HYGROTHERMAL STRESS ANALYSIS OF PLASTIC BALL GRID ARRAY PACKAGE DURING SOLDER REFLOW

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Keywords: Ball Grid Array, Hygrothermal Stress, Moisture Diffusion, Solder Reflow

ABSTRACT

This paper studied the effects of the internal temperature and moisture of the PBGA package on the interfacial hygrothermal stresses (mainly the peeling and shear stresses) during the solder reflow process. By applying the failure criteria, the failure at the interfaces can be predicted. In the analysis, the finite element simulation was used to calculate the temperature distribution, the moisture diffusion and the hygrothermal stress. The design parameters and moisture content of PBGA package were varied to assess their effects on the hygrothermal stress at the interfaces. In the experiment, the moisture absorption and desorption processes of PBGA package were carried out in a hygrothermal chamber and an oven, respectively. The results can be used to optimize the design parameters of PBGA package for averting the popcorn cracking during the solder reflow process.

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I. INTRODUCTION

With a high I/O number, good electronic performance, high mechanical strength and a lower price, Plastic Ball Grid Array (PBGA) package has been in the mainstream. The general structure of PBGA package, as shown in Figure 1, consists of epoxy molding compound (EMC), die, die pad, die attach, solder mask, BT substrate, and solder ball. Some studies (Ahn and Kwon, 1995; Hawkins et al., 1995; Teo et al., 1998; Yeh and Chang, 1999a) had reported the failure of PBGA package during storage in the humid and heated conditions and solder reflow process. The PBGA package simultaneously absorbs the moisture and permeates inwards under humid and heated conditions for an extended period. The absorbed moisture can decrease the strength of adhesion at interfaces (Nguyen, 1993; Hawkins et al., 1995). When the PBGA package is under the solder reflow process, the high hygrothermal stresses at some special locations of already weakened interfaces are induced due to the coefficients of thermal expansion (CTE) mismatch among component materials and the expansion of absorbed moisture. If the stresses are higher than the interfacial strengths, initial delaminations occur and then delaminations propagate by the vapor pressure generated at the initial delamination areas and possibly leading to the eventual popcorn cracking. Delamination is one of the important damage modes of PBGA package and may be caused at the weak interfaces such as die/die attach, die pad/solder mask, solder mask/BT, etc (Hawkins et al., 1995; Teo et al., 1998; Yeh and Chang, 1999b). Because the delamination can degrade the long term operating reliability of PBGA package, it is our interests how averting the delamination initiation during the solder reflow.

Poboret et al. (1995) pointed out that the moisture content causing the failure of PBGA package is weight gain of 0.12%. In electronic packaging industry, the moisture content inside the PBGA package is reduced below weight gain of 0.08% prior to the solder reflow by using the dry packs or the oven for averting the popcorn cracking. However, the dry packs and the oven require a great number of processes that would increase the package processing time and cost. Therefore, packaging without using the dry packs and the oven is desirable for electronic packaging industry. Hawkins et al. (1995) pointed out that changing the die pad design can reduce the moisture between the die attach and die pad. Ahn and Kwon (1995) proposed that adding a thermal viahole to the BT substrate of the IC package can avert the popcorn cracking due to the moisture released via the thermal viahole during the reflowing process. One of the objectives of the present investigation is to study the effects of the material property of EMC, the package dimension parameters and the quantity of absorbed moisture on the interfacial hygrothermal stresses of PBGA package during the solder reflow. If the popcorn cracking of PBGA package can be averted by the suitable package design, the dry-packing and prebaking processes for the PBGA package would be avoided.

In this present study, the entire moisture and thermal simulations of PBGA package started from the moisture preconditioning to the subsequent solder reflow. In the analysis, the 2D finite element simulations of the heat transfer and moisture diffusion for the PBGA package were carried out during the moisture preconditioning, prebaking and solder reflow processes. The hygrothermal stress in the PBGA package was calculated during the solder reflow. The locations of the higher stress, especially at the interfaces, were examined. By applying the failure criteria, the initiation of interfacial delamination can be predicted. The parameters, such as EMC and BT sizes, the die size, the die adhesive thickness, the die pad size and the elastic modulus and CTE of EMC, were varied to assess their effects on the failure of PBGA packages. Besides, in order to study the effect of the quantity of absorbed moisture on the failure of PBGA packages, levels 1, 2 and 3 of JEDEC (1995) moisture test standard were simulated prior to the solder reflow. In the experiment, the moisture absorption and desorption processes of PBGA package were carried out in a hygrothermal chamber and an oven, respectively. The results of this paper can contribute to achieve the optimal design parameters of PBGA packages for averting the popcorn cracking during the solder reflow process.

II. ANALYSIS

During the deformation and damage processes of PBGA packages, the analysis includes (a) heat transfer (b) moisture diffusion (c) hygrothermal stress and (d) failure criteria

A. Governing Equations for Heat Transfer and Moisture Diffusion

For homogeneous and isotropic materials, the heat transfer coefficient k_x=k_y=k_x=k, and the two-dimensional Fourier equation in Cartesian coordinates can be expressed as (Bejan, 1993)

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+Q=c_p\rho\dot{T} \tag{1}$$

where T is the temperature, c_p is the specific heat, ρ is the mass density, $\dot{T}$ is ∂T/∂t, t is the time, and Q is the rate of internal heat generation per unit volume. The thermal conductivity coefficient is assumed to be constant, independent of the position and temperature.

The two-dimensional Fick equation for moisture diffusion is similar to the two-dimensional Fourier equation. The only changes are the replacement of T by the moisture content M and the replacement of $k/c_p\rho$ by the moisture diffusion coefficient D_m.

In this paper, Fourier and Fick equations were solved by using the finite element analysis and the eight-node plane element with one degree of freedom was also used.

B. Measurements of Moisture Diffusion Coefficient

The moisture diffusion coefficient D_m is a function of temperature and usually expressed as the following Arrhenius equation

$$D_m = D_0 \exp\left(-\frac{E_D}{RT}\right) \tag{2}$$

where E_D is the activation energy, D_0 is a constant, R is the ideal gas constant, and T is the temperature. E_D and D_0 can be obtained from the measurement of diffusion coefficients at different temperatures by the moisture diffusion experiments. Usually, the absorption diffusion coefficients of packaging materials are different from desorption diffusion coefficients.

The relationship between the moisture content and absorbed time at the early absorption experimental stage can be represented by (Crank, 1975)

$$M = \frac{4(M_\infty - M_i)}{H}\sqrt{\frac{D_m}{\pi}}\sqrt{t} \tag{3}$$

where M is the moisture content, M_∞ is the saturated moisture content, M_i is the initial moisture content, t is the absorbed time, and H is the specimen thickness. The absorption diffusion coefficients D_m can be obtained from the measurement of moisture content for a specified absorbed time by using equation (3).

The relationship between the moisture content and desorbed time at the early desorption experimental stage can be represented by (Crank, 1975)

$$M_\infty - M = \frac{4M_\infty}{H}\sqrt{\frac{D_m}{\pi}}\sqrt{t} \tag{4}$$

The absorption test method is also applied to the desorption test for measuring the desorption diffusion coefficient.

C. Initial and Boundary Conditions for Moisture Diffusion

The moisture concentration must be continuous at the interfaces between different materials when using the Fick equation to analyze the moisture diffusion. However, the saturated moisture content at the interfaces of PBGA package is discontinuous due to the saturated moisture content mismatch among different materials. The discontinuity can be averted by using the wetness fraction approach defined as follows (Wong et al., 1998)

$$w = \frac{M}{M_\infty} \tag{5}$$

where w is the wetness fraction, M is the moisture content, and M_∞ is the saturated moisture content. By using equation (5), the wetness fraction at a bimaterial interface is continuous. Therefore, by using the wetness fraction approach, the initial and boundary conditions for the moisture diffusion during the moisture preconditioning are assumed as follows

$$\begin{aligned} &w(x, y, 0) = 0 && \text{initial condition} \\ &w(x_{ext}, y_{ext}, t) = 1 && \text{boundary condition} \end{aligned}$$

where w=1 implies saturated wetness, and w=0 implies complete dryness. During the prebaking and solder reflow, the initial and boundary conditions for the moisture diffusion are assumed as follows

$$\begin{aligned} &w(x, y, 0) = w_0(x, y) && \text{initial condition} \\ &w(x_{ext}, y_{ext}, t) = 0 && \text{boundary condition} \end{aligned}$$

where $w_0(x, y)$ is the internal wetness fraction of the PBGA package just before carrying out the moisture desorption test. The moisture content M can be obtained by substituting the measured wetness fraction into equation (5).

D. Hygrothermal Stress Analysis

The strain increments can be obtained by multiplying the temperature change ΔT and moisture content change ΔM with the thermal expansion coefficient α_t and moisture expansion coefficient β_m of the material.

$$\varepsilon_t = \int_{T_1}^{T_2} \alpha_t dT = \alpha_t \Delta T \tag{6}$$

where ε_t is the thermal strain, T_1 and T_2 are temperatures at the beginning and the end states.

$$\varepsilon_m = \int_{M_1}^{M_2} \beta_m dM = \beta_m \Delta M \tag{7}$$

where ε_m is the moisture-induced strain, M_1 and M_2 are moistures at the beginning and the end states. Because it is difficult to obtain the moisture expansion coefficients of components of PBGA packages, Pecht et al. (1995) proposed another method for calculating the moisture-induced strain defined as follows

$$\varepsilon_m = \frac{1}{3}(1 - \nu_{\text{filler}}) \frac{\Delta W}{W_c} \frac{\rho_c}{\rho_w} \tag{8}$$

where ν_{filler} is the volume part of the filler inside the material, ΔW is the quantity of absorbed water, W_c is the dry mass of material, ρ_c is the specific density of material, and ρ_w is the specific density of water. In this paper, equation (8) was used for calculating the moisture-induced strain. The hygrothermal stress σ can be found as

$$\sigma = E\left(\varepsilon_T - \varepsilon_t - \varepsilon_m\right) \tag{9}$$

where E is the elastic modulus. The total strain ε_T can be calculated from the conventional finite element method used in solid mechanics in which the eight-node plane element with two degrees of freedom was used in the hygrothermal stress analysis. The interfaces in PBGA package are checked for failure according to the failure criteria.

E. Failure Criteria

Failures in PBGA package are mainly due to the stress reaching a critical value at interfaces between different materials. For PBGA packages, the failures at interfaces are mainly determined from the peeling stress σ_y and the shear stress τ_{xy}. The Tsai-Hill failure criteria can be properly modified as (Mei and Liu, 1995)

$$\sqrt{\left(\frac{\sigma_y}{\sigma_y^f}\right)^2+\left(\frac{\tau_{xy}}{\tau_{xy}^f}\right)^2}=f_d \tag{10}$$

where $\sigma^f{}_y$ is the critical peeling stress, $\tau^f{}_{xy}$ is the critical shear stress, and f_d is the failure index. The interfaces fail when $f_d \geqq 1$.

III. MOISTURE DIFFUSION EXPERIMENT

Moisture experiments on the PBGA package and its components were carried out for characterizing the moisture diffusion of PBGA package and for calculating the diffusion coefficients and saturated moisture contents of components of PBGA package, respectively. PBGA packages with 256 I/O's of 1.27-mm pitch were prepared and the top and bottom views are shown in Figure 2. The experimental procedure referred to JEDEC moisture test standard. The PBGA packages and its components were divided into three groups and each group included ten samples. First, all PBGA samples were dry baked in a constant temperature oven at 125℃ for 24 hours. Later, three baked groups of packages were subjected to three different JEDEC moisture levels as follows

Level 1: 85℃/85%RH for 168 hours

Level 2: 85℃/60%RH for 168 hours

Level 3: 30℃/60%RH for 192 hours.

Figure 3 shows the moisture absorption curves at JEDEC levels 1, 2, and 3 for the PBGA package. From figure 3, the moisture in the PBGA package reaches a saturated weight gain of 0.45% after 120 hours for level 1, 0.25% after 72 hours for level 2, and 0.2% after 168 hours for level 3. The PBGA package has the highest weight gain for level 1 and the lowest for level 3. After the moisture absorption test, all packages were baked at 125℃ for 48 hours. Figure 4 shows the moisture desorption curves at baking temperature 125℃ for PBGA packages subjected to the moisture absorption preconditioning. From figure 4, the weight loss in PBGA packages subjected to JEDEC moisture levels 1,2, and 3 can be all reduced below 0.08% after baking for 8 hours. The weight loss of 0.08% in the PBGA package is the allowable highest moisture content for the electronic packaging industry. Therefore, the PBGA package is usually prebaked at 125℃ for 8 hours prior to the solder reflow. Figure 5 depicts the moisture desorption curves at baking temperatures 125℃ and 145℃ for PBGA packages subjected to JEDEC level 1. From figure 5, the moisture desorption is faster at 145℃ than at 125℃. The weight loss is reduced to 0.067% after 4 hours at 145℃. Hence, on the basis of PBGA package without failure, properly increasing the baking temperature can save the baking time and cost.

From the results of moisture experiments and equations (2), (3) and (4), the absorption and desorption diffusion constants of components of PBGA package were calculated and listed in table 1. The saturated moisture contents at JEDEC levels 1, 2 and 3 for the components of PBGA package were also measured and shown in table 2. From table 2, solder mask has the highest saturated moisture content, die attach holding the second high at JEDEC levels 1, 2 and 3.

IV. RESULTS AND DISCUSSION

Owing to the symmetry of the PBGA package, only the right half of PBGA package is analyzed for computational efficiency in this present study. Figure 6 is the cross-sectional dimension of the PBGA package and the material properties are listed in table 3, in which x, y and z are the Cartesian coordinates with xy plane as the symmetric cross-section of PBGA package. The initial state inside the PBGA package is assumed such that the moisture content is 0 and the stress-free temperature is 25℃. No internal heat source inside the PBGA package is generated in the analysis.

A. Moisture Absorption Diffusion

Figure 7 is the mesh of the PBGA package, 1396 elements and 4615 nodes, used in the moisture diffusion analysis by the finite element method. The unmeshed areas, such as the die, die pad, pad and solder pad of PBGA package, were not analyzed because the materials absorbed no moisture. Figure 8 shows the wetness fraction absorption distribution of the PBGA package at JEDEC levels 1 and 3 after 8, 32, 120 and 168 hours, respectively. The moisture content inside PBGA package can be obtained from the wetness fraction of materials multiplied by the saturated moisture content at the corresponding environment listed in table 2. According to figure 8, the moisture diffuses from the environment downward through EMC and upward through BT to the PBGA package. Since the thickness of PBGA package in the y-direction is thinner, the moisture diffusion in y-direction is faster than that in the x-direction. The result shows that the moisture diffusion in the y-direction significantly influences the saturated moisture content inside the PBGA package. EMC reaches saturation state after 32 hours at level 1 and 120 hours at level 3. According to figure 8 and table 2, the moisture content inside the PBGA package increases with higher temperature and higher environmental humidity.

B. Moisture Desorption Diffusion

Figure 9 shows the wetness fraction desorption distribution of the PBGA package subjected to JEDEC level 1 at baking temperatures 125℃ and 145℃ after 2, 8, 16 and 24 hours, respectively. According to figure 9, EMC was completely dry baked after 8 hours at 125℃ and 2 hours at 145℃; the die attach and solder mask were almost dry baked after 24 hours at 125℃ and 16 hours at 145 ℃. At the early desorption stage, the desorption diffusion at 145℃ is about 4 times than that at 125 ℃.

C. Hygrothermal Stress at Interfaces

In this paper, the solder reflow simulation of PBGA package is referred to VPR (Vapor Phase Reflow) test standard (JEDEC, 1995). During VPR, the temperature increases to 215℃ from the room temperature 25℃, and stays for 60 seconds, then cools to the room temperature. The same process was repeated for three times. Because the initiation of delamination in the PBGA package mainly is related to the peeling and shear stresses at interfaces, the stress analysis in the present study focuses on the peeling and shear stresses at various interfaces, such as EMC/die, die/die attach, die attach/solder mask, solder mask/die pad and die pad/BT interfaces. The mesh of the PBGA package, 1689 elements and 5272 nodes, used in the hygrothermal stress by the finite element method is shown in figure 10. Figure 11 shows the boundary conditions. The top node on the axis of symmetry is hinged. The hygrothermal stresses at the analyzed interfaces of PBGA package after JEDEC moisture level 1 and subsequent solder reflow processes are shown in figure 12 for peeling stress (σ_y) and shear stress (τ_{xy}). As can be seen in figure 12, the singular stresses are induced at the corners of analyzed interfaces. The solder mask/die pad and die pad/BT interfaces, near the corners of die also generate the singular stresses. It should be noted that the induced peeling and shear stresses at interfaces are quite small except for corners.

From table 2, the solder mask and die attach areas have the highest saturated moisture content, and the similar results by other most researchers indicate that the weak areas in PBGA package are near the die attach (Ahn and Kwon, 1995; Hawkins et al., 1995; Tan et al., 1996; Teo et al., 1998). Therefore, the hygrothermal stress at the die attach/solder mask interface was first considered and plotted.

To study the effects of the quantity of moisture on the hygrothermal stress at interfaces after the solder reflow, the moisture inside the PBGA package is varied by using different JEDEC moisture levels preconditioning. The hygrothermal stresses at die attach/solder mask interface after different JEDEC moisture levels and subsequent solder reflow processes are shown in figure 13 for peeling, shear and normal stress (σ_x). From figure 13, it can be seen that the quantity of moisture affects slightly the peeling and shear stresses, but significantly affects the normal stress. The normal stress increases with the higher moisture content. The effects of the quantity of moisture on the peeling, shear and normal stresses at other interfaces are listed in table 4. It can be seen that the quantity of moisture only affects significantly the normal stress at the analyzed interfaces. Since the initiation of interfacial delamination is independent of the normal stress, the primary effect of the moisture on the delamination initiation of PBGA package under the solder reflow is the degradation of the adhesive strength at interfaces, rather than affecting the peeling and shear stresses. Therefore, the delamination initiation is considered mainly due to CTE mismatch between different materials.

To study the effects of the material property of EMC on the hygrothermal stress at interfaces, the elastic modulus and CTE of EMC are varied in analysis. The hygrothermal stress at die attach/solder mask interface by using the different elastic modului (4.5GPa, 14.5GPa, 24.5GPa) and CTE ($30\times10^{-6}, 50\times10^{-6}, 70\times10^{-6}$) of EMC are shown, respectively, in figures 14 and 15 for peeling and shear stresses. From the figures, the larger the elastic modulus and CTE of EMC, the higher the peeling and shear stresses near the corners. Changing the elastic modulus and CTE of EMC only affects the peeling and shear stresses near the interface corners. Other interfaces analyzed have similar results to that at die attach/solder mask interface and listed in table 5. From table 5, selecting smaller elastic modulus and smaller CTE of EMC can reduce the stress concentration near the corners of interfaces.

To study the effects of PBGA dimension change on the hygrothermal stress at interfaces, the dimensions of PBGA package are varied and listed in table 6 for analysis. The analytical results are shown in table 7. As can be seen in the table, for the thinner EMC and die, both the peeling and shear stresses decrease near the corners of the five interfaces analyzed. However, the shear stress decreases more for the thinner EMC while the peeling stress decreases more for the thinner die. For the thicker die attach, the shear stress decreases near the corners of die/die attach and die attach/solder mask interfaces. For the thinner BT, the peeling stress decreases near the corners of solder mask/die pad and die pad/BT interfaces. For the thinner die pad and Cu pad, the peeling and shear stresses decrease near the corners of analyzed interfaces except for EMC/die interface, and decrease significantly at die attach/solder mask and solder mask/die pad interfaces. Changing the lengths of die, die attach and die pad, and the size of package has no significant influence on the hygrothermal stress near corners of the five analyzed interfaces. Therefore, properly decreasing the thicknesses of EMC and die is the most beneficial to reduce the stress concentration at all analyzed interfaces.

V. CONCLUSIONS

The hygrothermal stress of PBGA package was investigated according to the environmental changes of moisture and temperature. The design parameters and moisture content of PBGA packages were varied to assess their effects on the interfacial hygrothermal stress. The following conclusions can be made:

1. The PBGA package absorbs the highest moisture at JEDEC level 1 and the lowest at JEDEC level 3.
2. The weight loss in the PBGA package subjected to JEDEC levels preconditioning can be reduced below 0.08% at 125℃ for 8 hours. Moreover, higher baking temperature can save the baking time and cost for PBGA package.
3. During the solder reflow, the induced peeling and shear stresses at interfaces are quite small except at corners. Therefore, the delamiantion initiation may firstly occur at the interface corners.
4. The quantity of moisture in the PBGA package slightly affects the peeling and shear stresses, but significantly affects the normal stress at the interfaces.
5. The primary effect of moisture on the delamination initiation of PBGA package is the degradation of the adhesive strength at interfaces. The delaminations are induced mainly due to the thermomechanical stress at interfaces.
6. Selecting the smaller elastic modulus and CTE of EMC can reduce the interfacial stress concentration.
7. Properly decreasing the thicknesses of EMC and die is the most beneficial to reduce the interfacial stress concentration.

ACKNOWLEDGEMENT

This work was supported by the National Science Council, Taiwan, R.O.C., through grant NSC89-2212-E007-025. The support from National Center for High-performance Computing by providing supercomputer VPP 300 is greatly acknowledged. The authors would also like to thank Advanced Semiconductor Engineering, Inc. (ASE) and Mr. Kuo-Ming Chen, deputy manager of R&D Division of the CAESAR Technology Inc., Taiwan, R.O.C., for providing the PBGA and package components used for the moisture diffusion experiments.

NOMENCLATURE

c_p	specific heat (J/kg・℃)
D_m	moisture diffusion coefficient (mm^2/s)
D_0	constant
E	elastic modulus (Pa)
E_D	activation energy (J/mol)
f_d	failure index
H	specimen thickness (mm)
k	heat transfer coefficient (w/m・℃)
L	length (mm)
M	moisture content (mg/mm^3)
M_i	initial moisture content (mg/mm^3)
M_∞	saturated moisture content (mg/mm^3)
M_1	moisture at the beginning state (mg/mm^3)
M_2	moisture at the end state (mg/mm^3)
ΔM	moisture content change (mg/mm^3)
Q	internal heat generation (J/m^3・s)
R	ideal gas constant (J/mol・K)
t	time (s)
T	temperature (℃)
$\dot{T}$	$\partial T/\partial t$
T_1	temperature at the beginning state (℃)
T_2	temperature at the end state (℃)
ΔT	temperature change (℃)
Th	thickness (mm)
W	wetness fraction
$w_0(x, y)$	internal wetness fraction of the PBGA package just before carrying out the moisture desorption test
W_c	dry mass of material (mg)
ΔW	quantity of absorbed water (mg)

α_t	thermal expansion coefficient
β_m	moisture expansion coefficient
ε_t	thermal strain
ε_m	moisture-induced strain
ε_T	total strain
ν_{filler}	volume part of the filler inside the material
ρ	mass density (kg/m^3)
ρ_c	specific density of material (kg/m^3)
ρ_w	specific density of water (kg/m^3)
σ_x	normal stress (Pa)
σ_y	peeling stress (Pa)
σ^f_y	critical peeling stress (Pa)
τ_{xy}	shear stress (Pa)
τ^f_{xy}	critical shear stress (Pa)

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塑封球柵陣列封裝之迴焊濕熱應力分析

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摘要

本研究分析含濕氣之 PBGA 在迴焊過程中界面產生的濕熱應力,並利用脫層破壞準則來預測界面脫層的發生。PBGA 之熱傳導、濕氣擴散過程及內部濕熱應力則利用有限單元法來模擬計算。文中探討濕氣含量、封膠材料性質及組成材料尺寸對 PBGA 界面濕熱應力的影響,同時進行 PBGA 吸濕與去濕實驗,以獲取 PBGA 吸濕與去濕之特性與數據。

關鍵字:球柵陣列,濕熱應力,濕氣擴散,迴焊

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CAPTIONS

Table 1. Moisture diffusion constants of PBGA package

Table 2. Saturated moisture contents of PBGA package

Table 3. Material properties of PBGA package

Table 4. Effects of moisture on hygrothermal stress at the analyzed interfaces

Table 5. Effects of E and CTE of EMC on hygrothermal stress at the corners of analyzed interfaces

Table 6. Different dimensions used in analysis for PBGA package (Unit: mm)

Table 7. Effects of dimensions of PBGA package on hygrothermal stress at the corners of analyzed interfaces

Figure 1. Schematic of plastic ball grid array package

Figure 2. (a) Top view (b) bottom view of PBGA package

Figure 3. Moisture absorption curves at JEDEC levels 1, 2, and 3 for PBGA package

Figure 4. Moisture desorption curves at 125℃ for PBGA package subjected to moisture absorption preconditioning

Figure 5. Moisture desorption curves at 125℃ and 145℃ for PBGA package subjected to level 1 preconditioning

Figure 6. Cross-sectional dimension of PBGA package

Figure 7. Finite element mesh of PBGA package for moisture diffusion analysis

Figure 8. Wetness fraction absorption distribution of PBGA package after various times for JEDEC levels 1 and 3

Figure 9. Wetness fraction desorption distribution of PBGA package subjected to JEDEC level 1 preconditioning at 125℃ and 145℃ after various times

Figure 10. Finite element mesh of PBGA package for hygrothermal stress analysis

Figure 11. Schematic of boundary conditions of PBGA package

Figure 12. (a) Peeling stress (b) shear stress at five analyzed interfaces

Figure 13. (a) Peeling stress (b) shear stress (c) normal stress at die attach/solder mask interface

Figure 14. (a) Peeling stress (b) shear stress at die attach/solder mask interface for different elastic modulus

Figure 15. (a) Peeling stress (b) shear stress at die attach/solder mask interface for different CTE of EMC

Table 1. Moisture diffusion constants of PBGA package

	Absorption		Desorption	
Material	$D_0\,(mm^2/s)$	$E_D\,(J/mol)$	$D_0\,(mm^2/s)$	$E_D\,(J/mol)$
EMC	1.46	3.25×10^4	3.97×10^7	8.91×10^4
Die Attach	6.962	4.57×10^4	2.003	3.78×10^4
Solder Mask	5.5×10^{-4}	1.61×10^4	2.708	3.82×10^4
BT	0.078	2.69×10^4	2.89×10^5	7.58×10^4

Table 2. Saturated moisture contents of PBGA package

	$85\,^{\circ}C$ /85%RH	$85\,^{\circ}C$ /60%RH	$30\,^{\circ}C$ /60%RH
Material	$M_\infty\,(mg/mm^3)$	$M_\infty\,(mg/mm^3)$	$M_\infty\,(mg/mm^3)$
EMC	4.178×10^{-3}	2.949×10^{-3}	2.257×10^{-3}
Die Attach	0.0267	0.0189	0.0148
Solder Mask	0.0387	0.0273	0.0167
BT	7.865×10^{-3}	5.552×10^{-3}	4.339×10^{-3}

Table 3. Material properties of PBGA package

Material	EMC	Die	Die Attach	Solder Mask	Die Pad	BT	Solder Ball
E (GPa)	14.5	162	8.96	3.448	117	26 x,z 11 y	26.447
CTE ($ppm/^{\circ}C$)	13 x,z 50 y	2.3	15	30	16.7	15 x,z 52 y	25.2
ν	0.32	0.28	0.25	0.35	0.34	0.39 xy,yz 0.11 xz	0.36
K ($w/m\,^{\circ}C$)	0.84	110	4.5	0.2	389	3	51
c_p ($J/kg\,^{\circ}C$)	1884	712	703	1190	385	1190	150
ρ (kg/m^3)	1900	2330	3800	1995	8942	1995	8470

Source: Hong and Su, 1998

Table 4. Effects of moisture on hygrothermal stress at the analyzed interfaces

Moisture	EMC/Die			Die/Die Attach			Die Attach/Solder Mask			Solder Mask/Die Pad			Die Pad/BT		
	σ_y	τ_{xy}	σ_x	σ_y	τ_{xy}	σ_x	σ_y	τ_{xy}	σ_x	σ_y	τ_{xy}	σ_x	σ_y	τ_{xy}	σ_x
↑	X	X	↑	X	X	↑	X	X	↑	X	X	↓	X	X	↓

Note: σ_y : peeling stress τ_{xy} : shear stress σ_x : normal stress ↑: increase ↓: dcerease

X : no significant influence

Table 5. Effects of E and CTE of EMC on hygrothermal stress at the corners of analyzed interfaces

	EMC/Die		Die/Die Attach		Die Attach/Solder Mask		Solder Mask/Die Pad		Die Pad/BT	
	σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}
E ↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
CTE ↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

Table 6. Different dimensions used in analysis for PBGA package (Unit: mm)

	EMC	Die		Die Attach		Die Pad & Cu Pad		BT	Size of PBGA
	Th	Th	L	Th	L	Th	L	Th	
↓	0.83	0.2	4.2	0.01	4.2	0.03	8.1	0.285	23
Original	1.13	0.3	6.2	0.02	6.2	0.04	10.1	0.435	27
↑	1.43	0.4	8.2	0.03	8.2	0.05	12.1	0.585	31

Note: Th: thickness L: length

Table 7. Effects of dimensions of PBGA package on hygrothermal stress at the corners of analyzed interfaces

		EMC/Die		Die/Die Attach		Die Attach / Solder Mask		Solder Mask/ Die Pad		Die Pad/BT	
		σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}	σ_y	τ_{xy}
EMC	Th ↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
Die	Th ↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
	L	×	×	×	×	×	×	×	×	×	×
Die Attach	Th ↑	×	×	×	↓	×	↓	×	×	×	×
	L ↓	×	×	×	×	×	×	×	×	×	×
Die Pad & Cu Pad	Th ↓	×	×	↓	↓	↓	↓	↓	↓	↓	↓
	L	×	×	×	×	×	×	×	×	×	×
BT	Th ↓	×	×	×	×	×	×	↓	×	↓	×
Size of PBGA		×	×	×	×	×	×	×	×	×	×

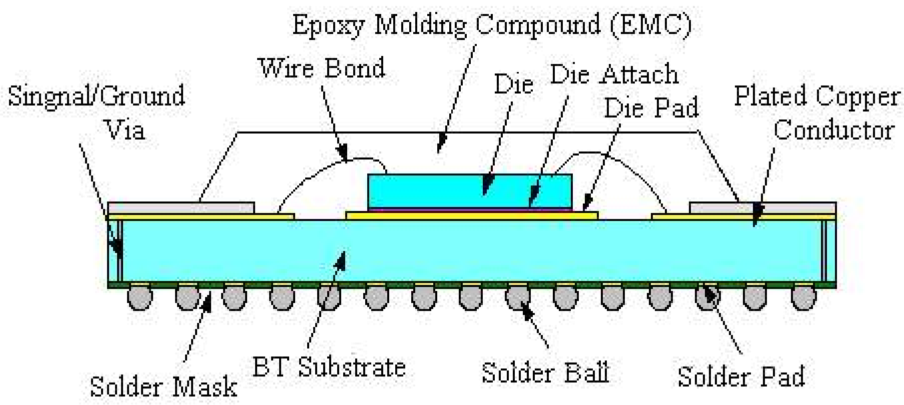


Figure 1. Schematic of plastic ball grid array package (Source: Lau, 1995)

(a) (b)

Figure 2. (a) Top view (b) bottom view of PBGA package

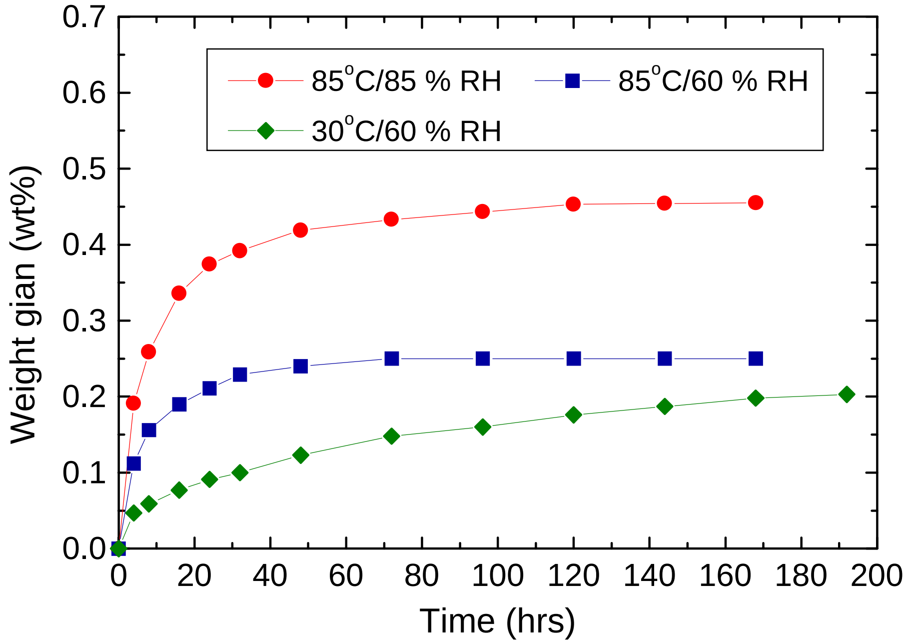


Figure 3. Moisture absorption curves at JEDEC levels 1, 2, and 3 for PBGA package

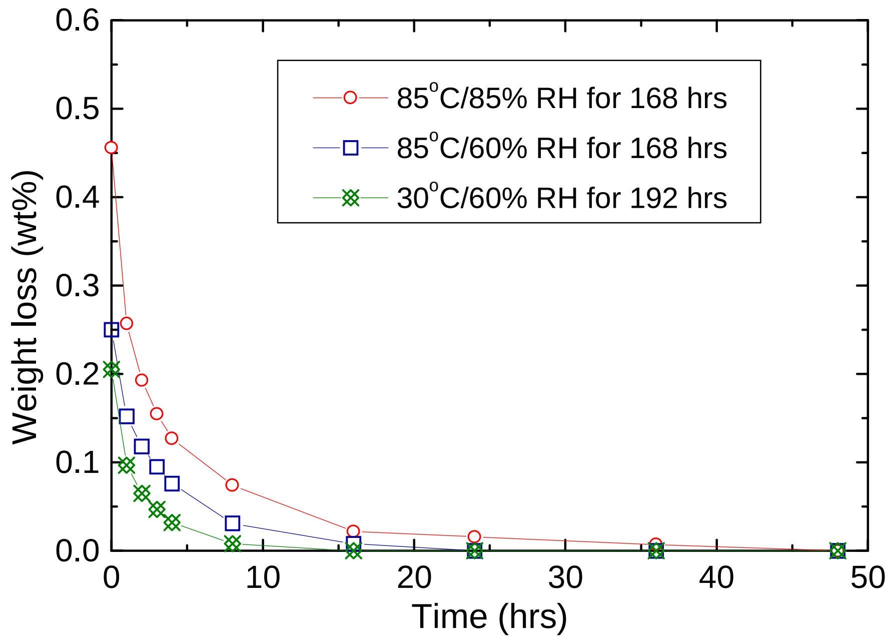


Figure 4. Moisture desorption curves at 125℃ for PBGA package subjected to moisture absorption preconditioning

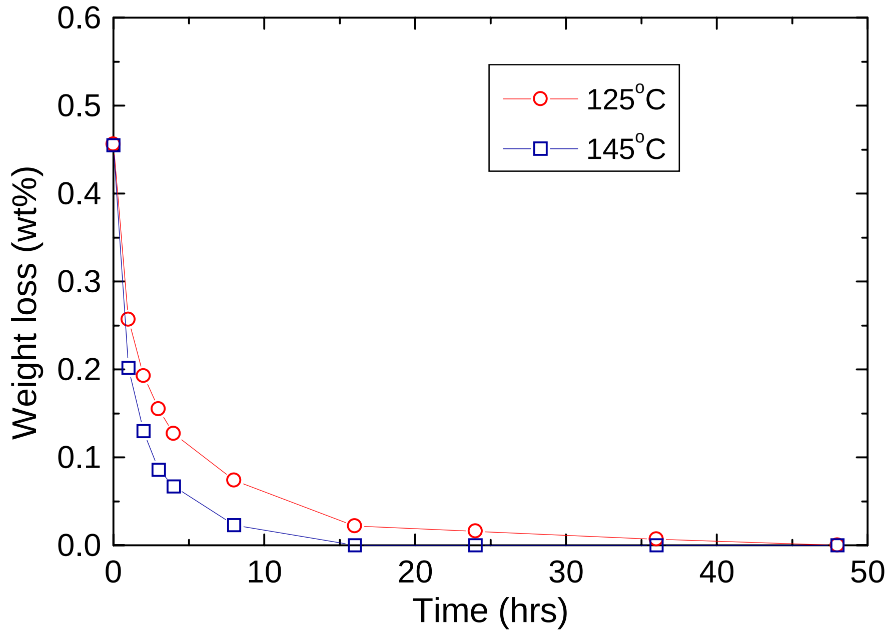


Figure 5. Moisture desorption curves at 125℃ and 145℃ for PBGA package subjected to level 1 preconditioning

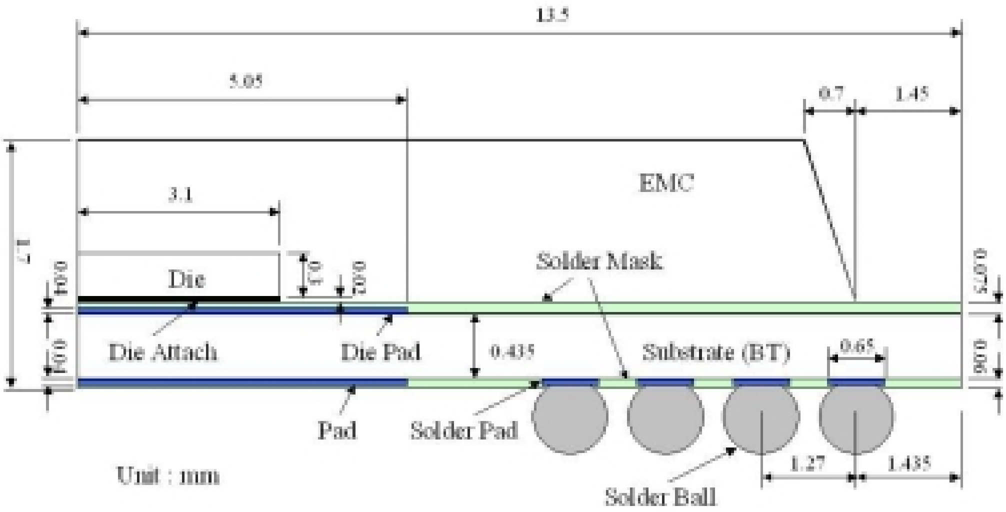


Figure 6. Cross-sectional dimension of PBGA package

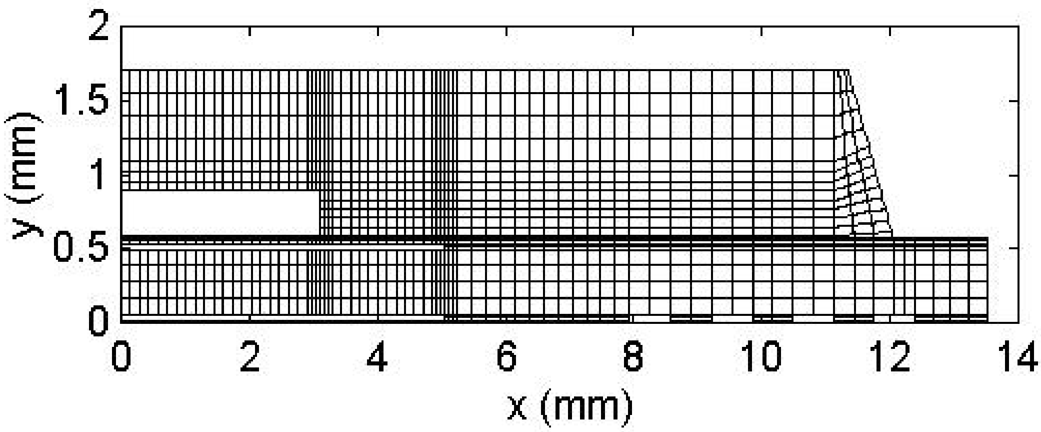
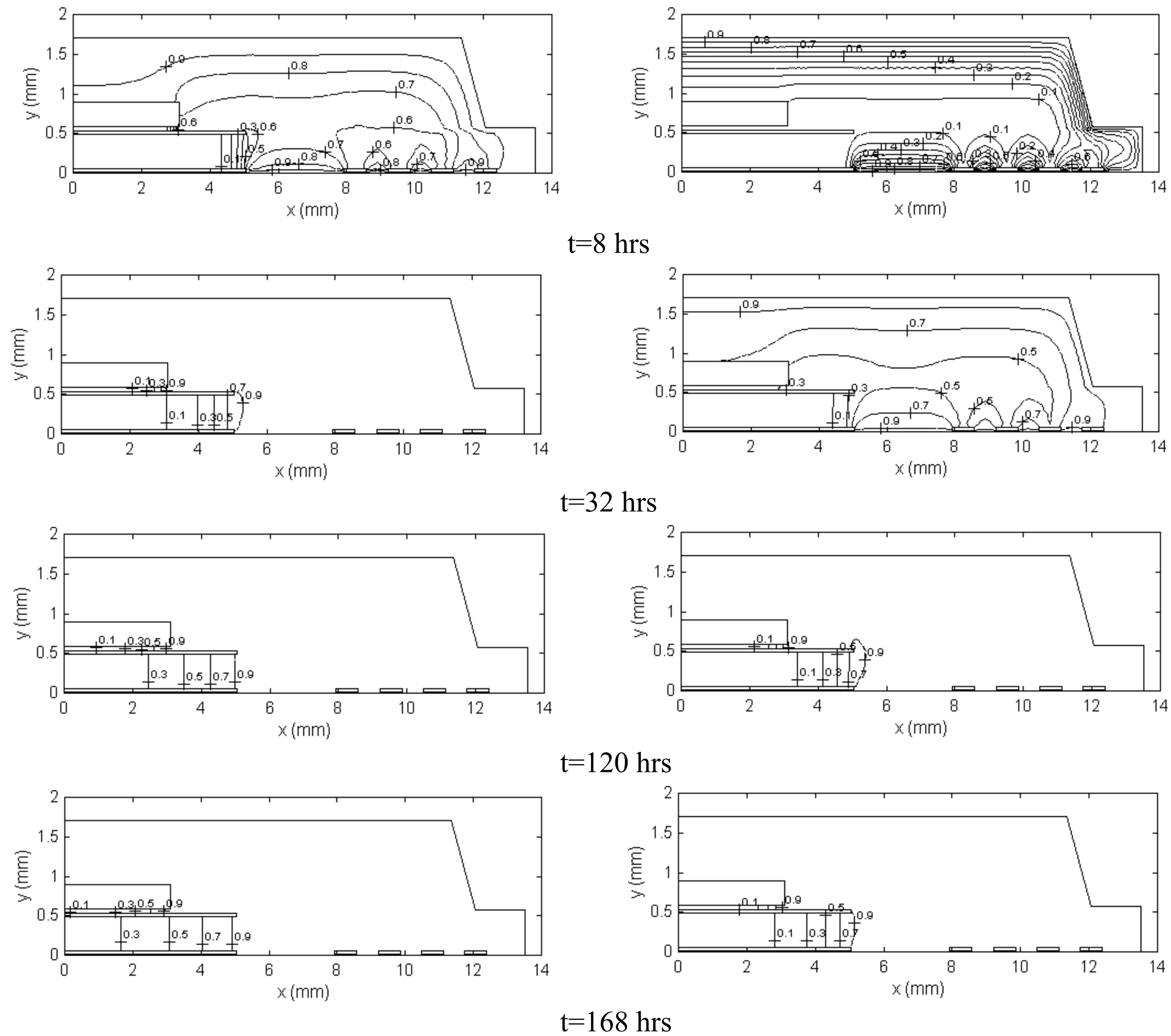


Figure 7. Finite element mesh of PBGA package for moisture diffusion analysis



(a) 85℃/85%RH (b) 30℃/60%RH

Figure 8. Wetness fraction absorption distribution of PBGA package after various times for JEDEC levels 1 and 3

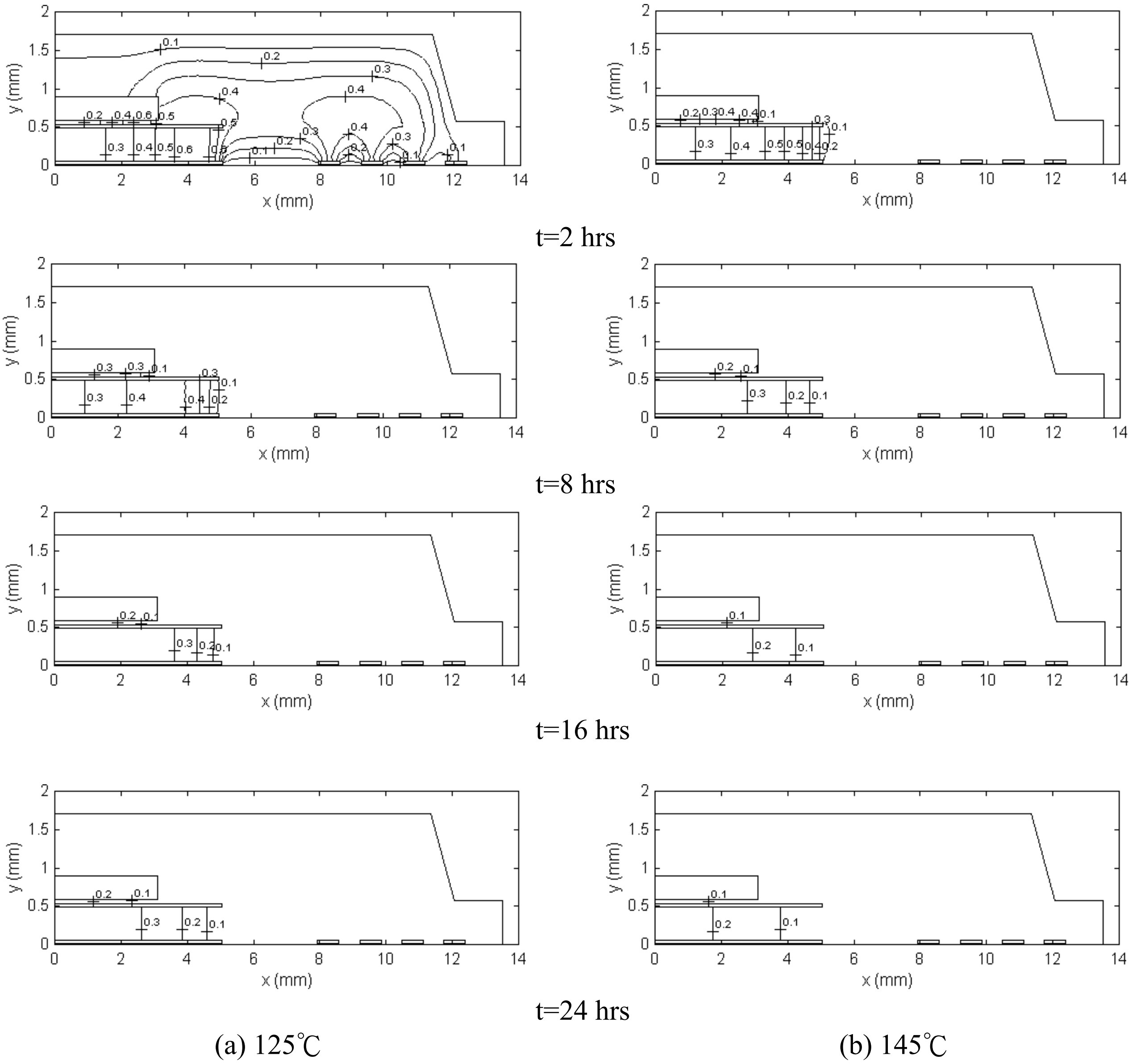


Figure 9. Wetness fraction desorption distribution of PBGA package subjected to JEDEC level 1 preconditioning at 125℃ and 145℃ after various times

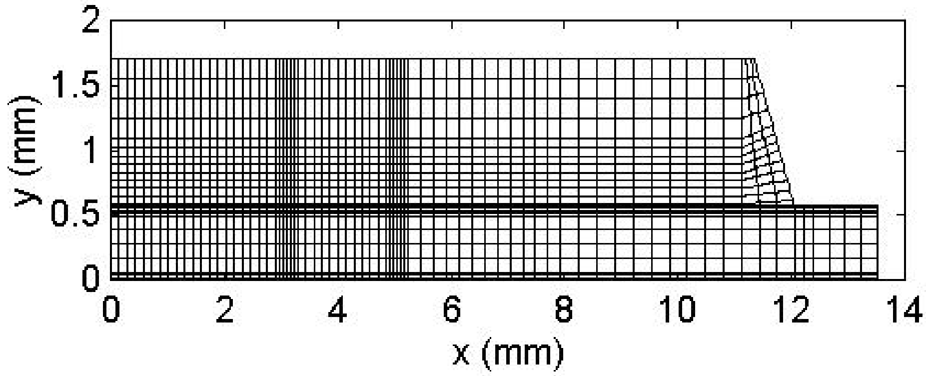


Figure 10. Finite element mesh of PBGA package for hygrothermal stress analysis

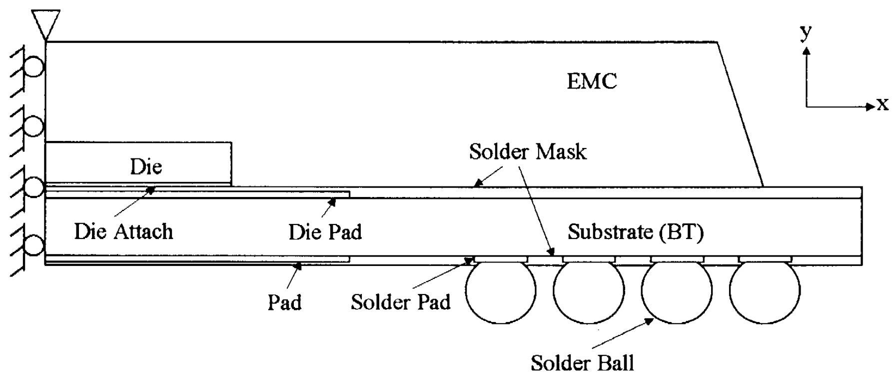


Figure 11. Schematic of boundary conditions of PBGA package

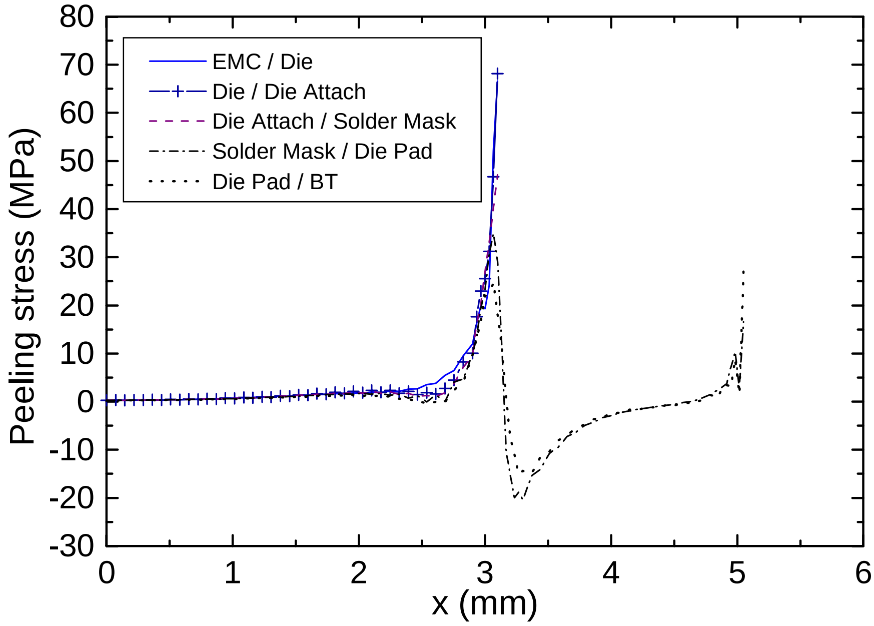


Figure 12. (a)

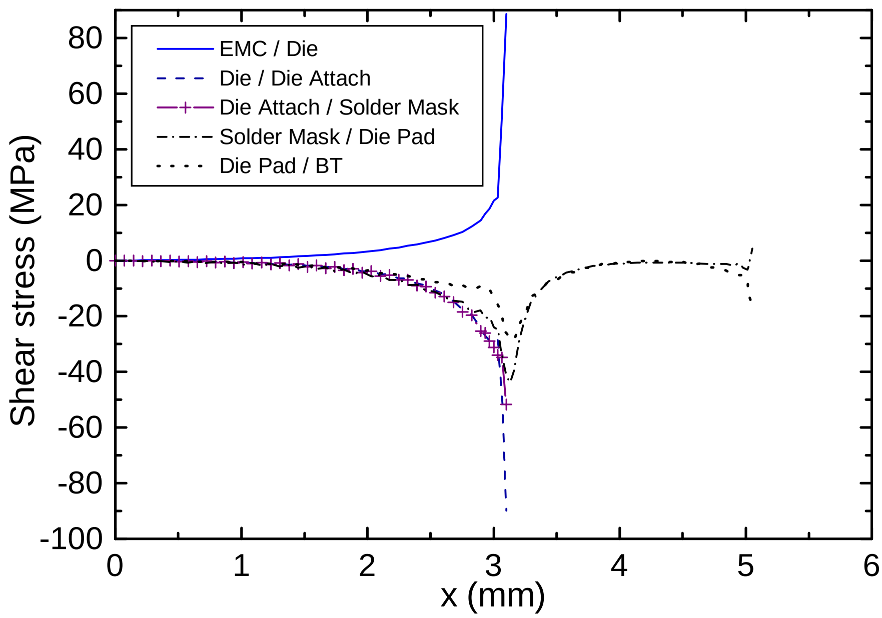


Figure 12. (b)

Figure 12. (a) Peeling stress (b) shear stress at five analyzed interfaces

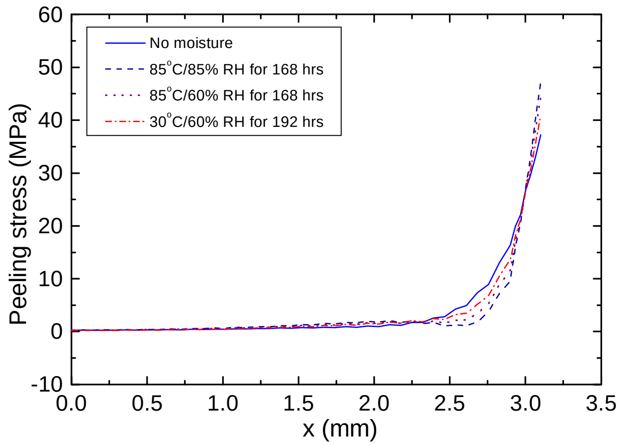


Figure 13. (a)

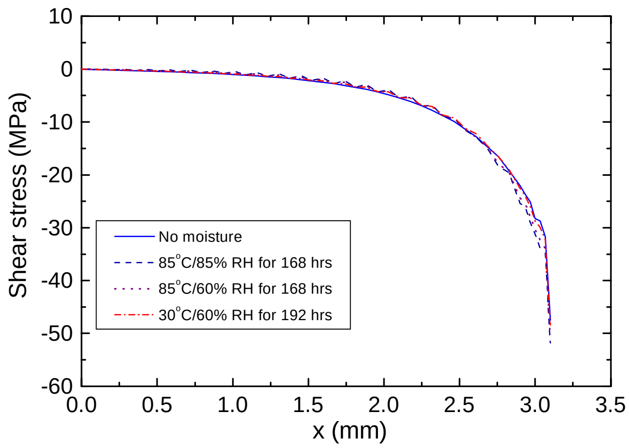


Figure 13. (b)

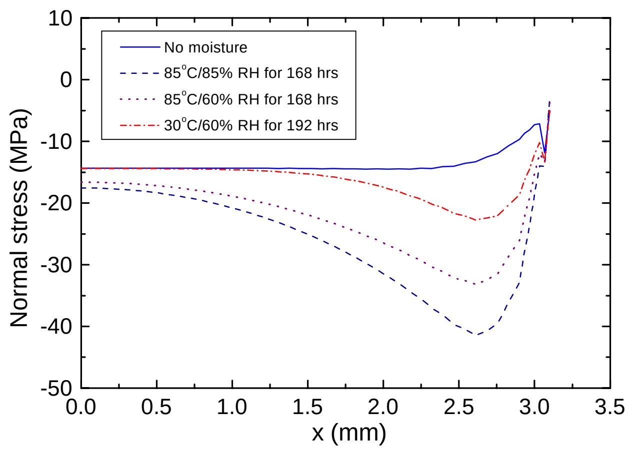


Figure 13. (c)

Figure 13. (a) Peeling stress (b) shear stress (c) normal stress at die attach/solder mask interface

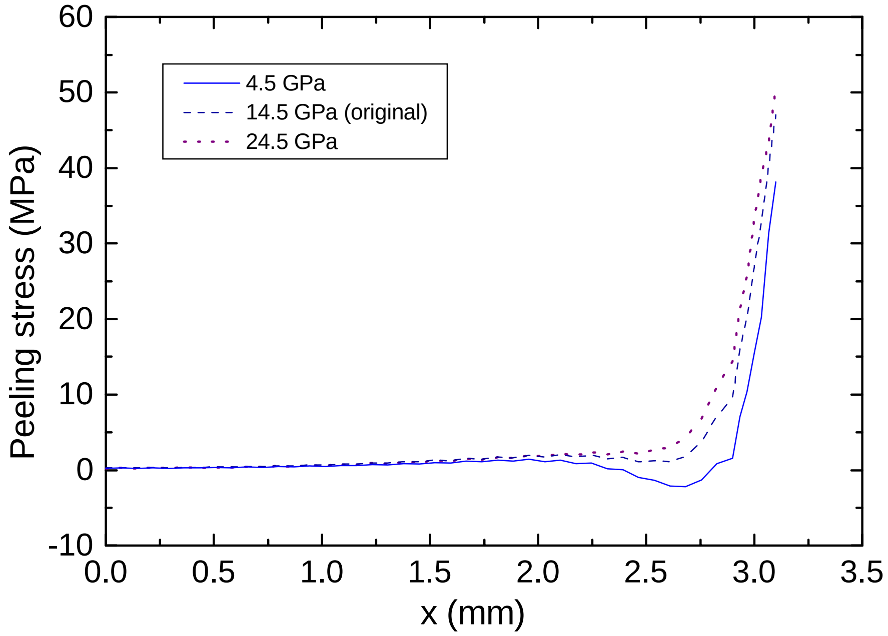


Figure 14. (a)

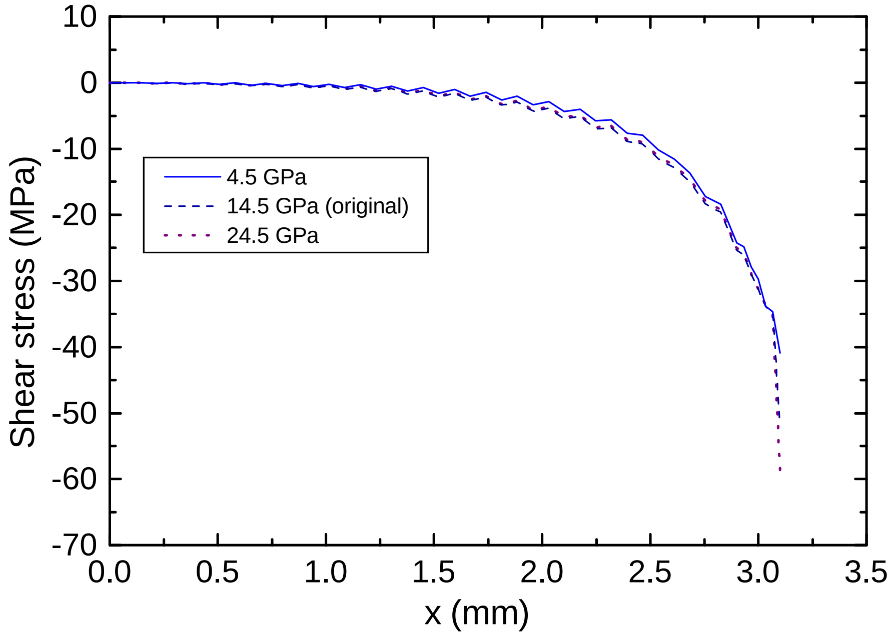


Figure 14. (b)

Figure 14. (a) Peeling stress (b) shear stress at die attach/solder mask interface for different elastic modulus

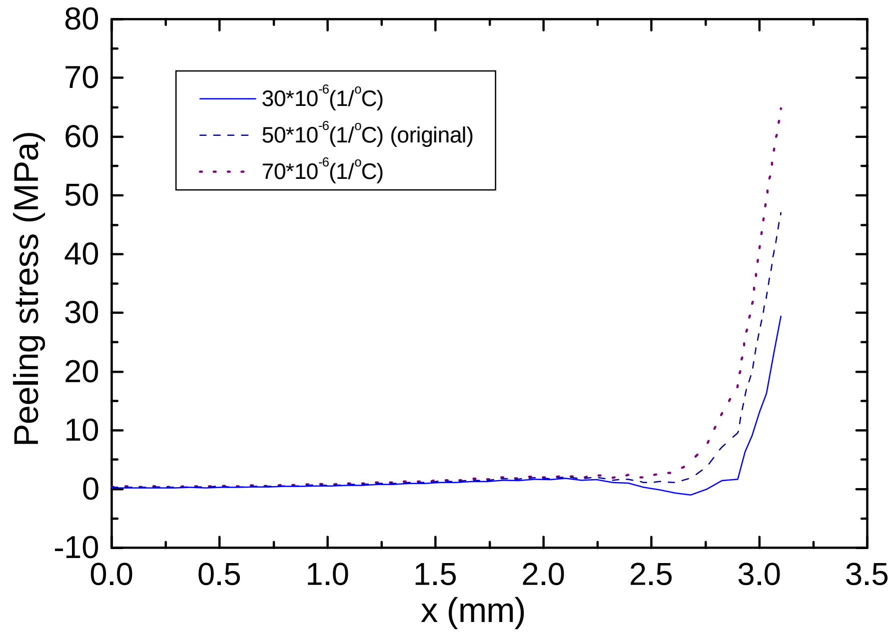


Figure 15.(a)

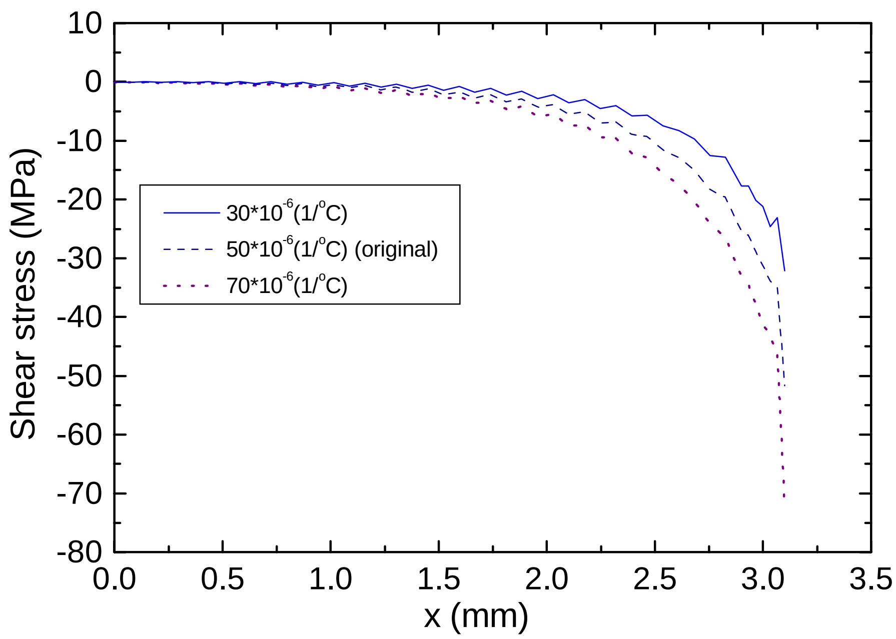


Figure 15.(b)

Figure 15. (a) Peeling stress (b) shear stress at die attach/solder mask interface for different CTE of EMC