Effects of Lead Widths and Pitches on Reliability of Soldered Joints and Optimum Simulation for QFP Devices

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Abstract - *The FEM method was used to analyze the effects of lead widths and pitches on reliability of soldered joints. The optimum simulation for QFP devices was also researched, the results indicate that when the lead pitches are the same, the maximum equivalent stress of the soldered joints increases with the increase of lead widths, while the reliability of the soldered joints reduces. When the lead widths are the same, the maximum equivalent stress of the soldered joints doesn't decrease completely with the increase of lead pitches, and a minimum value of the maximum equivalent stress values exists in all the curves. Under this condition the maximum equivalent stress of the soldered joints is relatively the least, the reliability of soldered joints is high and the assembly is excellent. The simulating results indicate that, as the best parameter setting, the lead width is 0.2mm and lead pitch is 0.3mm (the distance between two leads is 0.1mm). This parameter setting is beneficial to the micromation of QFP devices now. The minimum value of the maximum equivalent stress of soldered joints exists while lead width is 0.25mm and lead pitch is 0.35mm (the distance between two leads is 0.1mm). In such a setting, the devices can serve for a long time, the reliability is the highest, and the assembly is excellent. The simulating results also indicate that the limit of QFP occurs when the lead width is 0.15mm and lead pitch is 0.2mm. This is significant for the high lead count and micromation of assembly.*

Key words: QFP; maximum equivalent stress; soldered joints; assembly optimization; finite element method

1.0 Introduction

With the development of the design and manufacturing technique of IC chips, SMT is evolving towards high density and high reliability, which challenge the outline packages such as QFP, SOJ, SQFP, SSOP. More and more attentions are focused on assembly micromation with high reliability of soldered joints [1-3].

Quad Flat Package (QFP) is typical in the outline packages, and its lead pitches change from early 0.8mm to 0.65mm and 0.5mm now. QFP with lead pitches of 0.65mm and 0.5mm becomes the common devices used in electric equipments of the industry and military [4], QFP with lead pitches of 0.4mm and 0.3mm has been used in China recently. In practice, the yield rate of devices is low, the devices can't serve for a long time, and defects are easy to exist in the soldering process. Some experts consider lead pitch of 0.3mm as the limit value for QFP [5-6], which goes against the micromation of the outline package.

The research was carried out on the basis of the reliability and feasibility of the pitches. The batch production QFP with lead pitch of 0.3mm or less is not available because it is limited by technical problems such as the precision of the lead frame, which is yet to be solved with the fast development of the SMT technology. The effects of the mechanical properties on the reliability of the soldered joints are considered. The mechanical properties of the soldered joints are difficulty to measure directly since the soldered joints of micro-electronic devices are very small and complicated, while the reliability of the soldered joints can be evaluated using finite element method easily and effectively[7-8]. In this paper, the finite element method was used to analyze the effects of lead widths and pitches on reliability of soldered joints in three dimension, and the optimal parameters were pursued by the combination optimization.

2.0 FEM Model

2.1 The True Model and Parameters of QFP

QFP64 devices were studied in this paper. FEM model was created with the material of soldered joints and the parameter of the leads. The original sizes of the model are listed in Fig.1, in which *a* represents the distance between two leads, *b* represents the lead pitch, and *b* is a lead width bigger than *a*. The size of PCB is 20mm×20mm×2.0mm. The primary components of thermal model are Al_2O_3 ceramic carrier, Cu leads, soldered joints and PCB (FR-4). Moreover, the metal pads on the components and the pad on the PCB were ignored. The soldered joints were supposed to be dense without the existence of voids.

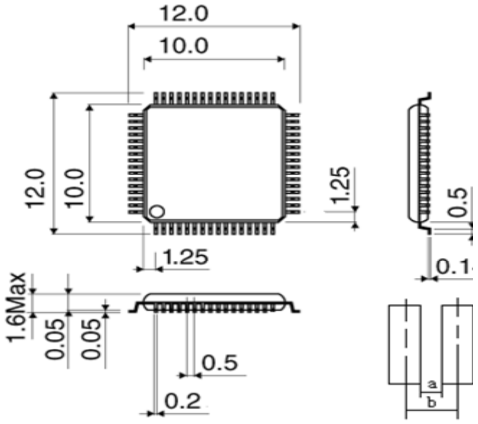


Fig.1 The original sizes of QFP

The solder of the joints is Sn60Pb40 eutectic alloy with low melting point. The packaging temperature and the serving temperature of components are 0.48～0.75 times higher than the melting point of the solder. At such a temperature the mechanical deformation of soldered joints is viscoplasticity[9-10]. The materials of FR-4 and PCB of the assembly are linear elastic and isotropic, and their properties aren't influenced by temperature. The performance parameters are listed in Table 1 and Table 2.

Table1 Performance parameters of isotropic materials

Materials	modulus of elasticity E（GPa）	Poisson ratio γ	CET (10^{-6}/℃)	Thermal conductivity W/（m℃）
PCB	11.0	0.28	15	0.25
Ceramic	26.5	0.23	6.9	18
Cu lead	117	0.3	16.6	393

Table2 Performance parameters of Sn60Pb40 [11]

temperature（℃）	modulus of elasticity E(MPa)	Poisson ratio γ	CET α (10^{-6}/℃)	yield stress (MPa)
-55℃	47966	0.3516	24.1	43.2
-35℃	46892	0.3540	24.6	37.51
-15℃	45779	0.3565	25.0	32.05
5℃	44377	0.3600	25.2	29.86
22℃	43251	0.3628	25.4	29.1
50℃	41334	0.3650	26.1	22.96
75℃	39445	0.3700	26.7	17.4
100℃	36854	0.3774	27.3	12.31
125℃	34568	0.3839	27.9	9.35

2.2 Boundary Conditions and Temperature Loads

The inner surface of the PCB and Al_2O_3 carrier are fixed rigidly with zero value of displacement, and two outside lines of PCB are fixed rigidly with zero value too. The loading model is a temperature loading according to MIL-STD-8833, and FEM was used for analyzing the mechanical properties of assemblies. As shown in Fig.2, the temperature cycled between -55℃ and 125℃, maintained for 15 min at the highest and lowest temperature respectively, and increased with the rate of 12℃/min. The thermal stress is supposed to be zero at the temperature of 20℃. The stress and strain of soldered joints varied periodically through the first three cycles, and became stable in the fourth cycle.

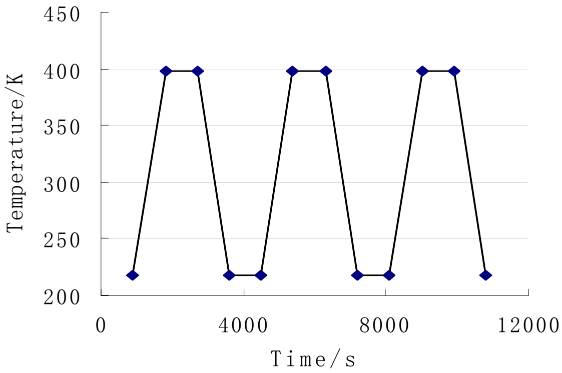
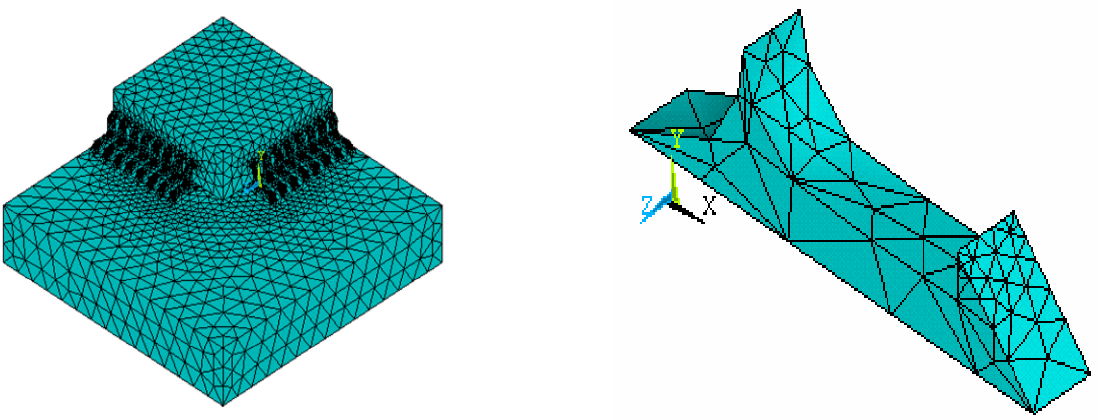


Fig.2 Specification of temperature cycling loads

2.3 Construction of Geometry Model and Meshing

By considering the symmetry of the model and the powerful functions in ANSYS, 1/4 of the device was chosen to create a model. Firstly, element type was defined as 3-D solid70 and different material properties were input into preprocessor. Then, the geometry model was created, and the model was meshed to generate a mesh with a well-controlled precision, as is shown in Fig.3.



(a) FEM model of the device **(b) FEM model of the soldered joint**

Fig.3 The finite element model

3.0 Effects of lead widths and pitches on reliability of soldered joints and optimum simulation for QFP devices

The stress-strain photogram was evaluated in postprocessor after four thermal cycles. The periodical alternative stress occurs in the device because the temperature range is the serving temperature range of the device [12-13]. To study the effects of lead widths and pitches on reliability of soldered joints, the maximum equivalent stress used for analysis was tested when all parameters were at the same temperature. The position with maximum equivalent stress is the place where crack grows [14-16]. This conclusion is comparable and of reference value.

The original lead width of QFP devices is 0.2mm, and the lead pitch is 0.5mm, as is shown in Fig.1. The lead width and lead pitch was changed respectively, and the trend of the maximum equivalent stress of the soldered joints was studied to obtain optimum sizes, which will be useful for guiding the production in practice.

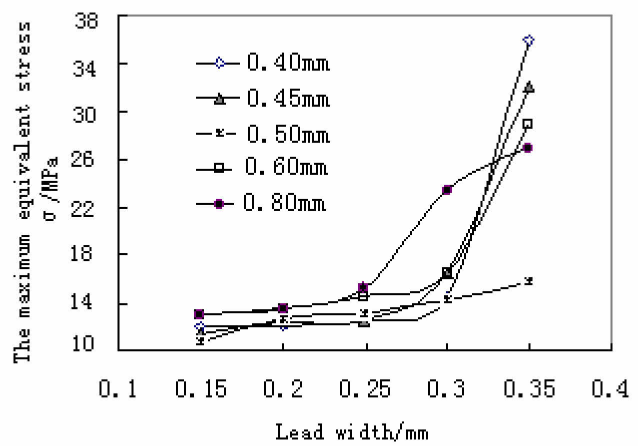


Fig.4 Effects of lead width on the maximum equivalent stress of the soldered joints

When the lead pitch is fixed, the trend of the maximum equivalent stress of the soldered joints with the lead width being changed is shown in Fig.4. The consumption of solder is different with different lead width, and the volume of solder increases with the increase of the lead width.

As in Fig.4, the maximum equivalent stress of the soldered joints increases with the increase of the lead width. With the increase of the lead width，the lead rigidity increases, the buffer effect to the strain decrease, and the stress transferred to the soldered joints increases, making the maximum equivalent stress accumulate; the constraining degree between leads and soldered joints increases, and stress increases too, while the excess stress is prone to induce fatigue failure. It's useful of decreasing the lead width to reduce the stress and strain and improve the reliability of the soldered joints. This kind of design of small lead width is important to the development of miniaturization and micromation of the micro-electronic devices in the future, because the fine lead pitch and small lead width are in favor of the outline package miniaturization and micromation. Contrarily, with the increase of the lead numbers, the defects such as bridging, cracks, voids appear with the small lead width and fine lead pitch in the jointing and packaging process, which brings in a new challenge to the soldering worker and the soldering technology.

To find out the effects of lead widths and pitches on the reliability of soldered joints and optimum simulation for assemblies, five different lead pitches (0.15mm, 0.2mm, 0.25mm, 0.3mm, 0.35mm) were used to analyze the trends of the maximum equivalent stress of the soldered joints with the lead width fixed, as shown in Fig.5 through Fig.9.

As Fig.5 shows, when the lead width is fixed with 0.15mm, the distance between two leads is 0.05mm and the lead pitch is 0.2mm. The maximum equivalent stress of the soldered joints exists at the minimum value of 7.6MPa. The reliability of the soldered joints in this process is preferable and the device is quite excellent, which is in favor of the development of the assembly miniaturization. But, there are lots of difficulties in the production and the package of the 0.3mm lead pitch QFP at present, and the development of QFP is affected by the high precision process technology and new package formations exist more and more (such as BGA、CSP、WLP). Then, it can be predicted from the optimum simulation for QFP devices that the lead width of 0.15mm and the lead pitch of 0.2mm (the distance between two leads of 0.05mm) are a limit in the development of QFP. The conclusion is of important guidance to the development of the high lead count and micromation of devices. As indicated in Fig.6, when the lead width is fixed with 0.2mm, the distance between two leads is 0.1mm and the lead pitch is 0.3mm. The maximum equivalent stress of the soldered joints exists at a minimum value of 11.3MPa. The conclusion is of importance guidance to the development of process designing, improving the reliability of the soldered joints and long serving life of the 0.3mm lead pitch QFP. The lead width of 0.2mm, the distance between two leads of 0.1mm and the lead pitch is 0.3mm are the optimal parameter setting for the QFP.

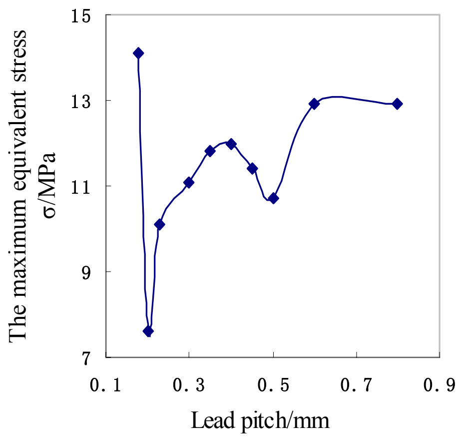


Fig.5 Effects of lead pitch on the maximum equivalent stress of the soldered joints when lead width is 0.15mm

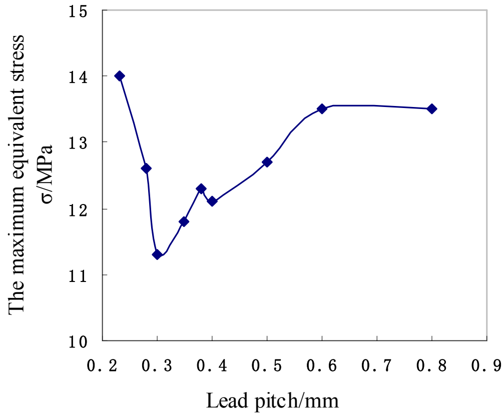


Fig.6 Effects of lead pitch on the maximum equivalent stress of the soldered joints when lead width is 0.2mm

As Fig.7 shows, when the lead width is fixed with 0.25mm, the distance between two leads is 0.1mm and lead pitch is 0.35mm. The maximum equivalent stress exists at a minimum value of 6.07MPa; the smaller the minimum of the maximum equivalent stress is, the higher the reliability of the soldered joints is, and the higher the serving life of the devices is, which the optimum condition is.

As shown in Fig.8, when the lead width is fixed with 0.3mm, the distance between two leads is 0.05mm as well as the lead pitch is 0.35mm. The stress of the soldered joints exists at a minimum value of 10.6MPa.

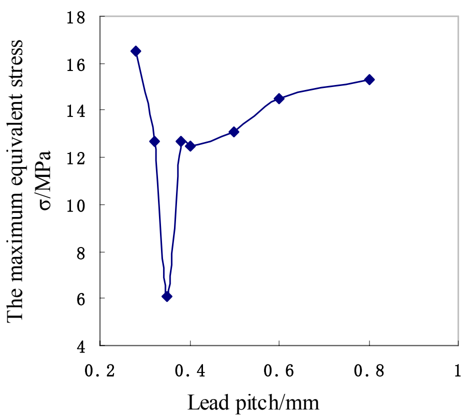


Fig.7 Effects of lead pitch on the maximum equivalent stress of the soldered joints when lead width is 0.25mm

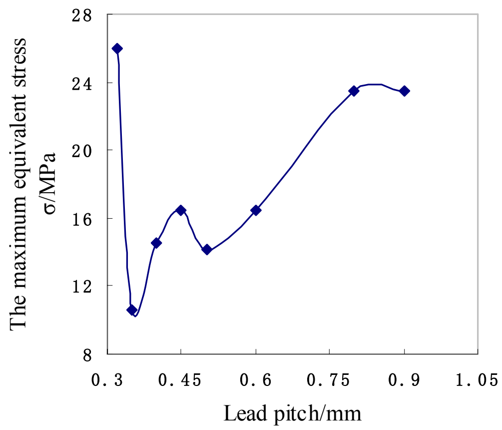


Fig.8 Effects of lead pitch on the maximum equivalent stress of the soldered joints when lead width is 0.3mm

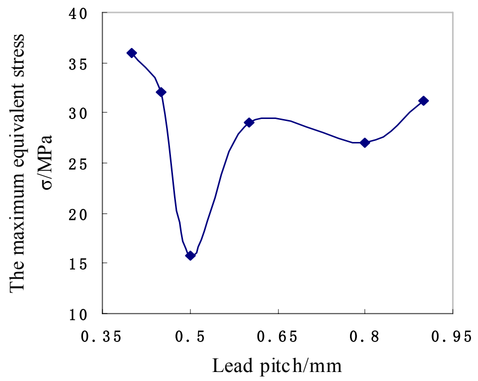


Fig.9 Effects of lead pitch on the maximum equivalent stress of the soldered joints when lead width is 0.35mm

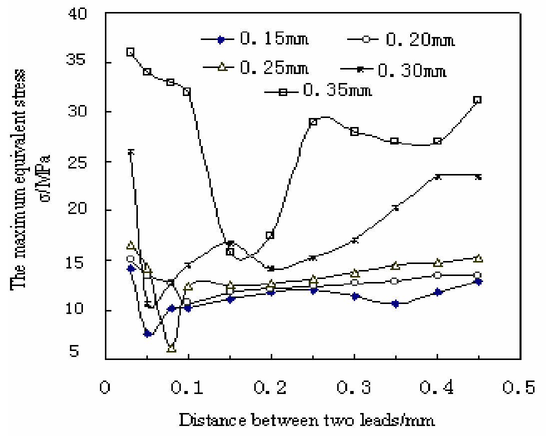


Fig.10 Effects of different distance between two leads on the maximum equivalent stress of the soldered joints

As Fig.9 shows, when the lead width is fixed with 0.35mm, the distance between two leads is 0.15mm as well as the lead pitch is 0.5mm. The maximum equivalent stress exists at a minimum value of 15.8Mpa. Many studies have been done to the reliability of the QFP with the above parameters. In this case, the maximum equivalent stress of the soldered joints is relatively less, meaning a higher reliability.

In Fig.10, for the different lead widths of the QFP devices, the maximum equivalent stress of the soldered joints does not decrease all the time with the lead pitches. The stress changes more dramatically while the distance between two leads is close to the limit value. According to the theory of the mechanics of materials[17], with the increase of the lead pitch the maximum equivalent stress should decrease all the time, because the bigger the lead pitch is, the smaller the constraining degree between two leads is, and the smaller the contraction stress, constraining stress, thermal stress are. Therefore, the maximum equivalent stress becomes small. A series of minimum stresses exist in Fig.10, indicating a potential to the miniaturization and micromation of the assemblies, even though they are conflicting with the traditional theory in the mechanics of materials.

The process parameters are of important meanings to high lead count of the IC, optimization of the devices parameters, small outline packaging and minimizing of the lead pitches.

4.0 Conclusions

(1) When the lead pitches are the same, the maximum equivalent stress of the soldered joints increases with the increase of lead widths, while the reliability of the soldered joints reduces. When the lead widths are the same, the maximum equivalent stress of the soldered joints doesn't decrease completely with the increase of lead pitches. A minimum value of the maximum equivalent stress values exists in all the curves. Under this condition the maximum equivalent stress of the soldered joints is relatively low, the r indicating a better reliability of soldered joints and a better assembly.

(2) A good parameter setting for the micromation of QFP devices is: the lead width is 0.2mm and lead pitch is 0.3mm (the distance between two leads is 0.1mm). The minimum value of the maximum equivalent stress of soldered joints exists while lead width is 0.25mm and lead pitch is 0.35mm (the distance between two leads is 0.1mm). The devices can serve for a long time, the reliability is the highest, and the assembly is in an excellent condition.

(3) The simulating results also indicate that when the lead width is 0.15mm and lead pitch is 0.2mm, the limit of QFP may occur.

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