Simulation Analysis of SnAgCu Brazed Joints Based on ANSYS-Workbench

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Abstract. With the continuous development of computer technology, simulation technology has been more widely used. Through the ANSYS-Workbench software to simulate the solder ball shear experiment, the strain stress and the overall deformation cloud map were obtained, and the distribution law of the solder ball and IMC stress and strain in the shear test was found. There is no significant difference compared with the actual experimental results. The reliability is high, which provides a certain reference for the development and experiment of SAC solder joints, and accelerates the development process.

Keywords. SAC solder joint; shear test; IMC; ANSYS-Workbench.

1. Preface
As the world pays more attention to environmental protection issues, more and more lead-free solders are being developed and used. Among them, SnAgCu solder is the most widely used. It mainly includes high-silver (containing 3.5% Ag) SAC and low-silver (containing 0.5% Ag) [1]. Two types of SAC. As a component of electronic packaging, lead-free solder joints, in addition to the basic conductive function, also play a physical support role, which is the key to ensuring the reliability of the packaging. The shear test of solder joints is a common method to test the welding strength of solder joints, and it is also an important reference for evaluating solder joint reliability.

The traditional experimental method for measuring the shear force of solder joints is more complicated and the measurement data will have certain errors depending on the equipment, and the time and labor costs are relatively large [2]. With the rapid development of computer simulation technology, many finite element methods and software have been applied to engineering technology for auxiliary analysis.

Numerical simulation stipulates that there are two ways to affect the stress of the node element. One is the stress intensity, that is, the failure condition of the electronic package is when the stress value reaches the limit, and the other is the damage durability, that is, the failure condition of the electronic package is gradually accumulated to the endurance of the material. The ultimate strength fails. In electronic packaging, the fatigue fracture of solder joints under thermal cycling and mechanical vibration is a permanent damage failure, but the solder joints belong to stress strength failure during the simulation process of the shear experiment [3]. The finite element software ANSYS can simulate and analyze the actual devices, saving a lot of manpower and material resources, and the research and development progress has been greatly improved.
2. SAC305 Shear Experiment Principle and Simulation Model Establishment

The shear experiment of solder joints is an important method to study the strength of solder joints, and computer simulation technology has a strong auxiliary analysis function. Therefore, the simulation software ANSYS-Workbench is used to carry out related numerical simulations on the shear experiment of SAC solder joints, and analyze the stress and strain of SAC solder joints during the shear simulation process [4].

2.1. Principle of Shear Experiment

SAC solder joints in electronic packaging are mainly subjected to shearing force to cause failure, so shear strength is extremely important for packaging reliability evaluation [5]. According to theoretical mechanics, the shear strength is the ratio of the shear force to the bonding area of the solder joint.

\[ T = \frac{Q}{A} \]  

In the formula: \( T \) is the shear strength; \( Q \) is the shear force; \( A \) is the joint area of the solder joint.

According to the principle of the shear experiment, the equipment required for the experiment is a shear force platform and an instrument for testing stress and strain. The schematic diagram of the experiment is shown in figure 1.

![Figure 1. Sketch of cutting equipment.](image1)

2.2. Establishment of Finite Element Model of SAC Solder Joint Shear Experiment

This thesis is based on the actual SAC solder joints, and the three-dimensional model of the solder joints is established by finite element. As shown in figure 2, the three-dimensional model is mainly composed of wedge, solder balls, IMC interface compound and copper plate.

![Figure 2. Three-dimensional model of solder joint shear experiment.](image2)
In the finite element model of SAC solder joints, except for solder joints, Cu disk and IMC interface compounds are considered to be linear elastic and isotropic [6]. The geometric dimensions and main material parameters of each part of the SAC solder joint model are listed in Table 1.

### Table 1. SAC welding joint components and their material properties.

| Component name | Material  | Size (μm) | Young modulus (MPa) | Poisson’s ratio (u) |
|----------------|-----------|-----------|---------------------|---------------------|
| Solder joint   | SAC305    | 650       | 48900               | 0.3                 |
| IMC            | Cu,Sn₅    | 3         | 92000               | 0.31                |
| Copper pad     | Cu        | Diameter=550 thickness=30 | 105000             | 0.35                |

Since the entire model is symmetric about the Y axis, a two-dimensional simulation model is established and then rotate it around the Y axis to obtain a three-dimensional simulation model. After the simulation model is obtained, it is meshed. In order to obtain the simulation results quickly and accurately [7], the grid division should not be too large, so six-node tetrahedral elements are used to divide a total of 47,668 grids. The grid division is shown in Figure 3.

![Figure 3. Grid division of solder ball simulation analysis.](image)

The finite element constraint condition is that the copper pads are fixed on the X, Y, and Z axes, allowing the solder balls to move freely. The solder joints and the IMC, and the IMC and the substrate are all bonded and bonded contacts, and there is no separate contact between the wedge and the solder ball, and only its normal movement is restricted. The shearing height of the riving knife is 60 μm, and the loading speed is 500 μm/s.

For SAC solders, after countless experiments, the stress and strain law of the solder joints conforms to the Anand constitutive model, so the Anand constitutive model parameters that come with ANSYS-Workbench can be imported into the solder joint material properties, so that the analysis is closer to the real situation [8].

### 3. Analysis of Numerical Simulation Experiment Results of Shearing Experiment

The relevant parameters of the three-dimensional model of SAC solder joints are: the diameter of the solder ball is 650μm, the shear speed is 500μm/s, the thickness of the IMC bonding layer is 3μm, and the shear height of the wedge is 60μm [9]. The stress distribution is obtained by the simulation.
analysis of the three-dimensional model of the shearing experiment. The situation is shown in figure 4, the strain distribution is shown in figure 5, and the plastic strain distribution is shown in figure 6.

Figure 4. Stress distribution of solder ball in shear simulation.

Figure 5. The strain distribution of the solder ball in the shear simulation experiment.

Figure 6. Welding spherical deformation in shear simulation experiment.

It can be seen from figure 4 that after the solder ball is pushed by the wedge, the stress gradually accumulates and transfers downwards. The weakest part of the IMC interface where the solder ball contacts the brazed board is also subjected to greater stress here. It can be seen from figure 5 that the
strain of the solder ball is gradually transferred from the contact surface of the wedge to the solder ball, and due to the loss of force, the strain gradually becomes smaller, and the strain is greatest in the part where the solder ball and the wedge are in contact. It can be seen from Figure 6 that the deformation of the solder ball is gradually reduced from the top to the bottom, and there is obvious delamination, and the deformation is the largest at the point of contact with the wedge, resulting in the collapse of the solder ball. It can be seen that for solder balls, try to increase the strength of the top and the part in contact with the load [10].

It can be seen from figure 4 that the wedge not only has an effect on the solder balls, but also has an effect on the IMC bonding layer and copper pads. Since the elastic modulus, yield strength, thermal expansion coefficient and other properties of the three are quite different, it can be seen that premature strain occurs at the pad, so the risk of solder joint failure is also the greatest. From figure 7, it can be seen that the plastic strain is the largest at the junction of the solder ball and the pad, and it is distributed in a fan shape and extends from the outer circle to the inner circle. The IMC plastic strain range on the side of the solder joint subjected to the thrust is greater than Therefore, pay attention to enhancing the strength of the force-bearing side of the solder joint layer, and take appropriate packaging protection measures.

![Figure 7. IMC plastic strain nephogram of shear experiment.](image)

### 4. Conclusion

A three-dimensional model simulation experiment was carried out on the solder ball shearing experiment. According to the actual experimental conditions, the thrust and deformation of the solder ball shearing were highly restored. There is only a small gap in comparison with the actual experimental data. Through the simulation experiment, it is also clearer to understand the internal stress and strain of the solder ball structure when it is stressed. The top gradually spreads to the bottom, and the top and the contact surface with the wedge are the most stressed. In addition, during the entire simulation process, the IMC joint surface is the first to undergo plastic deformation, which is the weakest part of the entire solder joint. This is consistent with the conclusions obtained from the actual shear experiment, which once again proves the simulation of ANSYS-Workbench Reliability has extremely high reference significance for the actual solder ball research and development, and also saves a lot of manpower and material resources.

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