Mechanical Strength Analysis of SMT Solder Joints by the Finite Element Method

The effects of shape, internal porosity and solder volume on the strength of the joint are analyzed

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ABSTRACT. Finite element calculation is applied to the analysis of stress inside surface mount technology (SMT) solder joints. The effects of shape, interior voids and volume of solder on the mechanical strength of SMT solder joints are analyzed and compared. This analysis is essential to the design and technology of SMT solder joints.

Introduction

The application of surface mount technology (SMT) has accelerated recently; however, the strength of SMT solder joints is cause for concern. An important reason for this concern is that the leads of a surface mount device (SMD) do not pass through the printed circuit board (PCB). As a result, unlike traditional through-the-hole technology (THT), the component and the PCB are connected only by SMT solder joints. Theoretical calculation shows that the maximum mechanical strength of a THT solder joint exceeds its design strength by one order or more, while the maximum mechanical strength of a SMT solder joint is less than 120% of its design strength (Ref. 1). So it can be seen that the SMT solder joint is not as safe as the THT joint. In addition, the mechanical strength of SMT is influenced by many factors such as the shape of the solder joints and the defects in them. In this paper, the effects of these factors on the mechanical strength of the solder joints are investigated. This certainly helps explain SMT technological conditions.

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Because of the extremely small size of the SMT solder joints, it is very difficult to analyze the strength of these joints with any method of testing, to say nothing of trying to analyze the effect of each factor on the solder joints. Fortunately, finite element calculation is a suitable method of analysis.

Calculation Model

Figure 1 shows a typical surface-mounted assembly. It consists of three major parts: the surface mount component, the printed circuit board, and the solder joint. Here, it is assumed the copper conductor and the PCB are a whole part, while the SMD is another one. The material of the PCB is FR-4 epoxy/glass, the solder is 63Sn-37Pb, and the chip component is Al_2O_3 ceramic. The relevant physical and mechanical properties are listed in Table 1.

The mechanical load on the SMT solder joint comes from two sources: one is induced by an external load such as bending deformation of the PCB, another is thermal stress inside the solder joint caused by thermal expansion coefficient difference between the SMD and PCB while the machine is at work.

In this paper, the former source is investigated. A two-dimensional linear elastic stress analysis is applied to the stress condition inside the solder joint under normal temperature. A share software called ELCUT was used to bring about the numerical calculation. According to the material's limit of yielding given in the reference, it is assumed that there is horizontal tension, F, exerted on the symmetrical sides of the SMD. The constant value of F can be used as a criteria to analyze the variation of the stress distribution in the solder joints when the solder joints are influenced by various factors. Consequently, the effects of different factors on the mechanical strength can be examined. As the calculation model is two-dimensional and symmetrical, the freedom of motion vertical to X-Y planes can be recognized as zero. At the same time, it is assumed that on the PCB the freedom of motion of the bottom side and its opposite side is zero. From Fig. 2, it can be found that there are three stress concentrated zones inside the solder joint: Zone 1, castle; Zone 2, solder internal joint; and Zone 3, corner of component. Consequently, the following analysis is of these zones.

KEY WORDS

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Finite Element Analysis
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PCB
Joint Strength

Table 1—Physical and Mechanical Properties of the Assembly

Materials	Young's modules 10^6 (N/m^2)	Poisson's Ratio
Solder	10335.3	0.40
Al_2O_3 Ceramic	254937.3	0.30
FR-4	11024.3	0.28

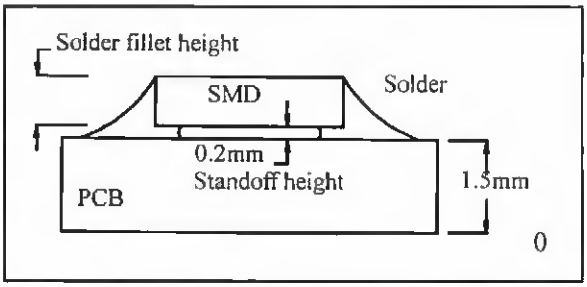

Fig. 1 — Surface mount technology with ceramic chip resistor.

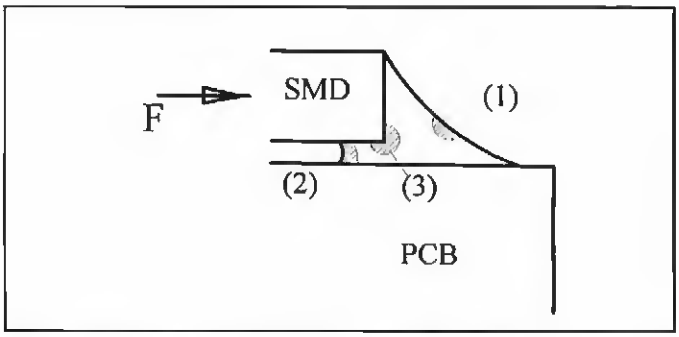

Fig. 2 — Zones of stress concentration inside a solder joint.

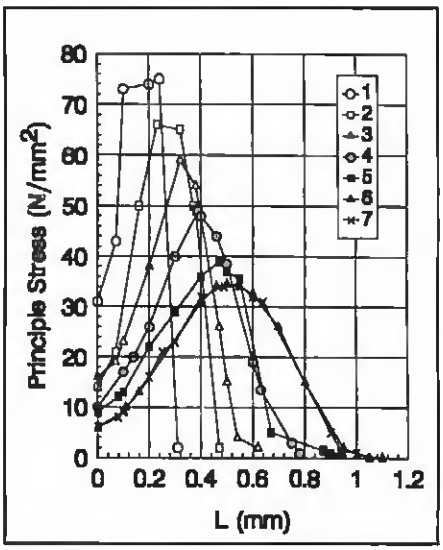

Fig. 3 — Variations of principal stress inside the solder joint.

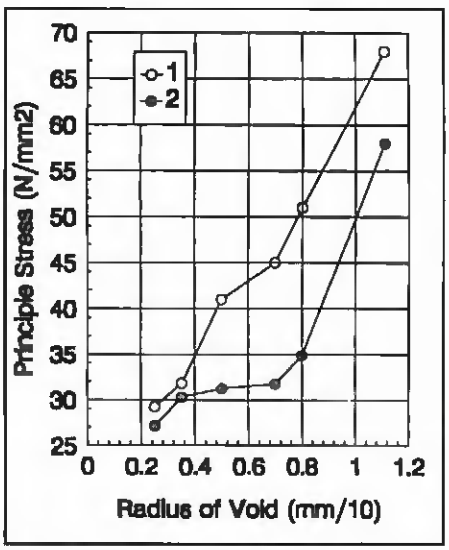

Fig. 4 — Effect of the size of voids.

Calculation Result and Analysis

The mechanical strength of the SMT solder joints may be influenced by various factors. Among these factors, the most important are the quantity of solder, and the shape and area of the solder joint's cross section.

Effect of the Cross-Sectional Areas of the Solder

In this investigation, a group of solder joints with different cross-sectional areas of solder are analyzed, but the materials to be soldered, wetting condition and the shape of the solder joints are the same. The variations in the cross-sectional areas of the solder are listed in Table 2.

Through the analysis of stress C inside the joints with different quantity of solder, it can be concluded that the distribution of the principal stress inside these solder joints is nearly the same. Figure 3 shows the variation of principal stress inside the solder joints with cross-sectional area along the castle. In this figure, the X axis L is the displacement along the castle while the Y axis is the principal stress along the castle. From Fig. 3, it can be seen that with the increase of the solder joint's cross-sectional area, the high-stress zone is always distributed a little bit below mid castle. However, the maximum value in stress concentration Zone 1 increases greatly with the decrease of the solder joint's cross-sectional area. This suggests that when the shape of the solder joint is the same, too little solder will decrease the mechanical strength of the solder joint. Moreover, it is found that when the shape of the solder joint is convex, the stress concentrated zone along the castle is distributed over the solder toe. As the shape of the solder joint becomes more convex, the stress at the solder toe becomes greater. Nevertheless, the distribution of the high-stress zones hasn't been greatly changed.

Effect of Voids inside the Solder Joint

For SMT solder joints, a void is a common discontinuity. The main reason for this is the outgassing of the volatile contents in the PCB or solder paste. The 3.4% volume shrinkage during the phase change of the solder is another reason. Since there are voids existing inside the solder joint, the solder joint's useful cross-sectional area will decrease. Therefore, the mechanical strength of the solder joint is decreased.

Effects of Different Size Voids

Figure 4 shows the effect of different size voids on the mechanical strength of the solder joints. From Curve 1, it can be seen that when voids of different volumes exist in the center of the same solder joint, the maximum principal stress along the castle increases as the solder joint's cross-sectional area increases. The variation of the stress is shown in Table 3. Curve 2 shows the variation of the max-

Table 2—Solder Area for Different Fillet Heights

No.	Fillet Height (mm)	Fillet Shape	Standoff Height (mm)	Solder Area (mm^2)
1	0.6	Concave	0.2	0.2954
2	0.5	Concave	0.2	0.2505
3	0.4	Concave	0.2	0.2266
4	0.3	Concave	0.2	0.1986
5	0.2	Concave	0.2	0.1779
6	0.1	Concave	0.2	0.1628
7	0.0	Concave	0.2	0.1501

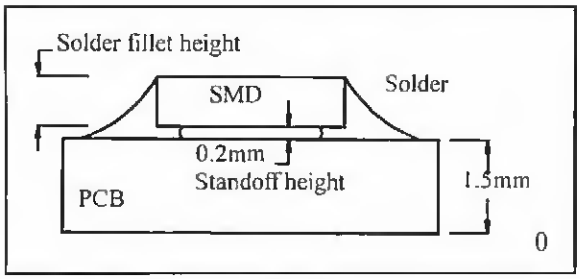

Fig. 5 — Void inside a solder joint.

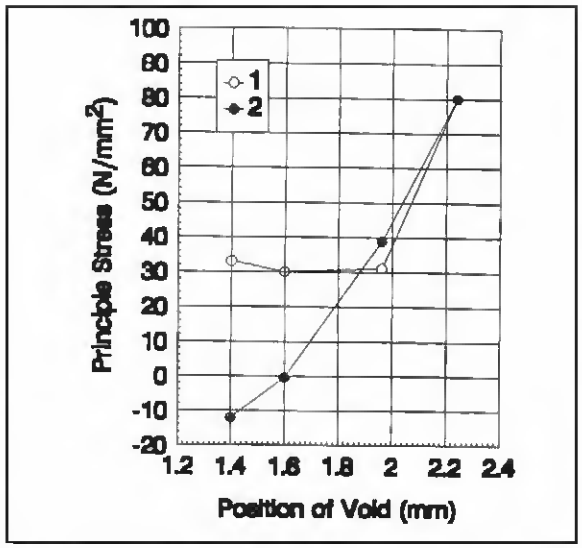

Fig. 6 — Effect of the void location.

Table 3—Void Size Effect on Area Ratio

No.	Void Radius (mm)	Solder Area (mm^2)	Area Ratio (%)
1	0.025	0.2946	0.665
2	0.035	0.2946	1.310
3	0.050	0.2946	2.660
4	0.070	0.2946	5.220
5	0.080	0.2946	6.820
6	0.110	0.2946	13.14

imum stress around the voids with changes in the solder joint's cross-sectional area.

Effects of Voids in Different Locations

Figure 5 shows a void inside the solder joint. In this case, the location of the voids may vary just like its volume. Figure 6 shows the variations of principal-stress when there are voids of the same volume existing in different locations. Curve 1 shows the variation of maximum principal stress along the castle with the changes in location of the voids. So it is obvious that the closer the voids are to the solder toe, the greater the maximum principal stress along the castle is. Curve 2 shows the variation of maximum principal stress along the perimeter of the voids. The calculation above suggests that the principal stress inside the solder joint varies with the joint's cross-sectional area and its location. In addition, considering the extremely small SMT solder joint, the voids inside them considerably decrease their useful cross-sectional area, and therefore, decrease the mechanical strength of the solder joints.

Conclusion

1) The cross-sectional area of solder changes the distribution of stress inside the joint, and it also directly affects the mechanical strength of the solder joint. For concave solder joints, the peak value of the principal stress will increase considerably if there is less solder. While for convex joints, the principal stress in the solder toe will rise considerably with the increase in the quantity of the solder.

2) Voids also influence the distribution of the stress inside the SMT solder joint. The maximum principal stress will increase when the cross-sectional area of the voids increases or the voids are close to the solder toe. In addition, the voids decrease the useful cross-sectional area of the solder joint, and therefore, decrease the mechanical strength of the solder joint.

Reference

1. Lau, J. H., and Keely, C. A. 1989. Dynamic characterization of surface mount component leads for solder joint inspection, IEEE.