Steady-State Structural Analysis on Copper and Gold Wire Bonding using ANSYS

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Abstract - **The aim for this analysis is to perform simulation and steady-state analysis in structural discipline on wire bonding for various force and pressure loading on both copper (Cu) and gold (Au) materials. This analysis will consider the size, temperature and properties of each material which resulting the stress on structural. The features of the copper material such as much lower cost, high conductivity, high melting point and strong resistance make it an ideal choice for many new applications. The scope of this study includes the modeling of wire bonding, defining the geometries and properties of each material using finite element method. Simulation is conducted using software ANSYS Multiphysics in order to analyze the structural characteristics and the stress distribution of copper and gold wire bonding under thermocompression wire bonding process. This research focused on two parts; the free air ball and heat affected zone of the wire bonding structure. Results show that von Mises stress of gold wire bonding simulation is 1.25% than copper at pressure 300MPa while 9.1% difference at pressure 500MPa. For first principal, copper and gold show 6.45% difference at 300MPa and 9.35% difference at 500MPa**

***Keywords** – wire bonding, finite-element method, force, pressure, von Mises stress, first principal stress.*

I. INTRODUCTION

Wire bonding process has been the most important interconnection technology in semiconductor device packaging [3]. The common material that used in wire bond process is gold which has good conductivity. However the price of gold has been highly increased. The IC packaging industries are now focused on copper wire as the replacement for gold wire. There were lots of researches and studies that have been published on copper and gold wire bonding, but the materials refinery development and equipments continuous improvement is still needed. Wire bonding consists of three parts which are free air ball (FAB), heat affected zone (HAZ) and as-drawn wire. The wire bonding process cycle involved with electrical breakdown which heats with high temperature (up to 400°C) and melts the wire and roll up into a ball. This ball then will be pressed on the pad.

Copper have an excellent conductivity which it have low resistance, its conductivity is up to 40% higher than gold [5]. Copper ends to cause damage to the surface of the chip because it is harder than gold. However the fact that its price has much lower than gold, a lot of research and analysis have been done to obtain the most reliability wire bonding. This research will focused on thermocompression bonding process by applying force and pressure simultaneously. In this study, the simulation was carried out with the dimensions of both gold and copper wire bonding with condition for pressure and force.

II. METHODOLOGY

This study develops a methodology that applies static (steady-state) analysis which results on the stress of wire bonding. With a uniform temperature of 125°C (398K), the analysis will varies the pressure and force loading on copper and gold wire bonding. Temperature of 250°C (523K) is set to the area of heated affected zone since the wire is threaded through the capillary. Figure 1 shows the flow chart of the project.

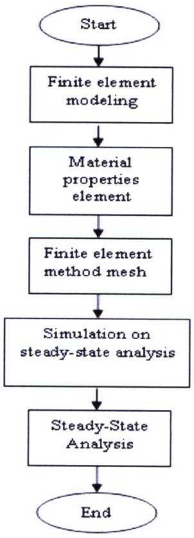


Figure 1 Flow chart of the project

A. *Finite Element Method*

At first, based on implicit method is applied to determine the material properties of the solid model, mesh and node conditions. In modeling the element type for the analysis is solid 45 for linear 3D model and solid 95 for quadratic 3D model. As for material properties, isotropic is chosen for the analysis.

B. *Modeling*

A 3D-model is developed using ANSYS for copper and gold wire bonding. The dimension of both free air ball and heat affected zone are designed in two different materials which are copper and gold, to compare the stress of the wire bonding considering the pressure, force and temperature. As part of the 3D-model, the Aluminum pad with the dimension of 1 um thickness also included. The pressure is transferred to the Aluminum pad during the wire bonding process. However the Cu/Low K microstructure and capillary are not including in this design.

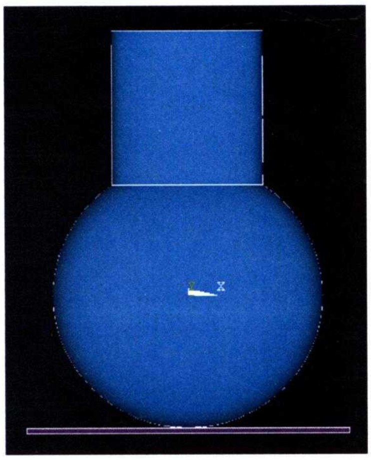


Figure 2 Wire bonding on the Aluminum pad 3D-model

Table 1 shows the geometries and materials properties defined in this study. The dimension of the wire bonding had chosen the average dimension from previous reseach [2].

TABLE I. DIMENSIONS OF FAB, HAZ AND PAD

Model Geometries	Dimension (um)
Wire diameter	25.4
HAZ length	17.4
FAB diameter	45.2
Aluminum pad (thickness)	1
Dimension of pad	54 x 54

C. *Material Properties*

The material properties are defined input as functions of temperature. Table 2 consists of properties such as Poisson's Ratio, Young's Modulus and density of gold and copper. These properties will determine the element that used in the simulation.

TABLE II. PROPERTIES OF MATERIAL

Properties	Copper	Gold	Aluminum
Poisson's Ratio, ν	0.355	0.44	0.334
Young's Modulus, E (GPa)	110	79	70
Density (lb/inc^3)	0.324	0.698	0.098

D. *Finite Element Method Mesh*

In meshing process, the method that been used is patch-independent where it uses a top-down approach. This method is to create nodes (volume mesh) and extracts surface mesh from boundaries [12]. Wire bonding is meshed with MESH200 with brick 8-node. The shape of the model changes significantly, therefore a fine mesh scheme with sufficient accuracy is needed [2]. The mesh is set to free process and the global size to mesh is set to 0.2 to get more accurate mesh result.

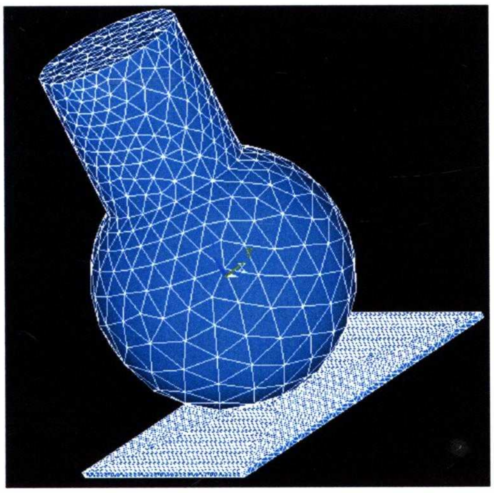


Figure 3 the meshed wire and free air ball

E. *Simulation*

This study simulates under a steady-state structural analysis. Table 3 shows the value of loading to simulate the stress of wire bonding. The variable inputs for this simulation such as pressure, force and temperature. As for pressure, two inputs are taken to see the differences of the reliability of the structure. This paper will take the minimum and maximum pressure as the variable inputs.

Five inputs of force which are 0.2N, 0.4N, 0.6N, 0.8N and 1.0N for each pressure and materials are put on the simulation. Temperature is a constant value which contain of surrounding temperature and capillary temperature which are 125°C (398K) and 250°C (523K) respectively.

TABLE III. TYPES OF LOADING FOR SIMULATION OF WIRE BONDING PROCESS

Type	Loading
Force (N)	0.2, 0.4, 0.6, 0.8, 0.8 and 1.0
Pressure (MPa)	300MPa and 500MPa
Uniform Temperature	125°C (398K)
Capillary Temperature	250°C (523K)

For each inputs are gather on nodal of the structure where the key point is in figure 3. The pressure and force are representing the capillary smashed the wire bonding in real process. This resulting to the shape deformed in figure 4.

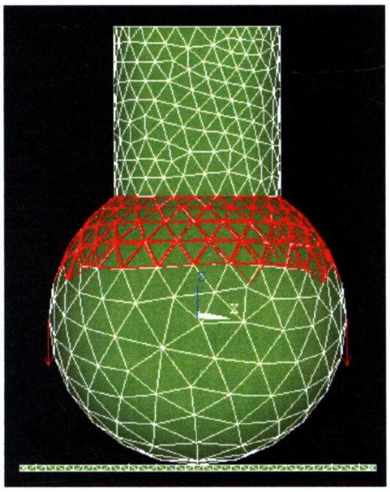


Figure 4 point of forces, pressures and temperature

III. RESULT AND DISCUSSION

Since this paper research is an initial analysis, the results are limited where the data taken only on the structural analysis. The varies of force, pressure and temperature on free air ball and wire, Von Misses stress and first principal stress data taken, to see the change on structural body.

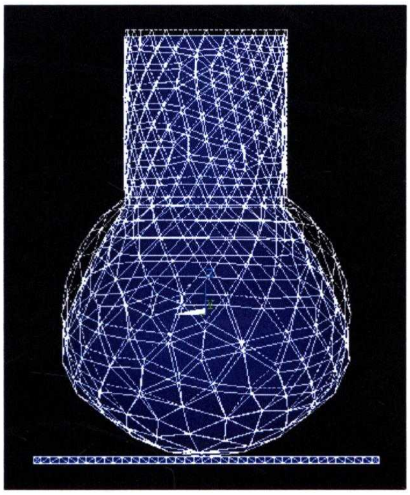


Figure 5 the deformed and un-deformed shape after simulation

Figure 5 shows that the shape is not deformed exactly like in real process, as in this research, force and pressure loading are replacing the capillary. The force and the pressure give a small effect to the formation of the free air ball to bond on the pad. However, by nodal solution of contour plot, the von Mises and first principal stress can be obtained.

Figure 6 shows the formation of wire bonding process. The free air ball is being pressed by force and pressure, also influenced by high temperature at the area of capillary supposed to hit. The changes of the color represent the stress that formed in the simulation process.

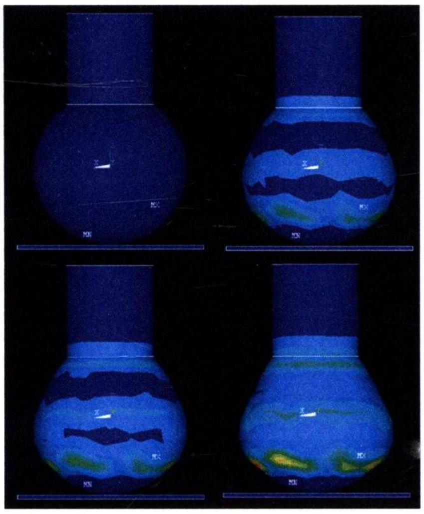


Figure 6 the formation on wire bonding process

The structures in figure 7 and figure 8 represent the form of contour-maps of equivalent stresses accordingly to the investigated criteria. The bonding process observed by plotting the von Mises stress. The average of maximum equivalent stress (SMX) is taken as the result. The Von Mises is a combination of three principal axes (x, y, and z) stresses into an equivalent stress, which is then compared to the yield stress of the material. The maximum deflection is the degree to which a structural element is displaced under a load.

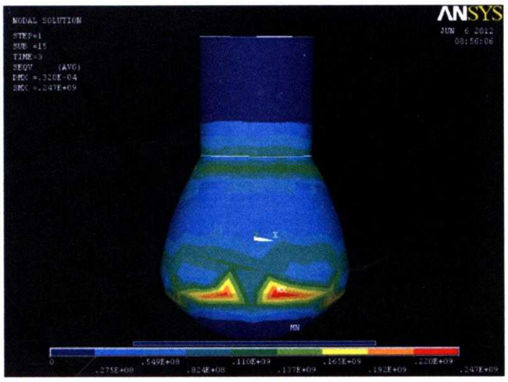


Figure 7 the distribution stress of copper model

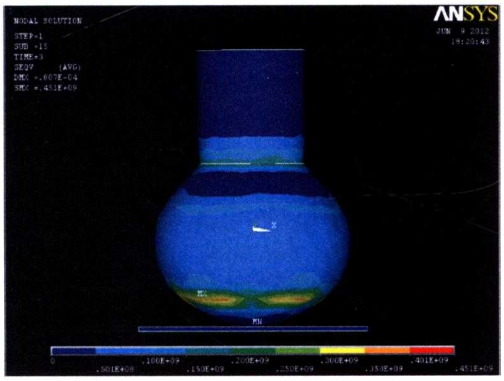


Figure 8 the distribution stress of gold model

The first principal shows the different formation of stress distribution. The maximum and minimum extensional stresses in a stress state at a point. Figure 9 and 10 show the formation of the first principal in a simulation of copper and gold wire bonding process, respectively.

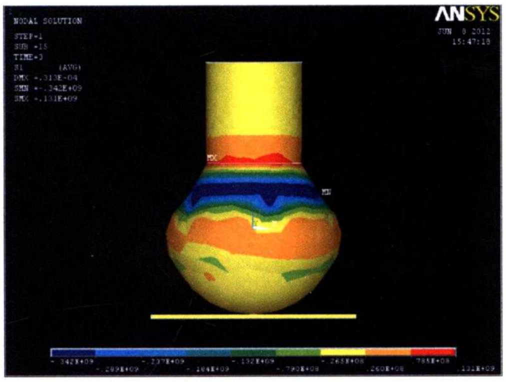


Figure 9 the formation of first principal of copper wire bonding process

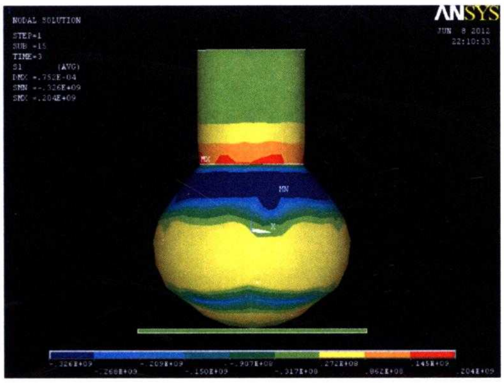
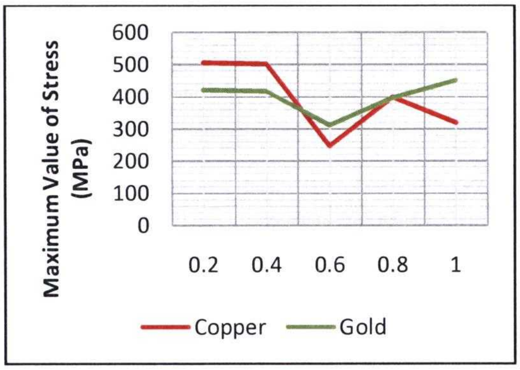


Figure 10 the formation of first principal of gold wire bonding process

Table 3 and 4 shows the data resulting from the simulation of copper wire bonding at pressure 300MPa and 500MPa respectively. As the graphs plotted for each table shows the stress causes by force and pressure.

TABLE IV. VON MISES STRESS ON COPPER AND GOLD WIRE BONDING AT PRESSURE = 300MPA

Force (N)	**Maximum Equivalent Stress (MPa)**	
	Copper	***Gold***
0.2	505	421
0.4	501	417
0.6	247	311
0.8	399	396
1.0	319	451

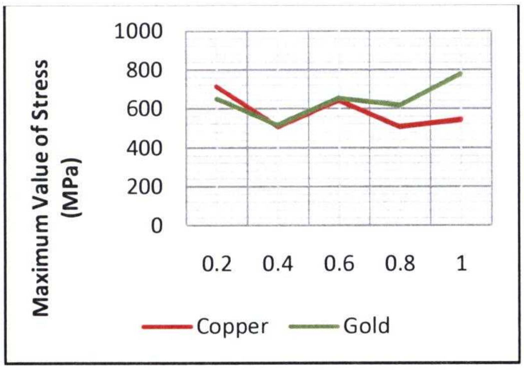


Graph 1 Stress of copper and gold wire bonding at pressure 300MPa

Graph 1 show that copper wire bonding has big differences for each force loading compare to gold. Both copper and gold wire bonding obtain a lower stress at pressure 300MPa and force 0.6N loading. While at pressure 500MPa, copper wire bonding obtain more approximate stress than gold wire bonding showed in graph 2. Von Mises in contour plot shows that the stresses of gold and copper wire bonding at pressure 500MPa are higher than at pressure 300MPa.

TABLE V. VON MISES STRESS ON COPPER AND GOLD WIRE BONDING AT PRESSURE = 500MPA

Force	**Maximum Equivalent Stress (MPa)**	
	Copper	***Gold***
0.2	713	649
0.4	509	515
0.6	641	652
0.8	508	613
1.0	543	777

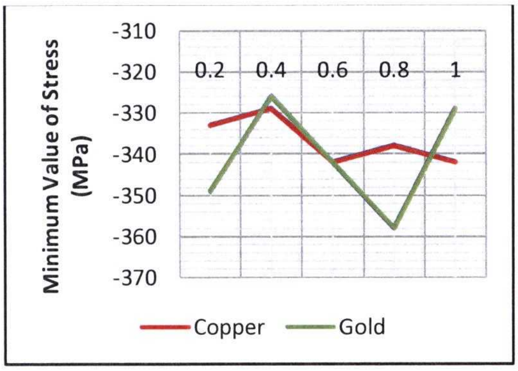


Graph 2 Stress of copper and gold wire bonding at pressure 500MPa

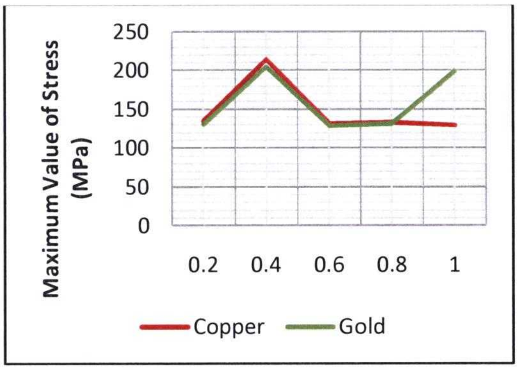
First principal stress plotted in this study where the minimum and maximum equivalent stress of each copper and gold wire bonding data was taken. The minimum stress of first principal at pressure 300MPa shows that non-uniform lines are plotted in graph 3. However, the minimum stress of copper wire bonding show a small different at force 0.6N to 1.0N loading. Graph 4 shows an equivalent stress of each copper and gold wire bonding except at force 1.0N loading.

TABLE VI. FIRST PRINCIPAL STRESS ON COPPER AND GOLD WIRE BONDING AT PRESSURE = 300MPA

Force	**First Principal Stress (MPa)**			
	Copper		***Gold***	
	Minimum	***Maximum***	***Minimum***	***Maximum***
0.2	-333	134	-349	130
0.4	-329	214	-326	204
0.6	-342	131	-342	128
0.8	-338	133	-358	131
1.0	-342	129	-329	199



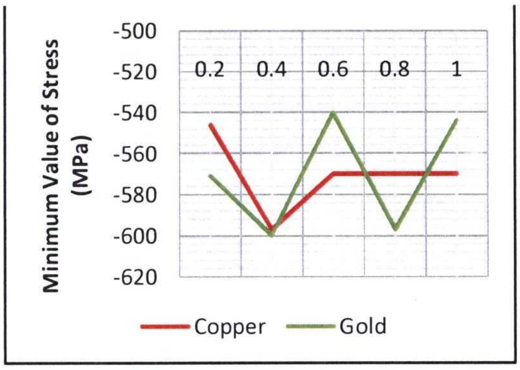
Graph 3 Minimum Stress of copper and gold wire bonding at pressure 300MPa



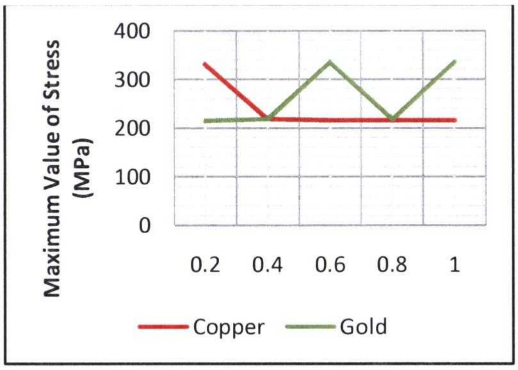
Graph 4 Maximum Stress of copper and gold wire bonding at pressure 300MPa

TABLE VII. FIRST PRINCIPAL STRESS ON COPPER AND GOLD WIRE BONDING AT PRESSURE = 500MPA

Force	**First Principal Stress (MPa)**			
	Copper		***Gold***	
	Minimum	***Maximum***	***Minimum***	***Maximum***
0.2	-546	331	-571	214
0.4	-597	217	-600	217
0.6	-570	215	-540	334
0.8	-570	215	-597	217
1.0	-570	215	-544	334



Graph 5 Minimum Stress of copper and gold wire bonding at pressure 500MPa



Graph 6 Maximum Stress of copper and gold wire bonding at pressure 500MPa

At pressure 500MPa, the first principal stress of copper wire bonding shows an approximate values. At force 0.6N to 1.0N loading, the minimum stress resulting a linear line, and at force 0.4N to 1.0N loading, the maximum stress also resulting a linear line, compare to gold wire bonding which the first principal stress is unstable for both pressure.

IV. CONCLUSION

In this research paper, structural analysis are performed to investigate the reliability of the gold and copper wire bonding depending on the free air ball (FAB) and heat affected zone (HAZ) dimension, its properties value, and the forces, pressure and temperature that influence the bonding process. Copper shows good performance in term of stress in the steady-state analysis where the average of von Mises stress of gold wire bonding simulation is 1.25% higher than copper wire bonding at pressure 300MPa. The difference of 1.25% shows that gold is softer than copper. While at pressure 500MPa shows the difference of 9.1% between gold and copper wire bonding. Percentages between two materials show that gold have unstable stress at pressure 500MPa.

For first principal, copper and gold show 6.45% difference at 300MPa and 9.35% difference at 500MPa where stress of gold is higher than copper. The stress results of the simulation are not accurate since there were limitations of the design. However, the results are not in failure conditions since the stress are below than the young's modulus. Copper has high conductivity, where it has less resistance and gives a good performance in semiconductor and microelectronic applications.

RECOMMENDATION

For this analysis, the process is analyzed through thermocompressor process by replacing the capillary with force, pressure and high temperature. The analysis of wire bonding in reality is influenced by the temperature or heat from Cu/Low-K layer under the Aluminum pad. Therefore, for the next research I propose the research to be continued with adding the capillary and the layer design to get the more efficient simulation. Other than structural analysis, the simulation should also consider the transient analysis.

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REFERENCES

[1] Chang-Lin Yeh, and Yi-Shao Lai, "Comprehensive Dynamic Analysis of Wirebonding on Cu/Low-K Wafers," IEEE Transactions On Advanced Packaging, vol. 29, no. 2, May 2006.

[2] Hsiang-Chen Hsu, Chin-Yuan Hu, Wei-Yao Chang, Chang-Lin Yeh, and Yi-Shao Lai, "Dynamic Finite Element Analysis on Underlay Microstucture of Cu/Low-K Wafer during Wirebonding," Finite Element Analysis, Published by Sciyo, Chap 20, 2010.

[3] Jonathan Tan, Boon Hoe Toh, and Hong Meng Ho, "Modelling of Free Air Ball for Copper Wire Bonding", Kulicke & Soffa Pte. Ltd., Electronics Packaging Technology Conference, 2004, IEEE. [3]

[4] Wei-Yao Chang, Hsiang-Chen Hsu, Shen-Li Fu, Yi-Shao Lai, and Chang-Lin Yeh, "An Investigation on Heat Affected Zone for Au Wire/Cu Wire and Advanced Finite Element Wirbonding Model," Dep. of Mechanical and Automation Eng., I-Shou University, 2008, IEEE.

[5] Usman Chaundhry, Danytza Corral, Greg Ryan, "TI's Journey to High-Volume copper wire bonding production," Texas Instruments Incorporated, 2012.

[6] Wei Mu, Zhaohua Wu, Chunyue Huang, " The Principal Component Analysis of Cu Stud Bump Shaping Parameters, International Conference on Electronic Packaging Tech. & High Density Packaging (ICEPT-HDP), 2009, IEEE.

[7] Thomas L. Landers, William D. Brown, Earnest W. Malstrom, and Neil M. Schmitt, "Electronics Manufacturing Processes," Prentice Hall, Chap 4, pp. 95-102.

[8] Erdogan Madenci, and Ibrahim Guven, "The Finite Element Method and Applications in Engineering Using ANSYS," Springer, 2006.

[9] Tutorials ANSYS, ANSYS, Inc., 2009.

[10] Paul Dufour, "Picking an Element Type for Structural Analysis, Belcan Engineering Group, Inc., 2003.

[11] O. L. Anderson, H. Christensen, and P. Andreatch, Technique for Connecting Electrical Leads to Semiconductors, Journal of Applied Physics 28, No. 8 (August 1957): 923

[12] ANSYS, Meshing Methods: Tetrahedral. http://www.ansys.com/Products/Workflow+Technology/ANSYS+Workbench+Platform/ANSYS+Meshing/Features/Meshing+Methods:+Tetrahedral. @2012 ANSYS, Inc.