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Research Article

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Dynamic behavior of VFBGA solder joints under drop impact

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ABSTRACT

Based on the JEDEC standards, the three-dimensional finite element model of the board level VFBGA package was established, and the reliability of the lead-free solder under dropping impact was observed. An impact life prediction model, which is formulated according to the power law, and the maximum peeling stress of the critical solder joint is proposed for the drop test of the board level to estimate the number of drops to failure. The average impact life for two lead-free solders Sn3.0Ag0.5Cu and Sn3.5Ag is 132.84 and 59.02 respectively, with Sn3.0Ag0.5Cu in the drop test demonstrating a better ability to resist the deformation.

Key words: strain rate effect; drop/impact; life prediction

INTRODUCTION

The study of the solder joint reliability in the packaging system, which usually uses the finite element simulation method to delve into the behavior of the stress and strain, such as using the technique of LS-DYNA or sub-modeling to study the board level BGA drop test [1, 2]. Tee and Luan [3] introduced the Input-G method, which saved a large amount of solution time, to study the dynamic responses of PCB and solder joints reliability under drop impact loading. Jing-en Luan [4] proposed an Input-G method with the implicit transient dynamic analysis, which demonstrated great superiority to analyze the interrelationship between the PCB dynamic responses and solder joint reliability. Yi-Shao Lai [5] employed three linear models to describe mechanical properties of solder, and established a mechanical model with a chip scale package, and analyzed the model reliability in different drop test conditions. Most of these studies assumed elastic that bi-linear or tri-linear constitutive relationship for the solder joint model in the package drop impact of numerical simulation, while ignoring the obvious strain rate properties of solder joints under the impact loading. The overall strain rate of electronic components in service is not high during the fall or impact. Solder joints, as the key parts to connect different electronic components with PCB board, are likely to have experience deformation in the strain rate of $10^3 s^{-1}$ during the drop impact due to its small size and the mechanical inertia of the device components. In addition, the actual temperature of solder joints can reach its melting point of 10%-40% in the actual condition. Thus, it is vital and urgent to obtain the precise material parameters considering temperature and strain rate in the drop impact research.

EXPERIMENTAL SECTION

Finite element model

VFBGA packages model with different solder joints Sn3.5Ag, Sn3.0Ag0.5Cu and Sn37Pb are proposed. The material model uses Cowper-Symonds model, whose parameter obtained from dynamic experiment data. The impact of the acceleration curve can be considered as a PCB boundary condition in modeling and be put to PCB subassembly directly. The drop table, fixture, contact surface, and friction of guiding rods are not simulated. Figure.1 shows the quarter symmetry of the finite element model.

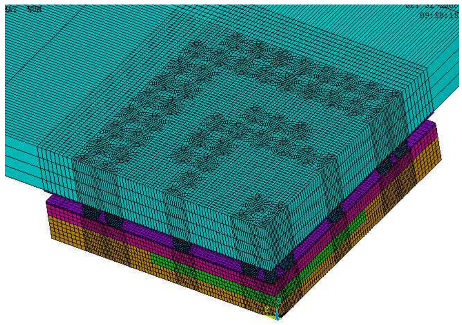


Figure.1 VFBGA model

RESULTS AND DISCUSSION

Stress in the solder joints

According to results of the finite element calculation, all stresses vary cyclically under PCB vibration and decay gradually. Solder joints need to withstand the stress because of the different bending coefficients between electronic packaging devices and the PCB board. Thus, the failure mode of solder joints is peel-dominant and it shows that the maximum normal peeling stress can be regarded as failure criteria for the solder joints under the drop impact. The peeling stresses for three solder joints are shown in Figure.2 at different temperatures. In the room temperature, the peeling stress for Sn-Ag is 191.5MPa, which is bigger than Sn-Ag-Cu 148.0MPa and Sn-Pb 130.6MPa. In the actual working condition, the temperature of solder joints can reach its melting point of about 10% -40%. In the same drop test conditions, the peeling stress for Sn-Ag at 60℃ is 142.9MPa, for Sn-Ag-Cu is 116.5MPa and for Sn-Pb is 83.5MPa. Peeling stresses are significantly lower when the temperature increases. Temperature effect is not negligible in solder joints under the drop impact.

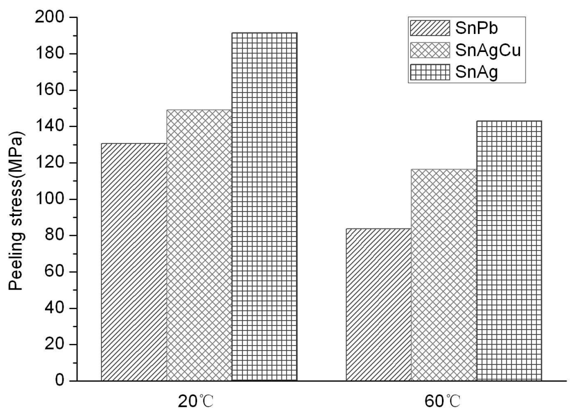
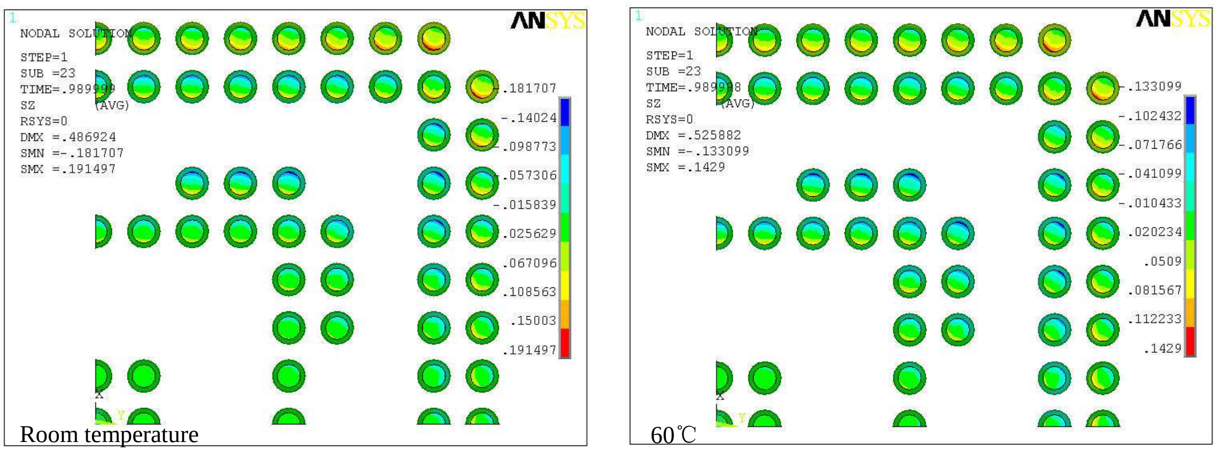
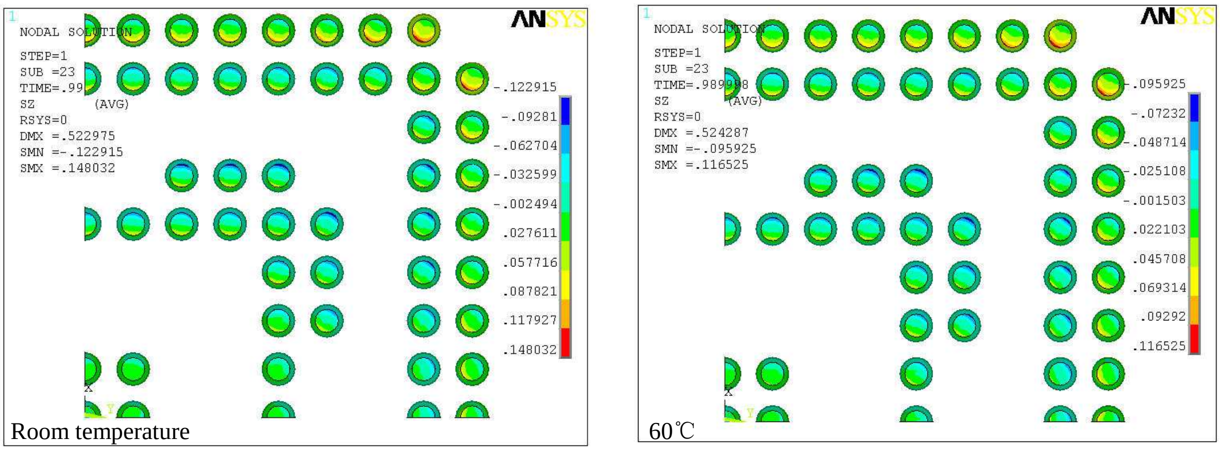


Figure.2 The peeling stresses for three solder joints at different temperature



a) Sn-Ag



b) Sn-Ag-Cu

Figure.3 The contour of peeling stress at room temperature and 60℃ in the critical solder joints under condition B (unit: GPa)

Figure 3 shows the peeling stress distribution state at the package side. The maximum value of the stress appears on the corner, near the inner. This stress concentration pattern agrees with the observed crack propagation [5]. From the location of the maximum value, the crack begins to appear, and gradually spreads outward, and leads to the failure of the solder joint finally.

Impact life prediction model

As discussed in Section 3, the peeling stress is considered as the critical stress component and leads to the failure of solder joints. The power law is used to build a life prediction model including the mean impact life and the peeling stress. The formula is as follows [6]

$$N_{50} = C_1 \sigma_z^{C_2} \tag{2}$$

N_{50} and σ_z are respectively the mean impact life (the number of drops to failure when the failure rate is 50%) and the maximum peeling stress (MPa) in the critical solder ball. C_1 and C_2 are the correlation constants. C_1 and C_2 in this study are cited from the literature. The maximum peeling stress is computed in the numerical simulation. According to the Eq.(2), the impact life of Sn-Ag and Sn-Ag-Cu at room temperature are calculated, as shown in Table.1.

Table 1 Impact life prediction through Power law

Material type	C_1	C_2	σ_z (MPa)	N_{50}
Sn3.5Ag	9.045E8	-3.1485	191.5	59.02
Sn3.0Ag0.5Cu			148.0	132.84

The higher the impact life is, the stronger ability the package possesses to withstand the impact, and the more opportunities the products have to endure dropping. The average impact life for Sn3.0Ag0.5Cu is 132.84, bigger than that Sn3.5Ag of 59.02. It indicates that Sn3.0Ag0.5Cu in the drop test shows better ability to resist the deformation.

CONCLUSION

Solder joints need to withstand the stress due to different bending coefficients among the components under PCB vibration. It leads to the failure of solder joint in the drop impact. Therefore, minimizing bending deformation for PCB in drop impact is proposed in product designing.

These three kinds of materials are strain rate sensitive materials. Thus, the dynamic constitutive models are indispensable to analyze the failure mechanism of solder joints in drop impact. When the temperature increases from room temperature to 60℃, the peeling stresses of three solder joints are significantly lower. The temperature effect is not negligible in solder joints under drop impact.

At the same condition of drop test, Sn-Ag has bigger peeling stress than Sn-Ag-Cu. The average impact life for two lead-free solders Sn3.0Ag0.5Cu and Sn3.5Ag are respectively 132.84 and 59.02, with Sn3.0Ag0.5Cu in the drop test showing a better ability to resist deformation.

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