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Fracture Behaviors of Miniature Size Specimens of Sn-5Sb Lead-Free Solder under Tensile and Fatigue Conditions

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Abstract

Tensile and low cycle fatigue properties of Sn-5Sb (mass%) solder were investigated with miniature size tensile specimens. The effects of temperature and strain rate on tensile properties and the effect of temperature on low cycle fatigue properties were examined. Moreover, fracture behaviors of the specimens were investigated. Tensile strength and 0.1% proof stress increased with increasing strain rate and decreased with increasing temperature. The effects of temperature and strain rate on elongation were negligible. Chisel point fracture was observed in all specimens after the tensile test. The low cycle fatigue life of Sn-5Sb obeyed the Manson-Coffin's equation and fatigue ductility exponent, α was approximately 0.6 in the temperature range from 25 ^{o}C to 150 ^{o}C. From the observation for fracture surfaces and side areas of the fractured parts, it was found that cracking such as phase boundary cracking is dominant under fatigue conditions in the miniature size Sn-5Sb alloy.

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Keywords: Lead-free solder; Sn-5Sb; Miniature size specimen; Fatigue properties; Fracture behaviors

1. Introduction

From the viewpoint of environmental problems, lead-free soldering has spread around the world. Sn-Ag-Cu lead-free solder such as Sn-3.0Ag-0.5Cu (mass%) has spread as the substitute of Sn-Pb eutectic solder. In power semiconductor modules, Pb-rich solder containing approximately 10 mass% Sn have been used as a die attach material. In recent years, many high-temperature lead-free solder such as Au-based, Zn-based, and Bi-based solder have been

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investigated to apply to lead-free solder for power devices. However, the optimum substitute material for Pb-rich solder has not been developed. Although Pb-rich solder used in the field of specific high-temperature solder has not been regulated by RoHS restriction yet, such lead-free solder is expected to be developed [1-6]. For the die attach material of the power module, both high thermal fatigue reliability and high heat resistance are required. Sn-Sb alloys have attracted attention as a candidate of the die attach material. In particular, Sn-5Sb (mass%) has been expected as a substitute for Pb-rich solder because it has excellent thermal fatigue properties and relatively high fracture strength. Then, many studies on mechanical and physical properties of a Sn-5Sb alloy have been conducted [2, 7]. In the conventional study, the large specimen with several millimeters diameter which is much larger than the real solder joint has been used to investigate the mechanical properties of solder alloys. Since the microstructure of the large specimen is different from that of the real solder joint, mechanical properties of them are also different [8]. Kariya et al. have developed the evaluation method of solder materials using a miniature size specimen with the microstructure similar to a real solder joint [8]. Using the method with the miniature size specimen, mechanical properties of many lead-free solder have been investigated [8-10]. The authors have investigated tensile and fatigue properties of Sn-5Sb with miniature size specimens in the previous study [11]. The aim of this study is to invesigate fracture behaiviors of the Sn-5Sb alloy under tensile and low cycle fatigue conditions using miniature size spesimens.

2. Experimental procedure

2.1. Specimen

An ingot of a Sn-5Sb (mass%) alloy was prepared. On the basis of the differential scanning calorimetry (DSC) measurement result, the solidus temperature and the melting finish temperature of the alloy were estimated to be 240 ^{o}C and 248 ^{o}C, respectively [11]. Solder wire with 1.2 mm diameter was fabricated by drawing the ingot. As-cast miniature size specimens with 2 mm gage length and 0.5 mm diameter were made from solder wire using a divided metal mold [8]. Casting was conducted using a hot plate, and the casting temperature and the maximum cooling rate in casting were 278 ^{o}C and 6 ^{o}C/s, respectively. In this study, as-cast miniature size specimens were used for both a tensile test and a low cycle fatigue test.

2.2. Microstructure observation

As-cast specimen was embedded in epoxy resin and the cross section perpendicular to the longitudinal direction was cut out to observe the microstructure of the specimen. The cross section was polished with #500-#4000 polishing papers and was subsequently polished using 1 μm alumina powder suspension. After polishing, the microstructure of the specimen was observed using an electron probe X-ray microanalyzer (EPMA).

2.3. Tensile test

A tensile test was conducted at a strain rate ranging from 2 x 10^{-3} s^{-1} to 2 x 10^{-2} s^{-1} at 25 ^{o}C, 125 ^{o}C and 150 ^{o}C. The test was conducted with a micro load test system (Saginomiyaseisakusho LMH207-10). Five specimens were tested under each condition. After the tensile test, fractured specimens were observed with a charge coupled device (CCD) microscope.

2.4. Low cycle fatigue test

A low cycle fatigue test was also conducted with the micro load test system. The test was conducted at a strain rate of 2 x 10^{-3} s^{-1} at temperatures of 25 ^{o}C, 125 ^{o}C and 150 ^{o}C [11]. In the test, strain was controlled using a symmetrical triangle wave and the total strain range, $\Delta\varepsilon_t$ was controlled in the range of 0.4 % to 2.0 %. Fig. 1 shows an example of hysteresis loop at fifth cycles in the low cycle fatigue test. The inelastic strain range, $\Delta\varepsilon_p$ was defined as shown in Fig. 1. The fatigue life was defined as the number of cycles in which the maximum load was reduced by 20%. After the low cycle fatigue test, fracture surfaces and side areas around fractured parts were observed using the EPMA.