solder joints

The target of the 4-point bending experiment is to apply mechanically a similar relative shear mismatch between the component and PCB as in thermal cycling. This is illustrated in Fig. 1.

In the thermal cycling experiment with a temperature swing of ΔT, the displacement mismatch between the PCB and component at each

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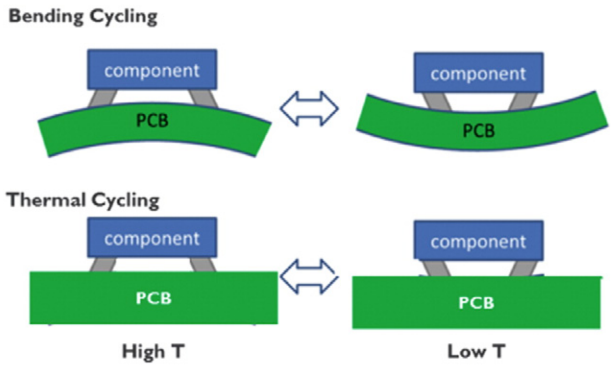

Fig. 1. Illustration of the similarity between thermal and bending cycling.

joint location is calculated in its most simplified form as follows:

$$\Delta l_{PCB-Comp} = DNP^{*}(CTE_{PCB}-CTE_{Comp})^{*}\Delta T \tag{1}$$

with DNP the Distance to Neutral Point, typically the center of the component. The Coefficient of Thermal Expansion (CTE) of the PCB is a weighted average of the FR4 laminate and the copper layers, the CTE of the component is also a weighted average, however more difficult to calculate due to the asymmetry of the package build-up. The joints having the highest DNP are typically the corner joints.

The concept of the mechanical cycling test is shown in Fig. 2. The PCB with the soldered components is placed between 4 bars, of which the two inner bars can move up and down. The 4-point bending creates a bending moment acting on the area between the two inner bars which is constant. Important notice is that the two outer and two inner bars should be aligned to the same center line. Therefore, the bending radius and thus the shear loading of the components assembled in this area is uniform.

The parameter which is applied in the four point bending experiment is the displacement **δ** of the moving inner bars relative to the static outer bars (Fig. 3).

This deflection depends linearly on the applied force according to the following equation:

$$\delta = \frac{F}{E_{PCB}{}^{*}I_{PCB}}\left(\frac{L_1}{2}\cdot\left(\frac{L_2-L_1}{2}\right)^2+\frac{1}{3}\left(\frac{L_2-L_1}{2}\right)^3\right) \tag{2}$$

with F is the force applied on each of the two inner bars (so total force applied by the motor is 2F), E_{PCB} is the elastic modulus of the PCB and I_{PCB} is the moment of inertia of the PCB.

The bending moment applied to the PCB in the area between the two inner bars is constant and equal to:

$$M = F\frac{L_2-L_1}{2} \tag{3}$$

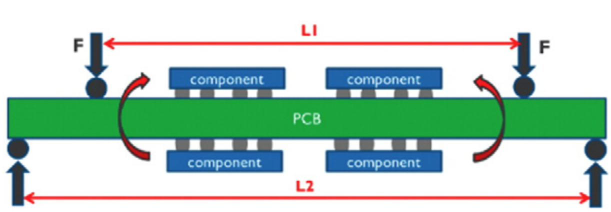

Fig. 2. Concept of the 4 point bending cycling testing of soldered components.

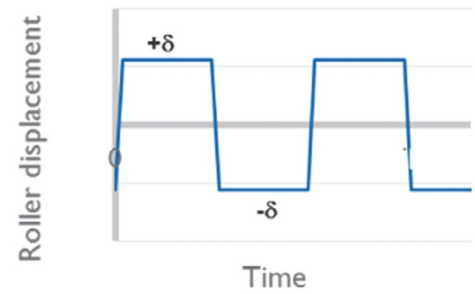

Fig. 3. Representation of the roller displacement during a bending cycling experiment.

This bending moment results in a curvature (in the inner area) equal to:

$$\frac{1}{\rho} = \frac{M}{E_{PCB}{}^{*}I_{PCB}} \tag{4}$$

Combining Eqs. (2), (3) and (4), the curvature can be written as function of the applied bar displacement δ as follows:

$$\frac{1}{\rho} = \frac{24}{\left(3^{*}L_2{}^2-4^{*}\left(\frac{L_2-L_1}{2}\right)^2\right)}\delta \tag{5}$$

The applied curvature results in a maximum strain ε_{PCB} at the PCB outer surfaces (top/bottom) equal to:

$$\epsilon_{PCB} = \frac{1}{\rho}\frac{h_{PCB}}{2} \tag{6}$$

with h_{PCB} is the PCB thickness.

Similar to Eq. (1), the strain can be translated into a relative displacement per cycle between component and PCB equal to:

$$\Delta l_{PCB-Comp} = DNP^{*}2^{*}\frac{1}{\rho}\frac{h_{PCB}}{2} \tag{7}$$

The factor 2 is added as in one cycle, the board is bent from $-1/\rho$ to $+1/\rho$ curvature which doubles the relative displacement. Combining Eqs. (5) and (7) results in this relationship between relative shear displacement and applied bar displacement:

$$\Delta l_{PCB-Comp} = DNP^{*}\frac{24h_{PCB}}{\left(3^{*}L_2{}^2-4^{*}\left(\frac{L_2-L_1}{2}\right)^2\right)}\delta \tag{8}$$

3. Description of the four point bending testing setup and test vehicle

The four-point bending system consists of four pairs of rollers as shown schematically in Fig. 4. The board under test is clamped between each pair of rollers which are in turn tightened together as shown in Fig. 4 and Fig. 5. An aluminum plate makes the connection of the inner

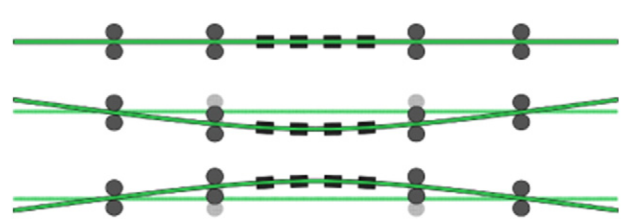

Fig. 4. Schematic drawing visualizing the concept of the four point bending cycling.