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Solder Fatigue in Tin-Lead and Silver-Tin-Copper (ROHs) solders

Tina Barcley
TAS Consulting
tbarcley@earthlink.net
www.thermalanalysissystems.com

Solder fatigue is a creep phenomenon. It can be caused by large temperature delta or small temperature deltas, power cycling and low power standby modes.

For solder fatigue caused by drastic temperature changes, matching thermal coefficients assures meeting military specifications. However, it can cause non-representative material concerns. For industries where power cycles and/or smaller temperature variations; the damage is due to cyclic warpage or increased cyclic strains on the solder joints. These deformations and strains are in-plane shear strains. Both of these phenomena can be calculated analytically or experimentally reproduced. If not analyzed or tested correctly, the in-plane stresses and strains are likely to underestimate the "effective strain" on the solder joints by 25%.

Standard thermal cycling is an unsuitable test for assessing power cycle damage to a design. Normally test cycling is based on a temperature delta and the differences in the coefficient of thermal expansion. In this case, it is very small so the calculation and testing would indicate a small damage total. The thermal cycling to experimentally produces these stresses must include longer durations to allow the stress relaxation to occur. Additionally localized temperature deltas should be simulated to add the damage that starts in the microcosm and moves into the system.

While all the above is true for both tin-lead and silver-tin-lead solders, there are other differences that are due to the material composition differences in the ROHs silver-tin-lead solders. It is generally accepted that high Ag SAC alloys (SAC305/405) have good thermal fatigue resistance and actually perform better than the popular SnPb solders.

The element responsible for this is silver. The presence of Ag results in Ag3Sn precipitates. These precipitates are responsible for the increased hardness and therefore strength seen in these solder types. The downside is the silver solders have lower acoustic impedance which is the root cause for poor high-strain rate response. So in environments where drops or acceleration shocks are common, stress is transferred to the solder substrate interface where the intermetallics (with low ductility) cause failure of the solder joint. Thus failures are more common in shock environments where drops or acceleration shocks are involved.

This paper will show why the differences occur and how to analyze both large and small temperature delta environments, as well as power cycling and standby modes. It will also take into account the mechanical mounting of the circuit board and circuit board assembly. All fatigues are additive and need to be understood from a system level.

The Problem

Lead-free solder has a higher Young's Modulus than lead-based solder, making it more brittle when mechanically stressed. Depending on how the circuit board is mounted, several bending modes can occur which can tremendously affect the solder joints on the circuit board. Fractures in the solder joint start from the small voids (Kirkendall) that happen during the solder process. These voids under the mechanical stress will fracture and will spread – causing the joint to fail. Depending on how sensitive your electronics are – this can be noticed quite quickly or just seem to be a reoccurring issue with the electronics. The Kirkendall voids are microscopic cavities in solder formed during the soldering process. When two different types of metal that are in contact are heated, dispersion occurs, which causes additional small voids or air pockets. Repeated thermal cycling causes the stress or expansion which causes the process and dispersion voids to link and form a crack.

The Analyses Difference

For a Coffin-Manson type equation – the stress deformation is expressed by a fatigue ductility factor. This is where you can modify for the different materials.

The temperature delta is where you can make a separate case for max type temperature extremes (found in automotive) or a low delta temperature average damage (found in aerospace). It was completely astonishing the first time I did this comparison analysis and found that an underhood automotive electronics fatigue was numerically quite similar to a geo-centric satellite electronics fatigue. In the automobile environment, the model went from -40 to 125C but only a few times per day, whereas the aerospace electronics has hourly cycles of only 25 to 70C.

Summary

Tin-lead and SAC 305 typically have very similar fatigue calculated for a particular solder joint. Since the fatigue is based on the temperature cycles, the difference from the mechanical shocks won't show up. You have to use a Palmgren Miner's equation which adds all the fatigues together. A true estimation of the system fatigue is the sum of all the mechanical, thermal, and acceleration fatigues. This is true of all stress and strain calculations.

For tin-lead, 99% of the fatigue is in the thermal element, so analysis has typically focused on that portion of the fatigue. With the SAC 305 family, acceleration and shock adds a surprise element. Since the material is sensitive to shock, a fairly small number can drastically change the results.