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# Low-Cycle Fatigue Behavior of 95.8Sn-3.5Ag-0.7Cu Solder Joints

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Low-cycle fatigue (LCF) behavior of 95.8Sn-3.5Ag-0.7Cu solder joints was investigated over a range of test temperatures (25°C, 75°C, and 125°C), frequencies (0.001 Hz, 0.01 Hz, and 0.1 Hz), and strain ranges (0.78%, 1.6%, and 3.1%). Effects of temperature and frequency on the LCF life were studied. Results show that the LCF lifetime decreases with an increase in test temperature or a decrease of test frequency, which is attributed to the longer exposure time to creep and the stress relaxation mechanism during fatigue testing. A modified Coffin–Manson model considering effects of temperature and frequency on the LCF life is proposed. The fatigue exponent and ductility coefficient were found to be influenced by both the temperature and frequency. By fitting the experimental data, the mathematical relations between the fatigue exponent and temperature, and ductility coefficient and temperature, were analyzed. Scanning electron microscopy (SEM) of the cross-sections and fracture surfaces of failed specimens at different temperature and frequency was applied to verify the failure mechanisms.

**Key words:** Low-cycle fatigue, temperature effect, frequency effect, Coffin–Manson model, lead-free solder

## INTRODUCTION

Portable digital electronic products such as digital cameras, personal digital assistants (PDAs), and cellular phones are growth areas for the electronics manufacturing industry. Product and packaging design trends continue to push for smaller form factor and increased functionalities.[1–3] Solder joints in portable digital electronic devices are continuously subjected to temperature and frequency variations and thermal strain that results from differences in thermal expansion coefficient.[4,5] Since the solder is softer than other components, most of the cyclic stress and strain take place in the solder. Therefore, fatigue failure, especially thermally induced, low-cycle fatigue (LCF) failure, is likely to occur in the solder.[6]

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The Sn-Ag-Cu (SAC) solder alloy system is widely used in the electronics industry because of its advantageous mechanical properties and solderability.[1] Therefore, understanding the LCF behavior of the deformation and fracture of SAC solder alloy is important for developing reliable portable digital electronic packages. Kanchanomai and Mutoh[7,8] studied the effect of temperature on the isothermal LCF behavior of 96.5Sn-3.5Ag at a constant frequency of 0.1 Hz and found that the LCF behavior under different temperatures (20°C, 85°C, and 120°C) follows the Coffin–Manson equation. Kanchanomai and Miyashita[9,10] investigated the effect of frequency on isothermal LCF behavior and mechanisms of crack initiation and propagation in 96.5Sn-3.5Ag at a constant temperature of 20°C, and proposed a frequency-modified Coffin–Manson model. Kariya et al.[11] found that the LCF life of Sn-3.5Ag-Bi determined by true fracture ductility in a total axial strain-controlled test could be