

GRID INDEPENDENT STUDY ON TETRAHEDRAL AND HEXAHEDRAL DOMINANT ELEMENTS TYPES IN FINITE ELEMENT ANALYSIS OF INTEGRATED CIRCUIT PACKAGE

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Abstract

The development of integrated circuit (IC) packaging is one of the important factors for the advanced production of the semiconductor industry. With the recent rise of innovative demand of the production technology, lot of issues had been raised at the manufacturing level especially at back-end production. In order to solve the problem, finite element analysis (FEA) is one of the methods that has been broadly used to evaluate the internal stress of IC package. The performance effect of tetrahedral or hexahedral dominance elements in the meshing stage may lead to the unswerving of FEA results. In such condition, the performance of the element type needs to be analyzed in order to determine which implementation leads to result with higher confident level. This study used the quasi-static simulation of FEA to determine the performance of tetrahedral and hexahedral dominance elements in FEA of IC package strength. The monitored stress was focused on the component levels of IC package, the die and the diepad. The IC package is modelled in three-dimensional case which represented as close as the actual product by simplifying certain parts. The performance evaluation had considered the effect of grid independent study for each of the element type. The maximum stress produced by using the tetrahedral element had been compared with the stress produced by the hexahedral dominance elements. Comparison of the performance showed that the value of the maximum stress produced from hexahedral dominance element was significantly higher at 16% to 40% than the solution obtained from the tetrahedral element. It is found that by using hexahedral element in the finite element analysis, a significant higher value of Von Mises stress is produced, which is more than 505 MPa in diepad. This stress value has been established by previous study within the plastic deformation range and also has good agreement with the physical examination.

Keywords: Finite element analysis, quasi-static, IC package strength, tetrahedral elements, hexahedral elements

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1.0 INTRODUCTION

Nowadays, integrated circuit (IC) industry plays a significant role in booming the technology of semiconductor device. The final stage in the industry is IC packaging which produces the IC package. With the current demand that needs the IC package to be much smaller, it is expected that there are lots of challenges to raise. The IC packaging is not exempted from facing several problems when alterations are made to cater to the changing of IC package dimension. Some of the problems can be solved by having a good explanation that is directly obtained by performing physical experimentation.

Alternatively lots of the problem might be justified at early stage by using the method of computer-aided engineering (CAE) analysis [1- 5]. However the numerical solution from the analysis via CAE software especially in the accuracy of finite element analysis needs to be prudently verified. The software will always produce the result by presenting the values that was calculated from the developed mathematical model. However the calculated values might not be converged towards to the correct estimated solution enough. Therefore the mesh grid independent study needs to be performed in order to verify the appropriate selected grid size to produce an accurate result [6, 7]. The selection of element type

also plays an important role to contribute the accuracy of the result. There are a lot of previous researches such as [8- 9] claimed that linear hexahedral provides better result and consistent accuracy. Tadepalli et al., [10] has found that linear tetrahedral provides very poor result in term shear stress predictions. In contrast with hexahedral elements, the stress prediction is more reasonable and the distribution of stresses looks more smooth and low noise.

There is a relative paucity of well-controlled studies focusing specifically on the comparison of using the tetrahedral and hexahedral dominance elements in finite element analysis of IC package. The effects of maximum stress produced at diepad (die-paddle) and die of IC package using both elements have not been closely examined. Therefore, the aim of this work is to examine the performance of tetrahedral and hexahedral dominance elements under a controlled condition of compression load for generated stress simulation in diepad and die of IC package. This paper also presents the results of stress distribution stability for both the element types. This study compares the accuracy and robustness in terms of grid independent effect of both tetrahedral and hexahedral element types. This study focuses on the analysis for the stresses produced in die and die-paddle (diepad) of IC package. The analysis is based on quasi-static analysis at a specific boundary condition.

2.0 METHODOLOGY

2.1 Load, Boundary Conditions and Material Setup

A standard leaded IC package consists of diepad, adhesive, die, wirebonds and leads. The result from this study will contribute to further exploration on die crack investigation due to external mechanical load at varies boundary conditions. The finite element analysis was performed on the 3D model of an exposed diepad type of IC package which called DSO type. The simplified 3D model is shown in Figure 1. The 3D model needs to be simplified because some of the components did not affect the stresses produced on the area of interest.

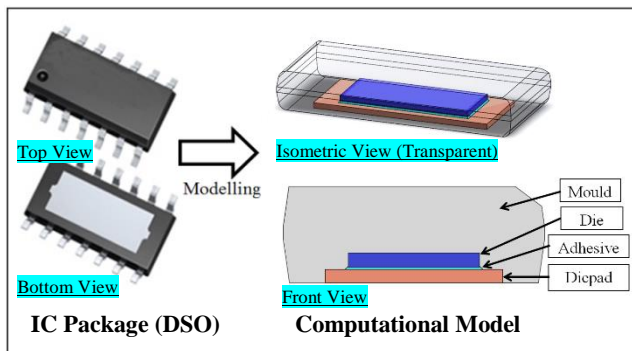


Figure 1 The simplified 3D model of IC package

A few assumptions have to be made since the wirebonds and leads components were excluded in the modelling process. Leads can be exempted in the analysis because there is no significant effect during any feasibly contact on this component in the assembly line. Meanwhile the wirebonds diameter was very thin ($\sim 25 \mu\text{m}$) and was assumed to have no effects on the stress travel during the impact of load [14]. Although those components were not counted in the analysis, the shape details for all other components were accurately modelled as identical as possible to the real product. The load applied in the analysis basically followed the value of load which originated in the series of physical experimentations of single pogo pin impact. The tests were conducted in a controlled condition which customarily closed to the actual production line. A constrain condition was set as fixed on the top of the mould package which followed a certain shape of support or constrain that was built as same as in the assembly line. The material properties used for this study are shown in the Table 1 [9- 11].

Table 1 Material properties

Component	Material	Modulus Young, E (GPa)	Poisson's Ratio, ν
Die/Chip	Silicon	168.9	0.28
Diepad	Copper (C19400)	121.0	0.33
Mould	EMC-CEL 9220 HF10	32.4	0.26
Adhesive	Adhesive (TS333LD)	7.7	0.25

2.2 Adjustment of Element Types and Size

Abaqus software offers several types of element for the meshing process of 3D model. By default, the software can be set as linear hexahedral element type if the component model is not having any complex geometry or any sharp tip dimension. Due to following exact shapes that is as same as real components, only die was constructed by 100% of linear hexahedral element by non-partitioned model. The others components which represented more than 90% of total volume of an IC package need to be well partitioned to be set as hexahedral element. In contrast with the setting of tetrahedral element, due to capability of the element to adapt at any shapes, every component was simply being adjusted to 100% of tetrahedral.

The optimization needs to be performed heuristically to utilize the hexahedral dominance type in the analysis. The other components (Diepad, Mould and Adhesive) that were set to use the tetrahedral element had to be changed to linear hexahedral dominance. The change is presented in the Table 2. Table 2 summaries the comparison of volume percentage of tetrahedral and hexahedral elements for both of the element types. During the changing process, while the adhesive and mould have some tetrahedral elements due to geometrical issue, the volume comprised by that

elements do not significantly affect the overall computational calculation which is below than 1%.

Table 2 Percentage of elements type for each of component

Component	Tetrahedral		Linear Hexahedral Dominance	
	T*	H*	T*	H*
Die/Chip	100.0%	0.0%	0.0%	100.0%
Diepad	100.0%	0.0%	0.0%	100%
Mould	100.0%	0.0%	0.9%	99.1%
Adhesive	100.0%	0.0%	0.3%	99.7%

T*- Percentage of tetrahedral volume, H*- Percentage of hexahedral volume

Finite element simulation time can very much depend on the assignment of elements size. In principle, big sized elements require less time to compute and usually the results is not too accurate towards to the right estimated solution. The accuracy of the results can be improved by reducing the element size until the respond of the calculated values do not significantly change. Two sets of tests were conducted to represent the effect of element size on the types of tetrahedral dominance and linear hexahedral dominance. The sets of tests have been developed for both of the types. The global size of mould was set to be constant for all sets of tests because mould component was considered to not have any significant effect on the stresses produced in die and diepad. At component level, the focus areas for the generated stresses are monitored at die and diepad.

Table 3 illustrates the normalized size of element used for every component. As shown in the Table 3, the biggest element size was applied on the mould. Die and adhesive have same size of elements which represent the smallest size compared to other components. The number of tests depended on the respond of the generated maximum stress. A new test will be developed if the value of generated maximum stress changes significantly. If the value of stress is not considerably altered while the grid is adjusted, it can be considered that the grid of mesh is independent to the targeted generated result. For instance, the 2nd test was set by reducing the element size of every component from set of 1st test (except for mould component). The result of 2nd test will be monitored and compared with the previous test (1st Test). Since the stresses (in die and diepad) changed significantly, the 3rd Test needed to be developed. The generated stress in die for every test can be referred in Figure 2 and Figure 3.

On the third test, it was found that the trend of generated maximum stress of the die for the previous tests was relatively stable and was considered as not affected by the change of element size. Therefore on the fourth test, the setting of element size was set to follow the second test details since the third test had no the effects for maximum stress except the diepad.

Table 3 Normalize element size in meshing process

Component	1 st Test	2 nd Test	3 rd Test	4 th Test
Die/Chip	0.25	0.20	0.15	0.20
Diepad	0.50	0.45	0.40	0.35
Adhesive	0.25	0.20	0.15	0.20
Mould	1.00	1.00	1.00	1.00

3.0 RESULTS AND DISCUSSION

3.1 Grid Independent Results

Figure 2 compares the maximum equivalent stress (Von Mises stress) generated on diepad for both of the elements types. In the figure, the maximum Von Mises (VM) stress is used as the failure stress reference due to the fact that the diepad was produced from the ductile material. The equation of localise Von Mises stress can be expressed as Equation 1.

$$\sigma_{VM(x,y,z)} = \frac{1}{\sqrt{2}} \left[(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 \dots \dots + (\sigma_{zz} - \sigma_{xx})^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2) \right]^{\frac{1}{2}} \tag{1}$$

In contrast, die is considered as brittle material and the most suitable measurement concerned is maximum principle stress. Based on the figure, it can be concluded that the analysis that uses hexahedral elements provides higher value of stress is more than 40% than that of tetrahedral. The best way to choose which one is giving the most reasonable stresses is to compare the calculated Von Mises stress with the real situation. In the real problem investigation, it was found that the IC package failure was indicated by a significant dent mark on the exposed surface of diepad as shown in Figure 3. Therefore it can be confirmed that plastic deformation happened on the diepad.

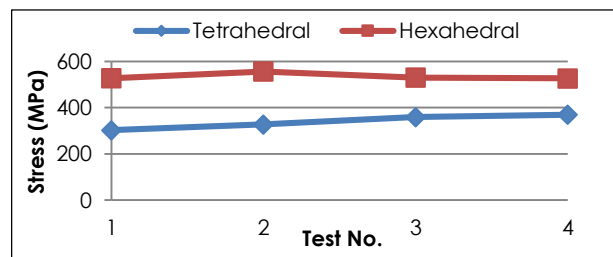


Figure 2 Maximum Von Mises stress of diepad

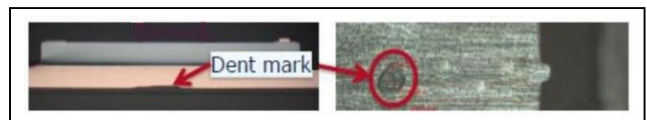


Figure 3 A dent mark on diepad was indicated during the investigation

By referring to Von Mises failure criterion, if the maximum yield stress generated in the ductile material has reached or exceeded the yield stress value of the material, the material structure will be distorted which will cause yielding. Diepad is built by copper (C19400) and has a range of yield strength values that depends on applied heat treatment during production. The range of yield strength is between 260 MPa and 505 MPa [9]. According to the result (Figure 2), only stresses from hexahedral dominance element are beyond the highest value of yield strength (>505 MPa). Thus it can be decided that stresses generated by hexahedral elements are the most reliable and has improved reasonable prediction.

Meanwhile the stresses generated for the die support the high confident level of selected element type. Hexahedral element is the best selection because the predicted stresses were 16% higher than tetrahedral elements as shown in Figure 4. The result is very important because the high stress produced might fall under range values of die cracking stresses as found in previous studies [13, 15, 16].

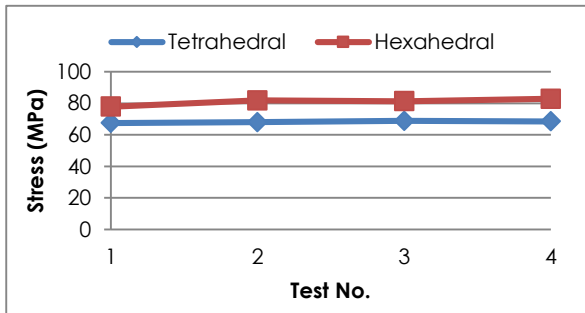


Figure 4 Maximum principle stress of die

In this study, the result of maximum principle stress was not near to the range of die cracking possibility. At higher level of external load, the value of maximum principle stress generated at the die can be close to the lower boundary level of die cracking possibility. If tetrahedral is used as type of elements, the predicted stresses might not yet reach the stress level of die cracking.

3.2 Evaluation on Stress Distribution

Another interesting result in this study was to find out which element type gave better visual stress distribution and showed consistent stresses prediction throughout the volume of components. Figure 5 and Figure 6 show stress distribution on the cross section of the package after an external load had been applied for tetrahedral and hexahedral dominance types respectively. The visualisation of stress distribution clearly shows that tetrahedral elements provide unstable distribution across the diepad body. Even if the die is using hexahedral element type, the stress travelled did not generate consistently through the diepad body.

The stress distribution of tetrahedral elements was not as smooth as compared to hexahedral elements. In addition, the study also found some degree of difficulty to obtain accurate data on surface of cross section. This problem happens due to the nature of tetrahedral mathematical model that able to adapt into any orientations according to the shape needed. Every element of tetrahedral is not structured in the equal angle of position that could raise the problem called distortion quality measure [17]. Unlike for the hexahedral elements, nodes in the tetrahedral element are belonged to the different angle of surface. However the patterns of stress distribution are stills the same for both types of element.

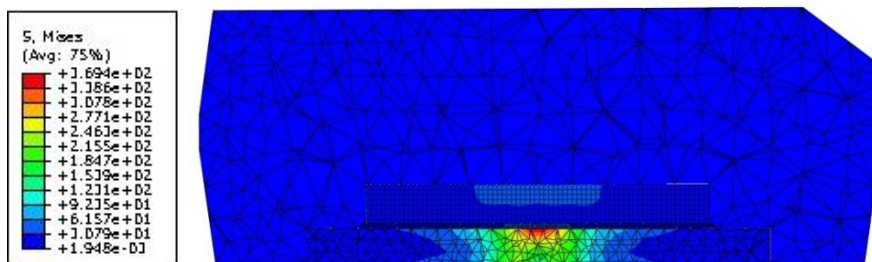


Figure 5 Tetrahedral elements for major volumes of model

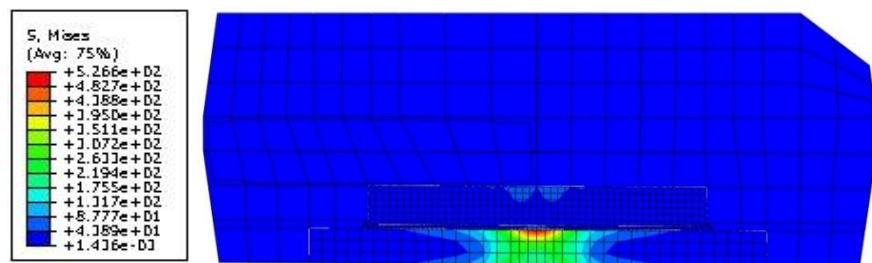


Figure 6 Hexahedral dominance elements for major volumes of model

4.0 CONCLUSION

This study set out to gain a better understanding of the tetrahedral and hexahedral dominance elements performance in finite element analysis of IC package strength specifically for the stress produced in die and diepad. Other purpose of this study was to investigate the stress distribution in term of the accuracy and the stability of stresses produced. The relevance of hexahedral element as the best choice of element in the finite elements analysis of IC package strength simulation is clearly supported by the current findings. The major finding was that the maximum stress generated for both the Von Mises stress and the maximum principle stress in the diepad and die respectively were really convinced on the use of hexahedral dominance elements. The stress value was significantly higher than the stress produced from the tetrahedral element. The study had also found that by using the hexahedral dominance type in the finite element analysis, better stress distribution and very accurate stresses travel in the IC package had been assuredly achieved. The results obtained simulating the real situation of dent indicated on the exposed diepad of IC package.

Further investigation and laboratory experimentation into the impact of mechanical stress on IC package for several boundary conditions are strongly recommended. A number of possible future studies using the similar condition of finite element analysis are apparent. It would be interesting to evaluate the effects of explicit dynamics study on the IC package strength.

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