# PREDICTIONS OF THERMAL CYCLING LIFE OF PBGA MICROPROCESSOR COMPONENTS WITH VARIATION OF MECHANICAL PROPERTIES OF THE PACKAGING MATERIALS

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By

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A thesis submitted in partial fulfillment of the requirements for the degree of

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## RECOMMENDATION OF THE BOARD OF EXAMINERS

This thesis titled "**PREDICTIONS OF THERMAL CYCLING LIFE OF PBGA MICROPROCESSOR COMPONENTS WITH VARIATION OF MECHANICAL PROPERTIES OF THE PACKAGING MATERIALS",** submitted by **Ahmad Shahedi Shakil**, Student No. **1014102014P,** Session: **October 2014**, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN MECHANICAL ENGINEERING on June 17, 2017.

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# DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or qualification.

________________________________ ________________

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Author

# DEDICATION

*Dedicated to My Parents*

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## ABSTRACT

Plastic Ball Grid Array (PBGA) is one of the most popular microprocessor components used in today's electronic industries. The primary objective is to transmit electronic signals from the chip to the PCB of the circuit. The package is made of several components with different mechanical properties. When PBGA is subjected to harsh environments, such as temperature fluctuation in different applications, thermal stress develops between package components due to mismatch in co-efficient of thermal expansions (CTE). Again, the processors operate at high BUS speed and generates high amount of heat. This heat should be dissipated to the surroundings in a short time. But if the heat is not properly dissipated, thermal stress develops in the IC components. As a result, solder joints between package substrate and PCB fails after a certain number of thermal cycles leading to interruption of I/O signal transmission. Number of thermal cycles upto failure is termed as thermal cycling life of the package. In the study, quarter symmetry finite element model of a PBGA package is developed to predict the location of critical solder ball with maximum damage accumulation during thermal cycling. Life prediction of the package has been made based on the failure of the critical solder ball. The same model is also used to investigate the effects of mechanical properties of some of the major component materials on the life of the package and to predict the thermal cycling life of PBGA package for different mechanical properties of its components. Thermal cycling life has been found as strong functions of mechanical properties of substrate materials, solder materials and molding compounds. Using the results from the analysis, maximum life or reliability of PBGA package has been predicted using optimum mechanical properties of the components. Finite element results have been validated using available data from experiments and numerical study in literature.

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# CHAPTER 1

# INTRODUCTION

## 1.1 General

The Plastic Ball Grid Array (PBGA) is a subset of Ball Grid Array. The Ball Grid Array or BGA package is a type of surface mount technology, or SMT that is used for integrated circuits. These types of packages are used to permanently mount devices such as microprocessors. PBGA is sometimes referred to as Motorola's Over Molded Pad Array Carrier or OMPAC package. It was developed by Motorola in the late 1980's for use in Motorola products such as radios, pagers and cellular telephones. Now-a-days, it is also being used in other applications e.g. automobiles, spaceships etc. for logical operations. PBGA uses plastic substrates with copper traces to transmit electronic signals between chip and PCB for processing of data. Due to more interconnections compared to other types of packages, reduced size and weight and reduced manufacturing cost, PBGA has become one of the most popular packaging alternatives for high I/O devices in the packaging industry. Thermal stresses may develop due to package temperature fluctuation for rapid signal transmission, harsh environments and complex configuration of packages. These stress cycling may lead to failure of solder balls in PBGA packages resulting in disconnection of signal to the processor.

Finite element simulations of Accelerated Life Testing (ALT) for the PBGA assemblies are performed using thermal cycling for the determination of various characteristics of the packaging architecture during its life cycle, i.e. critical locations of solder balls, failure modes, stress levels, etc. For the accurate prediction of the life of the PBGA packages, it is important to use the correct mechanical properties of the constituent materials. Furthermore, variation of the mechanical properties of a constituent material may also result in the variation of the life of the package. The orientation of different layers in a typical PBGA microprocessor package is shown in Figure 1.1. In the centre of package, silicon chip (die) is located. The chip is encapsulated by a molding compound. The purpose of the molding compound is to protect the silicon chip from damage due to harsh environments. The material under the die is called substrate material. Its function is to support the silicon chip and transmit electronic signals from the die to the printed circuit board (PCB). Between the substrate and the PCB, BGA solder balls are located. The bottom most layer is called the PCB board. During thermal cycling, the deformation and failure of the solder balls largely depends on the mechanical properties of the different components of the package.

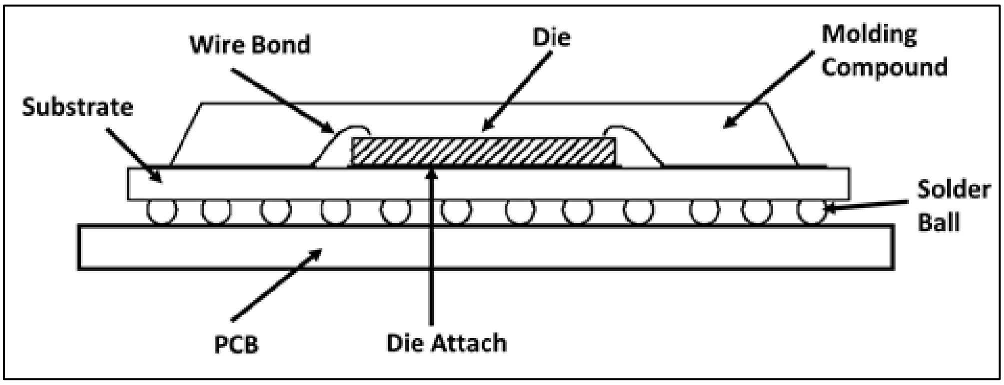



**Figure 1.1**: Schematic Diagram of PBGA Package

## 1.2 Overview of PBGA/BGA Packages

### 1.2.1 BGA Packages

With the increasing component density of today's electronic PCB, connectivity on many boards has become a problem. To assist in resolving this problem, an integrated circuit package known as the Ball Grid Array, BGA was introduced. The BGA components provide a far better solution for many boards, but care is required when soldering BGA components to ensure that the BGA solder process is correct and that the reliability is at least maintained or preferably improved.

The Ball Grid Array or BGA, is very different from packages using pins, such as the quad flat pack. The pins of the BGA package are arranged in a grid pattern and this gives rise to the name. In addition to this, instead of having the more traditional wire pins for the connections, balls of solder are used for interconnection. On the printed circuit board, PCB, onto which the BGA components are to be fitted there is a matching set of copper pads to provide the required connectivity.

The conventional quad flat pack style packages had very thin and close spaced pins, and these were very easy to damage, even in a controlled environment. Moreover, they required very close control of the soldering process. The BGA package was developed to overcome these problems, and improve reliability from the soldered joints.

### 1.2.2 Advantages of BGA Packages

The Ball Grid Array provides a number of benefits to IC and equipment manufacturers as well as providing benefits to the eventual users of equipment. Some of the BGA benefits over other technologies include:

- Efficient use of PCB space, allowing connections to be made under the SMD package and not just around its periphery, leading to more interconnections.
- Better thermal and electrical performance. BGA packages offer power and ground planes for low inductances and controlled impedance traces for signals as well as being able to remove heat via the pads, etc.
- Improvements in manufacturing yields as a result of the improved soldering. BGAs allow wide spacing between connections as well as a better level of solderability.
- Reduction in package thickness which is a great advantage when many assemblies need to be made much thinner, e.g. mobile phones, etc.

- Reduction in weight of microprocessor components.

### 1.2.3 Different Types of BGA Packages

In order to meet the variety of requirements for different types of assembly and equipment, a number of BGA variants have been developed.

- **MAPBGA - Molded Array Process Ball Grid Array:** This BGA package is suitable for low-performance to mid-performance devices that require packaging with low inductance, ease of surface mounting. It provides a low cost option with high level of reliability.
- **PBGA - Plastic Ball Grid Array:** This BGA package is suitable for mid- to high-performance devices that require low inductance, ease of surface mounting, relatively low cost, while also retaining high levels of reliability. It has some additional copper layers in the substrate that enable increased power dissipation levels to be handled.
- **TEPBGA - Thermally Enhanced Plastic Ball Grid Array:** This package is used for much higher heat dissipation application. It uses thick copper planes in the substrate to draw heat from the die to the customer board.
- **TBGA - Tape Ball Grid Array:** This BGA provides a mid- to high-end solution for applications needing high thermal performance without an external heatsink.
- **PoP - Package on Package:** This package is used in applications where space is at a real premium. It allows for stacking a memory package on top of a base device.
- **MicroBGA:** This type of BGA package is smaller than the standard BGA package. There are three pitches that are prevalent in the industry: 0.65, 0.75 and 0.8mm.

### 1.2.4 BGA Soldering Process

One of the initial fears over the use of BGA components was their solderability and whether soldering BGA components could be made as reliable. As the copper pads are under the device and not visible, it is necessary to ensure the correct process is used and it is fully optimized. Fortunately, BGA solder techniques have proved to be very reliable, and once the process is set up correctly BGA solder reliability is normally higher than that for quad flat packs. This means that any BGA assembly tends to be more reliable. Therefore, its use is now widespread in both mass production of electronic packaging.

For the BGA solder process, reflow techniques are used. The reason for this is that the whole assembly needs to be brought up to a temperature whereby the solder will melt underneath the BGA components themselves. This can only be achieved using reflow techniques.

For BGA soldering, the solder balls on the package have a very carefully controlled amount of solder. During heating process, solder ball melts. Surface tension causes the molten solder to hold the package in the correct alignment with the circuit board, while the solder cools and solidifies. The composition of the solder alloy and the soldering temperature are carefully chosen so that the solder does not completely melt, but stays semi-liquid, allowing each ball to stay separate from its neighbours.

### 1.2.5 BGA Solder Joint Inspection

BGA inspection is one area of the manufacturing process that has raised a considerable amount of interest since the introduction of the first BGA components. BGA inspection cannot be achieved using straightforward optical techniques because the solder joints are underneath the BGA components and they are not visible. This creates problems for BGA inspection. It also created a considerable degree of unease about the technology when it was first introduced and many manufacturers undertook tests to ensure that they were able to solder the BGA components satisfactorily. The main problem with soldering BGA components is that sufficient heat must be applied to ensure that all the balls in the grid melt sufficiently for every BGA solder joint to be satisfactorily made.

Again, the solder joints cannot be fully tested by checking the electrical performance. While this form of test of the BGA solder process will reveal conductivity at that time, it does not give a full picture of how the BGA solder process has succeeded. It is possible that the joint may not be adequately made and that over time it will fail. For this, the only satisfactory means of test is a form of BGA inspection using X-rays. This form of BGA inspection is able to look through the device at the soldered joint beneath.

### 1.2.6 BGA Rework

It is not easy to rework BGA assemblies unless the correct equipment is available. If a BGA component is found as faulty, it can be removed by locally heating the package component to melt the solder underneath it.

In the BGA rework process, great care is needed to ensure that only the BGA is heated and removed. Other devices nearby need to be affected as little as possible otherwise they may be damaged.

BGA technology in general and in particular the BGA soldering process have proved themselves to be very successful since they were first introduced. They are now an integral part of the PCB assembly process used in most companies for mass production and for prototype PCB assembly.

Lead free soldering is now a major issue on the agenda of companies manufacturing electronics equipment. Lead is a major constituent of traditional solder and as a result there are concerns over the amount of lead entering the environment. As a result, there has been legislation in many areas of the world and a consequent impetus to move to lead free soldering.

### 1.2.7 Lead Free Solder in BGA Packages

Lead free soldering has arisen because of legislation being enacted around the globe. In the EC the WEEE (Waste from Electrical and Electronics Equipment) Directive has brought a sharp focus onto lead free soldering technology. Although this directive is mainly about recycling, it also contains clauses aimed at banning the use of lead in certain categories of electrical and electronic equipment. This gives rise to the need for lead free soldering.

The solder that was traditionally used comprised a mixture of 63% tin and 37% lead. Although this accounted for typically less than 1% of the usage of lead, it nevertheless posed a perceived environmental threat because in countries such as the UK, most electronic equipment is disposed of in landfill sites. There was a concern that the lead could then leach into ground water supplies.

The move to lead free soldering is of great importance to many areas of industry. Electronic circuitry is included in a very wide range of products including computers, white goods, brown goods, telecommunications, and other electronics. As lead free soldering technology is slightly different to that using traditional tin-lead solder, it is of great interest to industry as a whole.

## 1.3 Literature Review

Modern microprocessors are often exposed to harsh environments where these are subjected to extreme change of temperatures [1-2]. Finite element simulations of Accelerated Life Testing (ALT) for the plastic ball grid array (PBGA) assemblies are normally performed using thermal cycling, where the test assemblies are subjected to harsh changes in temperature over a much shorter period of time than the expected field exposure of the parts [3]. In thermal cycling experiments, packages mainly fail due to fatigue in solder balls which causes crack initiation and propagation with cycle. Darveaux [4] has presented energy dissipation based models for crack initiation and crack growth rate in solder joints. These types of models have been subsequently used by many researchers for life prediction of the SnPb and SAC solders.

Previous studies revealed that the cycle to failure largely depends on the mechanical/microstructural properties of the lead free solder alloy. Lee and coworkers [5] have shown that aging degrades the thermal cycling reliability of lead free PBGA assemblies subjected to ALT. Kariya et al. [6] have reported that with increasing the silver percentage of SAC solder, the shear fatigue life of the solder joints is decreased. Kang et al. [7] have reported from their experimental investigation that the thermal cycling life of CBGA assemblies is improved if lower silver content solder joints are used. Hong et al. [8] showed the thermo-mechanical analysis to study the thermal stresses and reliability problems of a flip chip plastic ball grid array (FCPBGA) chip scale package (CSP). The results showed that the chip-outline solder joint may fail earlier than any other solder joint in the modeled package. Variation of the geometric configuration/mechanical properties of other packaging materials may also result in the variation of life of the PBGA components. Lee et al. [9] have presented a non-linear numerical study to investigate the effect of chip dimension and substrate thickness on the solder joint reliability of plastic ball grid array (PBGA) packages. Bongtae et al. [10] showed that for a FCPBGA package, optimizing the CTE of the substrate layer can improve the thermal cycling reliability of the package.

Yanga et al., [11] investigated the thermal stress and strain of Plastic Ball Grid Array (PBGA) for reliability evaluation and failure analysis. A one-eighth model is built to estimate the thermal stress and strain of PBGA under thermal cycling temperature (0°C–100°C). The results show that the maximum equivalent stress and equivalent plastic strain occur in the second outer solder joint and close to the position of chip. Yi et al.,[12] on their paper provided a design and material selection guideline for a plastic ball grid array (PBGA) package in order to improve its reliability and manufacturing ability after post mold cure. Their study showed that the material properties such as modulus and CTE of molding compounds play an important role in warpage and reliability of PBGA packages.

He et al. [13] worked on the numerical analysis of warpage in PBGA and PCBA in consideration of the residual stresses produced during SMT reflow process. Results show that the CTE mismatch between the components causes warpage and internal stress in the package. Low CTE of key components can significantly reduce the residue stress around the die area, which can effectively eliminate cracks and delaminations between silicon die and adjacent components. Tang, et al. [14] showed in their research that plastic substrate provides a cost effective solution to BGA assembly with high density I/Os. It also acts as a buffer to the mismatch of coefficient of thermal expansion between die and printed circuit board, releasing thermal stress. Che, et al. [15] investigated thermal cycling reliability test and analysis for PBGA components with Sn-3.8Ag-0.7Cu solder joints.

Tsai et al. [16] investigated the thermomechanical behaviors of flip chip ball grid array (FCBGA) packages during reflow process, underfilling, underfill curing, and under thermal cycling tests (TCT). They suggested that the adequate die/substrate thickness ratio can reduce the die stress significantly and, as a result, increase the life of the TCT. Popp et al. [17] investigated the reliability of a flip chip plastic ball grid array (FC PBGA) cycled under power cycling and thermal cycling (TC) conditions. The characteristic life was found more than 45% greater for power cycling compared to thermal cycling. Qi et.al. [18] investigated the effects of temperature profile in accelerated thermal cycling of SnPb and Pb-free solder joints. The test results showed that the higher heating or cooling rate reduced the testing time while retaining the same failure modes of solder balls, and the damage per thermal cycle increased with applied temperature range. The Pb-free solder joints in the PBGA test vehicles lasted longer than the SnPb solder under all ramp rates and temperature differences. Zhang et al. [19] investigated the relationship between elevated temperature isothermal aging and the long-term thermal reliability of fine-pitch packages with Sn–1.0Ag–0.5Cu (SAC 105), Sn–3.0Ag–0.5Cu (SAC 305), and 63Sn–Pb solder ball interconnects. Significant cycle lifetime degradation was observed with aging for both SAC105 and SAC305 in different packages.

The properties of solder alloys are strongly dependent on both the temperature and strain rate. Jones et al. [20, 21] have observed an approximately linear relationship between the strength and temperature. Pang, Shi and co-workers [22] have observed similar experimental results, with a near linear relationship with temperature and a power law relation with the strain rate. Several other studies have also observed similar material behavior for both Sn-Pb eutectic and lead-free solder alloys [23-26]. The Ramberg-Osgood model describes the elastic-plastic behavior of materials, and can be used to describe to describe the stress-strain curve of solder materials [27]. The Anand viscoplastic constitutive model is often used to represent the deformation behavior of solders in electronic assemblies. Motalab, et al [28] have calculated Anand parameters for SAC 305 solder materials using stress-strain and creep data. Both sets of Anand parameters are found numerically similar in magnitude.

Gustafsson et al [29], conducted finite element analysis for BGA life prediction using different types of FEA models and compared the results of each model with experimental results. Schubert et al [30] developed life-prediction models of SnPb(Ag) and SnAgCu solder joints for thermal cycle conditions based on empirical power law relationship and evaluated the results by experiments. Their results show that for the same strain level, SnAgCu performs better than SnPbAg in higher strain range.

Tunga et al [31] worked on Life Prediction of PBGA Packages with SnAgCu Solder Joints. They found that reliability of each and every solder joint in a package as a function of the number of cycles was found by assuming that the failure follows a Weibull reliability function. Along with accumulated strain and accumulated work, normal strain of solder balls was also considered in the study. Uegai et al [32] worked on thermal fatigue life prediction method for BGA/FBGA solder joints with basic crack propagation study. They evaluated fatigue crack growth curve of BGA solder joints using experimental and finite element analysis.

Tee et al [33] worked on board level solder joint life prediction of TFBGA packages considering detailed pad design, realistic shape of solder joint and nonlinear material properties. Maximum strain energy density has been found at the outmost diagonal solder ball. Design analysis has been performed for the package using different conditions.

A number of research have been conducted to determine the life of a microprocessor component and to investigate the effects of material properties of a single material on the thermal cycling life. However, the effects of a single material e.g. solder material, combined with variations of mechanical properties of other components e.g. substrate of molding compound, remained unaddressed. This study is required to determine the optimum set of material properties to enhance life of such packages.

## 1.4 Previous Works Related to the Study

### 1.4.1 Experimental Procedures

In our previous study, the PBGA components under investigation became available from an anonymous motherboard. The intel® microprocessor on one of the PCBs is shown in Figure 1.2. Three test vehicles of the similar kind were selected for the experiments to measure the stress-strain data of the substrate laminates of these packages. Initially the packages were separated from the motherboards using a precision cutting machine. After slitting the packages into two halves, one half is allocated for microscopic analysis and another half is allocated for tensile testing. Figure 1.3 shows some of the processing stages of the PBGA components. The stress-strain properties of the substrates have been characterized using tensile specimens extracted from actual PBGA components. In this case, the PBGA components have been polished from the molding compound (top) side of the part until the die is exposed. The silicon was then removed using the etching process, and the remaining mold compound was polished away. This left only the substrate laminate with attached solder balls. A second phase of polishing was then done to remove the solder balls and leave only the BT substrate, which could then be cut up into thin 31 mm × 3 mm × 0.6 mm tensile specimens.


**Figure 1.2:** The Test Vehicle with the PBGA Component

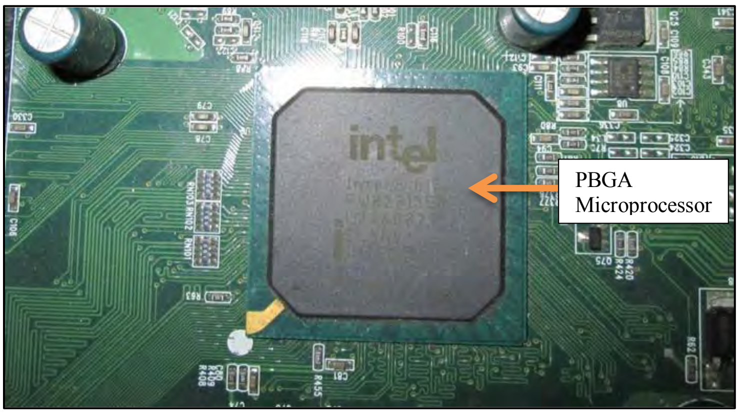


**Figure 1.3:** Processing of the PBGA Component for the Tensile Testing of Substrate and for Microscopic Analysis.

### 1.4.2 Microscopic Analysis

Identification of different layers in the PBGA package and to determine their dimensions, microscopic analyses of the package cross section is performed. The results have been used in the finite element modeling of the package. Surface polishing is done for this purpose.

Emery papers and velvet cloth rotator polishing machine were used for fine finishing of the cross section of the packages. After the polishing, the arrangements of different layers of the package are observed by an optical microscope. Figure 1.4 shows the cross section obtained from the microscope for package no. 1.

Although the packages are identical in macroscopic observation but the substrates are different due to the differences in copper layer orientation. This leads to the variation of the mechanical properties of the substrate material from one package to other.

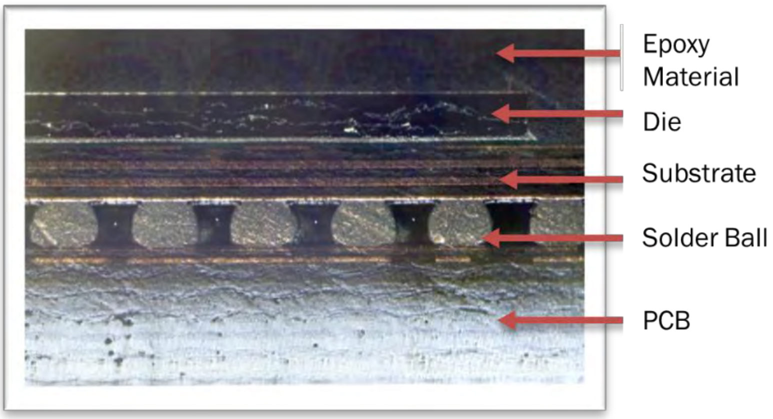



**Figure 1.4:** Cross Section of PBGA Microprocessor under the Optical Microscope

### 1.4.3 Tensile Test Results for Substrate Material

The stress-strain properties of the substrates have been characterized using tensile specimens extracted from actual PBGA components. Figure 1.5 shows the tensile test specimen. Tensile tests are done in Instron 2716-020 50KN testing machine. Stress-strain data were measured for each sample and modulus of elasticity was calculated from the curves.

The stress-strain curve for the substrate material extracted from different packages is shown in Figure 1.6. The elastic modulus, ultimate tensile strength, and the ultimate elongations are recorded from the test. The variation of the stress-strain curves in the substrate materials from three different packages can be visualized in Figure 1.6. As mentioned earlier, the differences are due to the variation in the orientation of copper layer in the substrate. The extracted values of the elastic modulus for all the specimens are listed in Table 1.1. The elastic modulus has been found within the range of 17-23 GPa. Using the experimental data as reference, effects of substrate elastic modulus on thermal cycling life have been investigated in this study.

**Figure 1.5:** Tensile Test Specimen of the Substrate Material Extracted from PBGA Package.

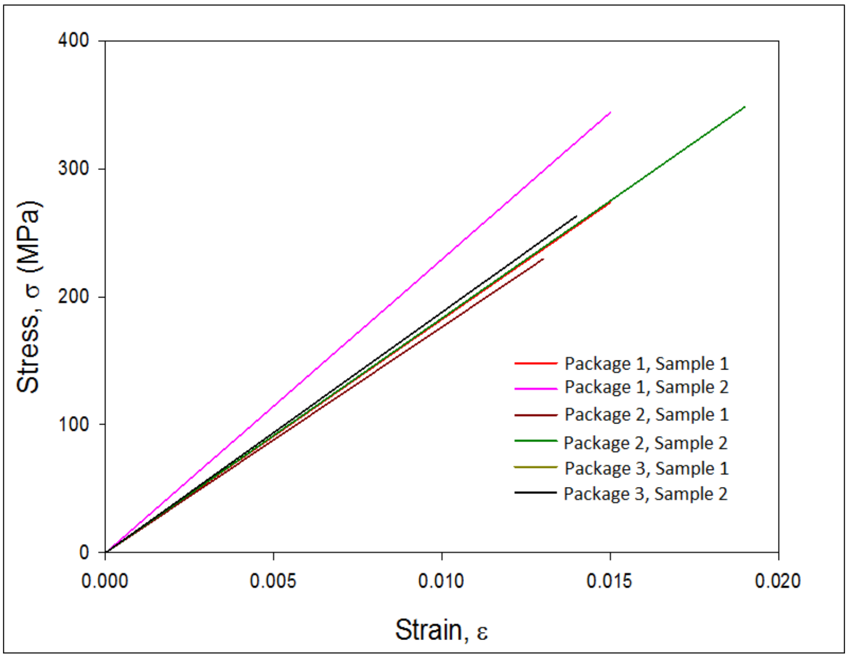


**Figure 1.6:** Stress-Strain Curves for the Substrate Materials from Different Packages.

**Table 1.1:** Tensile Test Results of Substrate Materials

| Package | Sample No | Modulus of Elasticity (GPa) |
|---|---|---|
| 1 | 1 | 18.200 |
| | 2 | 22.940 |
| 2 | 1 | 17.645 |
| | 2 | 18.334 |
| 3 | 1 | 19.776 |
| | 2 | 18.800 |

## 1.5 Objectives of the Study

The objectives of the study can be summarized as follows:

1. To develop a 3D finite element model of a PBGA microprocessor component for the simulations of accelerated life testing (ALT) and hence to identify the location of critical solder joint in the package.

2. To study the effects of silver percentage in SAC solder joint on the thermal cycling life of the PBGA component.

3. To investigate how the life of a PBGA component changes with the variation of mechanical properties of other constituent materials such as substrate layer, molding compound, and die attach materials.

4. To produce a set of criteria that can be followed to design the package architecture with appropriate material properties for the optimum life of the PBGA microprocessor component.

5. To validate the finite element models by comparing the predicted results with that obtained from the experimental investigations for the similar PBGA packages/components which are available in literature.

# CHAPTER 2

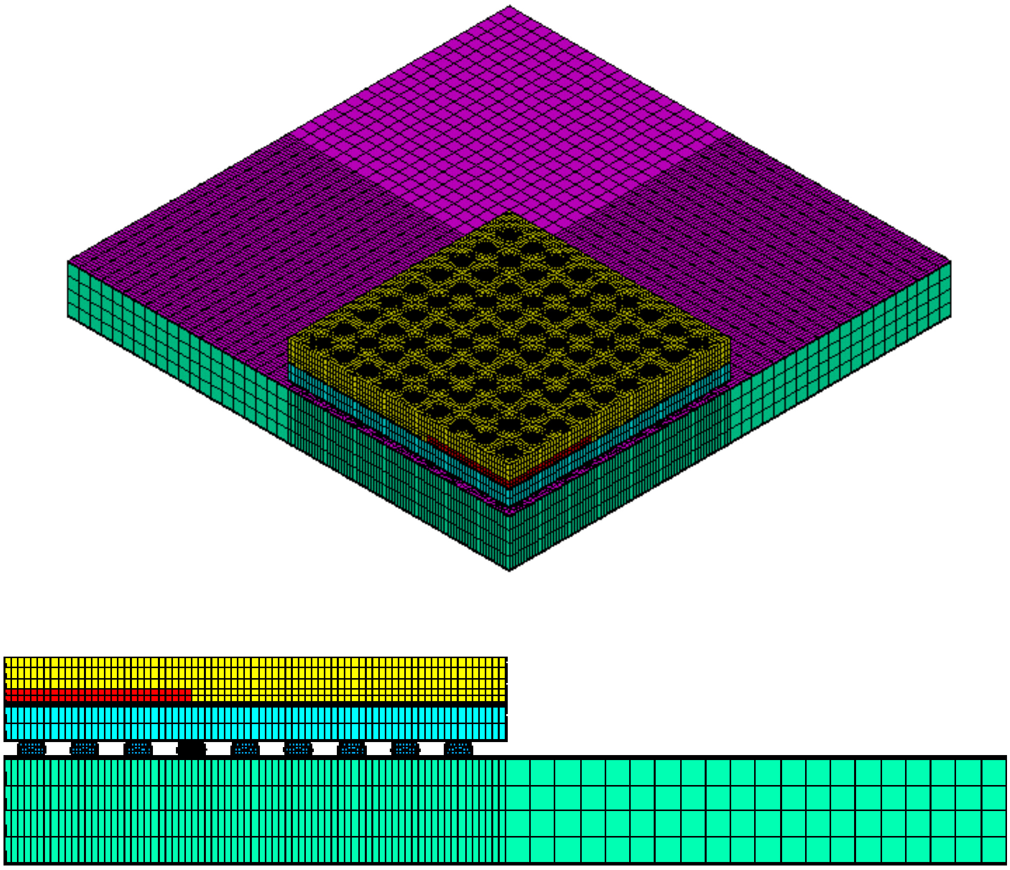
# DEVELOPMENT OF FINITE ELEMENT MODEL

## 2.1 Finite Element Modeling of PBGA Microprocessor

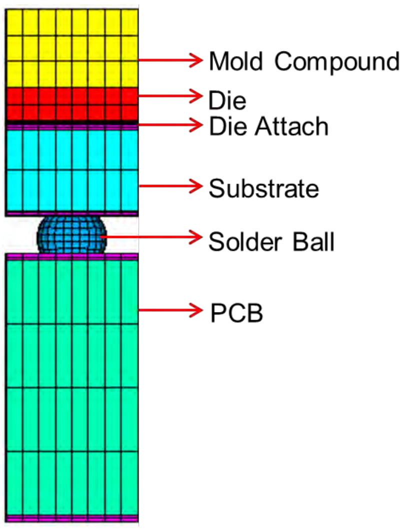
Three dimensional nonlinear finite element modeling of the BGA 324 microprocessor component has been developed in the commercially available finite element software ANSYS. Figure 2.1 (a) shows the quarter symmetry model of the PBGA package that was developed and solved using ANSYS finite element software. Figure 2.1 (b) shows different components of the PBGA model. The entire model utilized a structured finite element mesh with 650,450 elements and 703,110 nodes.

The 3D FEA model has a dimension of 15×15 mm. The model consists of different components. At the bottom of the package is the PCB with dimensions of 30×30×1.55 mm. Molding compound and substrate both have dimensions of 15×15×0.5 mm. Die attach material is placed between the silicon die and substrate with a thickness of 0.02 mm. the height of solder balls is 0.275 mm with maximum diameter or width of 0.424 mm and neck diameter or width of 0.32 mm. The silicon die has dimensions of 5.6×5.6×0.2 mm. Since the package has a total 324 solder balls, the quarter model consists of a perimeter array of 72 solder balls.

The solder balls were modeled in ANSYS with VISCO107 structural elements with 8 nodes having three degrees of freedom at each node. This element is designed to solve both isochoric (volume preserving) rate-independent and rate-dependent large strain plasticity problems. For the other materials in the model, SOLID45 structural solid elements have been used, which are 8 node elements with plasticity, creep, large deflection and large strain capabilities. Both types of elements are shown in Figure 2.2. Iterative solution procedures have been used due to the nonlinear material properties of the model. Typical solution run times were about 6 hours per thermal cycle using a workstation with intel core i7 processor and 16 GB of memory.



(a)




(b)

**Figure 2.1:** (a) Finite Element Mesh (Quarter Symmetry) of PBGA Package

(b) Different Components of PBGA Package Model

(a)

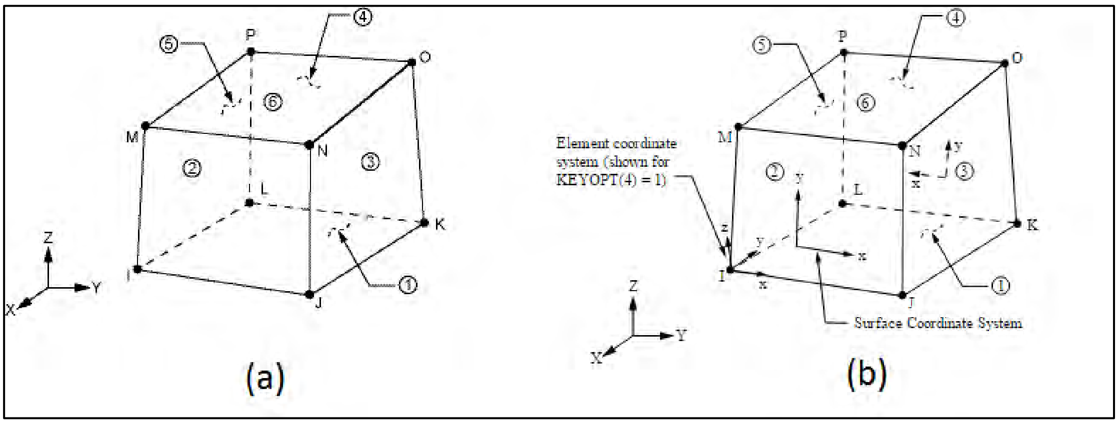



**Figure 2.2:** (a) VISCO107 Element; (b) SOLID45 Element.

## 2.2 Boundary Conditions and Applied Thermal Loading

The quarter model has been appropriately constrained along the axes of symmetry, so that for a node in a symmetry plane, the displacement component perpendicular to the symmetry plane was required to be zero. In addition, all three displacements were set to zero for the center node at the bottom surface of the PCB to prevent any rigid body motions. Applied boundary conditions are shown in Figure 2.3. The entire assembly was subjected to a time dependent temperature distribution to reflect the -40 to +125 C thermal cycling performed in the life testing experiments.  The ramp rate for this thermal cycling profile was 10.5 $^{o}$C/min, and the high and low temperature dwell times were each 20 minutes. The stress-free temperature of the package has been assumed to be T = 220 $^{o}$C, which is the solidification temperature of the lead free solder joints.  The applied thermal loading including the cool down after solder joint reflow and the first two thermal cycles is shown in Figure 2.4.

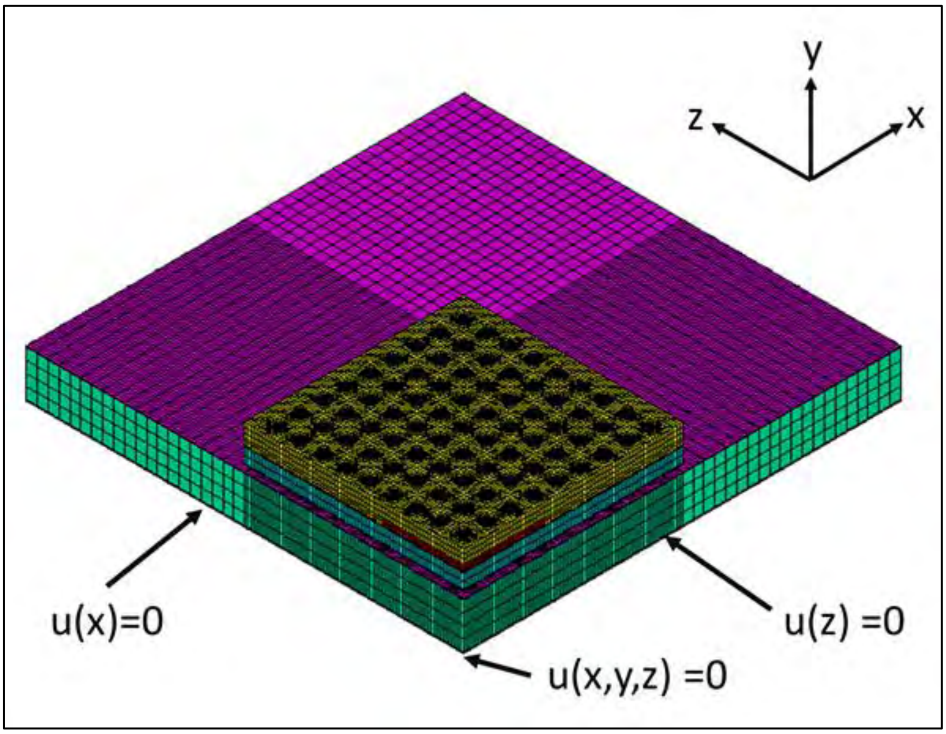



**Figure 2.3:** Applied Boundary Conditions

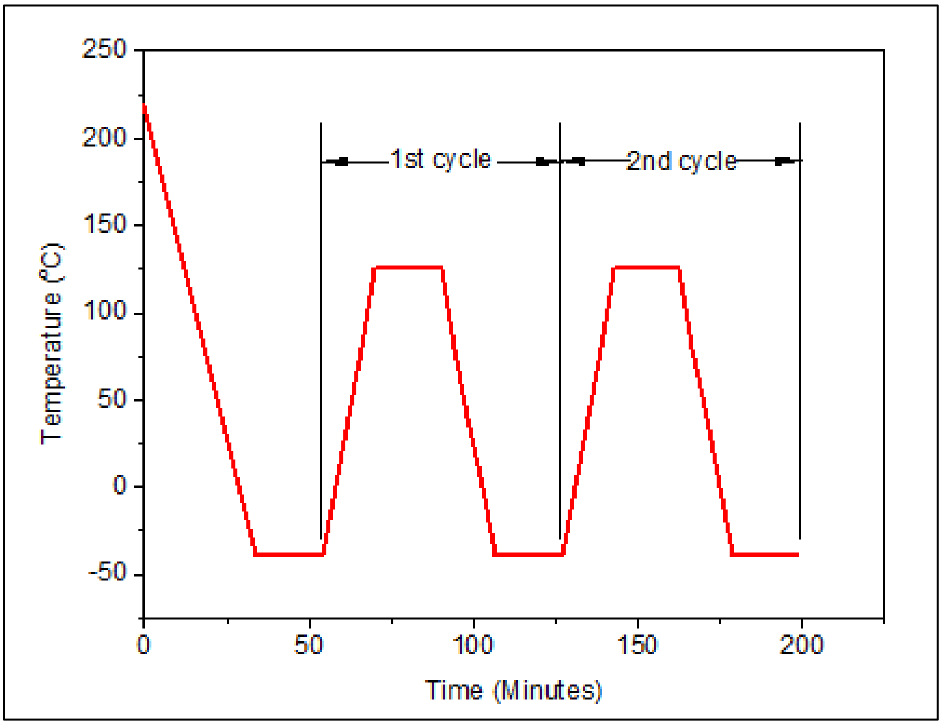



**Figure 2.4:** Applied Thermal Loading

## 2.3 Mechanical Properties of Different Package Components

Different types of mechanical behaviors are found for package components from literature and experimental analysis [34]. A summary of properties are shown in Table 2.1. Detailed properties of each component are discussed below.

**Table 2.1:** Mechanical Properties used in Package Materials [34]

| Material | Elastic Modulus (GPa) | | Poisson's Ratio | CTE (ppm/°C) |
|---|---|---|---|---|
| PCB | $E_x = 16.90$<br>$E_y = 7.44$<br>$E_z = 16.9$ | $G_{xy} = 3.33$<br>$G_{xz} = 7.62$<br>$G_{yz} = 3.33$ | $PR_{xy} = 0.39$<br>$PR_{xz} = 0.11$<br>$PR_{yz} = 0.39$ | $CTE_x = 14.5$<br>$CTE_y = 67.2$<br>$CTE_z = 14.5$ |
| Solder Mask | 3.1 | | 0.3 | 16.3 |

| | | | |
|---|---|---|---|
| Copper Pad | 128 | 0.34 | 16.3 |
| Solder Balls | Viscoplastic material<br>(Anand Model is used for FEA) | | |
| Substrate | 16-24 | 0.35 | 12.4 |
| Die Attach | Temp. dependent | 0.35 | Temp. dependent |
| Silicon Die | 169 | 0.28 | 2.54 |
| Molding Compound | Temp. dependent | 0.3 | Temp. Dependent |

### 2.3.1 Mechanical Properties of Substrate Materials

Substrate is the component that is placed between the silicon die and solder balls. It is mainly used to support the silicon die by holding on it and transmit electronic signals from the silicon die to the PCB through solder balls. Reliability of PBGA package is strongly dependent on mechanical properties of substrate materials. In the analysis, substrate materials are considered to be linear elastic.

Many manufacturers [35-38] are now producing the BT-epoxy substrate material for PBGA packages. Wide variation of mechanical properties (i.e. elastic modulus, UTS, etc.) has been observed from the substrates made by different companies. The elastic modulus has been found as low as 13 MPa and as high as 28 MPa indicating large variations.

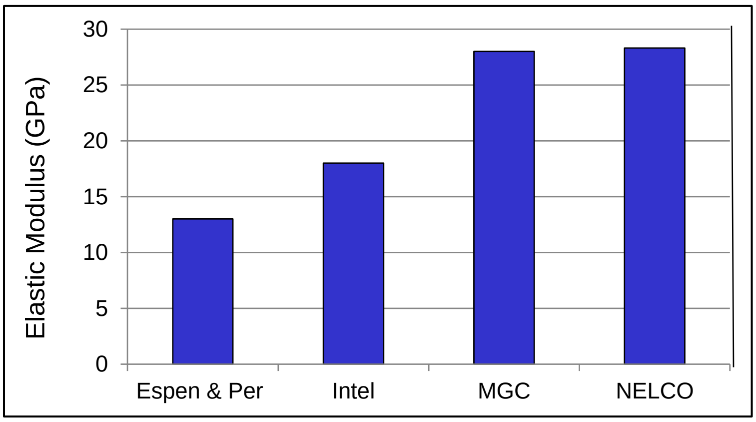


**Figure 2.5:** Variation of the Elastic Modulus of the Substrate Materials found in Literature [35-38]

As shown in Table 1.1, elastic moduli of substrate materials are found in the range of 17-23 MPa from previous experimental results. In our study, elastic moduli in the range of 16-24 MPa have been used to predict the thermal cycling life of the package. The CTE of substrates used is shown in Table 2.1. The Poisson's ratio used in the study is 0.35. However, Poisson's ratio has a significant effect on package life. Variation of life with Poisson's ratio of substrate materials will also be discussed in Chapter 4.

### 2.3.2 Mechanical Properties of Solder Balls

In PBGA packages, solder balls are used to transmit electronic signal from the silicon die to the PBC for effective and efficient performance and computation. Solder balls are placed between substrate materials and PCB. These are the most critical components of the package. Because the package usually fails at solder joints due to CTE mismatch.

In this study, the solder balls have been modeled as viscoplastic material with the Anand model [39]. The Anand model uses a scalar internal variable "s" to represent the isotropic resistance to plastic flow offered by the internal state of the material. It unifies the creep and rate-independent plastic behavior of the solder by making use of a stress equation, a flow equation, and an evolution equation. The model needs no explicit yield condition and no loading/unloading criterion. The model is already included in ANSYS.

For the one-dimensional case (uniaxial loading), the stress equation is given by

$$\sigma = cs; \; c < 1 \tag{1}$$

where, s is the internal valuable and c is a function of strain rate and temperature expressed as

$$c = c(\dot{\varepsilon}_p, T) = \frac{1}{\xi}\sinh^{-1}\left\{\left[\frac{\dot{\varepsilon}_p}{A} e^{\left(\frac{Q}{RT}\right)}\right]^m\right\} \quad (2)$$

where, $\dot{\varepsilon}_p$ is the plastic strain rate, A is the pre-exponential factor, ξ is the multiplier of stress, m is the strain rate sensitivity, Q is the activation energy, R is the universal gas constant, and T is the absolute temperature. By substitution of eq. (2) into eq (1), the reformatted stress equation becomes:

$$\sigma = \frac{s}{\xi}\sinh^{-1}\left\{\left[\frac{\dot{\varepsilon}_p}{A} e^{\left(\frac{Q}{RT}\right)}\right]^m\right\} \quad (3)$$

Rearranging Eq. (3) and solving for the strain rate yields the flow equation of the Anand model:

$$\dot{\varepsilon}_p = A\, e^{-\left(\frac{Q}{RT}\right)}\left[\sinh\left(\xi\frac{\sigma}{s}\right)\right]^{\frac{1}{m}} \quad (4)$$

The differential form of the evolution equation for the internal variable s is assumed to be of the form

$$\dot{s} = h\,(\sigma, s, T)\,\dot{\varepsilon}_p$$

$$\dot{s} = \left[h_0\left(1-\frac{s}{s^*}\right)^a \operatorname{sign}\left(1-\frac{s}{s^*}\right)\right]\dot{\varepsilon}_p ; \quad a > 1 \quad (5)$$

here, the term h (σ, s, T) is associated with the dynamic hardening and recovery processes. Parameter $h_o$ is the hardening constant, a is the strain rate sensitivity of the hardening process, and the term s* is expressed as

$$s^* = \hat{s}\left[\frac{\dot{\varepsilon}_p}{A}e^{\left(\frac{Q}{RT}\right)}\right]^n \tag{6}$$

where, $\hat{s}$ is a coefficient and n is the strain rate sensitivity of the saturation value of the deformation resistance. Equation (5) can be integrated to yield the final version of the evolution equation for the internal variable s:

$$s = \hat{s}\left[\frac{\dot{\varepsilon}_p}{A}e^{\left(\frac{Q}{RT}\right)}\right]^n - \left[\left(\hat{s}\left[\frac{\dot{\varepsilon}_p}{A}e^{\left(\frac{Q}{RT}\right)}\right]^n - s_o\right)^{(1-a)} + (a-1)\left\{(h_o)\left(\hat{s}\left[\frac{\dot{\varepsilon}_p}{A}e^{\left(\frac{Q}{RT}\right)}\right]^n\right)^{-a}\right\}\varepsilon_p\right]^{\frac{1}{1-a}} \tag{7}$$

or,

$$s = s(\dot{\varepsilon}_p, \varepsilon_p) \tag{8}$$

The final equations in the Anand model (1-D) are the stress equation in Eq. (3), the flow equation in Eq. (4), and the integrated evolution equation in Eq. (7). These expressions include 9 material parameters (constants): A, $\xi$, Q/R, m in Eqs. (3, 4); and constants $h_o$, a, $s_o$, $\hat{s}$, and n in Eq. (7).

In our analysis, four types of lead free solder materials are considered for life prediction. These solder materials are termed as SAC solders. SAC stands for Sn (tin), Ag (silver) and Copper. In the study, SAC 105, SAC 205, SAC 305 and SAC 405 have been used. In SAC 105, the silver percentage is 1.0% and the percentage of copper is 0.5%. The remaining 98.5% of the solder material is tin. Other solder materials are also termed in this way. Increase in silver content increases the modulus of elasticity of SAC materials. Therefore, SAC 105 has lower modulus of elasticity and SAC 405 has higher modulus of elasticity. In the study, reflowed SAC solders with no aging are considered. Anand parameters for these SAC solders are shown in Table 2.2. Temperature dependent stress- strain curves of solder balls are shown in Figure 2.6.

**Table 2.2:** Anand Parameter Variation for Different Reflowed SAC Alloys [39]

| Anand Par. | Units | SAC 105 | SAC 205 | SAC 305 | SAC 405 |
|---|---|---|---|---|---|
| $s_o$ | MPa | 7.5 | 16.5 | 21 | 23.65 |
| Q/R | 1/K | 8850 | 9090 | 9320 | 9580 |
| A | $sec^{-1}$ | 6900 | 4300 | 3501 | 3175 |
| $\xi$ | - | 4 | 4 | 4 | 4 |
| m | - | 0.215 | 0.238 | 0.25 | 0.263 |
| $h_o$ | MPa | 137500 | 169000 | 180000 | 183,000 |
| $\hat{s}$ | MPa | 25.1 | 29 | 30.2 | 31.3 |
| n | - | 0.0062 | 0.0087 | 0.01 | 0.011 |
| a | - | 1.96 | 1.84 | 1.78 | 1.77 |

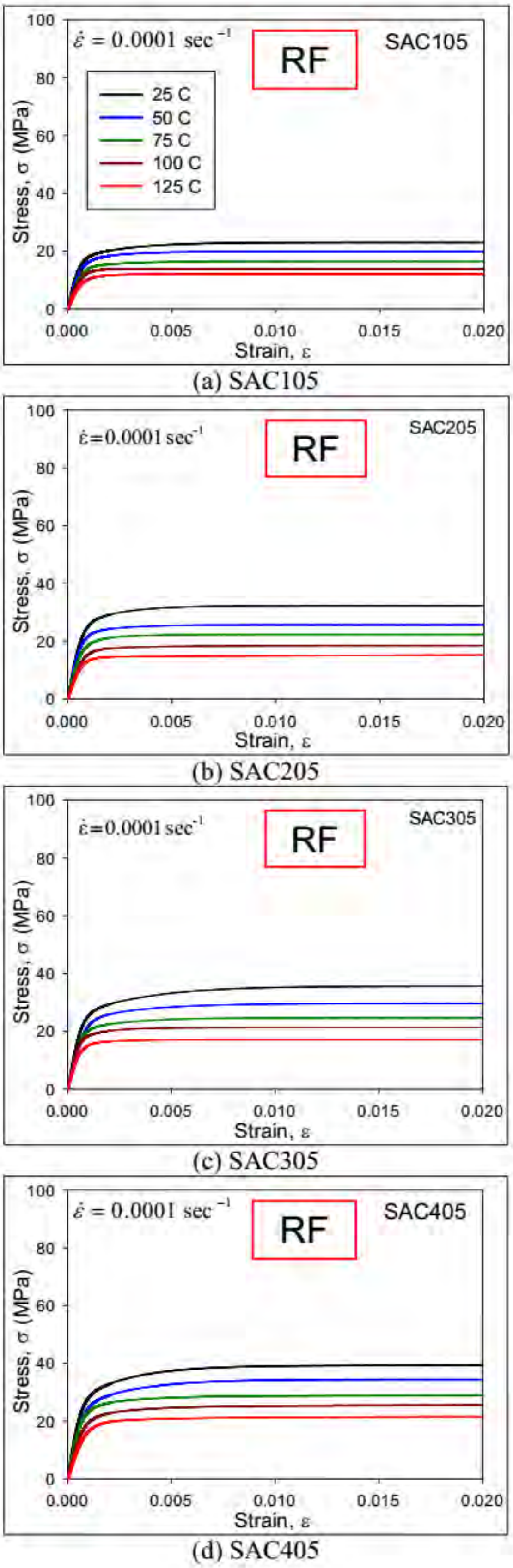



**Figure 2.6**: Stress-Strain Curves for Reflowed (RF) solder materials at a Strain Rate of 0.0001 $sec^{-1}$ for (a) SAC 105, (b) SAC 205, (c) SAC 305, and (d) SAC 405 [39]

### 2.3.3 Mechanical Properties of Molding Compounds

Molding compound, commonly termed as encapsulant, is one of the essential components of the package. It is used to protect the silicon die against damage due to harsh environment. In literature, molding compounds are usually considered as linear isotropic material. But it has been found that mechanical properties of molding compounds vary with temperature. In the study, four types of molding compounds have been considered. Molding compound 1 and 2 are selected from literature [40-41] and molding compounds 3 and 4 are selected from vendor data [42-43]. Temperature dependent stress-strain curves of molding compounds are shown in Figure 2.7. Elastic moduli of different molding compounds are shown in Table 2.3.

**Table 2.3:** Modulus of Elasticity of Molding compounds at 25 $^{o}$C.[40-43]

| Molding Compounds | Modulus of Elasticity at 25 $^{o}$C (GPa) | Ultimate Tensile Stress at 25 $^{o}$C (MPa) |
|---|---|---|
| Molding Compound 1 | 11.8 | 47.8 |
| Molding Compound 2 | 4.76 | 65.91 |
| Molding Compound 3 | 0.414 | 11.7 |
| Molding Compound 4 | 0.138 | 2.76 |

(a) Molding Compound 1

(b) Molding Compound 2

(c) Molding Compound 3

(d) Molding Compound 4

**Figure 2.7:** Temperature Dependent Stress-Strain Curves of Different Molding Compounds [40-43]

### 2.3.4 Mechanical Properties of Die Attach Materials

Die attach material is mainly used to attach the silicon die with substrates. Variation of life of PBGA package with mechanical properties of die attach materials is studied in the analysis. Three types of die attach materials are taken into account in the study. Elastic modulus and CTE are used for FEA that are taken from literature and vendor data [44-46]. Temperature dependent properties of different die attach materials are shown in Figure 2.8.

### 2.3.5 Mechanical Properties of other components

Silicon die is the component that processes I/O data. High amount of heat is generated during operation. Among all of the package components, silicon die is the strongest. In the study, silicon die has been considered as linear elastic isotropic material.

Printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. Components (e.g. capacitors, resistors or active devices) are generally soldered on the PCB. Advanced PCBs may contain components embedded in the substrate. PCB has been found as an orthotropic material.

Solder mask is also an important component of PBGA package. It is used to protect the PCB, solder balls and substrate from oxidation during high temperature assembly and from harsh environment. Copper pads are used to connect and place the solder balls on the PCB.

Thermal cycling life of PBGA packages is not strongly dependent on mechanical properties of PCB, solder mask, copper pad and silicon die. Properties of these materials are shown in Table 2.1.

**Figure 2.8:** Temperature Dependent Mechanical Properties of Different Die Attach Materials

# CHAPTER 3

# SIMULATION METHOLOGY

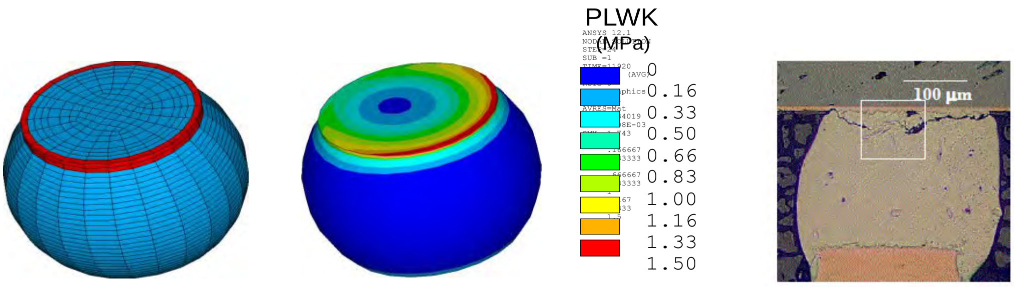
### 3.1 Load Application Process

The model is initially assumed to have a uniform temperature of 220 $^{o}$C, which is the solder solidification temperature. From this temperature, the model is first cooled to -40 $^{o}$C and then the thermal cycling starts at this temperature and two thermal cycles are simulated according to the thermal profile shown in Figure 2.4. The temperature ramp, dwell time etc. are given as several temperature load steps and different physical quantities such as deformations, strains, stresses, plastic energy dissipation etc. are solved for the model at each load steps. The results are recorded for every load step in a .rst result file. This file is used for subsequent postprocessing operation.

### 3.2 Post Processing of the Data

The PBGA package (Figure 2.1) was simulated for two thermal cycles between -40 $^{o}$C to 125 $^{o}$C (Figure 2.4). The plastic energy dissipation or plastic work (PLWK) after two thermal cycles was calculated and plastic energy dissipation per cycle was determined. The volume averaged plastic energy dissipation accumulated per cycle ($\Delta$W) is often taken to be the metric for damage accumulation and failure of solder joints. In this study, the solder ball with maximum $\Delta$W has been considered as critical solder ball in this PBGA assembly.

Following Che et al. [47], the outer ring of elements in the top two rows were used to calculate $\Delta$W for the second thermal cycle. Figure 3.1(a) shows the mesh plot of the critical solder joint with the ring elements. It has been observed that the finite element analysis predicts the maximum plastic energy dissipation near the top right side of the




critical solder joint in agreement with the origination of crack in a similar package that is also shown in Figure 3.1(c) according to Lamaye, et al. [48].

**Figure 3.1:** (a) Finite Element Mesh of a solder ball and the elements used for PLWK calculation, (b) Contours of PLWK in the Critical Solder Joint, (c) Crack Propagation in a PBGA Solder Ball [48].

(a)

### 3.3 Life Prediction Methology

Darveaux [4] has presented energy dissipation based models for life prediction in solder joints subjected to cyclic loading.

$$N_i = K_1 (\Delta W)^{K_2} \tag{9}$$

$$\frac{da}{dN} = K_3 (\Delta W)^{K_4} \tag{10}$$

where $N_i$ is the number of cycles to crack initiation, da/dN is the crack growth rate (assumed constant) occurring after crack initiation, ΔW is the energy dissipation per cycle in the solder sample (e.g. critical solder ball), and $K_1$, $K_2$, $K_3$, and $K_4$ are fitting constants that are used from Motalab, et al. [49] for SAC 305 solder balls assuming non-aged configuration. Once the crack location and path are known in the solder joint, the number of cycles to failure can be estimated using:

$$N_f = N_i + \frac{a_c}{\left[\frac{da}{dN}\right]} \tag{11}$$

where $N_f$ is the number of cycles to failure, $a_c$ is the length of the fully developed crack at failure/fracture, and $N_i$ and da/dN are calculated from $\Delta W$ using equations. (9-10).

Increase in $\Delta W$ leads to more plastic energy dissipation that results in less thermal cyclic life. Thermal cycling life is calculated for SAC 305 solder balls only due to due to the unavailability of $K_1$, $K_2$, $K_3$ and $K_4$ for other SAC solders.

For the analyses, solder balls under die shadow are considered for $\Delta W$ and life calculation because solder balls in this region are more constrained compared to other regions. Solder ball under die shadow with maximum $\Delta W$ is considered as the critical solder ball and that is used for life prediction calculation.

Maximum possible crack length, $a_c$ is the diameter of solder ball at the neck. The length of the crack has been used as 0.32 mm. Fitting constants $K_1$, $K_2$, $K_3$ and $K_4$ for SAC 305 has been shown in Table 3.1.

**Table 3.1:** Fitting Constants of Darveaux's Model For SAC 305 Solder [49]

| Solder material | $K_1$ (Cycles/MPa$^{K_2}$) | $K_2$ | $K_3$ (m/Cycles-MPa$^{K_2}$) | $K_4$ |
|---|---|---|---|---|
| SAC 305 | 37.97 | -2.8 | $1.4\times10^{-6}$ | 1.16 |

### 3.4 Sample Calculation

To calculate the package thermal cycling life, equations (9-11) are used. For instance, the value of plastic energy dissipation per cycle (ΔW) for substrate modulus of 16 GPa and Poisson's ratio of 0.25 has been found as 0.345 MPa from finite element analysis. Using the values of ΔW and fitting constants,

From equation (9), number of cycles to crack initiation,

$$N_i = K_1 (\Delta W)^{K_2} = 37.97(0.345)^{-2.8} = 747.4 \text{ cycles}$$

From equation (10), crack growth rate,

$$\frac{da}{dN} = K_3 (\Delta W)^{K_4} = (1.4 \times 10^{-6})(0.345)^{1.16} = 4.07 \times 10^{-7} \text{ m/cycle}$$

Therefore, from equation (11), package thermal cycling life,

$$N_f = N_i + \frac{a_c}{\left[\frac{da}{dN}\right]} = 747.4 + \frac{0.32 \times 10^{-3}}{4.07 \times 10^{-7}} = 1532.9 \text{ cycles}$$

Package life has been calculated in the same way for different values of ΔW for SAC 305 solder materials.

# CHAPTER 4

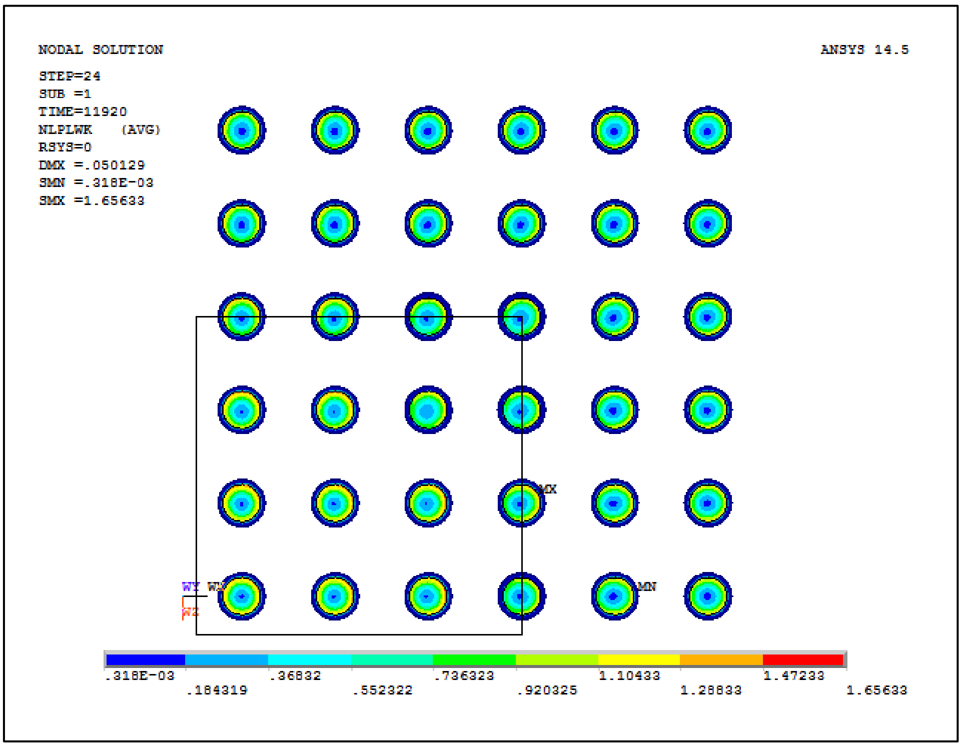
# RESULTS AND DISCUSSIONS

## 4.1 Variation of ΔW and Life of the PBGA Package Due to the Changes in the Material Properties

### 4.1.1 Effects of Modulus of Elasticity of Substrate Materials

Effects of elastic modulus of substrate materials on thermal cycling life of PBGA package has been investigated. Elastic modulus of 16 GPa, 18 GPa, 20 GPa, 22 GPa and 24 GPa has been considered as discussed in section 2.3.1. SAC 305 solder material has been considered in the package for the study. Variation of ΔW with elastic modulus of substrate has been studied. For the study, linear elastic mechanical properties of molding compound have been used in the package with the modulus of elasticity of 25 GPa. Die attach material number 1 (section 2.3.4) has been used in the package for this study. Equations (9-11) have been used to predict the thermal cycling life for each value of ΔW and a comparison has been made for life prediction of PBGA package for different elastic modulus of substrate material. Poisson's ratio of substrate material has been kept constant as 0.35 in the analysis. CTE of substrate material has also been considered constant for different modulus of elasticity. Other mechanical properties of different components are kept constant.

Figure 4.1 shows the location of critical solder ball with maximum plastic energy dissipation for this study. From the study, critical solder ball has been found in die shadow region. The location of critical solder ball has been found at second row and fourth column from package center. ΔW of the of critical solder ball has been




calculated for second thermal cycle. Location of critical solder ball has been found same for different moduli of elasticity of substrate materials in the investigation. Using ΔW along with fitting constants for SAC 305 [49], life of the package has been calculated for different moduli of elasticity using equations (9-11).

**Figure 4.1:** Location of Critical Solder Ball under Die Shadow

Figure 4.2 shows the variation of ΔW of the critical solder ball with modulus of elasticity of substrate materials. It can be inferred from the figure lue of ΔW has been increased with increasing the elastic modulus of subst als. So damage accumulation will be higher for higher value of modulus of elasticity of substrate materials. Minimum ΔW is found as 0.356 MPa for substr s of 16 GPa and maximum ΔW is found as 0.387 MPa for substrate modulus . With increase in modulus of elasticity from 16 GPa to 24 GPa, the value of ΔW increases by about 9%.

Using the values of ΔW, variation of thermal cycling life of PBGA package has been found as shown in Figure 4.3. The life has been calculated following the procedures mentioned in section 3.3. It has been found that thermal cycling life has been increased with decreasing the elastic modulus of substrate materials. So package reliability is higher for lower values of modulus of elasticity of substrate material. Maximum cycling life has been found as 1441 cycles for substrate modulus of 16 GPa and minimum life has been found as 1229.32 cycles for substrate modulus of 24 GPa. With decrease in modulus of elasticity from 24 GPa to 16 GPa, the thermal cycling life increases by about 17%.

**Figure 4.2:** Variation of ΔW of Critical Solder Material with Modulus of Elasticity

of Substrate Material.

**Figure 4.3:** Variation of Thermal Cycling Life of PBGA Package with Modulus of Elasticity of Substrate Material.

### 4.1.2 Effects of Poisson's Ratio of Substrate Materials

In the analysis, effects of Poisson's ratio of substrate material on life of PBGA package has been investigated. Four theoretical Poisson's ratios of substrate material are considered- 0.25, 0.3, 0.35 and 0.4. Variation of life with Poisson's ratio is investigated for elastic modulii of substrate material from 16 GPa to 24 GPa. SAC 305 solder balls are considered for the package in this investigation. Molding compound is considered to be linear elastic with a modulus of elasticity of 25 GPa. Die attach material number 1 is used for the package in the study. CTE of substrate material is assumed constant for different moduli of elasticity. Mechanical properties of other components are used as shown in Table 2.1.

In this study, location of critical solder ball under die shadow has been found same as of Figure 4.1. Life prediction of the PBGA package has been made based on this critical solder ball.

Figure 4.4 shows the variation of $\Delta W$ with Poisson's ratio for different moduli of elasticity of substrate materials. It is observed that the plastic energy dissipation per cycle ($\Delta W$) increases with increasing the Poisson's ratio of substrate having a fixed modulus of elasticity. From the figure, it has been found that the value of $\Delta W$ is minimum for Poisson's ratio of 0.25 for each elastic modulus of substrate materials leading to minimum damage accumulation. Also for a substrate having a constant Poisson's ratio, plastic energy dissipation per cycle increases with increasing the modulus of elasticity of the substrate. From the figure, it is observed that the value of $\Delta W$ is minimum for substrate elastic modulus of 16 GPa and maximum at 24 GPa. For increase in Poisson's ratio from 0.25 to 0.4, the value of $\Delta W$ increases by 8% for elastic modulus of 16 GPa and by 7.5% for elastic modulus of 24 GPa. Minimum $\Delta W$

is found as 0.345 MPa for substrate Poisson's ratio of 0.25 with modulus of elasticity of 16 GPa. Maximum ΔW is found as 0.398 MPa for substrate Poisson's ratio of 0.4 with modulus of elasticity of 24 GPa. Increase in ΔW from 0.345 MPa to 0.398 MPa is 15.4%.

Package life has been calculated in the same way as shown in section 3.3 for different values of ΔW for SAC 305 solder materials. Figure 4.5 shows the variation of thermal cycling life with Poisson's ratio for different moduli of elasticity of substrate materials. It is observed that thermal cycling life decreases with Poisson's ratio of substrate having a certain modulus of elasticity. From the figure, it has been found that the life is maximum for Poisson's ratio of 0.25 for each elastic modulus of substrate materials leading to more thermal cycling reliability. Also for a substrate having a constant Poisson's ratio, thermal cycling life decreases with increasing the modulus of elasticity of substrate material. From the figure, it is seen that the life is minimum for substrate elastic modulus of 24 GPa and maximum at 16 GPa. For decrease in Poisson's ratio from 0.4 to 0.25, the value of thermal cycling increases by about 15% for elastic modulus of 16 GPa and by 14% for elastic modulus of 24 GPa. Maximum life is found as 1532.9 cycles for substrate Poisson's ratio of 0.25 with modulus of elasticity of 16 GPa. Minimum life is found as 1166.43 cycles for substrate Poisson's ratio of 0.4 with modulus of elasticity of 24 GPa. Increase in life from 1166.43 cycles to 1532.9 cycles is about 31%.

**Figure 4.4:** Variation of ΔW with Poisson's Ratio for Different Elastic Moduli of Substrate Material.

**Figure 4.5:** Variation of Thermal Cycling Life with Poisson's Ratio for Different Elastic Moduli of Substrate Material (SAC 305)

### 4.1.3 Effects of Different SAC Alloys

As discussed in Article 2.3.2, four types of solder materials have been considered in the study for life prediction of PBGA packages- SAC 105, SAC 205, SAC 305 and SAC 405. SAC 105 material contains 1% silver whereas SAC 405 contains 4% silver. In the study, effects of silver contents of solder materials on thermal cycling life has been predicted. Variations have been observed for different moduli of elasticity of substrate materials. Poisson's ratio of substrate materials has been used as 0.35. CTEs of all solder materials are assumed constant. Die attach material number 1 has been used in the study. Molding compound has been considered again as linear elastic with the modulus of elasticity of 25 GPa. ΔW has been considered as damage accumulation parameter in the study. Location of critical solder ball has been found same as of Figure 4.1. Plastic energy dissipation per cycle of the critical solder ball has been considered for the analysis.

Figure 4.6 shows the variation of ΔW of critical solder balls with elastic modulus of substrate materials for different SAC solders. It is evident from the figure that for each SAC solder, the value of ΔW increases with increase in elastic modulus of substrate materials. For this study, ΔW is found minimum for 16 GPa and maximum for 24 GPa. It indicates that damage accumulation is higher for higher elastic modulus of substrate. Again for same elastic modulus of substrate materials, ΔW is maximum for SAC 405 solder material and minimum for SAC 105 solder. It can be inferred that damage accumulation increases with increase in silver content of solder materials.

For SAC 105 solder, minimum ΔW found is 0.257 MPa for substrate modulus of 16 GPa. Maximum ΔW for SAC 105 solder material is 0.277 MPa for substrate modulus of 24 GPa. With increase in substrate modulus from 16 GPa to 24 GPa, the value of ΔW increases by about 8% causing higher plastic energy dissipation for higher substrate modulus. For SAC 205 solder materials, the value of ΔW has been found from a minimum value of 0.327 MPa to a maximum value of 0.357 MPa, with an increase of plastic energy dissipation of about 9.2%. In case of SAC 305 solder materials, the value of ΔW ranges between the minimum value of 0.327 MPa and the maximum value of 0.357 MPa, showing an increase in ΔW of about 9% due to increase of substrate modulus from 16 GPa to 24 GPa. Similar trend has been found for SAC 405 solder materials. In this case, the value of ΔW is increased from 0.398 MPa to 0.439 MPa when the substrate modulus increases from 16 GPa to 24 GPa.

**Figure 4.6:** Variation of ΔW of Critical Solder Balls with Modulus of Elasticity of Substrate Materials for Different SAC Solders.

For SAC 305 solder balls, predicted package life has been calculated using equations (9-11) using values of fitting constants from [49]. Predicted results have been discussed in section 4.1.1. As SAC 305 is used in most cases, necessary data is available. However, for other solder materials, the study of package life is not so available in literature due to less usage. So the values of fitting constants for equations (9-11) have not been found from literature. As discussed before, the value of ΔW is an indication of damage accumulation in solder balls, from which some idea of thermal cycling life and package reliability can be found. So for other solder materials, package life has been discussed using the values of ΔW.

From Figure 4.6, it can be inferred that maximum package life will be found for SAC 105 solder materials due to less value of ΔW compared to other solder materials for a constant modulus of elasticity of substrate materials. Predicted cycling life will be minimum for SAC 405 solder ball among four solder materials. Predicted life of PBGA package for SAC 305 solder ball has been discussed in Article 3.2.2, where an increase of life has been found for a decrease in modulus of elasticity of substrate materials. Similar life prediction of package life will be found for other solder materials. For each solder material, the value of ΔW decreases with an increase in substrate modulus. As minimum ΔW indicates maximum package life, so the package life will increase with a decrease in elastic modulus of substrate materials. So in the analysis, minimum package will be at substrate modulus of 24 GPa and maximum package will be at substrate modulus of 16 GPa.

From the analysis, maximum package life will be for SAC 105 solder with substrate modulus of 16 GPa and minimum package life will be for SAC 405 solder material with substrate modulus of 24 GPa.

From above discussion, it can be summarized that with increase in silver content of solder materials, plastic energy dissipation per cycle increases, resulting in less package life and reliability. So less silver content of solder material is desired for higher package reliability.

### 4.1.4 Effects of Molding Compounds

Molding compound is an essential part of PBGA package. It is used to protect the package from harsh environments. Mechanical properties of molding compound also influence on the life of the packages. Conventionally molding compounds are modeled as linear elastic and room temperature properties are used for simulation purpose [50]. But in reality, molding compounds exhibit temperature dependent properties. In this study, four types of molding compounds have been considered to investigate their effect on life prediction. Mechanical properties of these materials are shown in Figure 2.6 and Table 2.4. CTEs of molding compounds are assumed constant.

In the study, effects of molding compound on life prediction have been investigated for different substrate and SAC solder materials. Figures (4.8-4.12) show variation of plastic energy dissipation per cycle with molding compounds for different SAC solder materials. Analysis are done for different elastic modulus of substrate materials.

Figure 4.7 shows the location of critical solder ball under die shadow for different temperature dependent mechanical properties of molding compounds. The location of critical solder ball is at second row and third column from package center. The location is different from the locations of critical solder ball found in sections 4.1.1-4.1.3. So changing material properties not only causes the variation in life, but also it influences on the fact which solder ball will fail first. In these sections, it has been mentioned that molding compound has been considered as linear elastic, which is traditionally used in literature. This assumption may cause inaccuracy in results. Therefore, temperature dependent properties of molding compounds should be considered for more accurate prediction of package life and reliability.

Figures (4.8-4.12) represent the variation of $\Delta W$ with different molding compounds for different solder materials and substrate elastic modulus. Figure 4.8 represents the results for substrate modulus of 16 GPa. It has been found that for the same solder material, the value of $\Delta W$ is minimum for molding compound 1 and maximum for molding compound 4. Molding compound 1 exhibits highest modulus of elasticity among all molding compounds and molding compound 4 exhibits lowest modulus of elasticity. Therefore, it can be inferred that the increase in modulus of elasticity of molding compound results in decrease of $\Delta W$ of the package.

Again it has been found that for the same molding compound, $\Delta W$ is minimum for SAC 105 solder material and maximum for SAC 405 solder material. This result is similar to the variation discussed in section 4.1.3. It indicates that regardless of mechanical properties of molding compounds, variation of ΔW with silver contents of different SAC solder materials will be similar.

Similar results are also obtained for the effects of mechanical properties of molding compounds and SAC solders on the life prediction of PBGA package for other substrate elastic moduli (18-24 GPa). For the fixed composition of molding compound and SAC solder, plastic energy dissipation has been found minimum for substrate modulus of 16 GPa and maximum for substrate modulus of 24 GPa.

From Figure 4.8, it has been observed that for substrate modulus of 16 GPa and for SAC 105 solder, minimum ΔW has been found as 0.277 MPa for molding compound 1 and maximum ΔW has been found as 0.3 MPa, showing in increase in ΔW of about 9% from minimum value. However, for SAC 405 solder material, minimum ΔW has been found as 0.426 MPa for molding compound 1 and maximum ΔW has been found as 0.437 MPa, showing in increase in ΔW of only about 3% from minimum value.

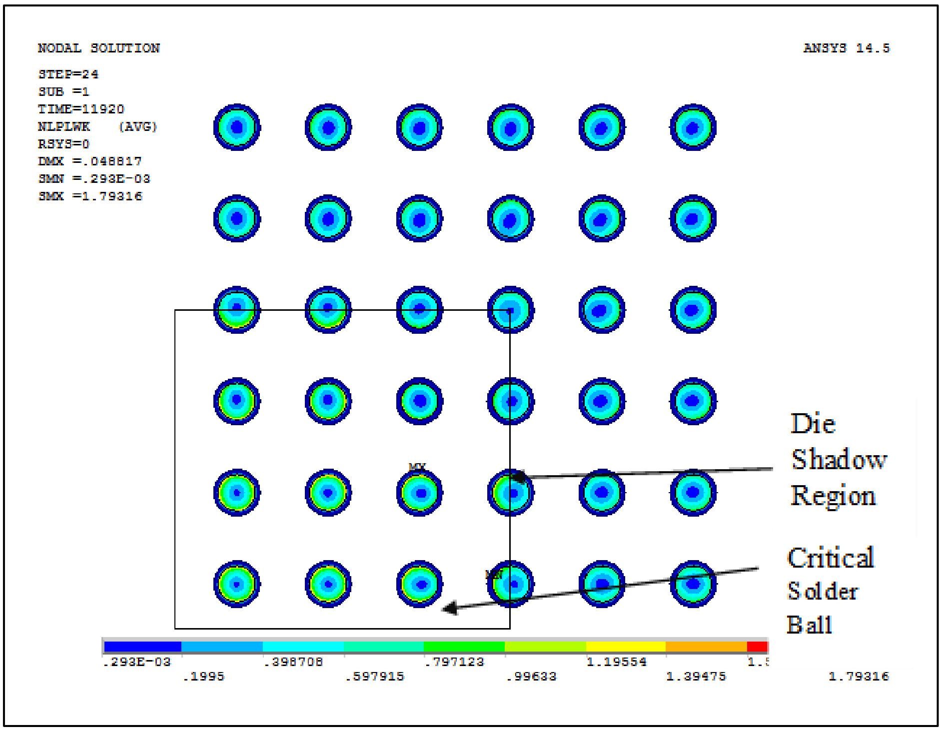
From Figure 4.9, it has been observed that for substrate modulus of 18 GPa and for SAC 105 solder, minimum ΔW has been found as 0.284 MPa for molding compound 1 and maximum ΔW has been found as 0.303 MPa, showing in increase in ΔW of about 7% from minimum value. However, for SAC 405 solder material, minimum ΔW has been found as 0.436 MPa for molding compound 1 and maximum ΔW has been found as 0.445 MPa, showing in increase in ΔW of only about 2% from minimum value.

From Figure 4.10, it has been observed that for substrate modulus of 20 GPa and for SAC 105 solder, minimum ΔW has been found as 0.289 MPa for molding compound 1 and maximum ΔW has been found as 0.306 MPa, showing in increase in ΔW of about 6% from minimum value. However, for SAC 405 solder material, minimum ΔW has been found as 0.445 MPa for molding compound 1 and maximum ΔW has been found as 0.456 MPa, showing in increase in ΔW of only about 3% from minimum value

From Figure 4.11, it has been observed that for substrate modulus of 22 GPa and for SAC 105 solder, minimum ΔW has been found as 0.294 MPa for molding compound 1 and maximum ΔW has been found as 0.309 MPa, showing in increase in ΔW of about 6% from minimum value. However, for SAC 405 solder material, minimum ΔW has been found as 0.453 MPa for molding compound 1 and maximum ΔW has been found as 0.465 MPa, showing in increase in ΔW of only about 3% from minimum value.

From Figure 4.12, it has been observed that for substrate modulus of 24 GPa and for SAC 105 solder, minimum ΔW has been found as 0.298 MPa for molding compound 1 and maximum ΔW has been found as 0.311 MPa, showing in increase in ΔW of about 5% from minimum value. However, for SAC 405 solder material, minimum ΔW has been found as 0.46 MPa for molding compound 1 and maximum ΔW has been found as 0.481 MPa, showing in increase in ΔW of about 4.5% from minimum value.

In this study, the value of minimum ΔW has been found as 0.277 MPa for the configuration with substrate modulus of 16 GPa, SAC 105 solder material and molding compound 1. Again, the value of maximum ΔW is 0.481 MPa for the configuration of substrate modulus of 24 GPa, SAC 405 solder material and molding compound 4. Change in ΔW from maximum to minimum value is about 43%, which



is very high. So package life is very much dependent on the selection of components materials (i.e. substrate, molding compound and solder materials).

**Figure 4.7:** Location of Critical Solder Ball under Die Shadow for Different Temperature Dependent Properties of Molding Compounds.

**Figure 4.8:** Variation of ΔW with Molding Compounds for Different SAC Solders at

Substrate Elastic Modulus of 16 GPa

**Figure 4.9:** Variation of ΔW with Molding Compounds for Different SAC Solders at Substrate Elastic Modulus of 18 GPa

**Figure 4.10:** Variation of ΔW with Molding Compounds for Different SAC Solders at Substrate Elastic Modulus of 20 GPa

**Figure 4.11:** Variation of $\Delta W$ with Molding Compounds for Different SAC Solders at Substrate Elastic Modulus of 22 GPa

**Figure 4.12:** Variation of ΔW with Molding Compounds for Different SAC Solders at Substrate Elastic Modulus of 24 GPa

Using the value of ΔW, we can predict the life of PBGA package. For the fixed substrate material and SAC solder mechanical properties, maximum life is expected for using molding compound 1 whereas minimum life is expected for molding compound 4. As molding compound 1 possess higher stiffnesses than other molding compounds, it can be inferred that higher elastic modulus of molding compound at different temperature results in higher thermal cycling life and reliability of PBGA package.

As previously found, for the fixed substrate material and molding compound properties, minimum life is expected for SAC 405 solder due to higher ΔW and maximum life is expected for SAC 105 solder due to lower ΔW. Therefore, with increase in silver contents of solder materials, thermal cycling lives have been decreased. Again, for the fixed molding compound and solder material properties, life is expected to decrease with increase in modulus of elasticity of substrate modulus from 16 GPa to 24 GPa.

Due to the minimum value of ΔW, maximum life is expected for the combination of substrate modulus of 16 GPa, SAC 105 solder material and molding compound 1 and minimum life is expected for substrate modulus of 24 GPa, SAC 405 solder material and molding compound 4 due to the maximum value of ΔW.

Variation of thermal cycling life with molding compound properties for different substrate material has been found for SAC 305 using equations (9-11). The variation is shown in Figure 4.13. From the figure, it is found that for each modulus of elasticity of substrate materials, thermal cycling life of PBGA package is highest for molding compound 1 and lowest for molding compound 4. Again for each molding compound, thermal cycling life increases with decreasing the substrate modulus from 24 GPa to 16 GPa. Maximum life for SAC 305 solder has been found as 1254 cycles for substrate modulus of 16 GPa and molding compound 1. Minimum life for SAC 305 solder is 1005 cycles for substrate modulus of 24 GPa and molding compound 4. So there is about 20% reduction in life for the change in configuration in this manner.

**Figure 4.13:** Variation of thermal cycling life of PBGA package with molding compound for SAC 305 solder material.

### 4.1.5 Effects of Die Attach Materials

Dependence of package cycling life on die attach materials has also been studied. In the analysis of package life in sections 4.1.1-4.1.4, die attach materials have been used. To investigate the variation of package life, three types of die attach materials have been considered. Temperature dependent elastic modulus and CTE of these materials have been shown in Figure 2.3.4. SAC 305 solder material has been considered for the study. Substrate elastic modulus of 24 GPa has been considered.

Figure 4.14 shows the variation of ΔW of the PBGA package with die attach materials. It has been found that the variation of ΔW with the properties of die attach materials is not so significant. For die attach material 1, the value of plastic energy dissipation is 0.387 MPa and for die attach material 3, the value of plastic energy dissipation is 0.388 MPa, suggesting only about 0.26% change in ΔW.

Using the values of ΔW, the variation of thermal cycling life of the PBGA package with die attach materials has been found using equations (9-11) as shown in Figure 4.15. It has been found that the variation of life with the properties of die attach materials is also not so significant due to less variation in ΔW. For die attach material 1, value of predicted life is 1229 cycles and for die attach material 3, the value of predicted life is 1224 cycles, suggesting only about 0.4% change in thermal cycling life.

**Figure 4.14:** Variation of ΔW of PBGA package with die attach materials for SAC 305 solder material.

**Figure 4.15:** Variation of thermal cycling life of PBGA package with die attach material for SAC 305 solder material.

## 4.2 Optimization of PBGA Package Architecture

Effects of different package components on thermal cycling life have been discussed in section 4.1. From the analysis, it has been found that package life is strongly dependent on substrate materials, solder materials, and molding compounds. In this section, optimum properties of package components for maximum package life has been discussed. Since the effects of die attach material is insignificant, die attach material 1 has been considered for the optimization.

To predict optimum package life, the minimum value of $\Delta W$ has been searched by simulation among all the available configurations of mechanical properties of substrate, molding compound and SAC solders. Due to unavailability of data in literature, CTEs for substrate materials, solder materials and molding compounds are assumed constant throughout the analysis.

Figures (4.16-4.18) show surface plots of plastic energy dissipation per cycle based on mechanical properties of any two of three package components- substrate material, solder material and molding compound. Each plot has been developed considering mechanical properties of third components for which minimum value of $\Delta W$ has been found. Using these plots, optimum mechanical properties of package components can be found for maximum thermal cycling life.

Figure 4.16 shows the combined effects of molding compounds and solder materials on plastic energy dissipation per cycle of the PBGA package. Substrate elastic modulus of 16 GPa has been considered as plastic energy dissipation per cycle has been found minimum for 16 GPa. From the plot, maximum $\Delta W$ has been found as 0.437 MPa for the combination of SAC 405 solder material and molding compound 4 (mold 4). On the other hand, minimum $\Delta W$ has been found as 0.277 MPa for the combination of SAC 105 solder material and molding compound 1 (mold 1). This combination can be used for optimal life of PBGA package.

Figure 4.17 shows the combined effects of substrate elastic moduli and solder materials on plastic energy dissipation per cycle of the PBGA package. Molding compound 1 has been considered as minimum plastic energy dissipation per cycle has been found for the material. From the plot, maximum ΔW has been found as 0.46 MPa for the combination of SAC 405 solder material and substrate modulus of 24 GPa. On the other hand, minimum ΔW has been found as 0.277 MPa for the combination of SAC 105 solder material and substrate elastic modulus of 16 GPa which has been found similar to minimum ΔW from Figure 4.16.

Figure 4.18 shows the combined effects of substrate elastic moduli and molding compounds on plastic energy dissipation per cycle of the PBGA package. SAC 105 solder material has been considered for optimization as minimum plastic energy dissipation per cycle has been found for the material. From the plot, maximum ΔW has been found as 0.311 MPa for the combination of molding compound 4 (mold 4) and substrate modulus of 24 GPa. On the other hand, minimum ΔW has been found as 0.277 MPa for the combination of molding compound 1 (mold 1) and substrate elastic modulus of 16 GPa which has been similar to results from Figures 4.16 and 4.17.

From above discussion, it has been found that minimum ΔW has been found as 0.277 MPa for the combination of SAC 105 solder material, molding compound 1 and substrate material with the modulus of elasticity of 16 GPa. As minimum ΔW indicates maximum package life, so the combination can be considered as optimum mechanical properties of package components. Therefore, the combination of SAC 105 solder material, molding compound 1, substrate material with the modulus of elasticity of 16 GPa and die attach material 1 is the optimum package configuration for maximizing the thermal cycling life of this package.

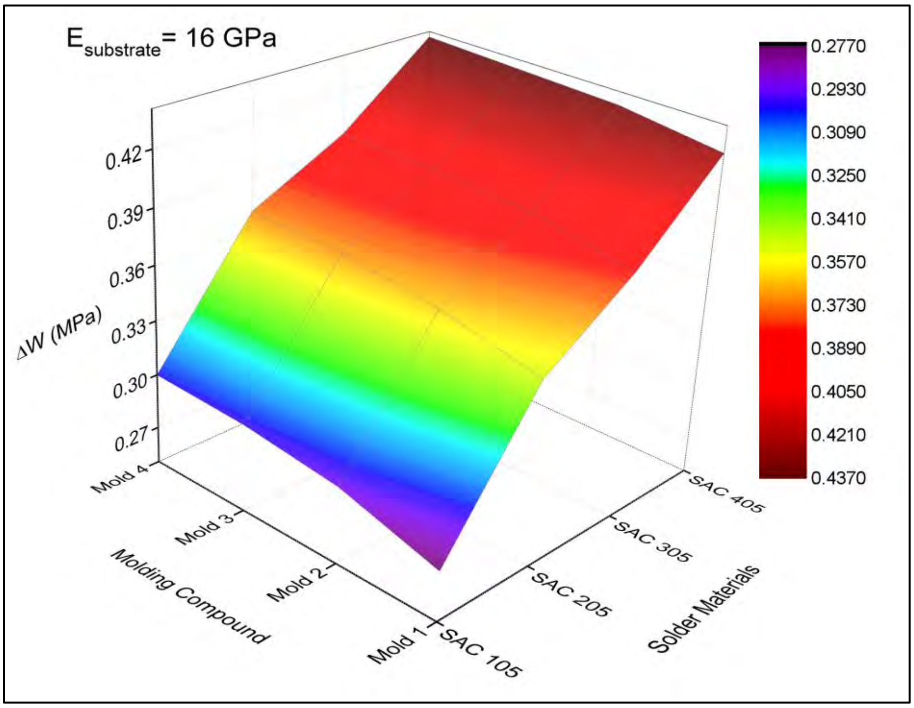



**Figure 4.16:** Variation of ΔW with Molding Compounds and Solder Materials for Substrate Modulus of 16 GPa.

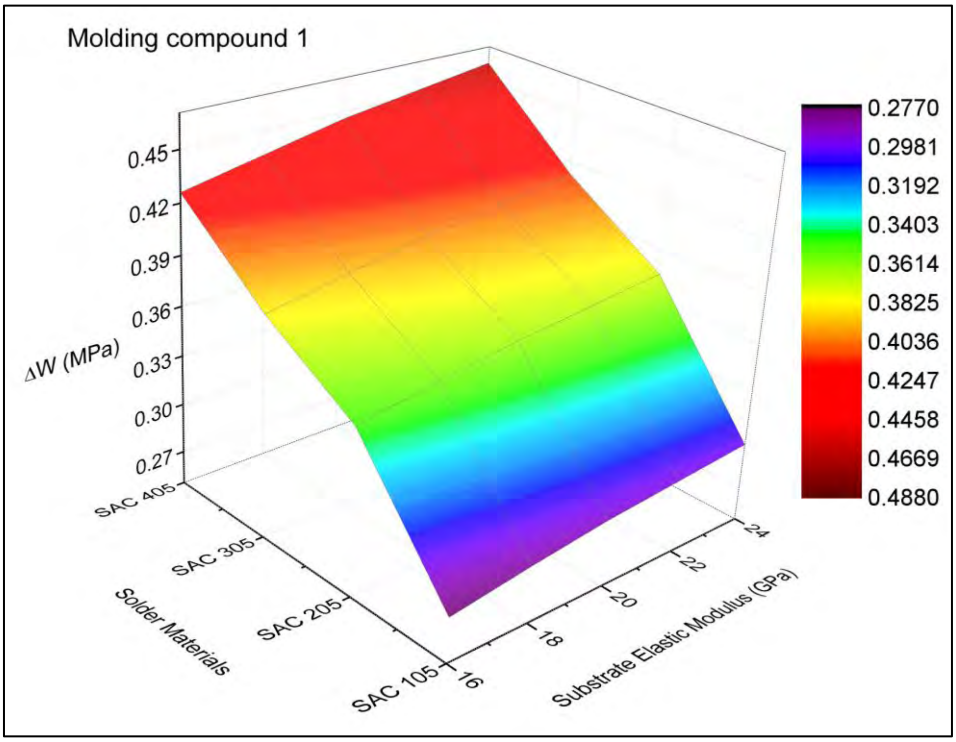


**Figure 4.17:** Variation of ΔW with Solder Materials and Substrate Elastic Moduli for Molding Compound 1.

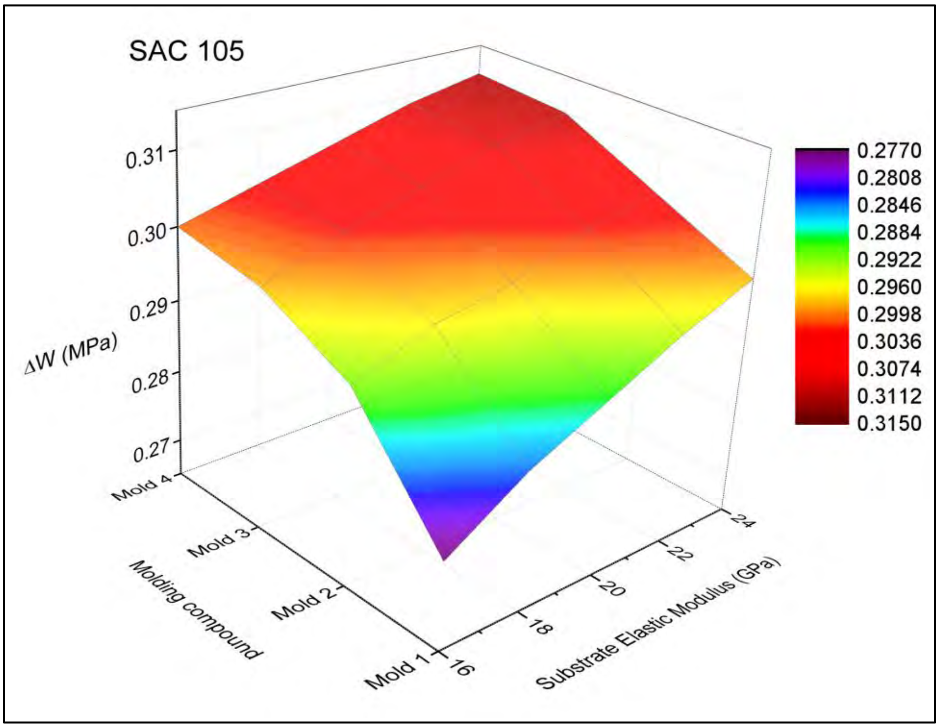



**Figure 4.18:** Variation of ΔW with Molding Compounds and Substrate Elastic Moduli for SAC 105 Solder Material.

For more accurate prediction of package life, CTE's of different package components such as substrate materials, solder materials and molding compounds should be determined because CTE's of the materials may vary with changing the elastic modulus of the materials. The variation of CTE have not been included in this study since the data are not available yet. However, theoretical study has been performed by assuming 10% variation of the CTEs of the materials under study. This will be discussed in section 4.4.

## 4.3 Validation of the Finite Element Model

In the previous section, optimum mechanical properties of some major components of a PBGA package have been identified for maximum package life. The results may vary from package to package due to different dimensions and different layout of components. Therefore, it is recommended to perform experimental analysis for each combination of PBGA package for proper validation of the FEA model and accurate prediction for maximum package life and reliability. Due to insufficient resources for experimental analysis, the trends of the FEA results have been matched with the results available in literature. Validation of the results found from finite element models is discussed below.

The finite element model predicts the critical solder ball to be the solder ball with maximum volume averaged plastic energy dissipation per cycle. Therefore, the location of crack will be initiated at the critical solder ball. In the study, location of critical solder ball has been found at die shadow region. Although in most literature, suggested location of critical solder ball is at outer corner of the package, failure can also occur at other locations [51]. Therefore, the critical location found in this study is consistent with literature.

From the FEA analysis, it has been found that damage accumulation is at the right most corner of the critical solder ball at shown in Figure 3.1(b). The result is in agreement with experimental results shown in Figure 3.1(c).

Effects of substrate elastic modulus on PBGA package life have been studied. It has been found that package life increases with decreasing the substrate elastic modulus from 24 GPa to 16 GPa. At low modulus of elasticity, the substrate becomes more flexible, contributing to less thermal stress to solder balls due to CTE mismatch. The findings are in agreement with literature [52-53] where flexible substrate material show better reliability than rigid substrate materials.

From this study, it is found that plastic energy dissipation per cycle of solder materials increases with increasing the silver percentage of SAC solder balls. Increase in silver contents increases the stiffness of the solder ball and reduces the ductility of the material. As a result, more thermal cycling life is expected for lower silver percentage of solder materials. Expected results are in agreement with literature [54], where higher reliability of PBGA package has been found for lower elastic modulus of leaded solder materials. But for more accurate prediction of cycling life, fitting constants in equations (9-11) are necessary for life calculation. Due to unavailability of necessary data, thermal cycling life has not been found for SAC 105, SAC 205 and SAC 405 solder materials. SAC 305 is widely used in packaging technology. Therefore, data for SAC 305 is available in literature. As a result, thermal cycling life has been predicted based on plastic energy dissipation per cycle ($\Delta W$) for other solder materials. So the comparison among solder materials remain less accurate for reliability prediction.

In literature, variation of package life with properties of molding compound has also been found [33]. In those studies, molding compound has been considered as linear elastic with a constant modulus of elasticity. Hence package life is discussed based on modulus of elasticity only. Those studies show that lower elastic modulus of molding compound helps to slightly increase thermal cycling life. Again the relationships are found for packages other than PBGA package. Effects of the mechanical behavior of a package component are not same for all types of electronic packages. In our study, temperature dependent stress-strain curves have been used to predict the thermal cycling life. In this case, yield stress and ultimate stress may have some contributions to damage accumulation and package reliability. Again, temperature dependent CTEs of molding compounds have not been found from literature. So the results cannot be compared to literature for validation.

Poisson's ratio refers to the ratio of lateral deformation to axial deformation. From the study, it is found that package life decreases with increase in Poisson's ratio of substrate material. Increase in Poisson's ratio results in more lateral deformation leading to more damage accumulation. From the literature, no direct relationship has not been found between thermal cycling life and Poisson's ratio of substrate materials.

Relationship between die attach material properties and package thermal cycling life is also not available in literature. In the analysis, effects of die attach material on package life has been found insignificant due to very small thickness of die attach compared to other components.

## 4.4 Effects of CTE of Different Components on Predicted Package Life

In the study, CTEs of different package components are assumed constant due to the unavailability of data. But in case of real materials, CTE may change with other mechanical properties of a material. For example, CTE of a material may increase with decrease in modulus of elasticity e.g. molding compound with lower CTE also have higher modulus of elasticity [55]. Values of CTE may have a significant effect on life of PBGA packages as developed stresses can change with CTEs of different materials.

To find out the change in package life with change in CTE, a hypothetical analysis has been performed. Three cases are considered in the analysis. For the first case, finite element analysis has been made for the combination of substrate modulus of 24 GPa, SAC 105 solder and linear elastic molding compound with modulus of elasticity of 25 GPa. In this study, package life has been found as 1230 cycles for $\Delta W$ of 0.387 MPa. If the CTE of substrate with the elastic modulus of 24 GPa is assumed 10% lower than the substrate elastic modulus of 16 GPa, the package life becomes 1156 cycles with a $\Delta W$ of 0.40 MPa. So, change in predicted life has been found about 6% from previous data for this change in CTE.

For the second case, change of CTE of SAC material is considered. For substrate modulus of 16 GPa and linear elastic molding compound with a modulus of elasticity of 25 GPa, the value of ΔW for SAC 405 is found as 0.398 MPa. For 10% reduction in CTE for SAC 405 solder than the SAC 105 solder material, the value of ΔW is found as 0.238 MPa, showing a reduction in ΔW about 40% from the value previously obtained. So there are significant effects of solder CTE on package life.

For the third case, change of CTE of molding compound has also been considered. For substrate modulus of 16 GPa and SAC 105 solder material, the value of ΔW found is 0.3 MPa for molding compound 4. For 10% increase in CTE of molding compound 4 than molding compound 1, the value of ΔW is found same as before. Therefore, CTE of molding compounds has been found less significant for the package reliability.

# CHAPTER 5

# CONCLUSIONS

## 5.1 Conclusions

The main objective of the thesis is to maximize the thermal cycling life of a PBGA package using suitable mechanical properties of package components. To accomplish this task, firstly the effects of different package components on thermal cycling life of PBGA package have been investigated. Main conclusions of this study are summarized as follows:

- A 3-D finite element model of the 324 I/O PBGA microprocessor component has been developed in commercial software ANSYS. Simulation of accelerated life testing (ALT) has been done between -40 $^oC$ to 125 $^oC$, upto two thermal cycles.
- Plastic energy dissipation per thermal cycle ($\Delta W$) in the solder ball has been considered as damage parameter of PBGA package. Solder ball with maximum $\Delta W$ has been considered as critical solder ball and the location of critical solder ball has been identified.
- In the study, critical solder ball has been found under the die shadow which is also in agreement with other studies of the literature. At first, molding compound has been considered as linear elastic which is traditionally assumed in literature. In this case, critical solder ball has been found at second row and fourth column from the package center. Position of critical solder ball has

shifted to the second row and third column as temperature dependent properties of molding compounds have been considered. Therefore, temperature dependent properties of molding compounds should be considered for correct predictions.

- Effects of substrate mechanical behavior on the thermal cycling life has been studied. It has been found that with increasing the substrate modulus from 16 GPa to 24 GPa, plastic energy dissipation in the critical solder ball increases by 9%. As a result, with the substrate elastic modulus changes from 24 GPa to 16 GPa, thermal cycling life increases by 17%.
- Variation of package cycling life with silver percentage in solder material has also been studied. It has been found that with silver content of solder materials increasing, damage accumulation also increases. Therefore, SAC 105 shows the minimum plastic energy dissipation than other solder materials. Due to the unavailability of life prediction model constants, thermal cycling life has not been calculated for SAC 105, SAC 205 and SAC 405 materials. Based on the finite element results, it is found that the package life is maximum for SAC 105 solder materials and minimum for SAC 405 solder materials. This is probably due to the fact that higher ductility is present in SAC 105 than SAC 405.
- To investigate the effects of mechanical behavior of molding compound on the thermal cycling life, four types of molding compound has been studied (molding compound 1 to 4). In all cases, temperature dependent stress-strain properties have been used in simulations. It has been found that the plastic energy dissipation per cycle ($\Delta W$) for SAC 105 critical solder ball increases by 6-9 % when the molding compound properties are changed from molding compound 1 to 4. So there is strong influence of molding compound properties on package life. The trend is same for all the SAC solder materials as well as for all the substrate materials.

- The effects of die attach materials' mechanical properties on the package life has also been studied. It has been found that package thermal cycling life is not a strong function of die attach materials. Package life has been found almost constant for different die attach materials.
- For optimization of the package architecture, different properties of substrate materials, SAC solder and molding compound have been considered in the analysis. Minimum value of ΔW has been found as 0.277 MPa for the configuration of substrate elastic modulus of 16 GPa, SAC 105 solder material and molding compound 1. This value is about 43% lower than value for the configuration for which maximum ΔW is found. Therefore, the optimum mechanical properties for this PBGA package are-
  (a) Substrate material with an elastic modulus of 16 GPa
  (b) SAC 105 solder material
  (c) Molding compound 1
  (d) Die attach material 1.

## 5.2 Limitations

- Due to unavailability of life prediction model constants (equations 9-11) for SAC 105, SAC 205 and SAC 405 materials, analysis has been based on plastic energy dissipation per cycle (ΔW) only. Life has been calculated only for SAC 305 solder.
- Due to unavailability of data, CTE and Poisson's ratio of some materials have been assumed constant. However, effects of CTE of those materials have been theoretically studied in section 4.4.

## 5.3 Recommendations for Future Works

- Effects of package dimensions (i.e. lengths, widths and thicknesses of different layers) on PBGA thermal cycling life may be studied using the FEA.
- Due to the limitations and lack of data relating to the mechanical properties of PCB, solder mask materials, investigation on effects of these materials' properties on the package life has not been done. This can be done in future studies.
- For more accurate results, it is important to include correct material behavior in ANSYS. Although the behavior of molding compound, solder material have been considered as temperature dependent elastic-plastic or viscoplastic, temperature dependent full stress-strain curves also need to include for substrate material, PCB, die attach materials. Once these data will be available, the analysis can be done for better results.
- The CTEs and Poisson's ratio of different materials also need to be measured experimentally. These data, once available, should be used in the finite element analysis for correct predictions of life.
- For more accurate life prediction of PBGA package, some experimental analysis can be made for the specific package. Fitting constants for life prediction model can be determined by performing some thermal cycling experiments with this package.
- Mechanical properties of any material degrades with aging. Therefore, aging effects can be considered in future study once the experimental data for each material of the package are available.

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