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Reliability analysis of different structure parameters of PCBA under drop impact

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Abstract. The establishing process of PCBA is modelled by finite element analysis software ABAQUS. Firstly, introduce the Input-G method and the fatigue life under drop impact are introduced and the mechanism of the solder joint failure in the process of drop is analysed. The main reason of solder joint failure is that the PCB component is suffering repeated tension and compression stress during the drop impact. Finally, the equivalent stress and peel stress of different solder joint and plate-level components under different impact acceleration are also analysed. The results show that the reliability of tin-silver copper joint is better than that of tin-lead solder joint, and the fatigue life of solder joint expectancy decrease as the impact pulse amplitude increases.

Key words: Board assembly; PBGA package; finite element analysis; drop impact; reliability

1. Introduction

It is well known that Drop impact test contains plate drop and product drop, and the plate drop is more maneuverable. Handheld electronic products tend to be miniaturized and versatile, which makes electronic packaging design to be of high density and small size. Compact handheld electronics often fall unexpectedly in transit, storage, and use, which make the printed circuit board subject to transient impact. The transient bending of the plate causes transient dynamic stresses at the solder joint and other joints, which brings about mechanical and electrical failure. The small solder joints between the circuit board and the chip become the most critical parts of the damage. The mechanical behaviour in the drop process becomes an important subject of the reliability research of electronic products.

2. PBGA solder joint structural parameter
The PBGA packaging model consists of a chip, a package body, a substrate, solder balls, copper pads, and PCB. The only heat source of the PBGA comes from the chip. The welding ball is a uniform array of 8x6, in which 0.05mm thickness pad is attached on upper and lower surfaces respectively. The pitch between the solder balls is 1mm. As can be seen from Table 1 and 2, the PBGA structure parameters and component parameters are given.

Table 1. Structural parameters of PBGA

| component     | Dimensions/mm                          |
|---------------|----------------------------------------|
| Solder joint  | Diameter:0.56 ×Height:0.42             |
| Copper pad    | Height:0.05                             |
| Package       | 12×8×0.625-8×6×0.275                    |
| Substrate     | 12×8×0.25                              |
| Chip          | 8×6×0.275                              |
| PCB           | 90×70×0.675                            |

Table 2. Material parameters

| Material       | Elastic modulus/ GPa | Density/ Kg/m$^3$ | Poisson’s ratio |
|----------------|----------------------|-------------------|-----------------|
| FR-4           | 22                   | 2680              | 0.28            |
| Cu             | 120                  | 8930              | 0.34            |
| Substrate      | 22                   | 1800              | 0.38            |
| Si             | 131                  | 2990              | 0.23            |
| Modelling compound | 28               | 1890              | 0.35            |
| Pb90Sn10       | 22.5                 | 10800             | 0.40            |
| Sn63Pb37       | 31.7                 | 8420              | 0.35            |
| Mix            | 33.5                 | 7531              | 0.35            |
| SAC387         | 38                   | 7500              | 0.38            |
| SAC305         | 54                   | 7400              | 0.40            |

3. **Input-G method**

Figure 1 shows the PCB under the impact pulse under the condition that the four screws are fixed. Establishing PCB installation model by ABAQUS software is a useful way. The simplicity of the Input-G allows it to calculate three times faster than the free fall model. Therefore, the Input-G method is an effective way to optimize reliability of PCB drop, and it is used by many scholars to analyse the reliability of solder joints under drop impact [1-3].
4. Life model of drop impact

To predict the fatigue failure of solder joints, damage parameter is a scalar of solder joint failure that should be first taken into considered. Generally, pressure and strain parameters are two damage parameters for drop test failure criteria. Peeling stress is the dominant factor in the reliability analysis of drop [4]. Therefore, the impact life model can be determined according to the simulated results of peeling stress and the actual measured life span. Numerical analysis can calculate the maximum peeling stress of the solder joint, when predict the life of the product or evaluate the performance of the product. Considering the fatigue life model with the maximum peel stress and fatigue life of the solder joints, the power criterion combines can be described as:

\[ N_{so} = C_1 \sigma_z^{C_2} \]  

\( N_{so} \) is the average drop impact life, \( \sigma_z \) is the critical delamination stress of the solder joint, \( C_1 \) and \( C_2 \) are correlation coefficients with values of \( 9.045 \times 10^8 \) and \(-3.1485\) [5].

5. Finite element analysis

5.1 Failure mechanism analysis under drop impact

In this paper, the conduct explicit transient dynamic analysis is based on ABAQUS software. In the process of free fall, the PCB board is suffering repeated tension and stress, and it will lead to solder joint fail. From the distribution of stress, the maximum stress of the whole component is 1595.9 MPa. S33 is the peeling stress that perpendicular to the PCB plate. The S33 stress is also to predict the solder joint failure life. From the distribution nephogram of peeling stress, the maximum peeling stress of PCB component is 554.35 MPa.

Firstly, the semi sinusoidal acceleration is simulated under the condition that the acceleration amplitude of 1500G and the pulse duration of 0.5ms. The half sine acceleration is the boundary condition that applied to the four screw holes of the PCB, and the direction is perpendicular to the PCB plate. In addition, apply the horizontal symmetry constraint to the symmetry surface of the model. The drop impact analysis of the model shows that the stress concentration location of the solder joint is located at four vertex angles, and the stress at the side of the PCB plate is the maximum. Because the model is symmetrical, select the point of maximum stress in one of the solder joints, and the distribution of Mises stress is in Figure 2. From Figure 3, we can see the distributions of the peel stress. As the solder joint is suffering a semi sinusoidal acceleration, the peeling stress and the Mises stress of the solder joint propagate in a sinusoidal form. Figure 4 is a curve of the critical solder joint stress with time, wherein S11, S12, S13, S22, S23 and S33 represent stress in each direction and each plane respectively. S33 represents the stress direction different from other stresses, and its amplitude is the largest. Therefore,
the peeling stress is the main cause of crack initiation, propagation and full fracture of solder joints, and it is the main basis for solder joint failure. The peeling stress of the spot leads to the growth of the internal cracks in the BGA solder ball, and the crack growth is the root cause of the solder ball failure in the drop reliability test [6]. \( S_{13} \) represents the shear stress in the X-Z direction with a peak value of 639 MPa.

![Figure 2. Mises stress curve of critical solder joint](image)

![Figure 3. Peel stress distribution of critical solder joint](image)

![Figure 4. Stress of critical solder joint](image)

One of the four vertex angles of the PCB board is selected. The displacement change is also shown in Figure 5. In 1.5ms, the displacement at the screw hole of the PCB plate is shifted in the negative direction of Z, and the maximum displacement change is 5.857mm. The displacement changes at the centre of the PCB are shown in Figure 6, the selected node is node 30257, and the maximum displacement is 6.099 mm. The deflection of PCB is the displacement of its apex angle relative to the centre displacement, shown as Figure 7. At 0.42ms, the deflection of PCB reaches the maximum value.
of 0.638 mm, and the deflection of PCB reaches the maximum value of -0.621 mm at 0.82 ms. The vibration of PCB changes periodically and decays gradually over time, the size and trend are close to the existing experimental results, which proves that the simulation results are true.

The comparison of the stress curve and deflection curve of PCB is in Figure 8. It is found that the general trend of the two is the same, and the peak value of the amplitude appears approximately the same. However, the peak value of stress lags slightly behind the peak of deflection, indicating that the stress in the solder joint is due to the deflection of the PCB. The displacement of PCB leads to tension and compression stress acting on the solder joint, which makes the solder joint become the key solder joint.

**Figure 5.** Displacement of PCB vertex

**Figure 6.** Displacement curve of PCB center

**Figure 7.** Displacement curve of PCB center point
Figure 8. Peeling stress curve of solder joint and PCB deflection curve

From the deflection curve and the peeling stress curve of the solder joint, we can know that the joints with four vertex angles are the key parts of the subject. In the solder joint, an 8x6 array is established with two paths, each of which starts from a vertex angle of the solder joint array and ends at the other corner. The two paths of X and Y are shown in Figure 9. The nodes selected on the X path are the 8 nodes of 1430, 107, 41, 110, 38, 53, 95, and 56. The nodes selected on the Y path are the 6 nodes of 1433, 1476, 1390, 1519, 1562, and 1347. The two paths are shown in Figure 10 and Figure 11 respectively.

Figure 9. Illustration of X direction and Y direction

From Figure 10 and Figure 11, it is found that the stress of the solder joint in the Y axis is slightly greater than that in the X axis. On the X path, the maximum stress is about 155 MPa, and the minimum stress is only 6.74 Mpa. While in the Y axis the maximum stress is 155.17 MPa, and the minimum stress is 6.74 MPa. The maximum stress at the solder joint on the X path and on the Y path appears at same level.

Figure 10. Distribution of Stress in X axis
5.2 Analysis of drop life under different parameters

5.2.1 Reliability analysis of solder joints under different solder joint materials. Materials not only play an important role in the vibration reliability of solder joints, but also play an important role in improving the reliability of drop impact reliability [7-8]. In this research, we study five different solder joint materials such as Pb90Sn10, Sn63Pb37, MIX, SAC387 and SAC305 respectively. The moduli, densities, and Poisson's ratios are given in Table 3. Under the same conditions, fatigue life can be obtained by changing the material of the solder joint.

| The material of solder joint | Maximum stress/MPa | Maximum peel stress/MPa | Fatigue life/ms |
|-----------------------------|---------------------|-------------------------|-----------------|
| Pb90Sn10                    | 714.48              | 264.54                  | 21.34           |
| Sn63Pb37                    | 722.12              | 274.78                  | 18.95           |
| MIX                         | 694.94              | 254.95                  | 23.97           |
| SAC387                      | 676.26              | 246.89                  | 26.52           |
| SAC305                      | 653.73              | 236.45                  | 30.38           |

As shown in Table 3, the fatigue life of tin lead solder joints is worse than that of tin silver copper. With the rapid development of lead-free electronic products, SAC solder joints will gradually replace tin lead materials because of their superior properties.

5.2.2 Reliability analysis of solder joints under different impact accelerations. Select the working conditions A, F and B, the corresponding peak acceleration is 500G, 900G and 1500G, the corresponding pulse time is 1.0ms, 0.7ms, 0.5ms. Conduct transient dynamics analysis of solder joints under the condition of Sn63Pb73. The equivalent stress distribution of the solder joints is under three conditions, as shown in Figure 12. The solder joint reaches the maximum stress at 0.64ms under the pulse acceleration of 500G, the solder joint reaches the maximum stress at 0.49ms under the pulse acceleration of 900G, and the stress acceleration of the solder joint at 1500G is at 0.40ms. With the increase of pulse acceleration, the time of maximum stress of solder joint is smaller. The reason is that the greater the pulse acceleration, the greater the hardness of the impact surface, the harder the impact surface and the more likely the solder joint failure. In addition, in the same time, the solder joint in 500G acceleration experienced 2 sinusoidal stress changes. The solder joint in 900G acceleration experienced 2.5 sinusoidal stress changes. The solder joint in 1500G acceleration experienced 3.5 sinusoidal stress changes. In summary, the greater the pulse acceleration is, the faster the solder joint reaches the...
maximum stress, and the more the semi sinusoidal stress changes in the solder joint in the same amount of time. By analysing the stress distribution of the solder joint, the maximum stress and the maximum peeling stress of the critical solder joint can be obtained. The fatigue life of solder joints is obtained by the life prediction formula based on the Power criterion, under the working conditions A, F and B. Thus, the fatigue life of solder joints is 18.95, 5.65 and 2.07 respectively. As shown in Table 4, the maximum peeling stress and the maximum equivalent stress of the solder joint decrease with the increase of the pulse acceleration of the solder joint. And the fatigue life of solder joint decreases with the increasing of shock pulse amplitude.

![Stress distribution](image)

**Figure 12.** Stress distribution at different pulse acceleration: (a) at 500G, (b) at 900G and (c) at 1500G

| Condition       | Maximum stress/MPa | Maximum peel stress/MPa | Fatigue life/ms |
|-----------------|--------------------|------------------------|-----------------|
| A (500G,1.0ms)  | 722.1              | 274.7                  | 18.95           |
| F (900G,0.7ms)  | 1105.3             | 403.4                  | 5.65            |
| B (1500G,0.5ms) | 1595.9             | 554.3                  | 2.07            |
6. Conclusion

In this paper, the drop process of the product is analyzed by means of explicit dynamic analysis. In addition, the application of Input-G method in drop test is studied, and this method can solve the problem of simulation of drop simulation. The fatigue life model of solder joints is established based on the Power criterion, and the failure mechanism of solder joints under working condition B is studied. Finally, the influence of different parameters on the fatigue life of solder joints is also investigated.

(1) In the same circumstances, the reliability of SnAgCu solder joints is better than that of tin-lead solder materials.

(2) In the same solder joint material, the maximum stress and the maximum peeling stress of the solder joint are measured respectively by changing the impact pulse acceleration. The results show that the fatigue life of the solder joint decreases as the amplitude of pulse impact acceleration increases.

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