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REDUCTION OF DESIGN STEPS FOR STACKED DIE QFN USING OPTIMIZATION TECHNIQUE

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ABSTRACT

Taguchi method has been shown to be successful in optimizing design parameters in the manufacturing industry. Finite element (FE) simulation, on the other hand, is used as a design tool and helps to reduce design time and cost. In this paper, the finite element analysis and Taguchi method were combined to aid in the design steps and to optimize the design parameters of Quad Flat No-Lead (QFN) stacked die package. Control factors of bottom die area and thickness, bottom epoxy thickness, top die area and thickness and top epoxy thickness of QFN package design were evaluated with finite element analysis. Both shear and principal stresses results were used as the evaluation variables. The results were then subjected to the Taguchi method to determine the optimal design parameters and to produce predicted stresses values. The predicted stresses results were then successfully verified with FE simulation.

INTRODUCTION

The trend toward miniaturization, multifunc-tional and high density Quad Flat No-Lead (QFN) packages especially for portable electronic devices is unrelenting. This can be seen clearly from the historical development of integrated circuit (IC) packaging [1-4] which has been continually focusing on miniaturization.

This trend is further driven by the continual and increasing demand of miniaturized IC packages by IC customers. Fig. 1 shows the trend of IC packaging and it clearly indicates that the size and hence the weight reduction are the most important considerations.

Conventional QFN package [5] comprises of silicon die, lead frame, mold compound and die attach paste [6]. During the designing stage, reliability issue, good electrical performance, reduce size and lower cost of production are important factors that need to be considered [7].

Single die package development cycle starts with a design step, build and test prototype steps and a further redesign step if the design prototype failed to meet the required specifications. The test step includes electrical and reliability test of which the latter is known to be costly due to its dependence on very expensive test equipment, highly skilled manpower for data analysis and expensive test samples.

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The total design cycle usually takes about three to four months [8]. The design step becomes even more complicated and risky with the multi stacked die design package.

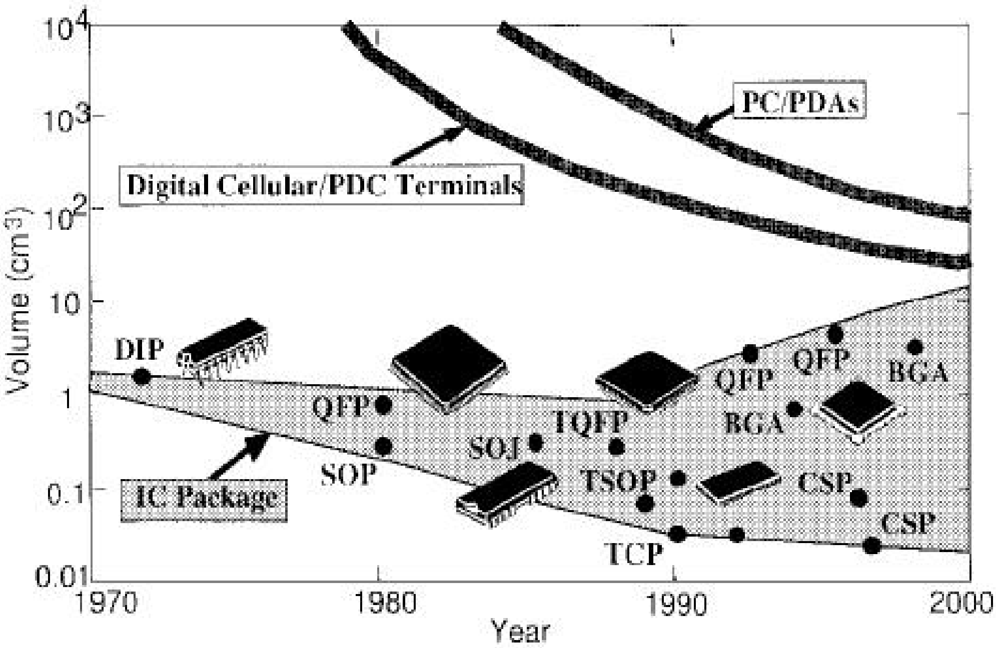

Figure 1: Trend of miniaturization of IC package [1].

Current option to reduced development cycle and hence cost of development is by employing finite element analysis (FEA) [9]. FEA has been widely used in semiconductor field as an analysis tool for reliability studies [10-13] and it has also been established as an effective tool for thermo mechanical reliability assessment of electronic assemblies [14]. However the process of testing various design possibilities and combinations still have to be carried out before an optimal design can be achieved.

Modern manufacturing industries have to resort to various optimization techniques in order to stay ahead of the competitors and to survive in the highly competitive business. Optimization technique helps to identify the best manufacturing parameters. These include factors such as manufacturing condition, material selection and manufacturing parameters. One of the most effective optimization techniques being used is the Taguchi method [15-17]. This method which is also called Robust Design method can significantly improve manufacturing productivity by consciously considering noise factors. It focuses on improving the fundamental function of the product or process and thereby facilitating flexible manufacturing designs and implicitly allows reliability to be built-in into the manufactured products rather than to leave them to post maintenance to ensure reliability [18].

The finite element analysis and Taguchi Method are very complimentary. If they were combined, it helps to optimise the design stage in terms of reduce design cycle

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time with optimised parameters together with improve reliability factors. This paper presents the steps of combining the two techniques and to show that the techniques can be verified using experimental data.

MATERIALS AND METHODOLOGY

Different stacked die design for QFN packages were modelled using The ANSYS software. The Taguchi method was employed using the Design of Expert software.

Finite Element Analysis

A quarter model geometry of the 3D stacked die QFN package was constructed in ANSYS. The model comprised of four layers to represent the four main components of QFN package which were the lead frame, the mold compound, the die and the epoxy layer. The model dimension was set at 7 mm x 7 mm x 0.85 mm with 48 leads. The variations of the control variables were determined using two level factorial design method.

In the pre-processing stage, material properties of each materials were defined. These values are shown in Table 1 to 4. The thermo-mechanical stresses analyses were then carried out with a reference temperature of 175ºC (and also be known as the die curing temperature).

Table 1: Material properties for silicone die.

Temperature (ºC)	Young's Modulus (GPa)	Poisson's Ratio
-73	188.4	0.2786
27	187.3	0.2783
127	186.0	0.2781
227	184.5	0.2778
345	184.5	0.2778

Table 2: Material properties for epoxy.

Temperature (ºC)	Young's Modulus (GPa)	Poisson's Ratio
-65	7.5	0.35
25	7.5	0.35
250	0.34	0.35
260	0.34	0.35

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Table 3: Material properties for mold compound.

Temperature (ºC)	Young's Modulus (GPa)	Poisson's Ratio
-65	28	0.3
25	28	0.3
240	0.8	0.3
260	0.8	0.3

Table 4: Material properties for lead frame.

Temperature (ºC)	Young's Modulus (GPa)	Poisson's Ratio
25	128.9	0.34

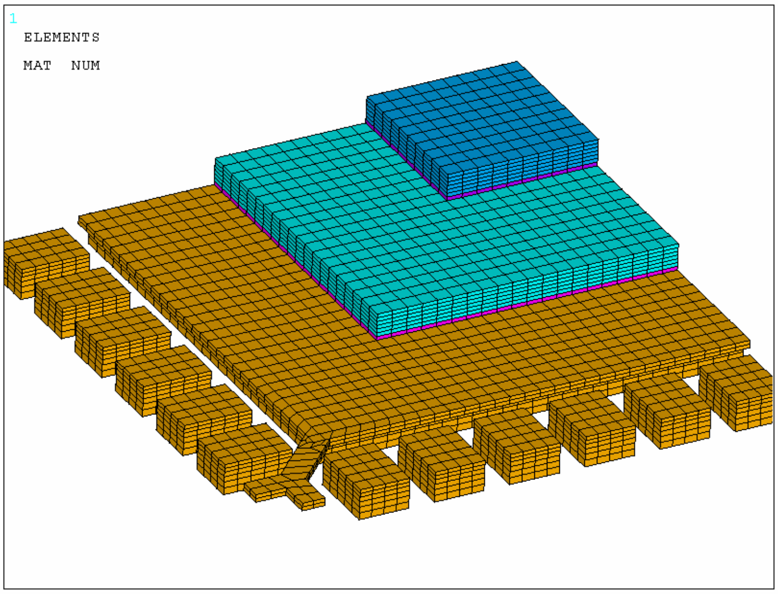

Figure 2: A meshed quarter model for a QFN package.

The completed geometry model was then auto meshed as shown in Fig. 2. The next stage in the FEA preparation was the setting of the boundary conditions and the external loads. The boundary conditions for this model were set as shown in Fig. 3 and 4. Fig. 3 shows the symmetrical boundary condition which were defined as the XZ plane and the YZ plane. The value was set to zero. Fig. 4 shows the nodes at the bottom area of the lead frame. They were assumed to be fixed with no displacement during the simulation process. Thus, they were set with no degrees of freedom.

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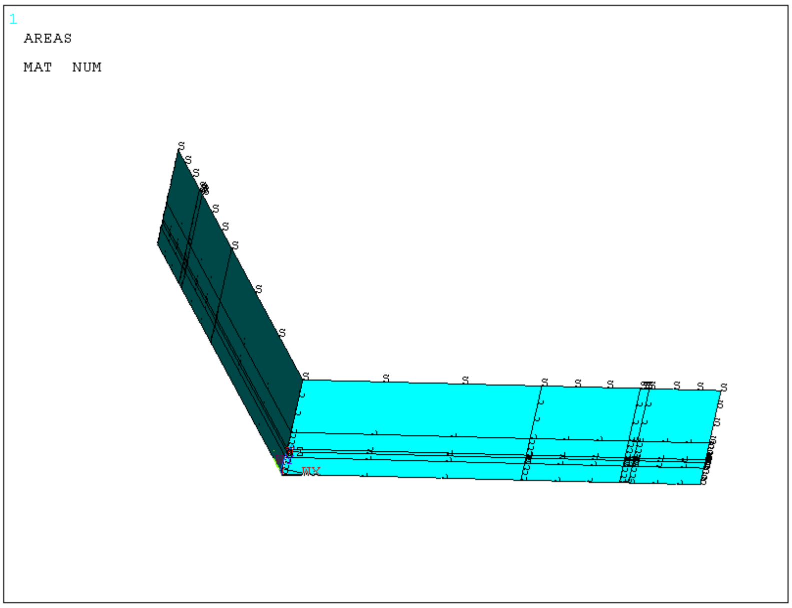

Figure 3: Symmetrical boundary condition.

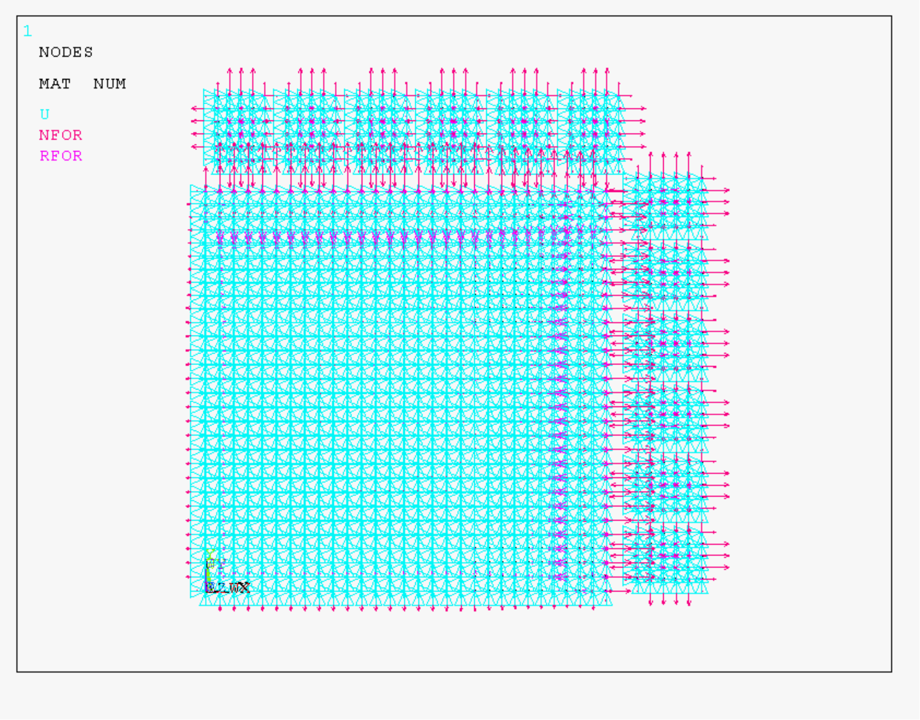

Figure 4: Fixed displacement boundary condition.

The birth and death element options in ANSYS were used as part of the input file to simulate the thermal cycle process. The simulated thermal cycle consisted of six stages. The first stage began with the bottom die attach set at 175ºC and it was then

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allowed to cool down to the room temperature of 25ºC. It was heated up until the glass transition temperature of 175ºC when the post mold cure (PMC) process was assumed to take place, i.e. when the mold compound encapsulated to the package. Finally, the total package was allowed to cool down again to ambient temperature of 25ºC. All the different design combinations were simulated and subjected to the same treatments.

Table 5: Control factors for stacked die design.

Control Factors		Level 1	Level 2
1	Bottom Die Thickness	0.15mm	0.25mm
2	Bottom Die Size	4 mm x 4 mm	5.08 mm x 5.08 mm
3	Bottom Epoxy Thickness	0.0254 mm	0.03048 mm
4	Top Die Thickness	0.15mm	0.25mm
5	Top Die Size	2 mm x 2 mm	3.3 mm x 3.3 mm
6	Top Epoxy Thickness	0.0254 mm	0.03048 mm

Table 6: Taguchi L8 orthogonal array.

Run	Control Factors					
	Bottom Die Thickness	Bottom Die Size	Bottom Epoxy Thickness	Top Die Thickness	Top Die Size	Top Epoxy Thickness
1	1	1	1	1	1	1
2	1	1	1	2	2	2
3	1	2	2	1	1	2
4	1	2	2	2	2	1
5	2	1	2	1	1	1
6	2	1	2	2	2	2
7	2	2	1	1	1	2
8	2	2	1	2	2	1

Taguchi Method

Table 5 shows the control factors for the stacked die design. The different combinations resulted in the two level Taguchi L8 orthogonal arrays are shown in Table 6 and 7.

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Table 7: Taguchi L8 orthogonal array with control factors.

Run	Control Factors					
	BDT (mm)	BDS (mm x mm)	BET (mm)	TDT (mm)	TDS (mm x mm)	TET (mm)
1	0.15	4x4	0.0254	0.15	2x2	0.0254
2	0.15	4x4	0.0254	0.25	3.3x 3.3	0.03048
3	0.15	5.08x 5.08	0.03048	0.15	2x2	0.03048
4	0.15	5.08x 5.08	0.03048	0.25	3.3x3.3	0.0254
5	0.25	4x4	0.03048	0.15	3.3x3.3	0.0254
6	0.25	4x4	0.03048	0.25	2x2	0.03048
7	0.25	5.08x 5.08	0.0254	0.15	3.3x3.3	0.03048
8	0.25	5.08x 5.08	0.0254	0.25	2x2	0.0254

Desirability Function

The target value for each stress response is set to be *smaller-the-better* which is defined as;

$$\textit{smaller-the-better} = 10\log[MSD] \qquad (1)$$

$$MSD = \frac{1}{n}(\ln y^2) \qquad (2)$$

where;

MSD = means square deviation
y = the measured response
n = the number of measurements

The desirability function is an objective function that ranges from zero to a unit value which is the goal to be achieved. The numerical optimization technique is used to maximize the desirability function. The characteristic of the goal may be altered by adjusting the weight or importance of the parameters. All responses and factors are set to achieve one desirability function. This resulted in a simultaneous function of geometric mean of all transformed responses:

$$D = (d_1 x d_2 x....x d_n)^{\frac{1}{n}} = \left(\prod_{i=1}^{n} d_i\right)^{\frac{1}{n}} \qquad (3)$$

where;
n = number of responses in the measure
D= Desirability Function
d= response

Experimental Works

The experimental works were performed on 8 samples based on the control factors which were used in the FEA. Referring to Table 7, all the FEA responses result were analyzed using The Taguchi method to get the optimal design. The optimized result

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from Taguchi Method was then simulated in order to verify the predicted optimal design.

RESULTS AND DISCUSSION

The FEA results of the die shear stress and 1st principal stress of top and bottom die were tabulated in Table 8. Each of these results was subjected to Taguchi method and the outcomes of the analysis were shown in Table 9. The optimized design parameters which had been suggested by The Taguchi method are shown in Table 10 and the expected responses are shown in Table 11.

Table 8: Die stress result from FEA.

Run	Bottom Die Shear Stress	Bottom Die 1st Principal Stress	Top Die Shear Stress	Top Die 1st Principal Stress
1	23.7	111	27.6	120
2	25.8	116	32.3	127
3	30.4	110	45.2	110
4	22.3	109	44.2	97.9
5	26.1	111	35.1	136
6	31.6	113	31.6	130
7	32.8	111	47.9	98.9
8	25.2	108	49.2	102

Table 9: Summary of die stress analysis.

Die Stress	Prd-R^2
Bot. Die Shear Stress	0.9934
Bot. Die 1st Prin. Stress	0.9755
Top Die Shear Stress	0.7879
Top Die 1st Prin. Stress	0.6735

Table 10: Optimal design stacked die.

Description	Dimension
Bottom Die Thickness	0.15 mm
Bottom Die Area	4 mm x 4 mm
Bottom Epoxy Thickness	0.0254 mm
Top Die Thickness	0.25 mm
Top Die Area	2 mm x 2 mm
Top Epoxy Thickness	0.0254 mm

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The optimal design parameters suggested by the Taguchi method was verified by FEA simulation and the comparison of the results is shown in Table 11. From this table, it clearly show that the error percentage smaller for the bottom die shear stress, the bottom die 1st principal stress, the top die shear stress and the top die 1st principal stress. All the percentage errors are less than 10%. The desirability function obtained is also relatively high which is 0.746 of the desired target.

Table 11: Taguchi Method and FEA comparison.

Die Stress	Taguchi	FEA	Error
Bot. Die Shear Stress	27.975	27.8	0.63%
Bot. Die 1st Prin. Stress	111. 725	120	1.9%
Top Die Shear Stress	21.625	23.3	7%
Top Die 1st Prin. Stress	110.75	111	0.22%

CONCLUSION

This study has demonstrated that FEA simulation in combination with the Taguchi method has produced optimised design parameters. It avoids the need any redesign steps as the output of the exercises is in optimised conditions and the Desirability function can be a useful tool for the optimization method. An experiment was performed in order to verify the suggested model and also need to confirm the optimum design that should be stronger and robust. The percentage of errors between the FEA result and Taguchi Method showed a minimum value. Thus, it can be concluded that FEA combination with Taguchi Method technique are very useful to help in design optimization with efficiently reduce the experimental cost and work.

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