Purdue University
Materials Engineering

Improving Manufacturing Quality of Electronic Devices Fabricated Using Pre-Soldering Deformation

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Ball grid array (BGA) circuit boards contain two boards with copper solder pads that are connected through solder balls that provide both electrical connections and structural. BGA boards warp during reflow due to the different CTE values of components which results in solder ball defects leading to poor connectivity. The solder balls were deformed prior to reflow at 1 N, 2 N, and 3 N per ball. The boards were reflowed with a blank board placed on top. Cross-sectional analysis using SEM was conducted to identify microstructural changes at the intermetallic Cu-Sn interface. The boards were sheared at constant velocity to failure to observe differences in brittle or ductile failure between deformed and undeformed samples. No signs of significant microstructural changes or defects towards the interface or deformed surface were observed. Mathematical and optical analysis of deformed area showed no correlation between load and ball displacement. Shear testing showed no difference between fracture surface of deformed and undeformed, suggesting similar mechanical properties.

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Project Background

Ball grid array (BGA) warpage occurs during reflow and is caused by a difference in thermal expansion between the epoxy printed circuit board (PCB) and the solder balls. BGA warpage can cause defects in solder joints, such as voids, cracks, and the head-in-pillow defect. Defects in solder joints cause failure in PCB connections and thus in products.

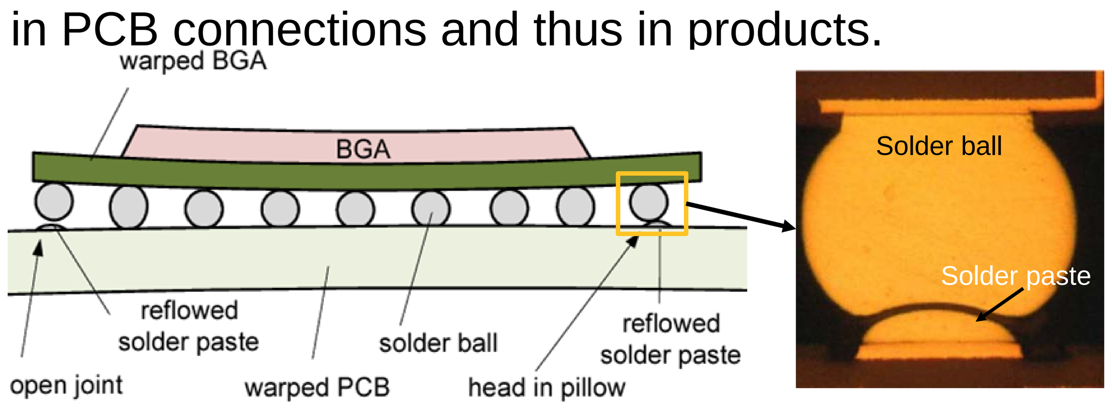


Figure 1: Head-in-pillow defect (1. Bušek, D., et al, 2. Arazna, A.)

SAC305 is used in Juniper Networks' products. SAC305 forms a Cu_6Sn_5 intermetallic layer with the Copper pad on the circuit board. Understanding the microstructures and properties of SAC305 is crucial to maintaining proper reflow conditions and forming strong connections. Solder balls have small size scales and thus display different mechanical behaviors (such as flow stress and yield stress). Tin is also anisotropic, and the various orientations of grains impact mechanical properties.

Experimental Procedure

Materials Used

Solder balls of 2 alloys 650 μm in diameter were used;

- 96.5%Tin - 3%Silver - 0.5%Copper (SAC305)
- 95.5%Tin - 4%Silver - 0.5%Copper (SAC405)

Two types of 12x12 mm solder pad PCBs were used;

- Electroless Nickel Immersion Gold (ENIG)
- Organic Solderability Preservative (OSP).

Test Vehicle Preparation

Eight balls were reflowed at the corners (two on each) of each board using Alpha OM-338 paste flux to create the BGA test samples. Each pair of solder balls was either left undeformed, or deformed at 10, 20, or 30 N using a Leco Microindenter and an Instron load cell.

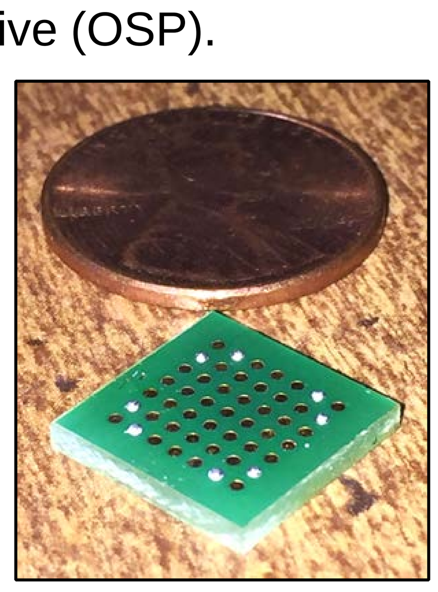


Figure 2. Reflowed single BGA with 8 solder balls. Penny for scale.

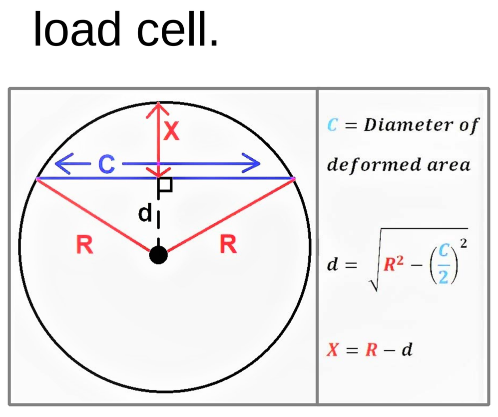


Figure 3. Geometric diagram of how the displacement (X) was calculated based on the deformed diameter (C) found optically, and radius (R).

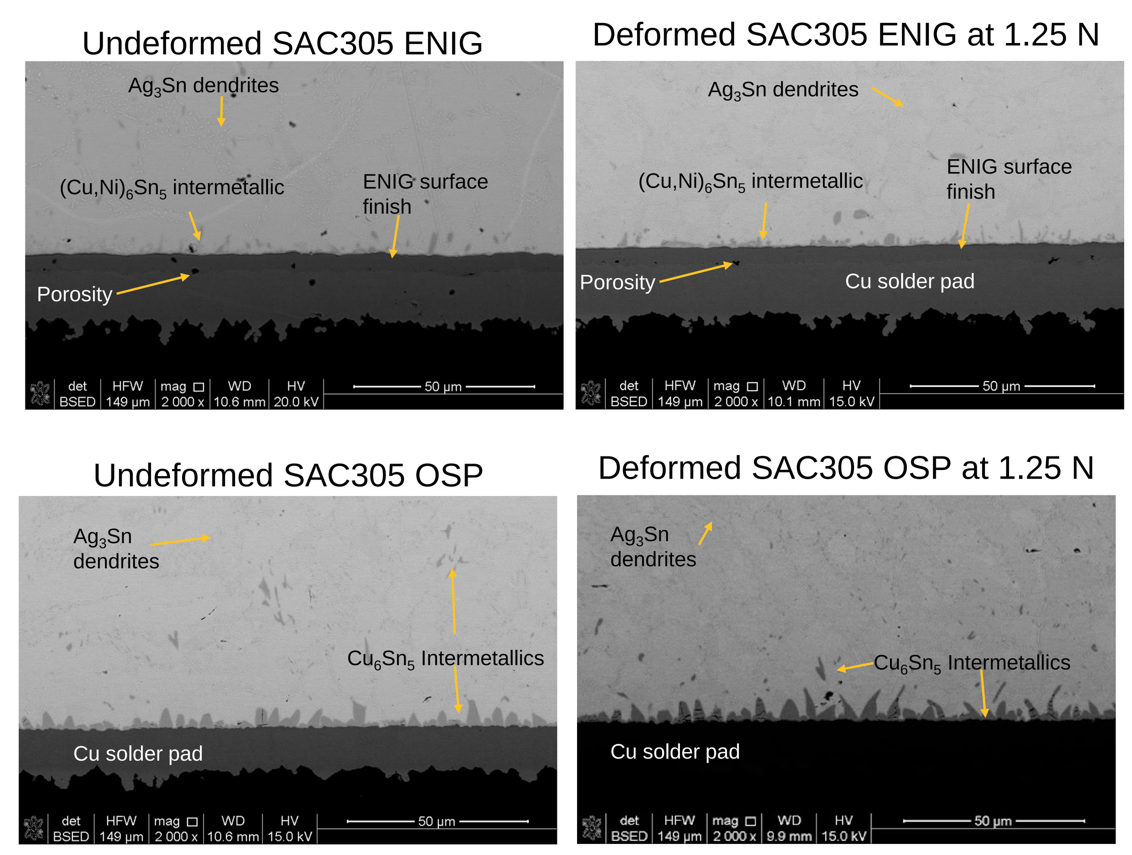
Deformation Analysis

Optical images of deformed areas were used to calculate displacement. The deformed PCBs were "sandwiched" by reflowing another PCB on top of the existing solder. SEM images were taken of solder balls to determine effect of deformation on microstructure and intermetallics.

Shear Testing

The sandwiched boards were sheared at a constant velocity to study structural integrity. A motor pulled one board at 2 μm/s on one axis, and load vs displacement was measured to determine strength of the solder. Optical images were taken of the shear surface and categorized as brittle or ductile failure.

Microstructure



Deforming the solder balls did not have a quantifiable impact on the solder ball microstructure. There were no unusual defects in the deformed solder ball interfaces.

Shear Testing

The fracture surface images of deformed sandwiched samples after shear testing showed no significant brittle failure as compared to the undeformed samples.

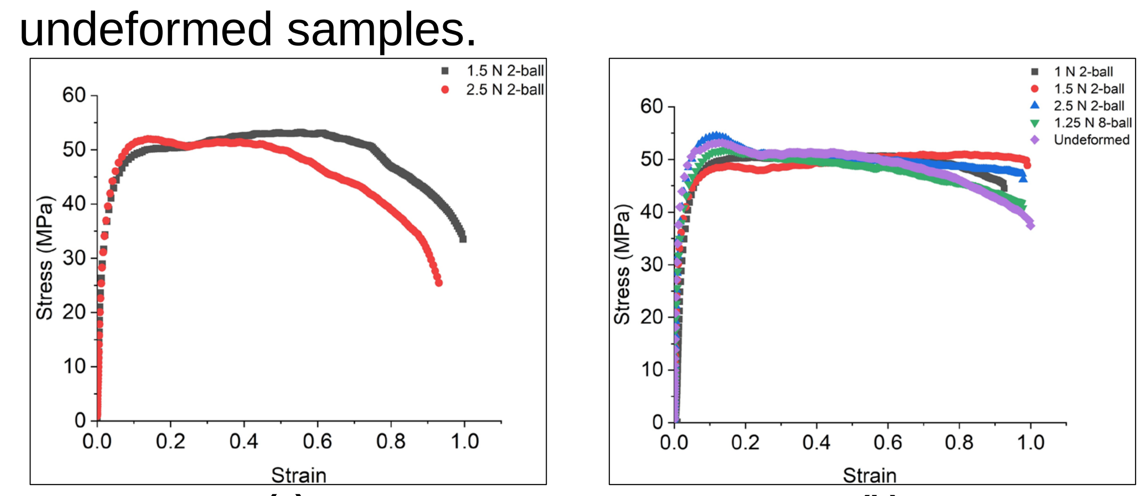


Figure 4. Stress vs strain curves from shear testing of deformed and undeformed, sandwiched SAC305 **(a)** OSP and **(b)** ENIG

The stress vs strain plots for deformed and undeformed samples showed no significant difference or trend. Any variation was likely caused by residual super glue left on test vehicle, tilting the samples off-axis.

Sandwiched Board

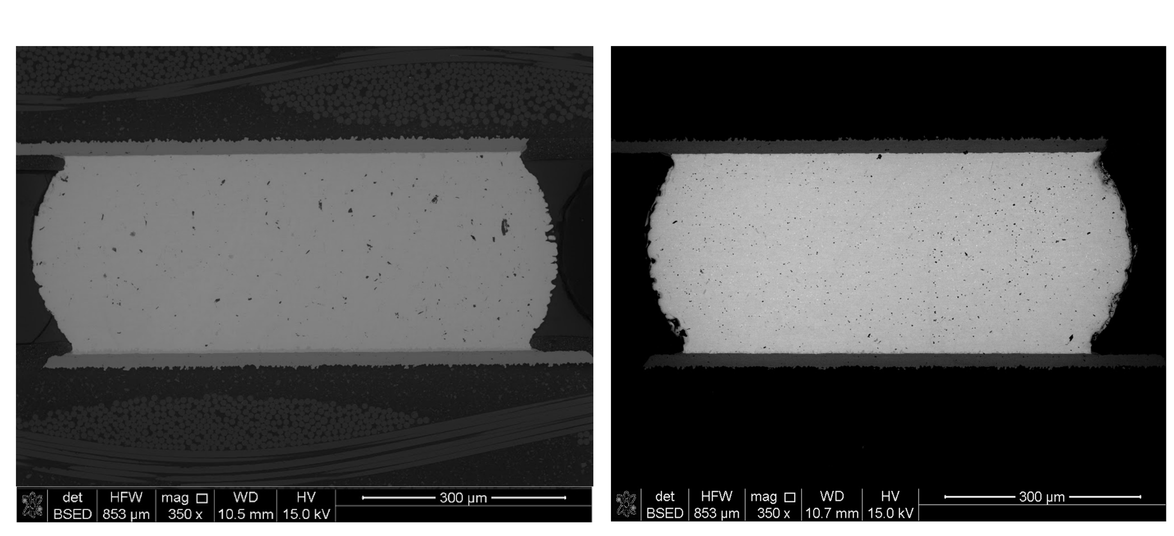


Figure 5. Micrographs of **(a)** an undeformed, sandwiched SAC305 ENIG board and **(b)** a deformed, sandwiched SAC305 ENIG board. Solder joint **(b)** was deformed at 1.25 N prior to forming the joint. The micrographs show that the undeformed ball and the deformed ball form intermetallics with the top board.

Sandwich structures made of deformed balls display similar microstructures and reflow properties. Any porosity and defects were observed in both deformed and undeformed boards. The solderability of the ball was not impacted by deformation.

Discussion

The undeformed and the deformed solder balls had similar microstructures. No unusual defects, such as cracking or delamination at the intermetallic interface between the solder ball and the solder pad were observed. This suggests that the force applied to the solder balls was enough to deform the top of the ball, but not enough to damage the interface. These results are positive for future applications where a higher number of solder balls will be deformed.

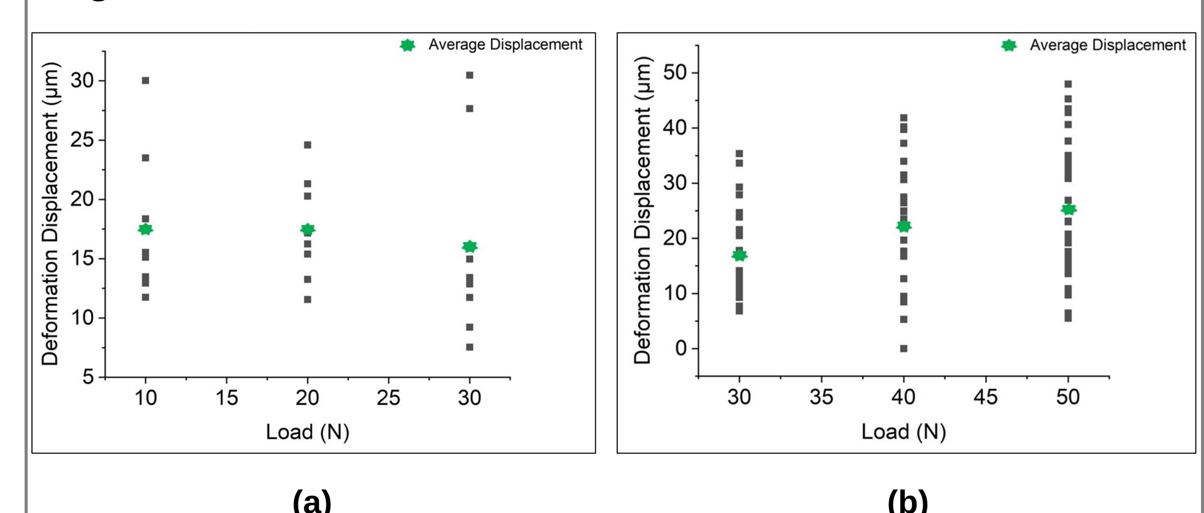


Figure 6. Load versus deformed displacement graphs for **(a)** SAC305 ENIG and **(b)** SAC305 OSP solder balls. Average displacements are shown in red. No trend can be observed.

Calculated displacement values, assuming a uniform sphere and an even distribution of displaced mass, showed significant variation, possibly due to initial height differences. If a large solder ball is adjacent to a smaller solder ball, then the smaller will deform less. A viable method for measuring these heights is necessary to determine planarity.

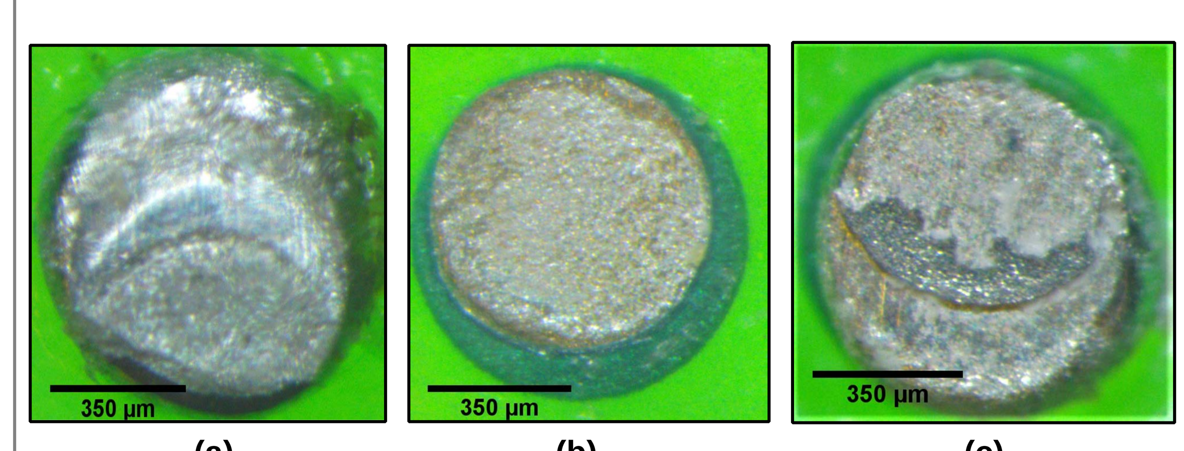


Figure 7. Optical images of 2 um/s constant velocity sheared sandwiched ENIG solder balls showing **(a)** ductile fracture, **(b)** brittle fracture and **(c)** brittle fracture after initial ductile slip.

Deformed samples showed no signs of abnormal or brittle failure compared to undeformed samples during shearing. This was expected since both had similar microstructures. Furthermore, the deformed samples were reflowed during sandwiching, relieving the internal stresses and resetting the solder balls to their original undeformed state.

Recommendation

The microstructures and shearing data for the deformed and undeformed solder balls were similar. There were no unusual defects in the intermetallic interface for the deformed solder balls. Deforming the solder balls prior to sandwiching should not have any impact on solderability. It is thus recommended to deform solder balls prior to sandwiching. Further testing is needed to determine exact deformation distance for specific loads, as well as a better method for measuring the height of the solder balls.

Acknowledgements

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