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Non-Destructive Evaluation of Crack Propagation in Solder Joints of Pressure Sensors Under Thermal Cycling Using Computed Tomography and Finite Element Analysis

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Summary:

This study investigates crack propagation in pressure sensor solder joints caused by thermal cycling, employing Computed Tomography (CT) for non-destructive monitoring and Finite Element Analysis (FEA) to simulate plastic strain distribution. By periodically examining the solder joints with CT during thermal cycles and measuring crack lengths, we predict the lifetime of the joints. The FEA complements this by predicting damaged regions, with both methods showing good agreement in lifetime estimations.

Keywords: solder, lifetime, FEM, CT, MEMS

Background, Motivation and Objective

Solder joint reliability is a cornerstone of electronic device performance, especially in components subjected to thermal cycling, which induce mechanical stress and can lead to crack formation and propagation. In MEMS sensors, where accuracy and durability are paramount, understanding the behavior of solder joints under temperature fluctuations is critical. Non-destructive testing methods, such as computed tomography (CT), have emerged as invaluable tools for investigating internal structures and defects in materials without compromising sample integrity [1, 2]. The integration of CT imaging with FEA offers a comprehensive understanding of crack initiation and propagation dynamics, and its impact on the lifetime of solder joints.

Description of the New Method or System

By periodically analyzing solder joints with CT imaging throughout thermal cycles and quantifying crack lengths, alongside simulating plastic strain via Finite Element Method (FEM), we seek to enhance lifetime predictions of solder joints. This approach addresses the need for advanced diagnostics and predictive models in the field, contributing to the development of more durable electronic components.

Results

A high-resolution 3D X-ray microscope was used to create the CT images which also reveal the internal structure of the solders (see Fig. 1).

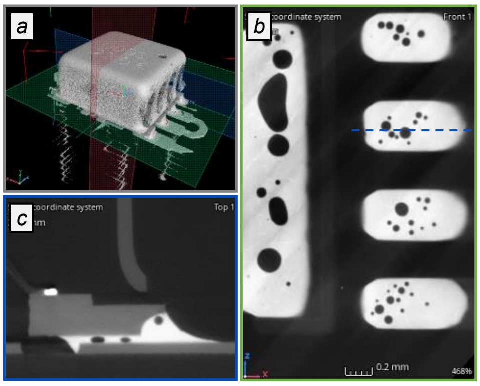

Fig. 1. 3D X-ray image of the sensor package (a). Tomographic image or slice in the horizontal (green) plane (b). Slice in the vertical (blue) plane, slice position is also shown by a blue dashed line (c).

The voids are natural remainings of the soldering process and normally do not influence solder lifetime [3].

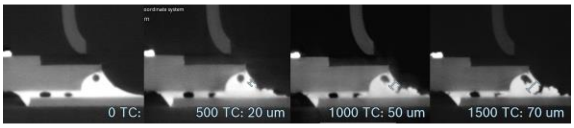

Fig. 2. Crack initiation and propagation throughout the thermal cycles (TC) between -40 / +150 °C.

Crack lengths were measured in every solder joint across all eight sensor packages (see Fig. 2). The expected solder lifetime is then calculated from the crack propagation speed.

The finite element model was created from the quarter of the PCB on which 4 sensor packages were soldered. The traces and layer structure of the PCB were considered in detail. The solder joint geometry was based on the initial CT images, but voids were not considered (see Fig. 3).

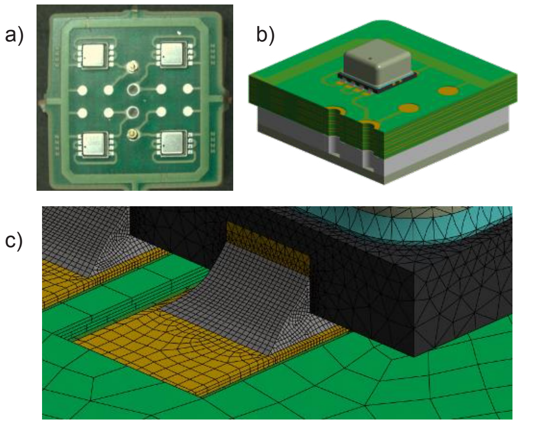

Fig. 3. The test PCB with four sensors (a), the geometry of the finite element model (b), and the finite element mesh at the solder joints (c).

The damage related parameter is the inelastic strain (accumulated plastic strain in the Ansys general purpose FEM software). To estimate the lifetime of the solder joints, the volume weighted average (VWA) accumulated plastic strain increment per cycle is calculated for each of the solders during postprocessing of the results. Finally the values are used in the Coffin-Manson relation to predict the expected lifetime of the solder joints.

The FE results show high load in the lower part of the outer solder meniscus, and at the outer circumference of the large middle solder (see. Fig. 4).

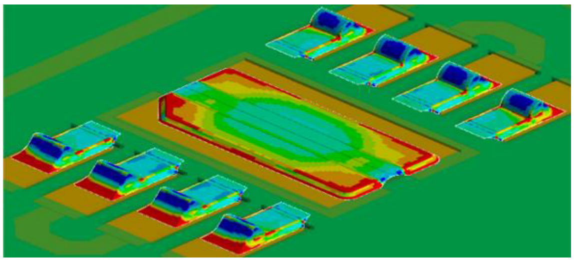

Fig. 4. Accumulated plastic strain distribution.

Simulation results show very similar distribution of the damage related parameter compared to damaged regions visible on final CT images (see. Fig. 5). Note the effect at the backside of the solder (to the most right on Fig. 5. b). Here, the solder resist touches the solder meniscus causing a more significant load leading to a localized crack formation. This geometric feature was considered in the simulation and the effect could be represent.

Fig. 6. shows the predicted lifetime of the solder joints based on crack length measurements, and on FEA using the Coffin-Manson relation.

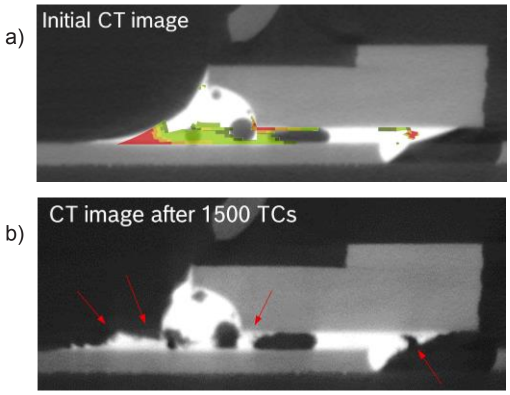

Fig. 5. Initial CT image overlayed with FE results showing high plastic strain accumulation (a). CT image after completing thermal cycling (b).

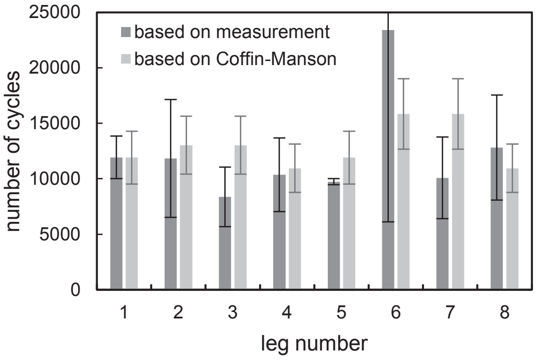

Fig. 6. Expected lifetime of solder joints averaged across all eight sensor packages based on crack length measurement and FEA (scattering for latter results is taken to be +/- 20%).

The results match, the difference is small for most legs, however there is a larger deviation for leg #6 and smaller ones for leg #3 and #7. The reasons could be tolerance related (allowed deviations in dimensions or in material properties, etc.) or the crack length measuring method could be further improved, e.g. by tracking the crack length or area in 3D.

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