Dynamic mechanical behavior of Sn-Ag-Cu lead-free solders by tensile test under high strain rate†

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1. Introduction

The high acceleration vibration or the impact shock environment of various electronic components inevitably causes the exposure to high strain rates and the severe deformation of micro interconnects. Most lead-free solders are harder compared to the conventional Sn-Pb eutectic solder and have lower elongation properties. For this reason, it has been pointed out that the drop impact resistance of mobile devices deteriorates. Nevertheless, few cases were studied in detail for high-speed impact deformation of the solder [1]. Considering the future situation that more electronics would be used under high acceleration shock conditions, and that the type and amount of automotive electronics would increase, knowing exactly the tensile behavior of lead-free solder at high-speed impact can be used for analyzing the impact corruption of lead-free solder joints. It is expected that useful information for the design of long life lead-free solder joints against destructive impact can be obtained.

In this study, therefore, for several lead-free solders, high strain rate tensile tests were carried out over three orders of magnitude faster than the rate of the tensile test in the former study [2][3], in particular, including additional low silver content solder (Sn-1Ag-0.7Cu) which has been frequently used recently due to its cost advantages. We aimed to clarify the differences from traditional tensile behavior and the deformation characteristics of lead-free solder.

2. Experimental

From the fundamental physical point of view, the mechanical properties of Sn-Ag-Cu solders (Ag content 1.0 - 4.0 vol %, Cu content 0.5-1.0 vol %) were investigated using a high speed universal tensile test machine in the high strain rate range ($1.6\times10^{-3}s^{-1}$ 1.6×10^{1} s^{-1}). Cylindrical test rods (diameter: 10mm, gauge length: 50mm) were provided for the tensile tests according to the testing method described in JIS Z 3198-2 adopted so far for the normal tensile test [4]. For Sn-Ag-Cu based lead-free solder alloys, mechanical properties were evaluated by a uniaxial tensile test method by using the ultra-dynamic structural testing system (maximum dynamic load: 1,200 kN, maximum cross head speed: 1200mm/s, stroke: 500mm). During tensile loading the deformation of a test rod was observed by the dynamic analysis system equipped with high speed CCD camera (Keyence VW-6000). The mechanical parameters such as the tensile strength and the break elongation were evaluated. The UTS (ultimate tensile strength) and the rupture elongation were compared with those of the normal tensile test results (1.6×10^{-3} s^{-1}). The fracture surfaces were observed by an optical microscope.

3. Results and Discussion

Typical fracture surfaces of Sn-Ag-Cu lead-free solder alloys by optical microscope observation are shown in **Fig. 1**. In these photographs Sn-Ag-Cu lead-free solder alloys revealed ductile failures of cup and cone rupture in any

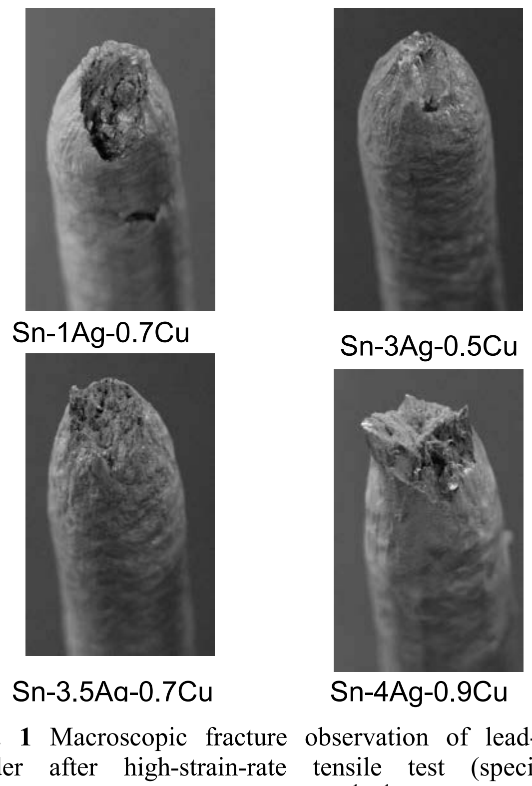

Fig. 1 Macroscopic fracture observation of lead-free solder after high-strain-rate tensile test (specimen diameter: 10mm, strain rate: 1.6×10^{1} s^{-1}).

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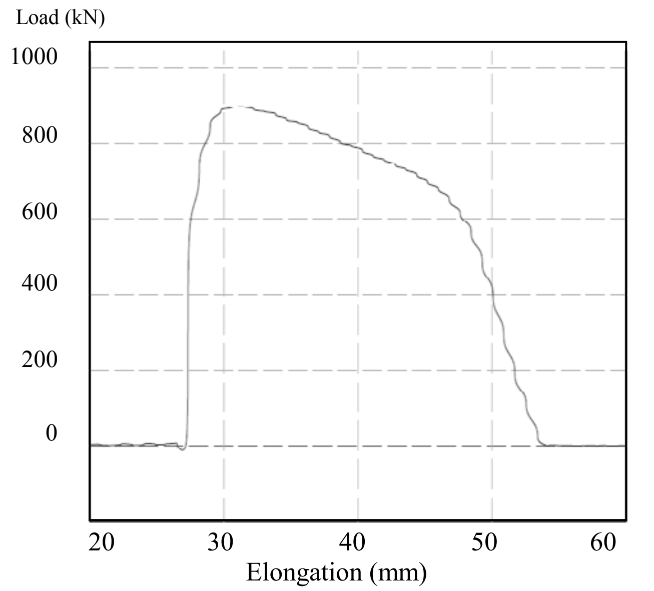

Fig. 2 Load – elongation curve of Sn-3Ag-0.5Cu under the high strain rate (strain rate: 1.6×10^1 s^{-1}).

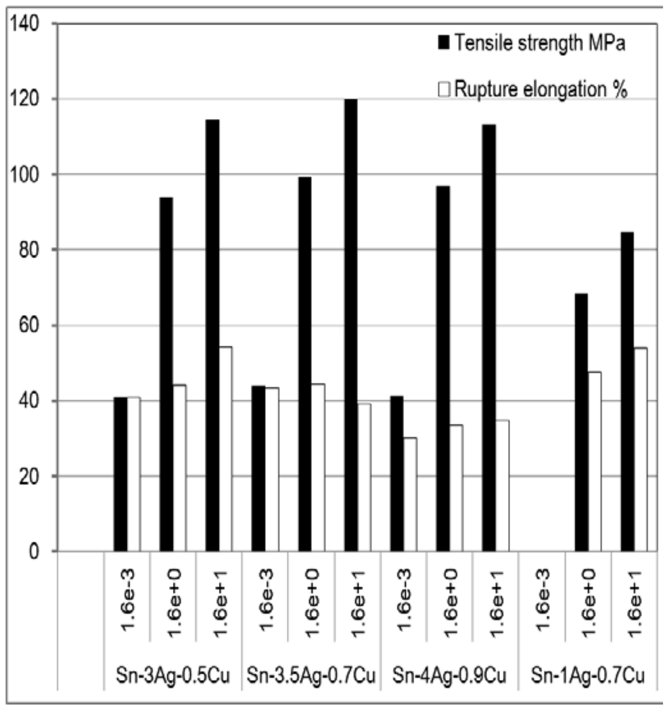

Fig. 3 Tensile strength and elongation of lead-free solder in high-speed tensile testing

composition. Among those, for Sn-3Ag-0.5Cu known as the most commonly-used eutectic lead-free solder, the extent of the necking was remarkable. The area of the fracture part was very small. Similarly, another nearly eutectic lead free solder, Sn-3.5Ag-0.7Cu exhibited the sharp cup-and-cone shape, though the cross-sectional area of breakage tends to increase. As for the hypereutectic alloy of Sn-4Ag-0.9Cu, the fracture area was larger than those of the former eutectic alloys, the macroscopic shape of the breakage showed the peripheral cleavage. On the other hand, the hypoeutectic alloy of Sn-1Ag-0.7Cu was intermediately ductile. The the fracture area had almost 45 degree angles to the tensile direction.

Figure 2 shows the typical load – elongation curve of the eutectic alloy Sn-3Ag-0.5Cu in the case of the high strain rate (strain rate: 1.6×10^1 s^{-1}). Since the strain rate is so high, even the ductile eutectic alloy exhibited a linear (elastic) region before the yielding point which was not observed under the low strain rate due to the creep phenomena.

Figure 3 shows the tensile strength and fracture elongation of high-strain-rate tensile testing of Sn-Ag-Cu lead-free solders. The top line of the horizontal axis indicates the strain rate for each alloy composition. Tensile strength increased more than twice as compared to the standard static tensile tests (strain rate: 1.6×10^{-3} s^{-1}) in all alloy compositions. As for the fracture elongation, on the contrary, the strain rate dependence was obscure regardless of the alloy composition.

4. Conclusions

Tensile tests under high strain rates of 1.6×10^0 $s^{-1}$to 1.6×10^1 s^{-1} were performed for the evaluation of the mechanical properties of several kinds of Sn-Ag-Cu lead-free solders. All Sn-Ag-Cu alloys showed ductile fractures. Eutectic composition revealed the highest strength under the high strain rate conditions. The tensile strength increased by 200-300 % compared to the value of the static tensile conditions at a typical strain rate of 1.6×10^{-3} s^{-1}. It was found that the load-elongation curve of each lead-free solder exhibited a clear elastic deformation under the highest strain rate of 1.6×10^1 s^{-1}. The rupture elongation did not show any clear dependence on the strain rate.

Acknowledgements

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