Failure Analysis: Evaluating a Low Strength Solder Joint

Rebecca Wheeling, Don Susan, Chris Finfrock, Celedonio Jaramillo, Christina Profazi
Sandia National Laboratories, Albuquerque, New Mexico, USA
rwheeli@sandia.gov
505-845-7621

"Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525."

Introduction (200 words)

As part of a surveillance effort, a 30-year-old solder joint that exhibited one third the required strength was identified. A failure analysis ensued, to identify the root cause of the low strength, the objective being to determine whether a materials aging mechanism was to blame.

50Sn-47Pb-3Sb solder was used in structural solder joints for a nickel component that was fabricated over 30 years ago. This alloy was likely chosen for its improved creep strength compared to binary Sn-Pb solder, though a reduction in "wettability" is reported to accompany the improved mechanical properties. Wettability refers to the ability to coat and react with a substrate surface, and is the basis for producing a high quality, metallurgical bond in a solder joint. A schematic for the cylindrical lap joint is shown in Figure 1.

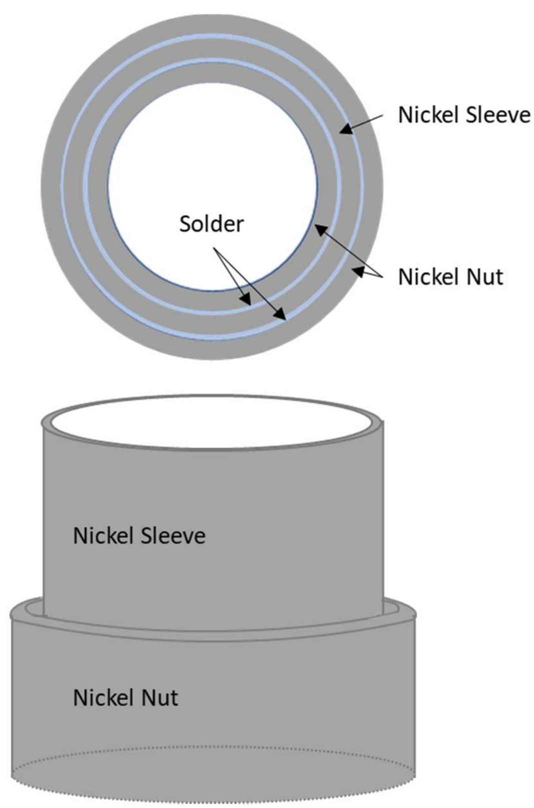

Figure 1. Schematic of the cylindrical double-lap joint. Note: this schematic is not to scale.

During fabrication, a number of units were pulled to failure. If these units did not meet the strength requirement, the lot was scrapped. In 2016, a surveillance effort to investigate current joint strengths after ~30 years of aging was initiated. Figure 2 shows load-displacement data from the pull tests.

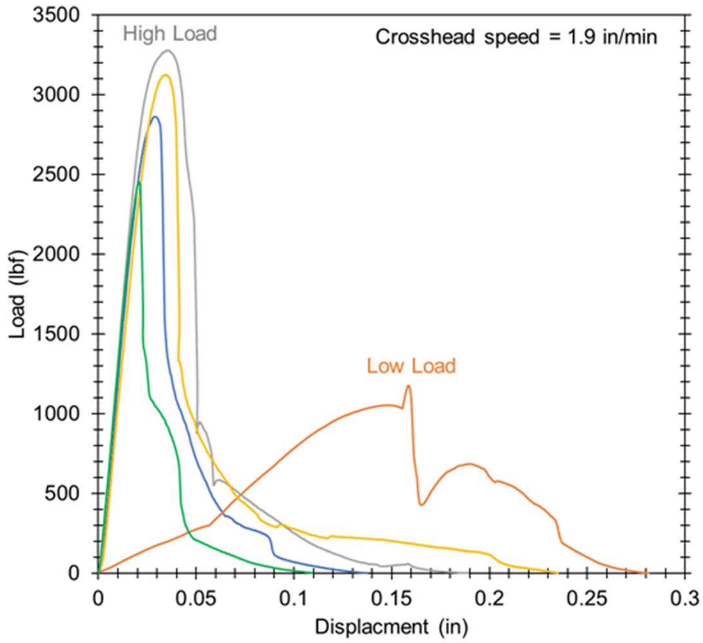

Figure 2. Surveillance pull-test load-displacement data.

While average strength values of the units decreased, a few units fell below the required strength value, and one unit exhibited very low strength compared to the others. A failure analysis was performed to explain this strength reduction.

Experimental Procedure (300 words)

Non-destructive and destructive characterization methods were used to examine and compare the low strength failure with higher strength failures as well as untested units. Fracture surfaces, failure locations, solder volume, porosity levels, solder hardness, solder composition, and solder microstructure were evaluated.

Optical and electron microscopy methods were used to initially examine the solder fracture surfaces, as received. Untested, high strength, lower strength, and the lowest strength units were then sectioned for viewing longitudinal and transverse orientations of the joints for further metallographic analyses.

Wavelength dispersive spectroscopy (WDS) was used for composition and microstructure evaluation via a scanning electron microscope (SEM)/electron probe microanalysis (EPMA), and microhardness testing was performed to compare the joints' mechanical properties.

Measured mechanical properties of aged bulk solder were compared with literature data to quantify the extent that aging contributed to strength degradation.

Results and Discussion (300 words)

Hardness testing, SEM imaging, and wavelength dispersive spectroscopy (WDS) reveal similar microstructures between untested, high, and low strength joints. These similarities indicate that the joints were all aged in similar conditions and confirm the solder composition to be the same. Hardness values hovered around a nominal 11 Vickers as shown in Figure 3.

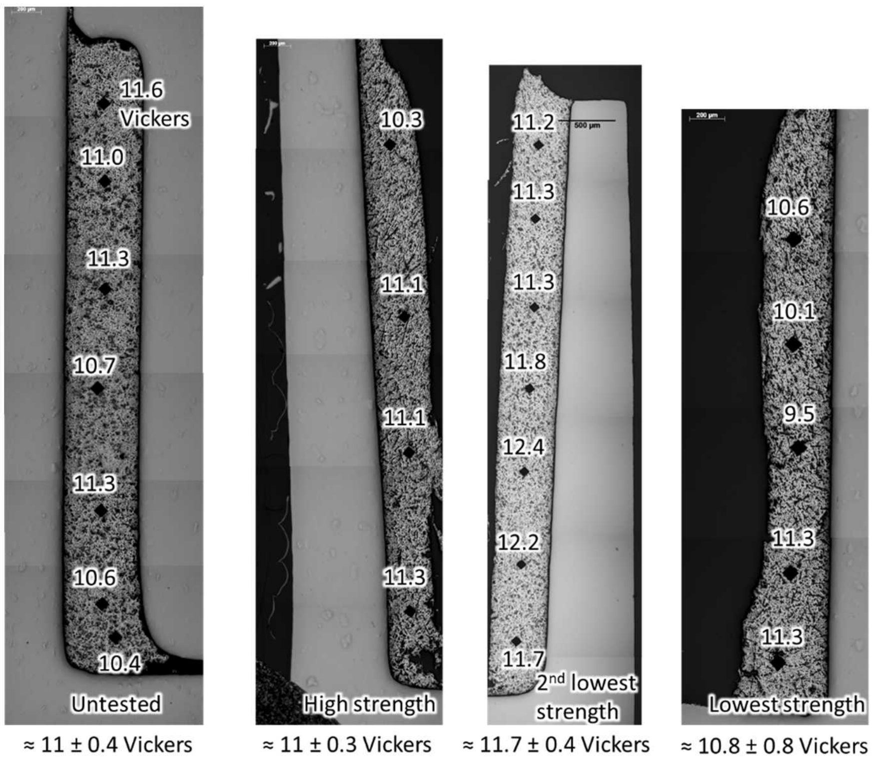

Figure 3. Microhardness indents and corresponding hardness values along the longitudinal axis of the solder joints. Average values are listed at the bottom of each joint.

WDS maps in Figure 4 show similar phase morphology and distribution throughout the solder joint between an untested, high, and low strength joint.

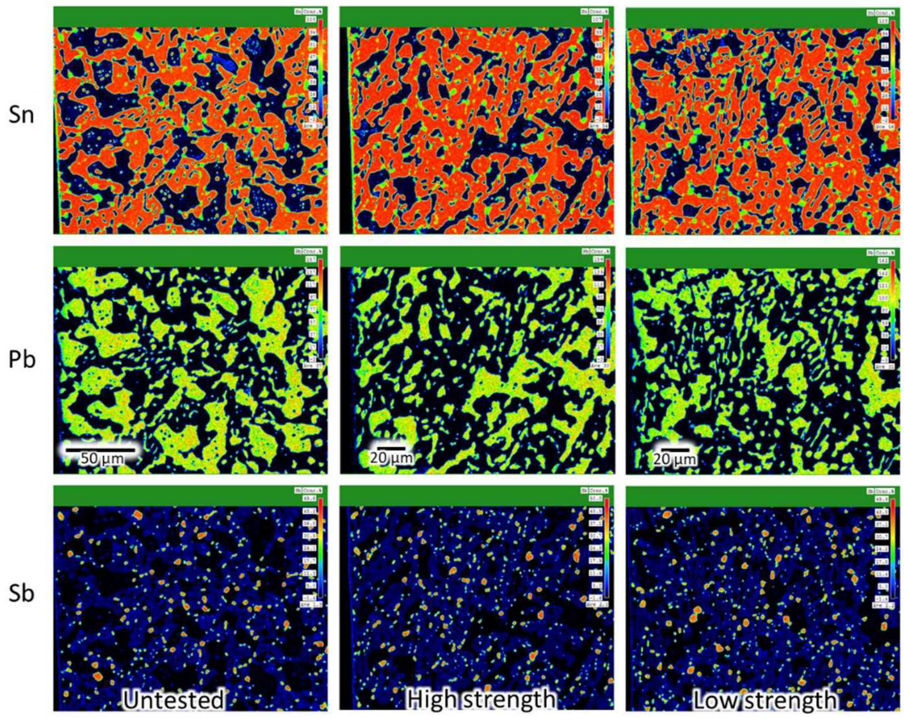

Figure 4. WDS maps of the bulk solder microstructure in high, average, and low strength units. Each column represents 3 different elements mapped onto the same image from a given sample. Each row maps a different element, from top to bottom: Sn, Pb, Sb. The colors correspond to signal intensity level, with red being the highest and blue being the lowest. Scale bars can be applied to their respective columns.

Fractographic and metallographic analyses identified 3 failure modes within the solder joints: 1) shear ductile; 2) porosity-assisted; and 3) interfacial. Higher fractions of porosity-assisted and interfacial failure likely contributed to low strength. Evidence of these failure modes in a high strength and 2 low strength joints is shown in Figure 5.

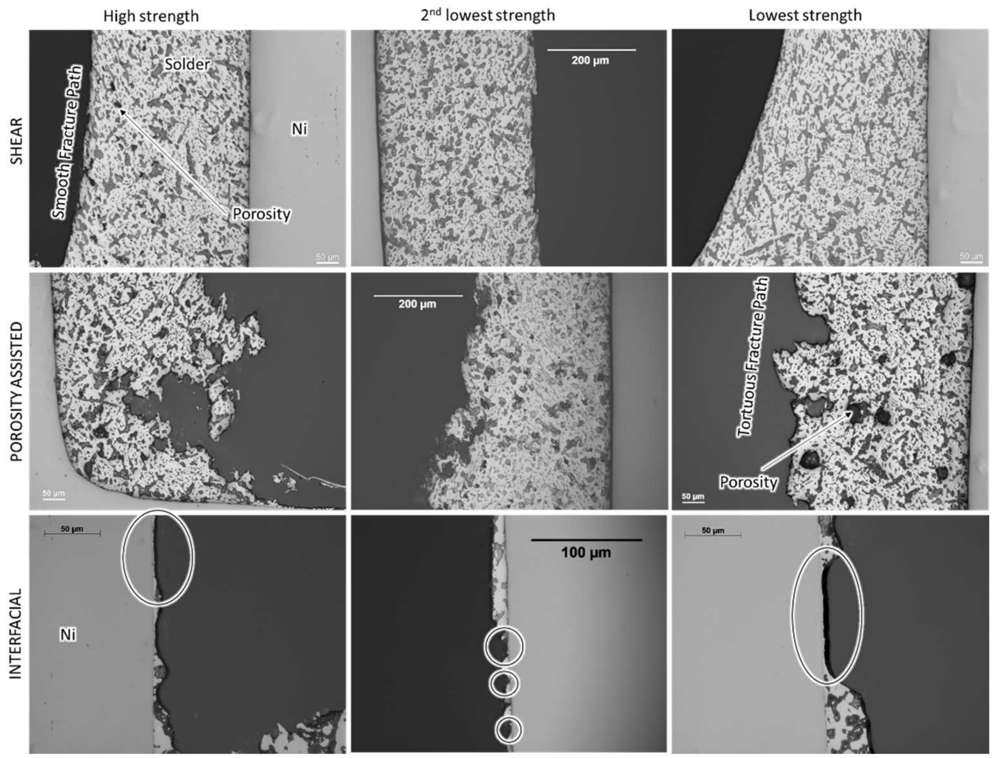

Figure 5. Optical images highlighting the 3 longitudinal fracture paths exhibited between high and low strength joints.

Conclusion (200 words)

Fractographic and metallographic comparisons between the high and low strength tested units suggest that the prevalent, local porosity-assisted and interfacial failure modes contributed to the low-strength failure. While other units exhibited some interfacial failure and porosity-assisted failure, the conditions were not as extreme as that exhibited in lowest strength unit. Figure 6 illustrates how these failure modes may have manifested during the tensile test.

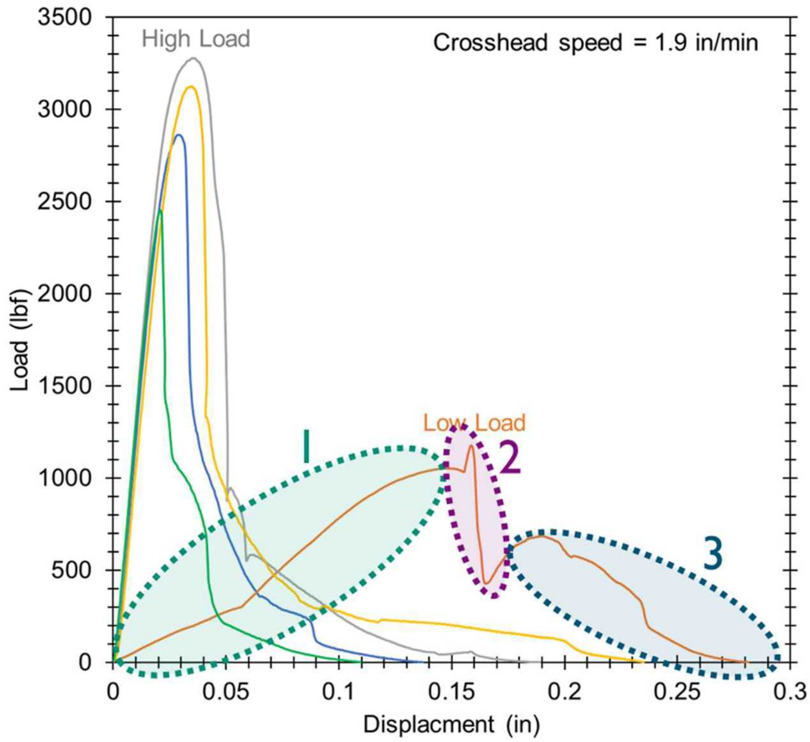

Figure 6. Load-displacement curves recorded during the surveillance tensile testing. The anomalous, low load curve is separated into 3 regions: 1) porosity-assisted failure; 2) rapid, interfacial failure; and 3) porosity-assisted failure with uneven loading conditions.

It is plausible that localized porosity aligned near a stress path contributed in regions 1 and 3, while rapid, interfacial failure occurred at region 2. Uneven loading likely resulted after the interfacial failure. Possible artifacts from testing are not presented or discussed.

The source of porosity could have been due to an undocumented process variable during the soldering procedure (i.e. inappropriate type/amount of flux). Poor wetting may have also resulted from inappropriate type/amount of flux in addition to joint disturbance prior to solidification, porosity accumulating at the interface, and/or improper cleaning methods, therefore facilitating interfacial failure.