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Electron Back-Scattered Diffraction Characterization of Microstructures in Dynamically Deformed Pb-Sn Solder

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There is an increasing concern about the dynamic reliability of packaged electronic components exposed to shock loading environments. In order to predict shock reliability, fundamental material property data is required at the appropriate strain rates. Solder, which is a critical structural element and typical failure point for packaged electronics, is specifically expected to be sensitive to strain-rate due to the active role of diffusion in its deformation. Our research uses dynamic testing of Pb-Sn solders employing a new high strain-rate servohydraulic method [1]. This unique approach differs from the split-Hopkinson bar technique that is routinely used in the literature in that it permits testing at the most appropriate strain rates for shock, in the range of 10^0-10^3 1/s, and it can also be used for traditional tensile testing at rates of 10^{-5}-10^1 1/s, thereby permitting a survey of strain rates spanning more than 7 orders of magnitude using one technique.

This paper describes the role of microstructure in the strain-rate sensitivity of eutectic 37Pb-63Sn solder processed by two conditions: normalized at 100C for 24hr and normalized+aged at 150C for 72 hr. Extensive development effort focused on identifying a method to cast the required threaded cylindrical tensile bars that was both void-free and similar in microstructure to solder balls found in electronic components. Centrifugal casting, lost-wax investment casting, and bullet-mold casting were all evaluated to identify the optimal processing method. Of these techniques, bullet-mold casting was found to meet the above requirements and produce a suitable, homogeneous microstructure.

The observed stress-strain constitutive behavior, shown in Figure 1, demonstrated quite repeatable measurements, with the two repeated datasets in coincidence for every strain rate and processing condition. In both conditions, the solder exhibited dramatic strain-rate sensitivity both in the yield strength and in the work hardening rate. Specifically, at quasi-static strain rates, solder plastically flowed quite easily with very little strain hardening, whereas in dynamic loading, solder became much more resistant to plastic flow, both with an increased yield stress and an increased work hardening rate.

Electron back-scatter diffraction (EBSD) techniques were used to try to connect the clear difference in mechanical behavior with a change in microstructure. Samples were prepared using standard metallographic preparation techniques with careful final polishing using a vibratory polisher with 0.05μm colloidal silica. The EBSD measurements were performed on a Zeiss Supra 55VP FEG-SEM at 20keV. The EBSD patterns were collected and analyzed using the Oxford/HKL Channel5 system with a Nordlys CCD detector. Both maps (50μm by 50μm) and large scale line scans (3mm) were taken to assess the local microstructure and the overall texture of the samples.

The EBSD measurements allowed us to asses several key microstructural quantities: (a) the spatial distribution, size, and shape of Sn-rich and Pb-rich phases, (b) the crystallographic microtexture of each phase, and (c) the distribution of intra grain misorientation which is related to the level of strain gradient plasticity in each phase. [2] The results show distinct differences in the microstructural deformation features when comparing low versus high strain rates (Figure 2). In the normalized condition, slow-rate (0.02in/sec) deformation favors subgrain formation in the Sn phase ($2^\circ<\theta<10^\circ$, red lines) within otherwise large (>50μm) Sn grains. In the higher strain rate sample (100in/sec), the microstructure for the Sn phase breaks up into ~5μm grains separated by high angle grain boundaries (>10˚).

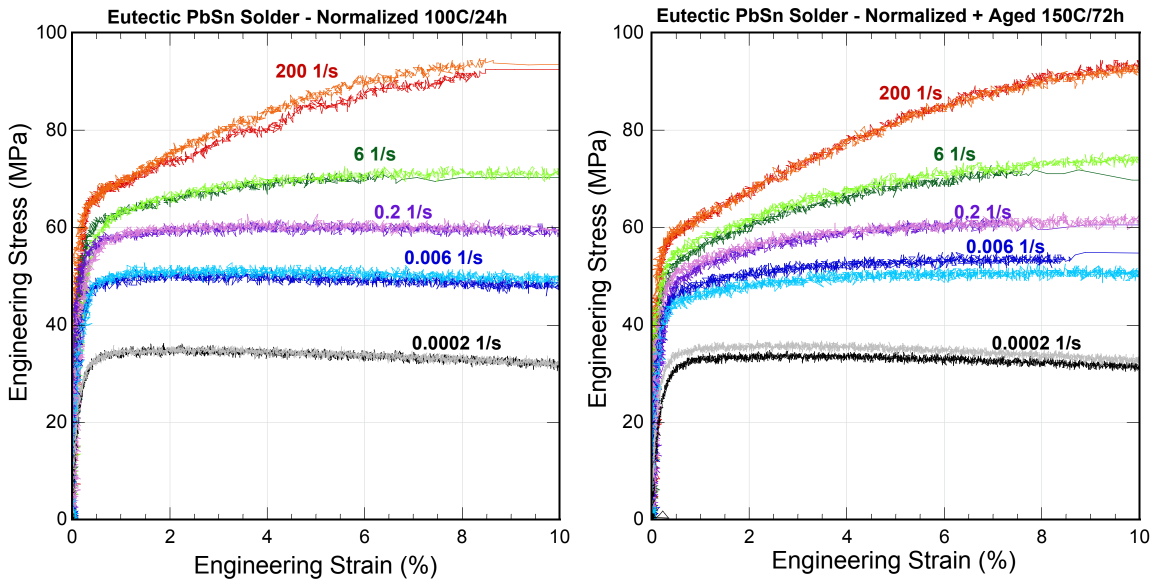

Figure 1. Tensile data strain rates in the range of $10^{-4}s^{-1}$ to $10^{2}s^{-1}$ for two solder conditions.

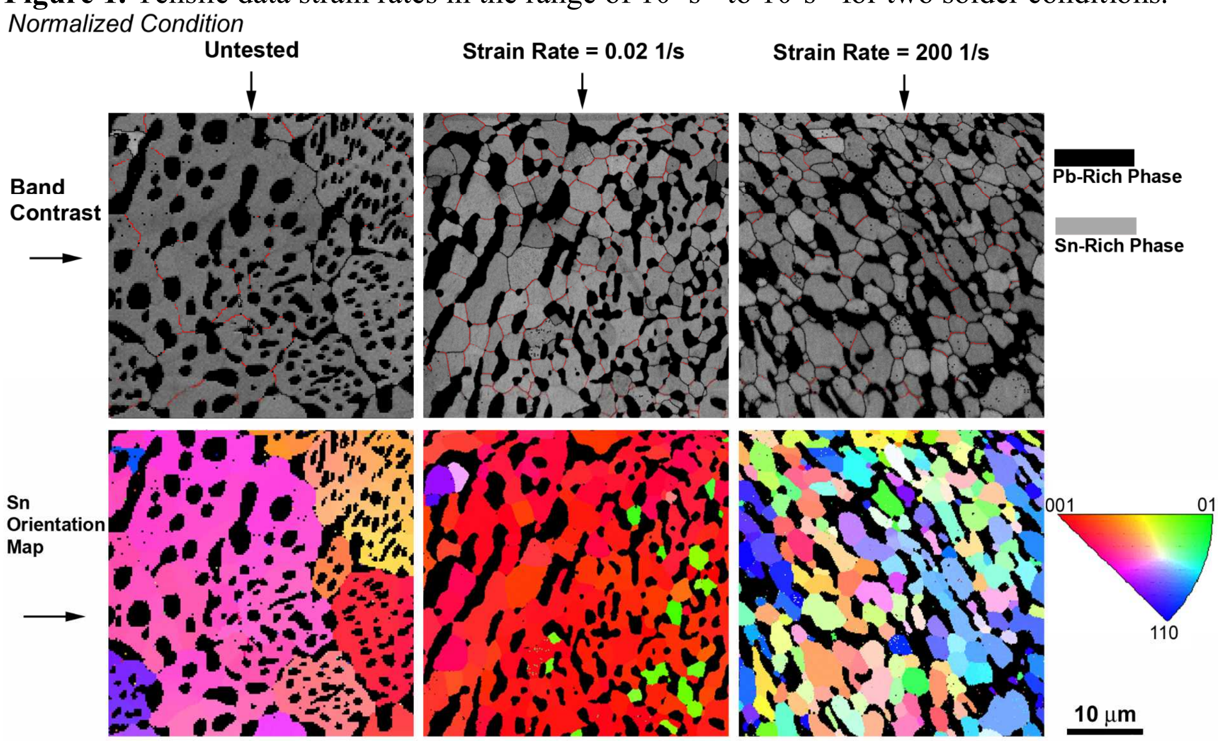

Figure 2. EBSD analysis of PbSn solder in the normalized condition before and after tensile testing at two strain rates. Red lines in the band contrast maps of the Sn phase indicate low angle boundaries (2˚<θ<10˚); black lines represent high angle grain boundaries (θ>10˚). The color scale in the Sn orientation maps (inverse pole figure) indicates relative grain orientation with respect to the tensile axis of the sample.

1. **Boyce, B.L., *SAND2005-5678*. 2006, SAND.**
2. **Brewer, L.N., et al. Microscopy and Microanalysis, 2006. 12: p. 85-91.**
3. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United Stated Department of Energy (DOE) under contract DE-AC0494AL85000.