Length Scale and Aging Effect on the Mechanical Properties of a 63Sn-37Pb Solder Alloy

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Abstract

In this work, uniaxial tensile testing of a 63Sn-37Pb alloy with different specimen sizes and aging conditions had been carried out. Although the stress-strain responses of different specimen sizes and aging conditions differs, the ultimate strength of the specimens with 16 hours, 100°C aging are similar for the sizes tested. The specimens with 25 days, 100°C aging have different stress-strain response with different sizes, and have a lower ultimate strength and higher failure strain compared to 16 hours, 100°C aging specimens.

Introduction

Surface mount technology of electronic components is becoming more popular to reduce the size of electronic packaging. In order to assess the reliability of the packaging, it becomes important to understand the thermal-mechanical properties of solder interconnects. Previously, all constitutive modeling of SnPb solder alloys was based on the thermal-mechanical testing of bulk material which is typically hundreds of times larger than the solder interconnects. As the size of solder interconnects becoming smaller and approaching similar length scale of the constituents particles (individual grains, size of different alloy phases), the thermal-mechanical properties may not resemble that of bulk scale [1]. Moreover, since room temperature is already a high homologous temperature for typical solder alloy, there is significant aging effect or grain coarsening during the service life of the electronic component. These effects may affect the thermal-mechanical properties of the solder interconnects even without repeated thermal or mechanical loading [2]. It is therefor important to study the mechanical properties of solder alloy with different sizes and different microstructures (results from various aging conditions). As a result, constitutive modeling of solders can also include parameters of length scale to better predict the reliability of solder interconnects.

Specimen preparation and testing

The solder alloy under this study is a 63Sn-37Pb alloy in solid wire form supplied by Kester Solder. Specimens of various sizes were fabricated by casting. All specimens were made with a circular cross section with three different diameter sizes: 1) 6.35mm; 2) 1.0mm; and 3) 0.35mm. The gage length of each specimen was made the same as the diameter size such that all specimens have a same geometry.

Figure 1 shows the casting mold for the 1mm specimen. Two brass rods were clamped to both ends of the aluminum mold. The mold was heated to 200°C, above the melting point of Pb-Sn solder which permits flowing the molten alloy into it. The mold was then cooled at a rate about 10°C/min, and the SnPb alloy solidified. The specimen, solder with brass ends, was released from the mold and transferred to a fixture, which prevents solder from deforming during

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handling and kept the assembly aligned. The solder assembly was placed in the oven for aging treatments to produce the desired microstructures. In the present study, two different aging treatments were used: 1) 16 hours in 100°C atmospheric air (16H); and 2) 25 days in 100°C atmospheric air (25D).

Uniaxial tensile tests using a MTS Tytron microforce testing system were performed on specimens with sizes 1.0mm and 0.35mm in diameter. Figure 2 shows the test setup, the two brass ends were attached to the load cell and the actuator of the Tytron loading frame, respectively. An extensometer was attached to the specimen for recording the strain at the gage section. The 6.35mm specimens were tested by conventional MTS servo-hydraulic loading frame since the failure strength of 6.35mm specimens far exceed the loading capacity of the Tytron system. A ramp function was applied to the displacement of the actuator such that the approximate strain rate at the gage section was 10^{-4} /s. All uniaxial tests were conducted in room temperature and run until the specimen failed. Three specimens were tested for each heat treatment and each size to ensure repeatability of test results.

Results and discussion

The stress-strain responses of specimen 2 from each size and each heat treatment were plot in Figure 3 for comparisons. All stress-strain curves have an initial elastic response, flat out with the ultimate strength and then following a rather constant strain softening rate until failure. Table 1 summarize the ultimate strength (σ_u) and failure strain (ϵ_f) for each specimen. In both Figure 3 and Table 1, specimen size is the specimen diameter in the gage section.

The results are preliminary. However, some trend can still be observed from all 1.0mm and 0.35mm specimens. In general, the specimens subjected to 25D aging have a lower σ_u and a less negative strain softening rate beyond yielding. And for 1mm specimens, ϵ_f is larger for 25D specimens than that of 16D specimens, however, this trend is not obvious for 0.35mm specimens.

It is then necessary to study the microstructure of specimens with different aging to draw a qualitative analysis of these observed trends. Here, we will study one 1mm specimen each of 16H and 25D aging. Figures 4a and 4b are scanning electron microscopy (SEM) image of the fracture surfaces of one 16H specimen and one 25D specimen normal to the axial loading direction, respectively. Obviously, both fracture surfaces reveal that the fracture is ductile in nature, and since the strain to failure ϵ_f for the 25D specimen is larger, there is a further reduction in final fracture area.

We can then focus on one small area to investigate the fracture mechanism. Figures 5a and 5b both show the high magnification SEM image on a same area of a 25D specimen. Figure 5a is a normal scanning while Figure 5b is a back-scattered scanning which better reveals the chemical composition, dark area corresponds to Sn-rich phase and bright area corresponds to Pb-rich phase. Figures 5a shows various fracture lines, and for the corresponding places in Figure 5b, these fracture lines usually occurred between Sn-rich and Pb-rich phases. We can conclude that fracture occurs along the interface between Sn-rich and Pb-rich phases. Figures 6a and 6b are SEM back-scattered images of one 16H and one 25D specimens respectively, which reveal the

composition of Sn- or Pb-rich phases. Obviously, the 25D aging have a coarser microstructure. A coarser microstructure will have a lower interfacial energy as well as mismatch stress and strain among different phases. Their effects on the macroscopic mechanical response will require further study [3].

Conclusions and Future Works

In this work, uniaxial tensile testing have been performed on a 63Sn-37Pb solder alloy with various sizes and microstructures. The effect on size, or length scale on the ultimate strength is not obvious, though the failure strain differs. In general, the specimens having coarser microstructures had lower ultimate strengths and higher failure strains.

In order to make the testing and hence the constitutive modeling more complete, experiments have to be done under different temperature, specimen geometry and different mode of loading (e.g. torsion), with specimens of different sizes and aging treatments.

References

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Size (mm)	Aging	Specimen 1		Specimen 2		Specimen 3	
		σ_u (MPa)	ϵ_f	σ_u (MPa)	ϵ_f	σ_u (MPa)	ϵ_f
6.35	16H	40.0	0.29	45.0	0.31	41.0	0.23
1.0	16H	42.5	0.63	40.7	0.66	41.0	0.58
1.0	25D	37.4	0.73	35.4	0.80	35.5	0.74
0.35	16H	41.1	0.67	41.3	0.75	43.2	0.52
0.35	25D	39.9	0.46	38.7	0.69	34.8	0.63

Table 1 Summary of test results of various specimens. Where sizes are specimen gage diameter. For aging, 16H = 16 hours in 100°C atmospheric air; 25D = 25 days in 100°C atmospheric air.

Figure 1 Specimen mold and brass ends for casting PbSn alloy specimens.

Figure 2 Specimen as mounted on MTS Tytron loading frame.

Figure 3 Stress-strain curves of various representative specimens with different sizes and heat treatments.

Figure 4a SEM image of fracture surface of a 1mm, 16H specimen, viewing normal to the axial loading direction.

Figure 4b SEM image of fracture surface of a 1mm, 25D specimen, viewing normal to the axial loading direction.

Figure 5a SEM image of a 1mm, 25D specimen, showing physical feature of a fracture site.

Figure 5b Back-scattered SEM image of a 1mm, 25D specimen, showing different Sn- or Pb-rich phases at a fracture site.

Figure 6a Back-scattered SEM image showing different phases of a 1mm, 16H specimen.

Figure 6b Back-scattered SEM image showing different phases of a 1mm, 25D specimen.