EFFECT OF VISCOELASTIC MODELING OF PCB ON THE BOARD LEVEL RELIABILITY OF WAFER CHIP SCALE PACKAGE (WCSP) IN COMPARISON TO ORTHOTROPIC LINEAR ELASTIC MODELING

by

AVINASH ANASKURE

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Abstract

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Avinash Anaskure, MS

The University of Texas at Arlington, 2016

Supervising Professor: Dereje Agonafer

The assessment of board level solder joint reliability during thermal cycling is very important for electronic packages. During thermal cycling, the mismatch in Coefficient of Thermal Expansion (CTE) between the materials used in the package induces stress on the solder interconnects and result in deformation stresses. Finite element tools are widely used for rapid design optimization and also for understanding board level reliability issues. Lumped board properties approach, explicit geometry approach, and ECAD approach are the three widely used approaches for creating models for PCBs. In the lumped board properties approach, orthotropic elastic material properties are assigned to PCBs. However, for temperatures near and beyond the glass transition temperature, materials behave in a viscoelastic manner. In which case, considering viscoelastic properties would result in a more accurate representation than the orthotropic elastic lump model.

In this thesis, a comparative study on the linear elastic and viscoelastic modeling of PCB is done and how it affects the board level reliability of Packages under thermal cycling. The viscoelastic material properties of PCBs are characterized using dynamic

mechanical analyzer (DMA). The frequency and temperature dependent complex moduli are obtained from the DMA. The obtained results are used to model the PCBs as viscoelastic materials on ANSYS. Thermal cycling is performed in ANSYS and the results obtained are compared to those obtained from the elastic modeling of PCBs for WCSP.

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Chapter 1

INTRODUCTION

1.1 Electronic Packages

Electronic packages are complex material systems operating under multiple loading conditions. To ensure product reliability, extensive reliability tests need to be performed before a product can be shipped. At the heart of reliability analysis is the concept that failure is a result of stress that exceeds strength of the material. Numerical methods, in particular finite element methods, are typically used for stress and strain analysis.

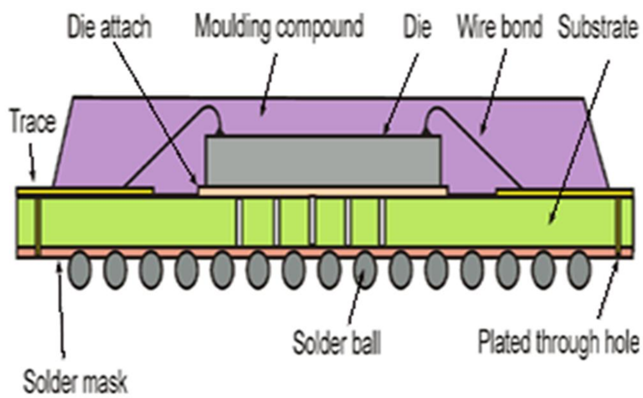

Figure 1.1 Electronic packages [1]

Reliability tests are important before any microelectronics product goes into market. The tests are becoming more challenging as more complex processes and products must be developed in shorter period of time. Furthermore, the next generation electronic packages are expected to perform with ten times higher reliability than today's packages. The Packages should perform under various stress environments, with temperatures ranging from -60 ^{o}C to 175 ^{o}C for the automotive and aerospace industries and -50 ^{o}C to 150 ^{o}C for the telecommunication, consumer and computer industries. Nowadays, product qualification requires many reliability tests such as thermal shock, temperature cycling, highly accelerated temperature and humidity stress test (HAST), to name a few. All of these tests require expensive equipment and long testing time.

Thermal cycling is one of the reliability test that has been used to evaluate the reliability of solder joint interconnect in microelectronics package. Thermo-mechanical stress is generated due to Coefficient of Thermal Expansion mismatch between board and package during temperature loading. Solder joint fatigue crack failure caused by thermo-mechanical mechanism is one of the major failures in microelectronics package. The purpose of thermal cycling is to characterize thermo-mechanical failure mechanism on microelectronics package.

Finite Element Analysis software is used to run the thermal cycling test virtually to evaluate the reliability of the solder joint. The solder joint reliability using finite element analysis is evaluated on the basis of physics based analysis and statistical based analysis. Physics based analysis is used to analyze the effect of several factors such as components geometry, material properties and loading conditions on the performance of solder joint reliability. The statistical analysis is used to find the critical factors and to see the interaction among the factors affecting the performance of solder joint reliability.

1.2 Types of Printed Circuit Board (PCB) Modeling

Depending on speed and accuracy desired in thermal and mechanical simulation. There are three approaches to PCB modeling [2].

1) Lumped board properties approach

- Assign orthotropic properties for the in-plane and normal directions.
- Useful for system-level setups (e.g. multiple boards/ racks), when board performance is not primary focus.
- Reduced solve time since mesh count is significantly lower and fraction is not computed.

2) Explicit geometry approach

- Model the geometry of traces, planes and vias.
- Results in high accuracy.

- very large mesh size leads to very long solution times.

3) ECAD approach

- Map the metal fraction in each layer from ECAD data.
- Requires import of an ECAD file.
- Leads to highly accurate and fast solutions.

1.3 Wafer Chip scale Package

Wafer Chip Scale Package (WCSP) is the silicon die with solder interconnects located on the active surface, and identification marking on the die backside. These solder interconnects are placed on the PCB through conventional SMT processes to form a working circuit. Texas Instruments has developed two different construction technologies to enable broad use of the WCSP in a variety of applications. These two approaches are called Direct Bump (or Bump-On-Pad [BOP]) and Re-Distribution Layer (RDL) technology.

Texas Instruments' RDL technology can be used on devices designed for WCSP as well as other package types. This method allows introduction of a broader portfolio of devices that may not have the production volume to justify the tooling costs of a brand new device. Using RDL technology, the solder bump is placed on a bond pad specially created in a different location than the bond pad originally designed for the wire bonding process. A cross-sectional view of a typical RDL application is given in Figure 1.2. RDL construction consists of:

- A protective polymer re-passivation layer (to cover the delicate silicon surface)
- A copper metal layer to move the interconnect to the proper array location
- A second polymer layer to insulate the RDL layer
- Under-bump metal (UBM) contact
- 300μm solder sphere

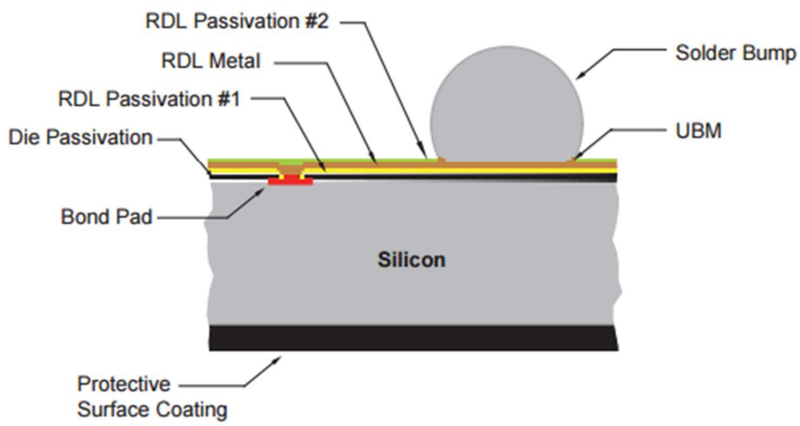

Figure 1.2 Wafer Chip Scale Package [3]

1.4 Motivation and Objective

PCB is a composite material made up of copper and prepeg materials such as FR4 and RCC. At higher temperatures, especially when temperature is near or go above the glass transition temperature, the PCB would behave in a viscoelastic way. This work studies the effect of viscoelastic modeling of PCBs on thermal cycling analysis.

Accelerated thermal cycling, drop testing, and power cycling are some of the common test methods used to assess board level reliability. These tests can be done experimentally or computationally using finite element simulation software such as ANSYS Workbench. Usually, the Printed circuit boards (PCBs) used for various packages are modeled as orthotropic elastic materials. However, as temperature gets close to glass transition temperature, materials behave in a viscoelastic manner. Hence, viscoelastic model would be more appropriate for performing these tests.

The objective of this project is twofold:

- Perform viscoelastic material characterization of PCBs
- Study the effect of viscoelastic modeling on thermal cycling analysis

Chapter 2

LITERATURE REVIEW

Alternating low and high temperature extremes induce thermo-mechanical stresses that cause solder joint fatigue crack failure. A thermal cycling test is used “to determine the ability of components and solder interconnects to withstand mechanical stresses induced by high and low temperatures” [4]. The thermal cycling test can be performed experimentally or using commercially available FEA software such as ANSYS. However, due to their speed and efficiency, numerical methods are used to study the failure life of components such as solder balls, and study the effect of the various design variables. In previous studies done by Zulkifli et al. [4] and Hossain et al. [5], design optimization study and temperature cycling analysis was done for various packages. In these studies, the printed circuit board (PCB) was modeled as elastic material. On the other hand, Liu et al. [6] has shown that the viscoelasticity of PCB materials affects the dynamic characteristic under board level drop impact. Mottahedi et al. [7] have worked on numerical analysis of relaxation test based on Prony series material model. As mentioned by them Prony series is one of the appropriate models in order to model the viscoelastic behaviors of elastomers. By using relaxation test the unknown Prony coefficients can be determined.

Fernanda et al. [8] have shown, how DMA is used to characterize the intrinsic evolution of storage (shear) modulus, G’ and loss (shear) modulus, G’’ with the frequency. In their work viscoelastic constitutive parameters were obtained, specifically for the considered material, directly from frequency domain experimental data, avoiding the used of time-domain experimental data.

S. W. Park and Y. R. Kim [9] have presented an efficient method of fitting Prony-series models to viscoelastic experimental data with power-law presmoothing. A direct fitting of a Prony-series function to experimental data without appropriate presmoothing is difficult when the data have significant variance. A power-law series comprising multiple power-law terms is found capable of portraying a globally smooth, broadband viscoelastic behavior with minimal impact from local variance in the data. However, from a computational point of view, a Prony series representation is preferred to a power-law series representation because of the computational efficiency associated with the exponential basis functions of a Prony series. In their paper, a procedure involving presmoothing of experimental data via power-law-series representation followed by fitting of a Prony-series model to the presmoothed data is discussed and illustrated.

Yan Hongqing et al. [10] have shown that the Prony series expression of the generalized Maxwell model can well describe the dynamic modulus-time curves of viscoelastic material. The dynamic modulus E*, which includes two parts of the storage modulus E' and the loss modulus E'', is obtained by dynamic frequency sweep (FS) test with the stress control mode by imposing a sinusoidal load on a specimen. The Prony series coefficients of the generalized Maxwell model obtained by fitting the dynamic modulus-time curves by non-linear fitting tool Origin software 8.0 are the same as that the fitted results by matrix method from the dynamic modulus E.

Chapter 3

MATERIAL CHARACTERIZATION

Material characterization is done to accurately predict the behavior of material under different loading conditions. By characterizing material, we determine different properties and structure of material. We will determine material properties required to analyze material fully in Finite Element Analysis. To predict more accurate results through ANSYS workbench, it is necessary to provide more accurate inputs. Material properties as mentioned below are determined.

- Coefficient of Thermal Expansion
- Young's Modulus
- Storage modulus (E') and Loss modulus (E'')

Following instruments were leveraged to determine the material properties.

- Thermo Mechanical Analyzer (TMA)
- Instron Microtester
- Shimadzu Tensile Testing Machine
- Dynamic Mechanical Analyzer (DMA)

. Procedure followed to perform tests is presented in following sections.

3.1 Coefficient of Thermal Expansion

Coefficient of Thermal Expansion (CTE) is the fractional change in length per degree of temperature change.

$$\alpha = \frac{\epsilon}{\Delta T}$$

Where,

α – Coefficient of Thermal Expansion (CTE) ppm/°C

ϵ - Strain (mm/mm)

ΔT – Difference in Temperature (°C)

In plane and out of plane CTE was measured using Thermo Mechanical Analyzer.

Figure 3.1 Thermo Mechanical Analyzer

There is no special requirement for the size of sample to be used for CTE measurement hence a 6x6 mm or 12x6 mm sample is used. In order to measure CTE along z direction, it is placed in quartz cylinder on its thickness. To measure CTE in xy plane, sample is placed along its length. The sample is subjected to a constant load of -100mN and a ramp of 5 ^{o}C/min. CTE is measured from 20 ^{o}C to 180 ^{o}C and given as input in ANSYS to correctly simulate the behavior of PCB material. A plot of CTE values calculated at different temperatures with interval of 10 ^{o}C is shown below.

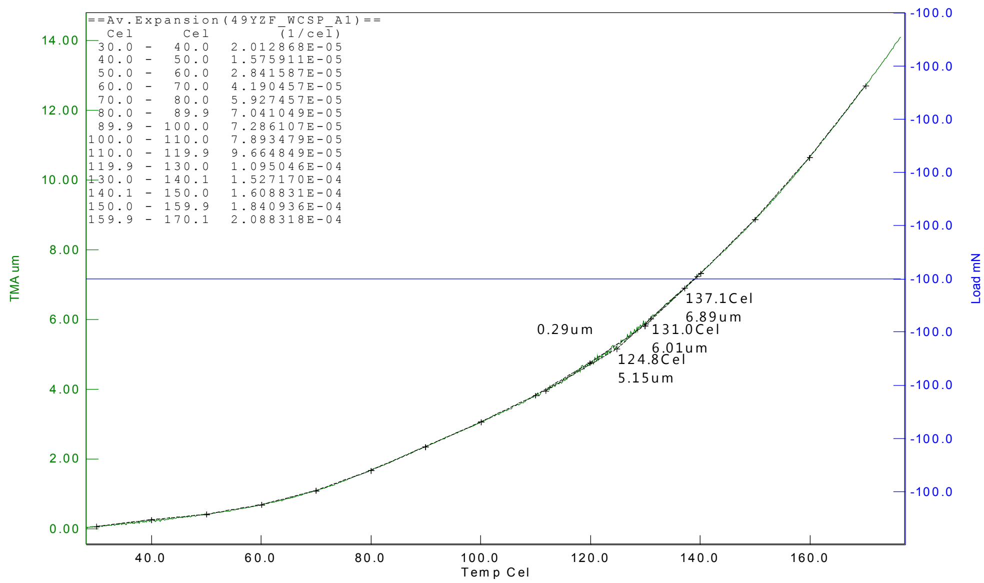

Figure 3.2 CTE values at different temperatures

3.2 Young's Modulus

Young's modulus, also known as the elastic modulus, is a measure of the stiffness of a solid material. Materials that deform by a small amount when tensile load is applied to them are said to be stiffer as compared to the materials that deform by a considerable amount when tensile or compressive loading is applied to them. Young's modulus defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material.

3.2.1 Instron Microtester

To determine Young's Modulus, Instron Microtester was used to apply tensile loading to the samples. An extensometer is placed on the sample to measure strain during sample extension. The extensometer is connected to software and the Instron is also connected which gives force-displacement graph during the test. We get Stress by dividing the load with the cross-sectional area of the sample and strain is measured using the extensometer.

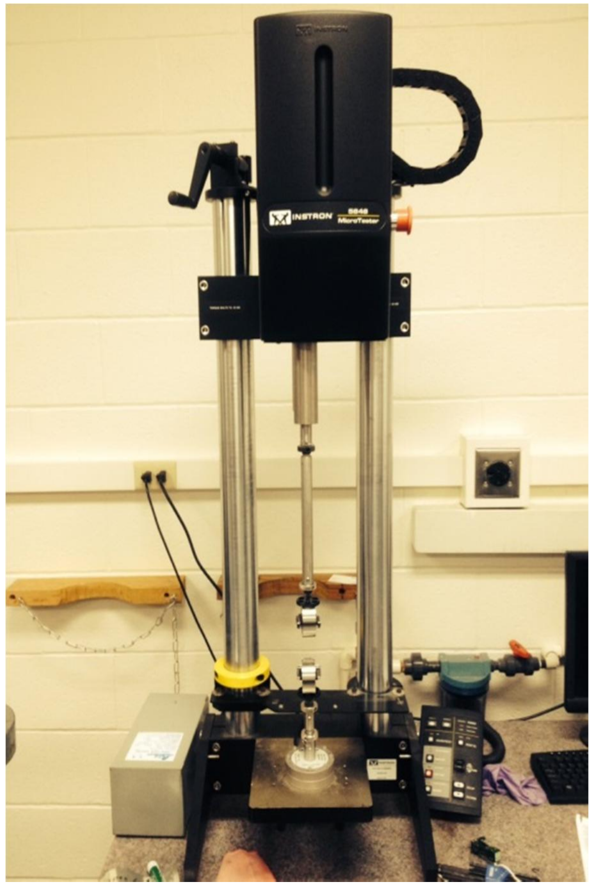

Figure 3.3 Instron Microtester

Dog bone sample for testing is prepared as per ASTM standard. For accurate measurement, it is necessary that there is enough grip section available for the Instron grips to hold the sample tightly during the test. The actual sample used during testing on Instron is as shown below.

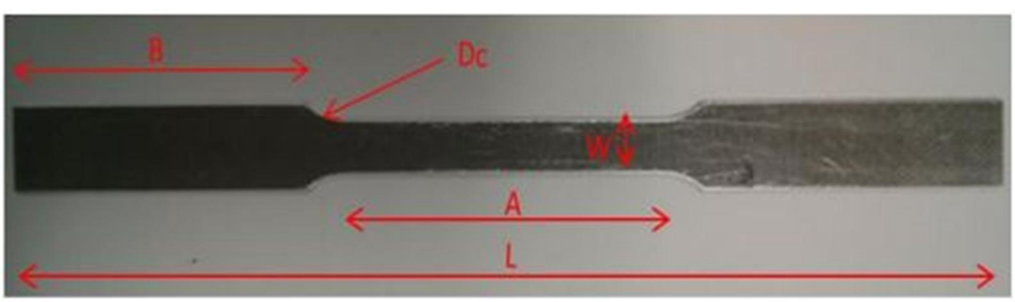

Figure 3.4 Dog bone sample

The dimensions of the sample as referred from the ASTM standards is given below

Table 3.1 Sample Dimensions

Dimension	Length (mm)
L - Length	100
W - Width	6
A – Length of reduced part	32
B – Length of grip section	30
Dc – Curvature distance	4
R – Radius of curvature	6

Instron Microtester 5848 with a maximum load cell of 2kN was used to apply force for measuring Young's modulus of PCB samples. The grip section of dog bone sample is clamped vertically between the two jaw faces of the Instron tester and an Extensometer is placed on the samples with its pins gripping the sample tightly. The Extensometer pins have an initial gap of 12mm between them, when tensile force is applied on the specimen, the extensometer pins which are tightly gripping the specimen open accordingly and the change in length is measured following which strain is calculated using Instron software. The test setup and procedure was benchmarked by testing it on an Aluminum sample. The experimental result was compared with the theoretical result and was found to be in complete agreement.

3.2.2 Shimadzu Tensile Testing Machine

Shimadzu Tensile Testing Machine is an AGS-X series machine incorporating normal functions. The sample was placed inside the jaws, with its length along the direction of loading. A force of 2N/m is applied on the samples. Software Trapezium was used to measure the young's modulus of the samples. The test is performed at room temperature.

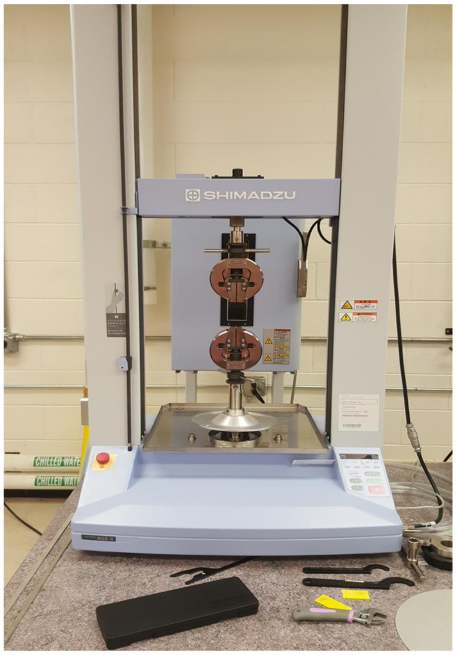

Figure 3.5 Shimadzu Tensile Testing Machine

Young’s modulus obtained at room temperature is as shown below. The data obtained from tensile testing machine is linearly fitted in MS excel.

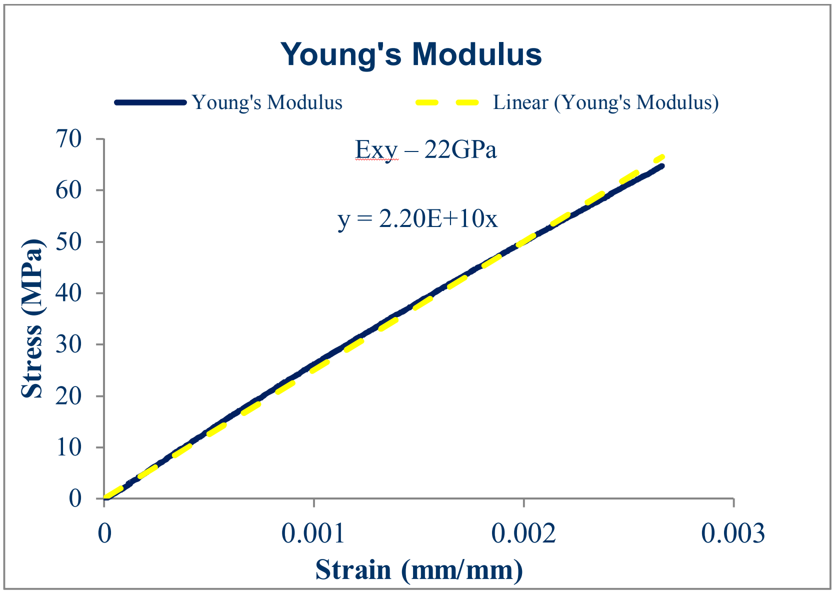

Figure 3.6 Young’s Modulus linear fit

3.3 Dynamic Mechanical Analyzer (DMA)

Dynamic Mechanical Analyzer was used to measure the frequency dependent storage and loss modulus. The Standard Analysis tool on the TA7000 software was used to generate the master curve. A non-linear fitting tool, OriginPro, was used to extract the Prony series constants used as an input in ANSYS.

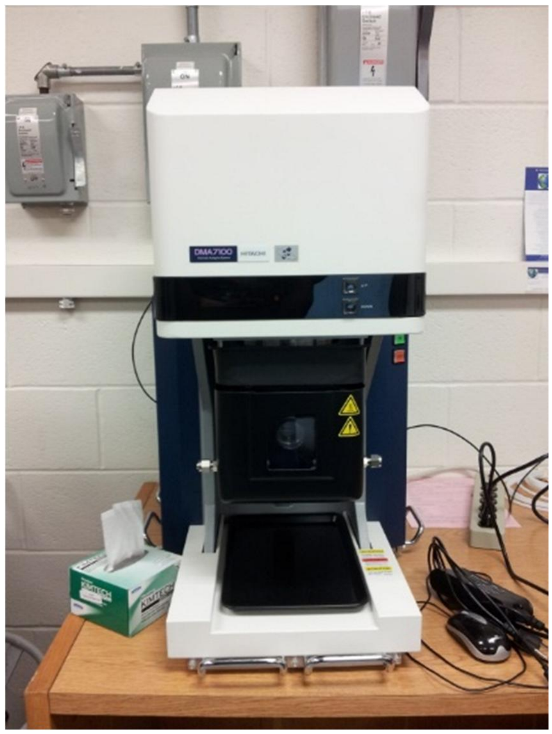

Figure 3.7 Dynamic Mechanical Analyzer

1 mm thick PCB from Texas Instruments as shown below was used to determine viscoelastic properties at different temperatures.

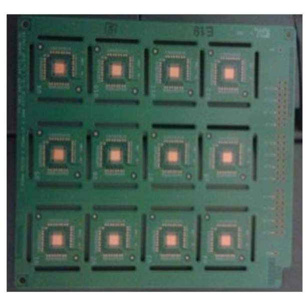

Figure 3.8 1 mm thick PCB

A 50x8 mm sample is cut as shown in the figure below for conducting experiments in DMA.

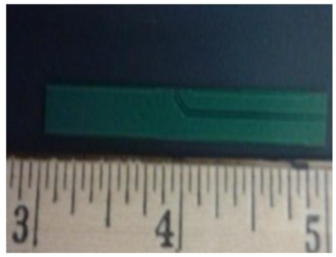

Figure 3.9 50mm by 8 mm for DMA

The experiment is done in DMA and data of Storage Modulus (E') and Loss Modulus (E'') is obtained for temperature range of 10 ^{o}C to 190 ^{o}C. We obtain curves at frequencies 0.1, 1, 2, 5 and 10 Hz. As it is seen in the figure below, the data obtained is smooth for the desired temperature range of modeling of viscoelastic material from 120 to 160 ^{o}C.

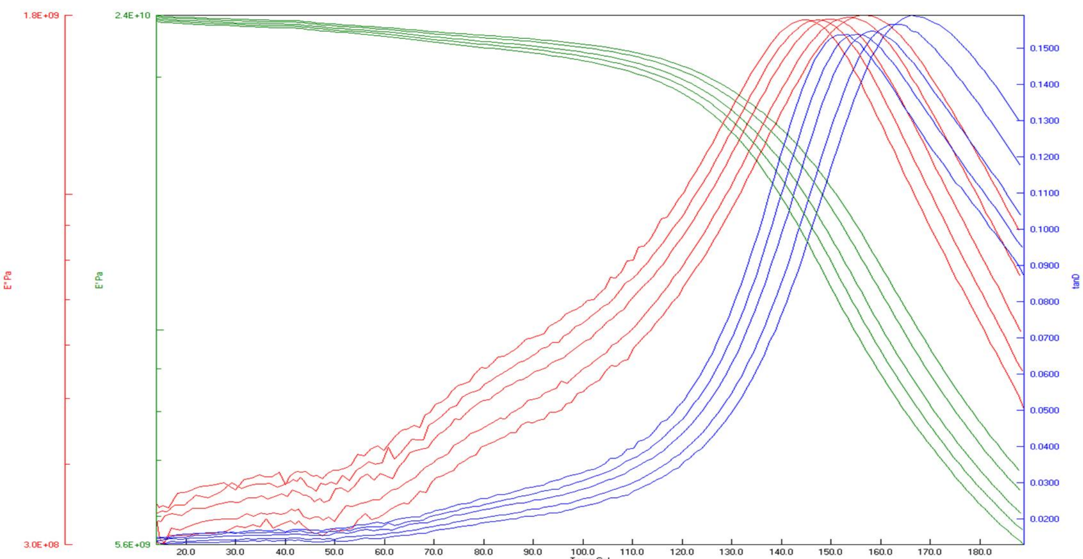

Figure 3.10 Temperature (°C) vs. Storage and Loss Modulus (Pa) and tangent of phase angle

Master curve analysis is done using standard analysis tool on the TA7000 software. The glass transition temperature is 147.6 ^{o}C and master curve is obtained at various temperature by using William-Landel-Ferry temperature shift function. The master curve at 100 ^{o}C is as shown in the figure below.

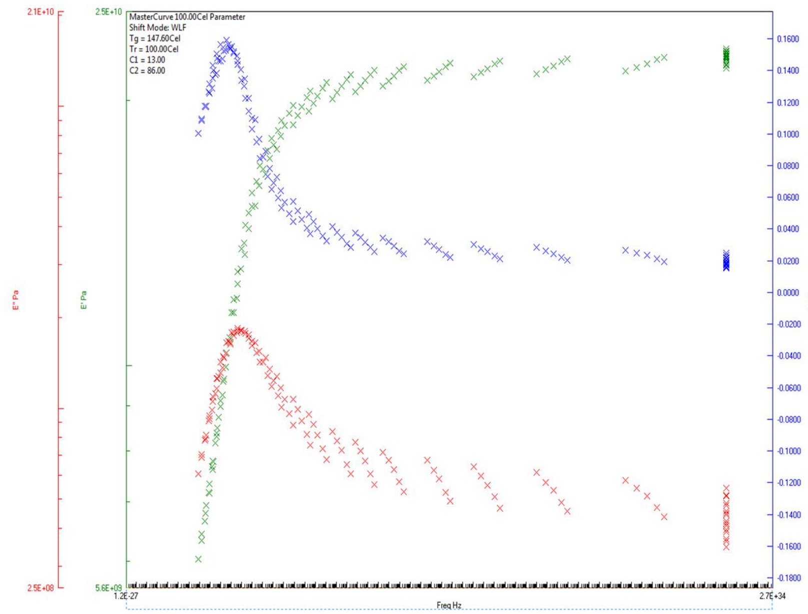

Figure 3.11 Master curve obtained from TA7000 software

Data from master curve like storage modulus and loss modulus is exported to excel sheet using TA7000 software. Least square method of non-linear fitting tool OriginPro is used to fit data. The Prony series constants were determined after fitting data which is to be used as input to model viscoelastic material in ANSYS. Curve fitting obtained from OriginPro fits well with the data points and is as shown below. Y-axis represents magnitude of complex modulus (Pa).

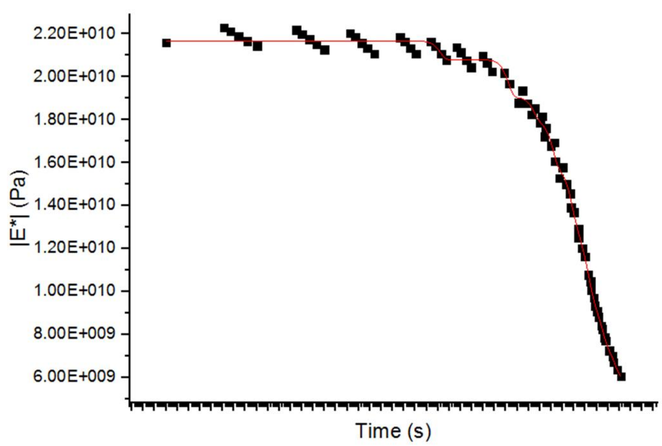

Figure 3.12 Non-linear fit using OriginPro

3.4 Prony series representation for shear modulus

Modeling of viscoelastic material is done by Maxwell model. The model consists of both elastic and viscous property of the material and consists of linear ideally viscous Newtonian damper and linear elastic hookian spring in series. Total strain is summation of strain in elastic and viscous elements. In applying instant displacement the viscous part needs some time to move. However the spring could move instantaneously.

Prony series is one of the best functions for modeling the behavior of the viscoelastic materials [7].

$$G(t) = G_0 \left[\alpha_\infty^G + \sum_{i=1}^{n_G} \alpha_i^G \exp\left(-\frac{t}{\tau_i^G} \right) \right]$$

Where,

G_0 = Relaxation moduli at t=0

n_G = Number of Prony terms

α_i^G = Relative moduli

τ_i^G = Relaxation time

Prony series represents shear modulus over time. Analysis of material properties when constant strain is applied. It would then lead to stress decrease over time. PCB material properties for modeling it as a viscoelastic material in Ansys is represented by Prony Series constants.

Chapter 4

MODELING AND ANALYSIS

4.1 Package Dimension

The WCSP is modeled in ANSYS Design Modeler. The package used in the analysis is 24x24 mm and the thickness is 1 mm. The solder array is 7x7 and the solder diameter is 0.25 mm. Dimensions of other parts like Die, RDL, Polyamide and mold compound are as shown in table below.

Table 4.1 Package dimensions

Parameter	Dimension (mm)
PCB	24x24x1
Solder Array	7x7
Solder Diameter	0.25
Die	2.8x2.8x0.25
RDL	2.8x2.8x0.02
Polyamide	2.8x2.8x0.01
Mold	3x3x0.43

The layout of solder balls provided by TI is as shown in the figure below. The solder balls are equally spaced with a pitch of 0.4 mm.

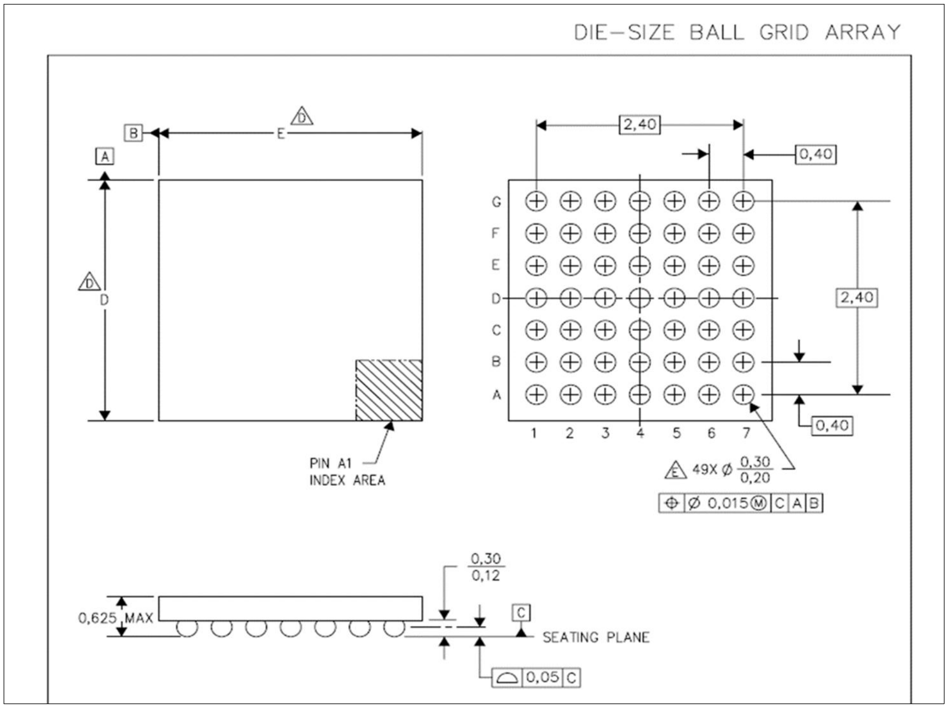

Figure 4.1 Solder ball arrangement [11]

4.2 Finite Element Model

A quarter symmetry model is used for the analysis as shown below, as it reduces the elements required for meshing and computational time.

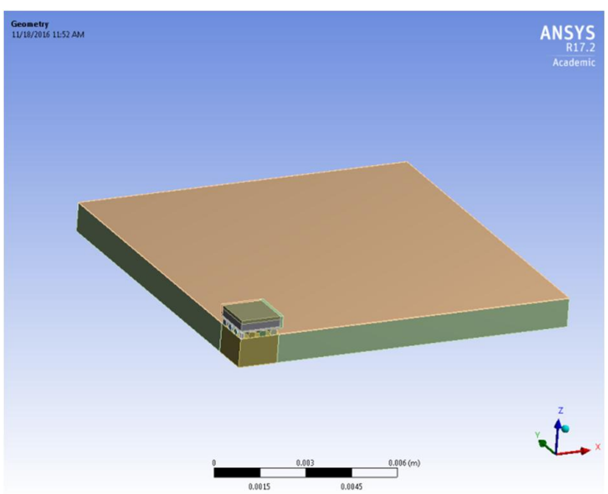

Figure 4.2 Geometry

The mesh is Hex dominant. The element type used for solder joint is VISCO107 and for other components, it is 20 noded Solid 187. It supports both linear and non-linear analysis. VISCO107 is defined by eight nodes having three degrees of freedom at each node or translations in the nodal x, y and z directions. The element is designed to solve both isochoric, rate-independent and rate-dependent large strain plasticity problems. VISCO107 element is suitable to be used with material based on Anand's laws i.e. solder joint. As mentioned earlier, SOLID 187 element is used for the 3-D modeling of solid structures. This element is defined by eight nodes having three degrees of freedom at each node or translations in the nodal x, y, and z directions and has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The number of elements used in the analysis is 159506.

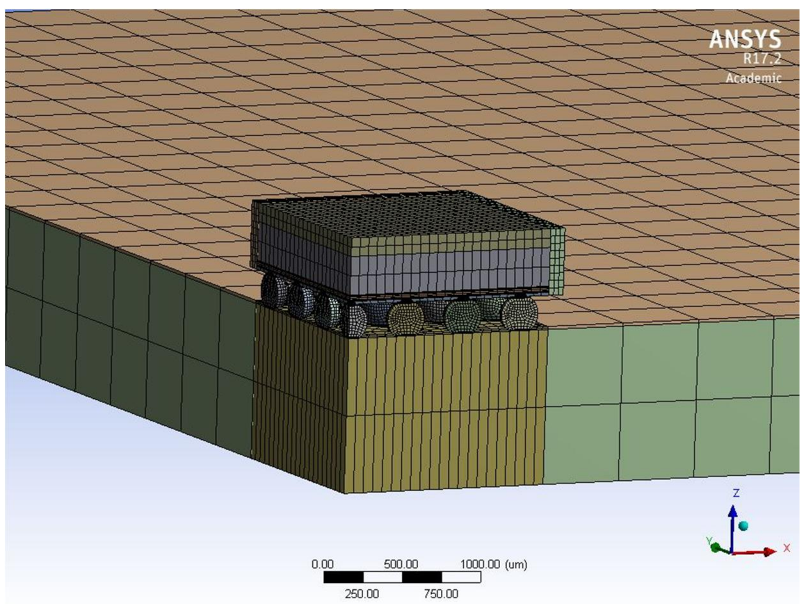

Figure 4.3 Quarter model mesh

Mesh is not continuous as there is bonded contact between elements, which has reduced significantly number of elements required to analyze model satisfactorily. In the figure below, we can see the finely meshed solder balls.

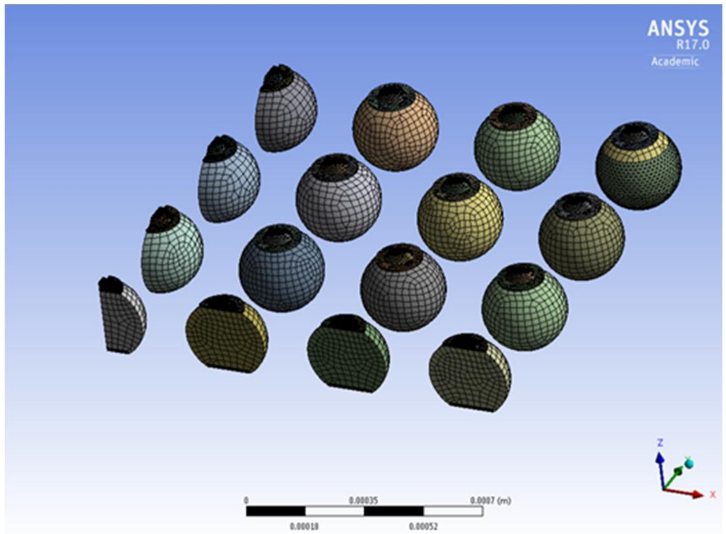

Figure 4.4 Solder ball mesh

4.3 Material properties used in model

All materials except SAC 396 and PCB were modeled linear elastic. SAC alloy was modeled as viscoplastic using Anand's viscoplastic model for SAC 396 [13]. PCB is modeled as orthotropic linear elastic and viscoelastic material. The material properties used for different materials are given in table 4.2 and 4.3 below.

Table 4.2 Material Properties [12]

Material	**Property**		
	E (GPa)	**CTE (ppm/°C)**	**v**
Die	131	3	0.28
RDL	130	16.8	0.34
Polyamide	1.2	52	0.25
Mold	24	20	0.3
Cu	110	17	0.34
Solder Mask	4	30	0.4

Table 4.3 Material Properties of PCB

Material	E(GPa)			CTE (ppm/°C)			v		
	X	Y	Z	X	Y	Z	xy	yz	xz
PCB (Orthotropic Linear)	22	22	0.1	20	20	60	0.11	0.39	0.39

PCB material properties for modeling it as a viscoelastic material is represented by Prony Series constants as shown in table 6 for 150 °C.

Table 4.4 Prony Series Constants

Relative moduli(i)	Relaxation time(i) (s)
0.082023	9.2217
0.075153	1.9581
0.062615	8.4836E-06
0.072695	58.437
0.057023	2952.2
0.090097	0.00737
0.05104	0.00053268
0.05938	393.61
0.066464	1.4171E-10
0.11397	0.20255

The elastic part of the constitutive law of SAC 396 can be described by a temperature-dependent Young's modulus and Poisson's ratio (v=0.40). The temperature-dependent Young's modulus is E=100501−194T (MPa) in which the absolute temperature T is in Kelvin. The coefficient of thermal expansion of the solder is taken to be 23.5 ppm/K.

Anand's viscoplasticity for solder can be described as follows

$$\frac{d\varepsilon_p}{dt} = A \sinh\left(\xi \frac{\sigma}{s}\right)^{\frac{1}{m}} \exp\left(-\frac{Q}{kT}\right)$$

With the rate of deformation resistance equation

$$\dot{s} = \left[h_0(|B|)^{\alpha}\frac{B}{|B|}\right]\frac{d\varepsilon_p}{dt}$$

where,

$$B = 1 - \frac{s}{s^*}$$

and

$$s^* = \hat{s}\left[\frac{1}{A}\frac{d\varepsilon_p}{dt}\exp\left(-\frac{Q}{kT}\right)\right]^n$$

There are nine material constants in Anand's viscoplasticity law which are given in table 4.5 below for SAC396.

Table 4.5 Anand's Constants for SAC396 [13]

S. No	Constant	Unit	Value
1	s_0	MPa	3.3
2	Q/R	1/K	9883
3	A	sec^{-1}	15.7E+06
4	ξ	Dimensionless	1.06
5	m	Dimensionless	0.3686
6	h_0	MPa	1077
7	$\hat{s}$	MPa	3.15
8	n	Dimensionless	0.0352
9	a	Dimensionless	1.6832

4.4 Loading and boundary condition

After package is modeled and meshed. The next step in analysis is subjecting the model to thermal cycling. Model is fixed at center to avoid rigid body displacement. Loading and boundary conditions applied on the model are as shown in figure 4.5.

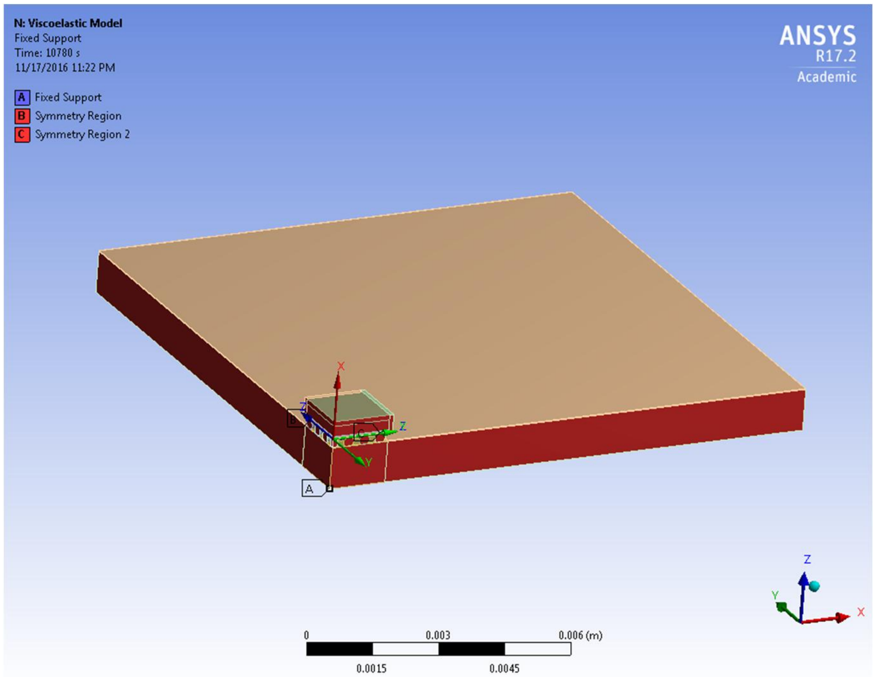

Figure 4.5 Boundary condition

- Symmetry boundary conditions at quarter symmetry cut faces
- One center node constrained in all direction
- Temperature loading –
  - ➢ The thermal cycling test follows the JEDEC standard No. JESD22-A104D
  - ➢ The test condition followed is M (-40 to 165 ºC)
  - ➢ The ramp rate was taken as 15 minutes and the soak time was also taken as 15 minutes

The temperature loading is as shown in the figure below.

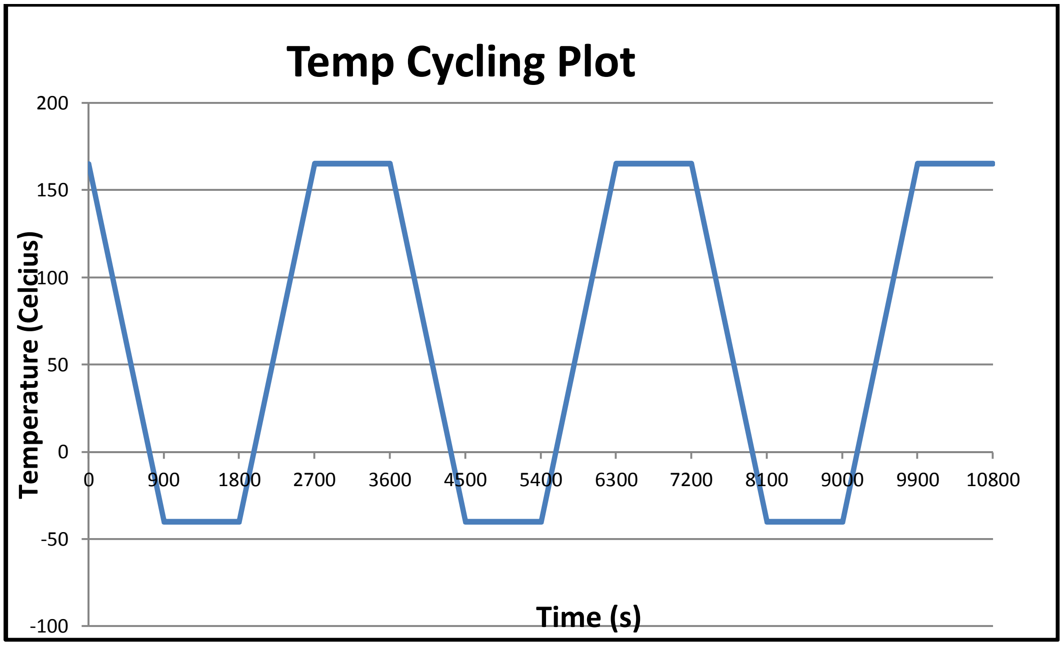

Figure 4.6 Temperature cycling plot

It is seen that increment of inelastic strain energy remains unchanged after a few cycles. Choice of three cycles for analysis is based on the trade-off of computational resource and the stabilization of the system under thermal cycling [14].

Chapter 5

RESULTS AND DISCUSSION

5.1 Strain Energy Density

Critical solder joint is determined by plotting strain energy density of all solder balls at the end of first cycle. As shown in fig. 5.1, the corner solder joint is found to be the critical solder joint.

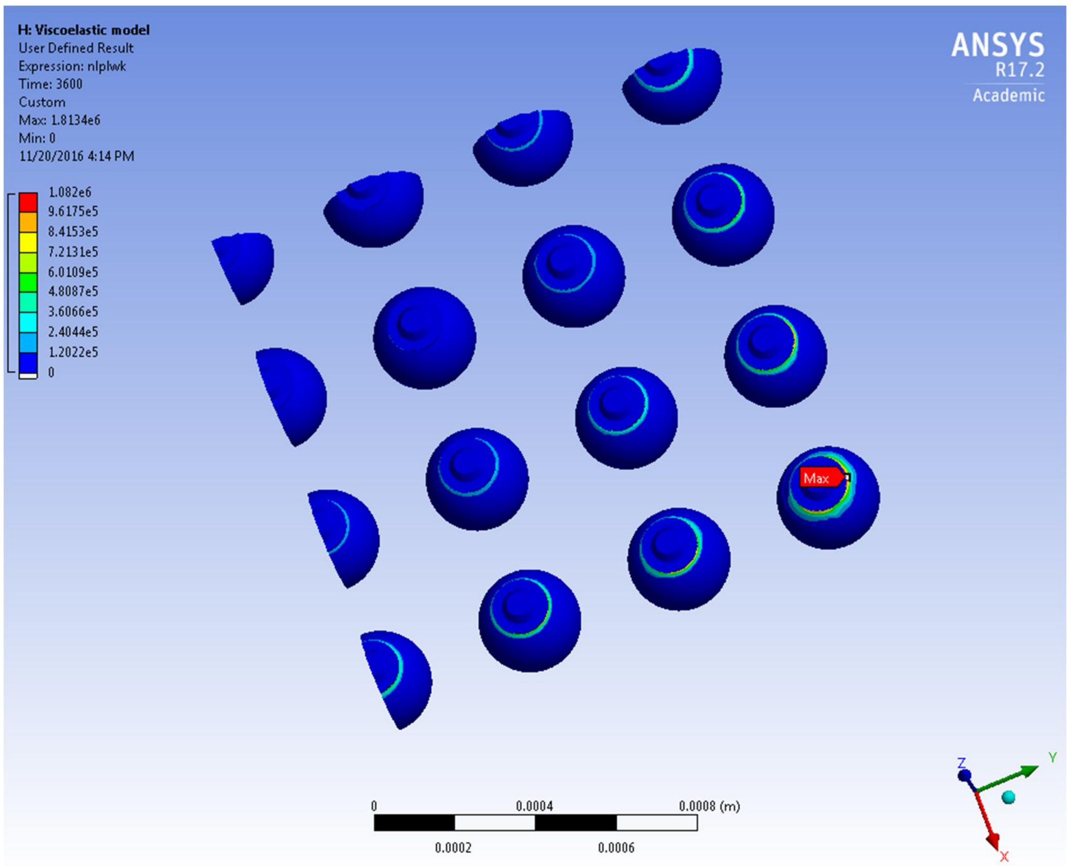

Figure 5.1 Strain energy density plot for viscoelastic model

The corner solder joint is used for calculating total strain, Von-Mises stress and plastic work in next part of the report. Stress free temperature is taken as 125 ^{o}C.

5.2 Total strain

The total strain in corner solder ball for orthotropic linear elastic model is 0.10357 mm/mm and for viscoelastic model it is 0.10695 mm/mm.

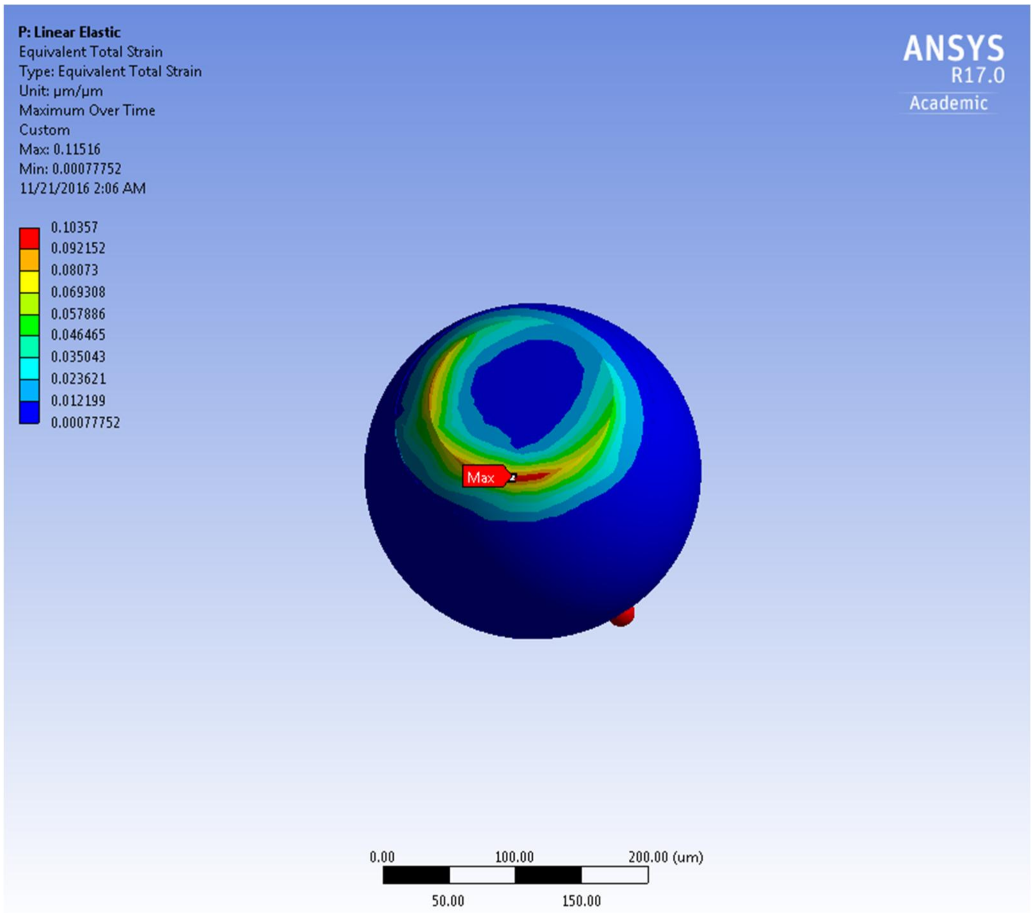

Figure 5.2 Total strain in corner solder ball for orthotropic linear elastic model

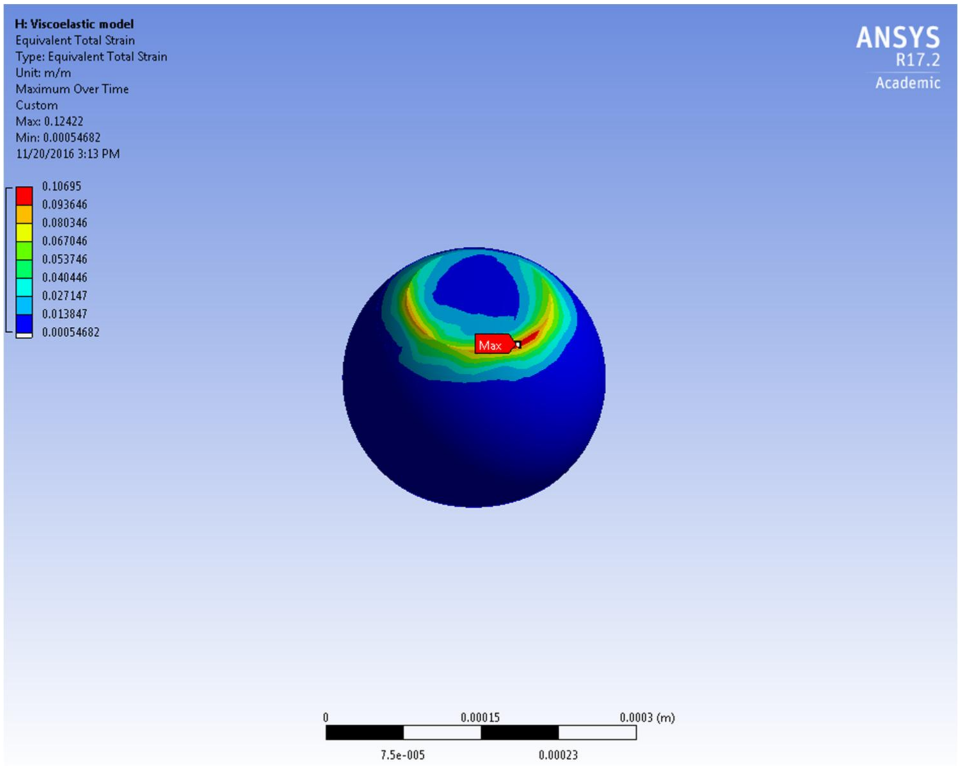

Figure 5.3 Total strain in corner solder ball for viscoelastic model

Total strain in corner solder ball for viscoelastic model is higher than that of elastic model by 3.2%. In viscoelastic case, material resistance against displacement is decreasing, hence for the same loading viscoelastic material will deform more compared to linear elastic material.

5.3 Von-Mises stress

The Von-Mises stress in corner solder ball for orthotropic linear elastic model is 28.36 MPa and for viscoelastic model it is 28.87 MPa.

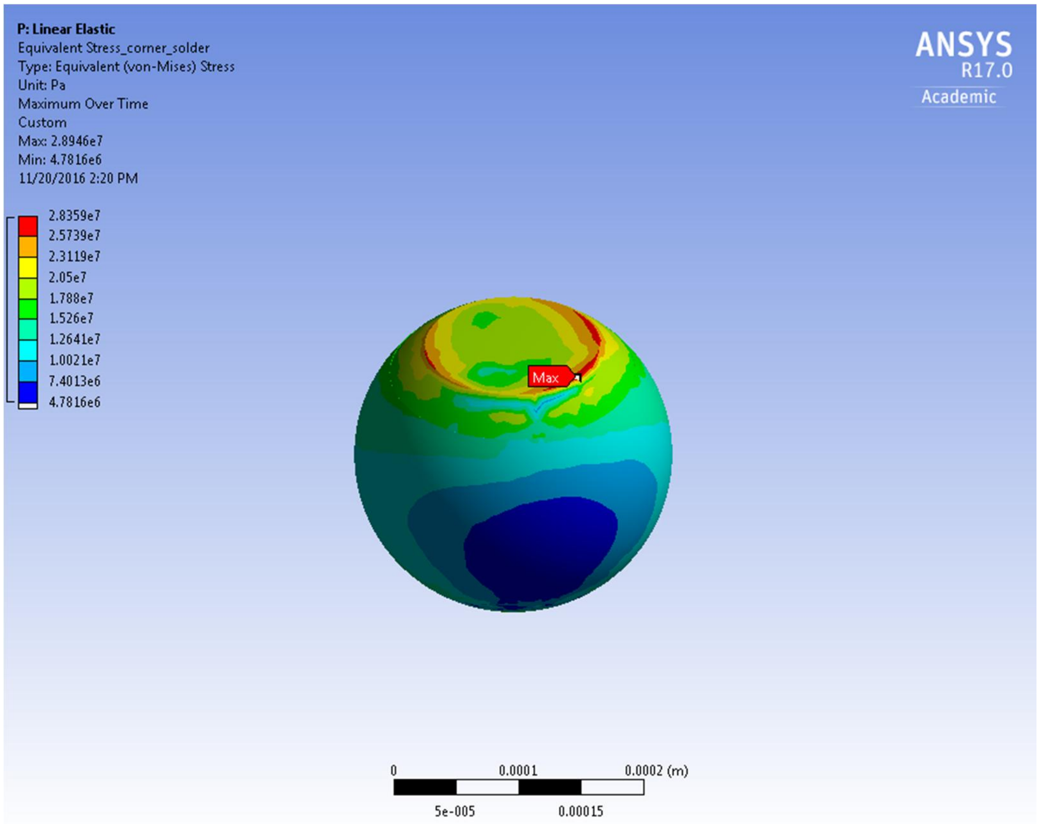

Figure 5.4 Von Mises stress in corner solder ball for linear elastic model

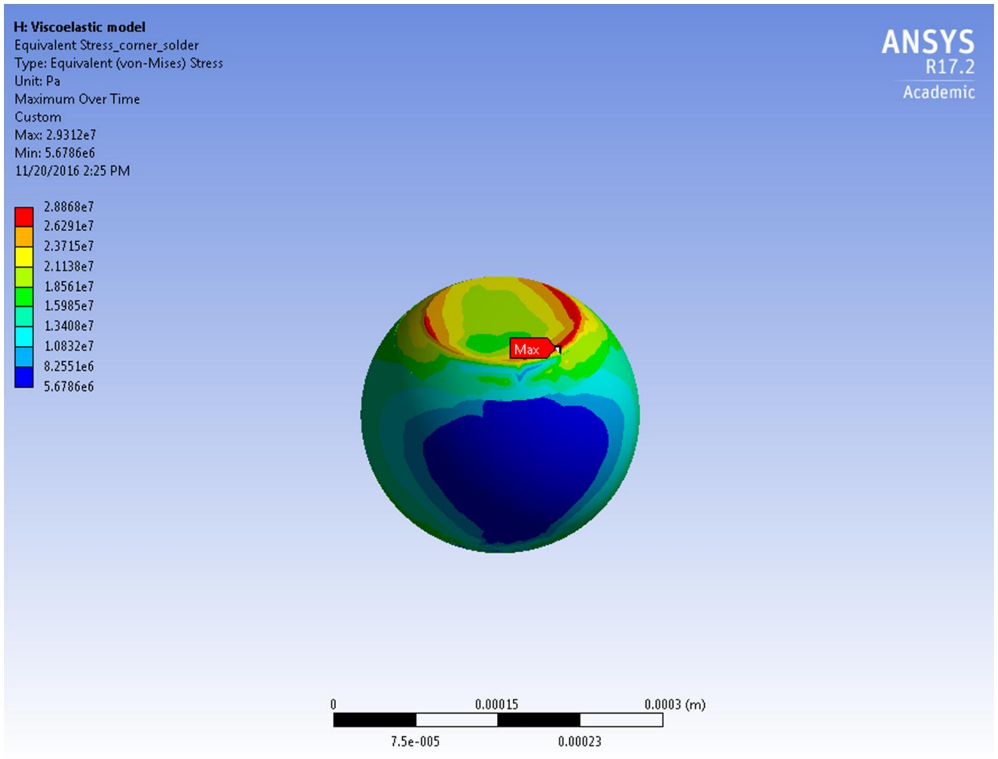

Figure 5.5 Von Mises stress in corner solder ball for viscoelastic model

Von Mises stress for corner solder ball of viscoelastic model is higher than that of linear elastic model by 1.8%. It is observed that total strain and Von-Mises stress are higher for viscoelastic model compared to linear elastic model which is as per anticipated behavior of viscoelastic material in the glass transition temperature range.

5.4 Darveaux's Solder Fatigue Life Method

Darveaux [15] has shown that the increment of inelastic strain energy density per thermal cycle can be used as a fatigue indicator

$$W^{in} = \int \sigma_{ij} \, d\varepsilon_{ij}^{in}$$

Where,

σ_{ij} = Stress tensor

ε_{ij}^{in} = Inelastic strain tensor

Experimentally it is shown that crack occurs in a solder about 25 μm from Under Bump Metal (UBM) for WCSP.

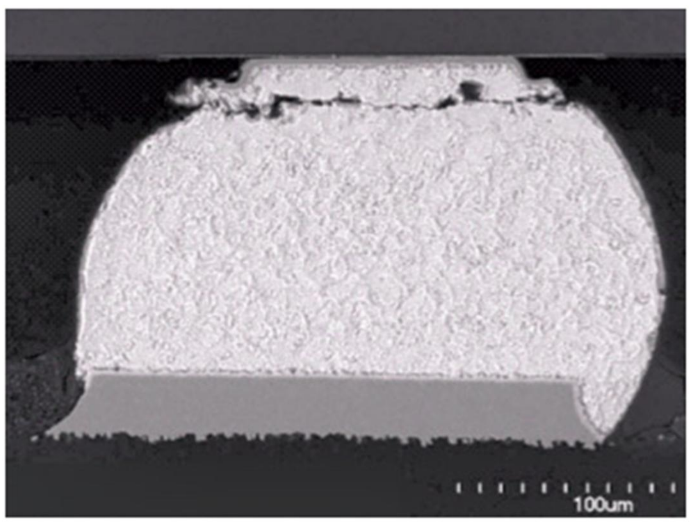

Figure 5.6 Solder fatigue crack failure [16]

Volume averaging technique is used to determine plastic work.

$$\Delta W_{ave} = \frac{\Sigma \, \Delta W \text{ x } V}{\Sigma \, V}$$

Where,

V = Volume of ith element

ΔW = Inelastic strain density of corresponding element

The summation is done for all the elements of the selected 25 μm region.

$$\Delta W = (\Delta W_{ave})_{3rd} - (\Delta W_{ave})_{2nd}$$

The fatigue indicator is increment of volume averaged inelastic strain energy between the end of second cycle and the end of third cycle.

Volume Average plastic work is compared for orthotropic linear model and Viscoelastic model.

Table 5.1 Volume Average plastic work

Parameter	Orthotropic linear elastic	Viscoelastic
Plastic Work (Pa)	23069	25515

Volume average plastic work for viscoelastic model is higher than that of Elastic model by 9.6%

5.5 Cycles to failure

The Volume average plastic work is related to life cycles to failure using Schubert et al. [17] correlation

$$N_f = \left(\frac{A}{\Delta W}\right)^k$$

Where,

N_f = Number of cycles to failure

ΔW = Volume average plastic work

A and k are parameters that were used from Zhao et al. [18] work on chip scale package.

Table 5.2 Cycles to failure

Parameter	Orthotropic linear elastic	Viscoelastic
Cycles to failure	3661	3491

Chapter 6

CONCLUSION

6.1 Summary and Conclusion

PCB was successfully characterized using DMA to get viscoelastic model which is later used in FEA model. Finite Element Analysis of WCSP was performed to assess board level reliability. Package was subjected to thermal cycling and plastic work obtained for critical solder joint. Plastic work for viscoelastic model is higher than that of orthotropic linear elastic model. Number of cycles to failure is higher for linear elastic model.

As seen from the results, the life cycles to failure in case of viscoelastic model is less than orthotropic linear elastic model by 4.9%. The results from the FEA model are complementing the observed stress relaxation behavior of viscoelastic material compared to orthotropic linear elastic. The material resistance to displacement is decreasing for viscoelastic model compared to orthotropic elastic model. This effect is coming from the viscous effect existing in the dashpot of the rheological Prony model. Higher value of total strain and Von-Mises stress for viscoelastic model. This eventually accounts for lower life cycles to failure for viscoelastic model as compared to orthotropic linear elastic model.

6.2 Future work

Present work can be extended to comparing the linear elastic and viscoelastic modeling for PCBs for QFN and other types of packages. Experimental data for thermal cycling is not available up to 165 ^{o}C. Experiment can be performed to determine number of cycles to failure under thermal cycling and compared with results obtained from Finite Element Analysis. Also packages can be analyzed to study effect of viscoelastic modeling of PCB on board level reliability for reflow condition and drop test.

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Biographical Information

Avinash Anaskure completed his Bachelor's degree in Mechanical Engineering from Shivaji University, Kolhapur, India. He received his Master of Technology degree in Mechanical Engineering (Machine Design) from Indian Institute of Technology, Roorkee, India in 2010. He pursued his M.S. in Mechanical Engineering from University of Texas at Arlington. He started working on reliability of packages under the guidance of Prof. Dereje Agonafer as Research Assistant. His work involves nonlinear modeling of materials and its effect on board level reliability. His research interests include fatigue failure, nonlinear material modeling and dynamic analysis. He plans to pursue career in a field, where his professional experience and education could be used.