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COMPARISON OF 2^K FACTORIAL AND TAGUCHI METHOD TO OPTIMIZE DESIGN PARAMETERS FOR QFN STACKED DIE

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ABSTRACT

Several optimization techniques are available in the literature and most of them are based on statistical treatments. Optimization technique helps to identify optimal design parameters in design work. This study used the 2^k factorial method to determine optimised design parameters. The control factors used in this study comprise of bottom die thickness, bottom die are, a top die thickness and top die area. Finite Element Analysis (FEA) was used as the simulation tool to simulate responses. The result was then compared to another study based on Taguchi method. The comparison shows that the 2k Method give better optimised parameters.

INTRODUCTION

In the past decade there has been an explosive growth of a class of mathematical methods of optimization techniques [1]. Many of these techniques have found numerous applications in various areas like biotechnology, plantation, water resources planning, manufacturing and others. The various types of optimization techniques have different specific purpose and target areas of applications. Several excellent surveys have been written on this topic. One interesting studies is on gradient estimation techniques for continues input parameter and the other on random search methods for discrete input parameters [2, 3]. Another study was performed [4] to classify and analyze different situations in simulation model optimization and suggestion for appropriate search algorithm. A study also has been done on the optimization of stochastic discrete event for dynamic systems [5]. Another area that used optimization techniques is in biotechnology [6]. It used the 2^k factorial method as a technique to get the optimum process conditions for enhanced production of surfactant. Taguchi method is another well-known optimization technique [7-9]. One such study using Taguchi has also been performed by Lin et al. [10] to optimize the electrical discharge machining process with multiple performances characteristic.

Both 2^k Factorial and Taguchi Method are well known in the industry includes semiconductor industry. Semiconductor industry nowadays is driving towards miniaturization, multi functionality and high density packages. It is especially required for new portable electronic devices such as hand-held cellular phone, Personal Digital Assistant (PDA), Global Positioning System (GPS), digital camera and camcoder [11-13]. One of the most popular IC package is Quad Flat No–Lead

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(QFN) package . It is famous because of its small footprint, good moisture resistant performance and its low height features. It also shows excellent thermal dissipation performance for exposed leadframe pad soldered onto the printed circuit board (PCB) [14-15]. An example of a QFN package is shown in Figure 1.

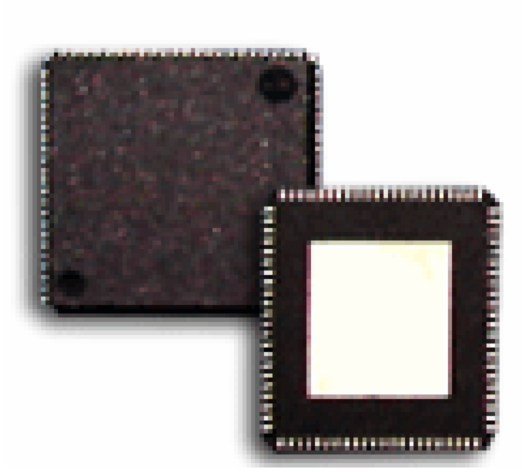

Figure 1: Example of QFN package.

As consumers demand more function in their hand-held nowadays, the need for more memory per space allocation become critical. Another technology that has become important in the IC industry to satisfy the market demand is stacking of dies into a package [16]. All these have led to excessive demand for manufacturers and designers to obtain optimized design parameters for IC packages. This problem can be easily solved by adopting a suitable optimization technique. The main objective of this paper is to compare two optimizations techniques that are well known in manufacturing industry that can be applied to Stacked Die QFN package design. The techniques are the 2^k factorial method and the Taguchi method. Both techniques will be evaluated to compare their effectiveness.

MATERIALS AND METHODS

Finite Element Analysis

In this paper, different stacked die design for QFN packages are modeled using FEA. Quarter model for 3D stacked die QFN package were build. The unit package sizes were set at 7 mm x 7 mm x 0.85 mm with 48 leads at the bottom of the package. Top and bottom die dimensions were selected as a factor to vary for two levels. The model contains four main components such as lead frame, mold compound, die and epoxy. During the pre-processing phase in FEA, material properties for each materials involved in this package were defined. Table 1 to Table 4 shows the material properties for each material. Finite element analysis of thermo-mechanical stresses were carried out with a reference temperature or zero stress temperature set at 175ºC (die curing temperature).

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The next step was automatic mesh generation. After the models were completely built, an automatic mesh computer generated was applied to the model. This important step was done as a description for the input data. Fig. 3 shows a quarter models for QFN package without mold compound for better visualization that has been completely meshed.

Table 1: Material properties for silicon 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

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 leadframe.

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

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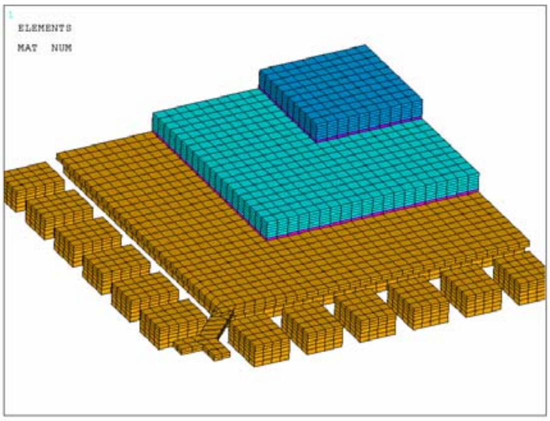

Figure 3: Meshed quarter model for QFN Package.

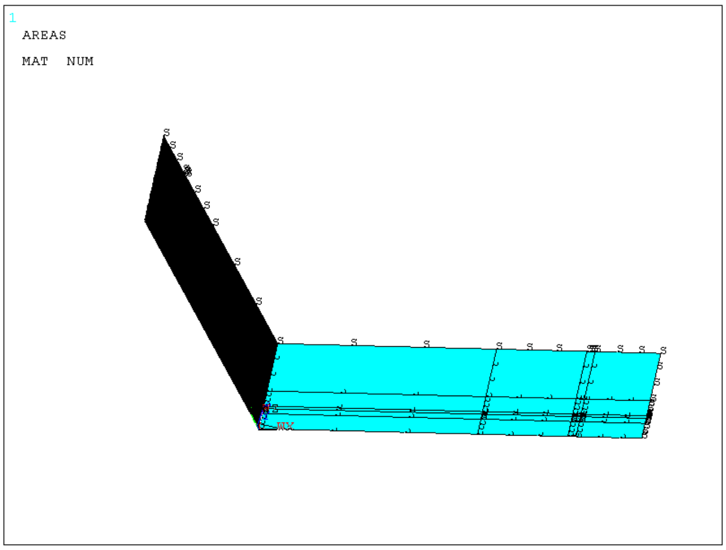

Figure 4: Symmetrical boundary condition.

Another step consist in pre-processing phase is boundary condition and loading. The boundary condition is defined for this model as shown in Fig. 4 and 5. Fig. 4 shows the symmetrical boundary condition that defined for XZ Plane and YZ Plane. Due to the symmetrical geometry model, both the XZ Plane = 0 and YZ Plane = 0 were set as symmetry boundary condition area. Fig. 5 shows the nodes at the bottom area of the lead frame were defined as 0 for Degree of Freedom. The area was set as 0 for displacement for any axis means the lead frame is assumed fix.

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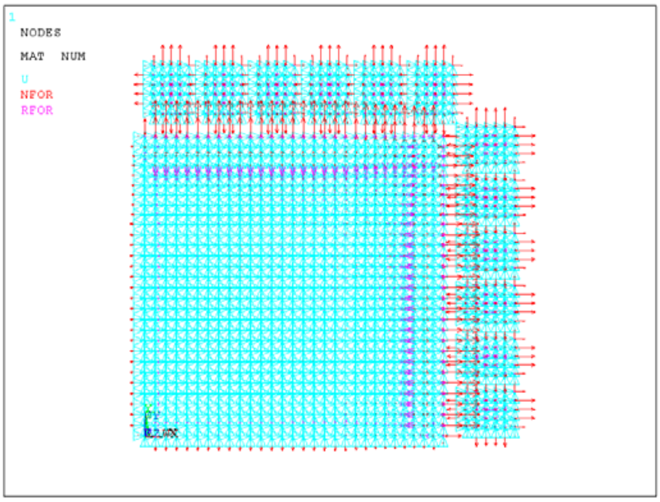

Figure 5: Fix displacement boundary.

Another boundary condition involved in this study was thermal loading. The thermal loading be used in this simulation was 260ºC. This value is in accordance to IPC/ JEDEC J-STD-020C. Table 5 shows package classification reflow temperatures for Pb-Free package. All models package thickness in this study is 0.85 mm and this is classified as less than 1.6 mm. From standard, a Pb-Free component shall be capable of being reworked at 260 °C within eight hours of removal from dry storage or bake.

Table 5: Pb-Free- Package classification reflows.

Package Thickness	Volume mm^3 <350	Volume mm^3 350-2000	Volume mm^3 >2000
<1.6 mm	260 + 0ºC	260 + 0ºC	260 + 0ºC
1.6 mm - 2.5 mm	260 + 0ºC	250 + 0ºC	245 + 0ºC
≥ 2.5 mm	250 + 0ºC	245 + 0ºC	245 + 0ºC

Following the solution phase, the post processing phase was selected to obtain important information. For this case, the values of plane shear stresses and 1st principal stresses were obtained. All the results obtained were then analyzed by statistical method to get the effect of the design factors to the package.

Table 6: Control factors for stacked die design.

Control Factors		Level 1	Level 2
1	Bottom Die Thickness	0.15 mm	0.25 mm
2	Bottom Die Size	4 mm x 4 mm	5.08 mm x 5.08 mm
3	Top Die Thickness	0.15 mm	0.25 mm
4	Top Die Size	2 mm x 2 mm	3.3 mm x 3.3 mm

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Table 7: Design matrix experiment for four factors.

Run No	Factor			
	Bottom Die Thickness (mm)	Bottom Die Size (mm x mm)	Top Die Thickness (mm)	Top Die Size (mm x mm)
1	0.15	4 x 4	0.15	2 x 2
2	0.25	4 x 4	0.15	2 x 2
3	0.15	5.08 x 5.08	0.15	2 x 2
4	0.25	5.08 x 5.08	0.15	2 x 2
5	0.15	4 x 4	0.25	2 x 2
6	0.25	4 x 4	0.25	2 x 2
7	0.15	5.08 x 5.08	0.25	2 x 2
8	0.25	5.08 x 5.08	0.25	2 x 2
9	0.15	4 x 4	0.15	3.3 x 3.3
10	0.25	4 x 4	0.15	3.3 x 3.3
11	0.15	5.08 x 5.08	0.15	3.3 x 3.3
12	0.25	5.08 x 5.08	0.15	3.3 x 3.3
13	0.15	4 x 4	0.25	3.3 x 3.3
14	0.25	4 x 4	0.25	3.3 x 3.3
15	0.15	5.08 x 5.08	0.25	3.3 x 3.3
16	0.25	5.08 x 5.08	0.25	3.3 x 3.3

2^k Factorial Design

The methods of analysis that be presented here is a 2^k factorial design. It is a statistical design with k factors each at two levels. The statistical model for a 2^k design would include k main effects, two-factor interactions, three factor interaction and one k-factor interactions. That is, for a 2^k design the complete model would contain $2^k – 1$ effect. Table 6 shows the control factor for stacked die design. They are bottom die size, bottom die thickness, top die size and top die thickness. The design matrix and the response data obtained from a single replicate of the 2^4 experiment are shown in Table 7. The 16 runs were made in random order. In this study, the response of each run was obtained from the results of simulation. The result that is significant were top die shear stress, top die 1st principal stress, bottom die shear stress and bottom die 1st principal stress.

Taguchi Method

The Taguchi method utilises two, three and mixed level fractional factorial design. Large screening designs seem to be particularly favored by Taguchi adherent. Taguchi refers to experimental design as "off-line quality control" because of it is a method of ensuring good performance in the design stage of products process. The aim of the design is to make a product or process less sensitive and more robust in the face of variations over which we have little or no control. In this paper, however, the design of experiment for the Taguchi method will not be discussed in details as it has already been discussed in another paper [17]. The results will discuss more on

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the comparison between the 2^k factorial method and the Taguchi method.

RESULTS AND DISCUSSIONS

Die shear stress and 1st principal stress for top and bottom die of each run were analyzed by 2^4 factorial designs to see the most significant factors. The responses were bottom die shear stress, bottom die 1st principal stress, top die shear stress and top die 1st principal stress. All the simulation results were summarized in Table 8.

Table 8: Summary of die stress analysis.

Die Stress	Significant Factors
Bot. Die Shear Stress	Bottom Die Thickness & Bottom Die Size
Bot. Die 1st Prin. Stress	Bottom Die Size & Bottom Die Thickness
Top Die Shear Stress	Top Die Thickness
Top Die 1st Prin. Stress	Top Die Thickness

The optimal design parameters proposed by the statistical method were shown in Table 9. Thin dies were suggested for both the bottom and the top die layer thickness. The optimal die size suggested were 5.08 mm x 5.08 mm for the bottom die and 2 mm x 2 mm for top the die. The factorial method also predicted all the related stresses responses. Comparisons between the FEA simulation results and the predicted results were done and the result is shown in Table 10.

Table 9: Optimal design stacked die.

Description	Dimension
Bottom Die Thickness	0.15 mm
Bottom Die Size	5.08 mm x 5.08 mm
Top Die Thickness	0.15 mm
Top Die Size	2 mm x 2 mm

Table 10: 2^k factorial design method and FEA comparison.

Response	2^k Factorial	FEA	Error
Bot. Die Shear Stress	1.19×10^7	1.19×10^7	0%
Bot. Die 1st Prin. Stress	3.5×10^7	3.5×10^7	0%
Top Die Shear Stress	2.26×10^6	2.26×10^6	0%
Top Die 1st Prin. Stress	2.95×10^7	2.95×10^7	0%

The percentage error is used to compare the differences. From Table 10, it can be deduced that both the predicted and the simulation results give similar values. Therefore, there is no error between the comparisons. Another comparison was

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done between the result from the 2^k Factorial Design and the Taguchi method. The Taguchi method result refers to the previous study [14]. The comparison is shown in Table 11.

Table 11: 2^k Factorial Design and Taguchi Method comparison.

2^k Factorial Design (MPa)	Error (%)	Taguchi Method (MPa)	Error (%)
1.9	0	27.975	0.63
35	0	111.725	1.9
2.26	0	21.625	7
29.5	0	110.75	0.22

From the comparison in Table 11, it is shown that the percentage error obtained by the Taguchi method is larger than the 2^k factorial design. This factorial design produced a more accurate prediction. Less error occurred in the 2^k factorial design because it requires more runs compared to the Taguchi method. The Taguchi method only deals with the minimum runs based on the orthogonal array.

CONCLUSION

From the result, it was clearly shown that the 2^k factorial design gave more accurate result than the Taguchi method in design optimization. 2^k factorial design is a precise technique to optimize design parameter in order to reduce design step.

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