Effect of creep deformation on thermal-fatigue life of solder connections

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Abstract

Considering the low melting points, solder materials exhibit creep deformation due to the visco-plastic properties even at room temperature. In electronic packaging structures, solder joints, as the critical components to provide electronic and mechanical connections, experience extensive local deformation resulting from creep behaviour, which affects the fatigue life greatly in the working state. Accelerated thermal cycling experiments are usually unaffordable and numerical simulations are preferred at minor effect of time and labor. As the most accepted constitutive model in the industry, the Anand model is employed in this study as the constitutive framework to describe the stress-strain relationships for the Sn-3.0Ag-0.5Cu (SAC305) solder material. The corresponding parameters in the Anand model are calibrated by performing uniaxial experiments by using dog-bone specimens at a wide range of temperature and strain rate. After implementation into finite element software ABAQUS, it is found that the stress-strain responses can be well reproduced by the calibrated Anand model at the level of material test. In order to take into account the temperature and stress dependent creep deformation of the SAC305 solder alloy, a hyperbolic-sine law creep model with well calibrated parameters to reflect the visco-plastic deformation during time. In the working scenario of electronic devices, the thermal-fatigue life can be predicted by the Coffin-Mansion model modified by Engelmaier, given that the elastic-plastic cyclic strain range is available from the finite element simulations. In the present study, two approaches are proposed to evaluate the effect of creep deformation on the thermal-fatigue life of solder connections in a typical plastic ball grid array (PBGA) packaging structure during thermal cycles with the range of -55℃~125℃, the ramping rate of 0.5℃/min and the dwelling period of 20 mins. Visco-plastic analysis is performed for the PBGA structure under thermal cycles with the Anand model to describe the constitutive behaviour of solder joints. As no contribution of creep deformation is observed during the dwelling stage, the creep deformation is theoretically calculated by using the hyperbolic-sine law creep model with the predicted stress at the most critical position of the solder joints with the maximum Mises stress. Therefore, the plastic strain response can be modified by superpose the creep strain at the dwelling stage, which can be adopted to estimate the thermal-fatigue life of the critical solder joint. This modification can be conveniently applied in the packaging industry as stress analysis based on elasto-plastic material models is readily performed. In order to ensure the proposed approach feasible for the possible conditions of electronic devices, an extensive parametric study is carried out by varying the parameters in the hyperbolic-sine law creep model such as the power law multiplier, the hyperbolic law multiplier and the stress order. By summarizing the relationships between equivalently plastic strain and fatigue life, the spectrum can be proposed for various creep parameters. Eventually, the dominant mechanism of creep characteristics to influence the thermal-fatigue life of solder materials can be revealed. The proposed approach sheds new light on the numerical estimation of thermal-fatigue life for solder joints under complicated working conditions.

Keywords: Creep; solder; thermal fatigue; constitutive model.