

Unit Warpage Control with Universal Die Thickness

Gu Bin*, Jun Dimaano Jr., Richen Chen, Eric Bool, Seow Fui Shi, Choon Ghee Ang, Nathapong Suthiwongsunthorn
United Test and Assembly Center Ltd
22 Ang Mo Kio Industrial Park 2, Singapore 569506
*Email: Gu_Bin@utacgroup.com

Abstract

The package warpage induced by residual stresses during molding process is one of the major thermo-mechanical reliability concerns in IC packaging. This paper proposes a method to find solution to unit warpage control with universal die thickness that ranges from 40 μm to 250 μm for the large FPBGA package. Firstly, the effect of each factor (mold cap thickness, substrate thickness, mold compound and die attach material) on warpage with these various die thickness was simulated and discussed. Then both tests and FEM simulations were conducted for few legs. The FEM simulation results were correlated with actual tests to determine the crying and smiling warpage boundary for satisfying warpage requirement in simulation. Based on actual tests and simulation results, three mold compounds (high CTE, middle CTE, low CTE), three mold cap thickness and two substrate thickness were selected to make full DoE simulation. Final simulation results showed that several combinations of mold cap thickness, substrate thickness and mold compound could be the solution to the warpage requirements with universal die thickness. Only a few more actual tests are needed to verify the final solution based on the simulation results.

Introduction

The package warpage induced by residual stresses during molding process is one of the major thermo-mechanical reliability concerns in IC packaging. [1] The occurrence of excessive unit warpage can lead to misalignment of parts and a variety of operational failures such as die cracking, delamination and solder bump failures. Fine pitch ball grid arrays (FPBGA) have been found to be more susceptible to effects of component warpage. [2] Therefore, the warpage requirements must be satisfied during packaging.

Intrinsic package warpage is largely driven by coefficient of thermal expansion mismatch between the various packaging material constituents. [3-4]

For a certain FPBGA package design, there are many factors that affect the warpage, such as die thickness, mold cap thickness, substrate thickness and mold compound, et al. Suitable combinations of these factors will be the solution to the package warpage control. Usually the die thickness can be controlled and fixed by grinding the wafer in packaging factory. So other factor can be fixed to predict the warpage. [5] But in some cases, chipped dies with various thicknesses (for example, 40~250 μm) have to be packaged to meet the warpage requirement. This will be even greater challenge with large FPBGA package bigger than 10x10mm.

This paper proposes a method to find solution to unit warpage control with universal die thickness for the large FPBGA package. Both FEM simulations and actual molding tests are conducted. Mold cap thickness, substrate thickness, mold compound and even die attach material play roles in the

warpage control. Full DoE of actual tests will be very costly and time-consuming. In this paper, the effect of each factor (mold cap thickness, substrate thickness, mold compound and die attach material) on warpage with these various die thickness was simulated and discussed. It found that die attach has little effect while others play important role. Few tests were conducted with one mold compound. The FEM simulation results were correlated with actual tests to determine the crying and smiling strip warpage boundary for satisfying unit warpage requirement in simulation. Based on actual tests and simulation results, three mold compounds (high CTE, middle CTE, low CTE), three mold cap thickness and two substrate thickness were selected to make full DoE simulation. Final simulation results showed that several combinations of mold cap thickness, substrate thickness and mold compound would be the solution to meeting the unit warpage requirements with universal die thickness. Only few actual tests are going to be conducted to verify the final solution based on the simulation results.

Configuration of package and substrate strip

In this paper, the warpage of a fine pitch BGA 14x18 mm package, as shown in Figure 1, with die thickness from 40 μm to 250 μm , is studied. The dimension of 3-UP substrate is 240x 74 mm, as shown in Figure 2 below. The substrate has two metal layers inside.

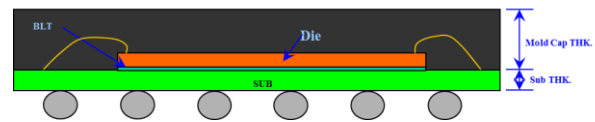


Figure 1. Schematic of fpBGA

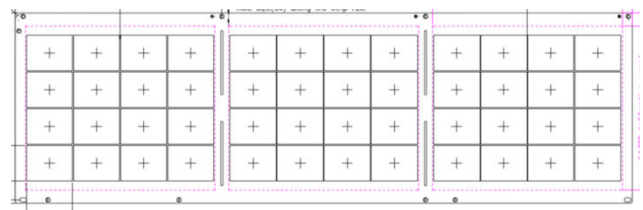


Figure 2. Lay out of 3-UP substrate

FEM modeling

Finite element numerical modeling is applied to predict the strip warpage. Due to symmetry, 3D quarter strip model is constructed for warpage study, as shown in Figure 3. Assuming stress free temperature is 185°C, the strip warpage at room temperature 25°C is simulated. All materials are linear elastic. The strip model instead of package model is created due to two reasons. One is that this is basically a straightforward trend analysis and strip warpage have same trend as package warpage. Secondly, the strip model can be

extended to discuss the panel effect further (1-up, 2-up or 3-up) if needed.

Table 1 lists the three EMC (high CTE EMC C, middle CTE EMC A, low CTE EMC B) and their equivalent CTE based on the formula in the note.

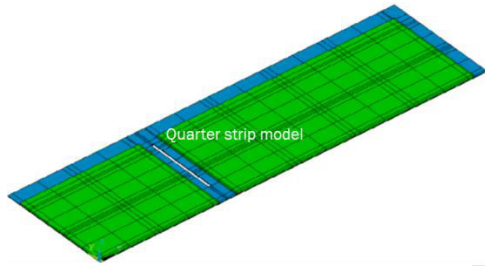


Figure 3a. Quarter strip model

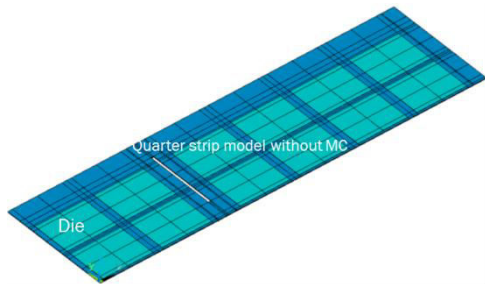


Figure 3b. Quarter strip model without MC

Table 1. EMC material properties

Item	EMC A	EMC B	EMC C
Tg [degree]	130	160	150
CTE1 [ppm/C]	8	10	10
CTE2 [ppm/C]	32	42	45
Equivalent CTE [ppm/C]	16.3	15.0	17.7

Note: Equivalent CTE = $[(185-T_g) \times CTE_2 + (T_g - 25) \times CTE_1] / (185 - 25)$

Strip warpage trend with different factors

In the simulation, the effect of each factor (mold cap thickness, substrate thickness, mold compound and die attach material) on warpage with these various die thickness was simulated. The EMC A is taken as the baseline.

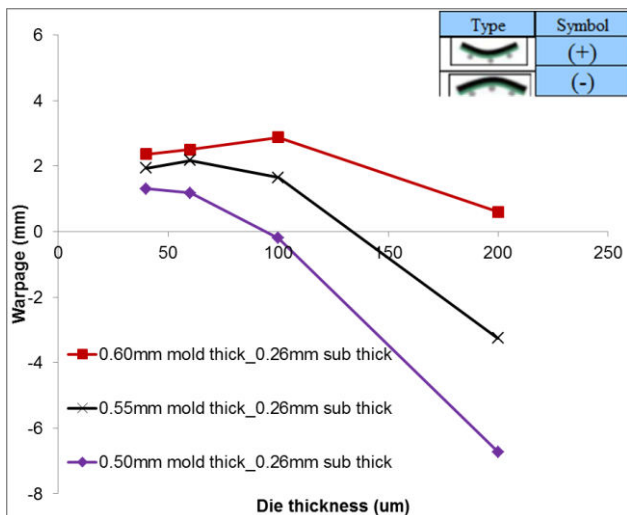


Figure 4. The effect of mold thickness

Figure 4 shows that thinner mold cap thickness causes the warpage to develop toward crying shape. Thicker die makes such effect greater. Figure 5 shows that increasing the substrate thickness have the same effect as decreasing the mold cap thickness. Figure 6 shows that low CTE MC moves the trend line downward (develop toward crying warpage). High CTE MC moves the trend line upward (develop toward smiling warpage). Figure 7 shows that die attach film (DAF) has little effect on the warpage.

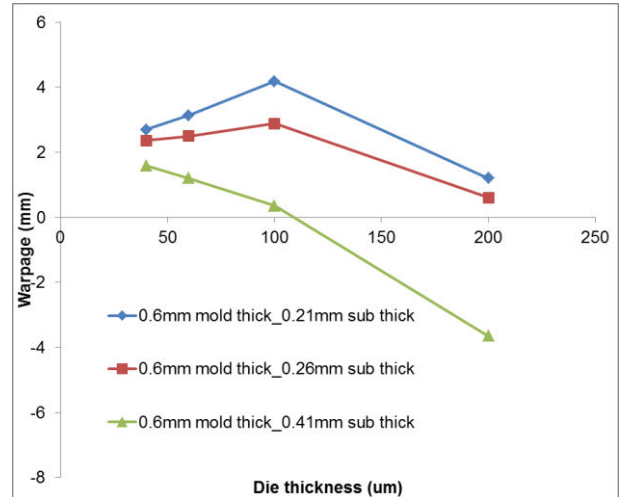


Figure 5. The effect of substrate thickness

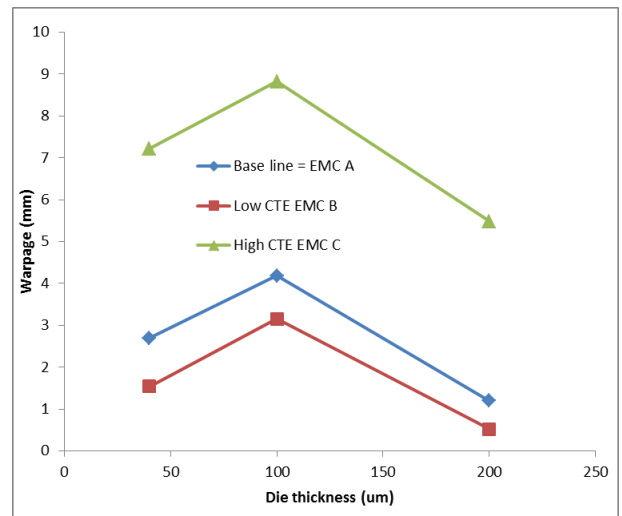


Figure 6. The effect of EMC

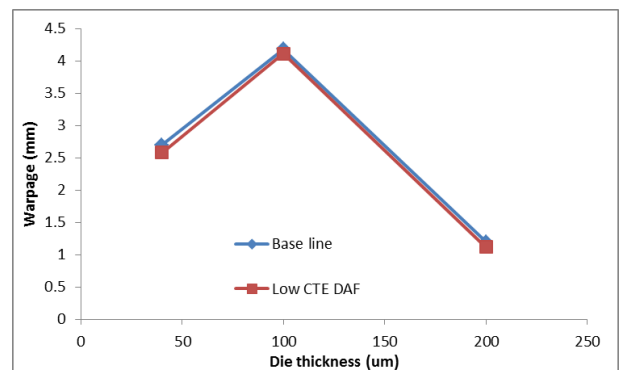


Figure 7. The effect of DAF

Table 2. Correlation between simulation and test

DOE Legs	Factor/level						Response			
	Strip format	Die thickness	Mold thickness	Sub thickness	Mold Cpd	DA material	Strip warpage (RT)	Actual Unit warpage measured in test (RT)		
							Simulation Warpage (mm)	Actual max warpage (mm)	Actual mean warpage (mm)	Actual warpage shape
1	3-Up	64um	0.6mm	0.21mm	EMC A	Base line DAF	3.14	0.13	0.10	Smile
2	3-Up	100um	0.6mm	0.21mm	EMC A	Base line DAF	4.18	0.15	0.11	Smile
3	3-Up	200um	0.6mm	0.21mm	EMC A	Base line DAF	1.20	0.09	0.06	Smile
4	3-Up	100um	0.6mm	0.21mm	EMC A	Low CTE DAF	4.11	0.14	0.11	Smile
5	3-Up	200um	0.6mm	0.21mm	EMC A	Low CTE DAF	1.12	0.10	0.06	Smile
6	3-Up	100um	0.45mm	0.36mm	EMC A	Low CTE DAF	-4.05	0.09	0.06	Cry
7	3-Up	200um	0.45mm	0.36mm	EMC A	Low CTE DAF	-11.63	0.11	0.10	Cry
8	3-Up	100um	0.45mm	0.21mm	EMC A	Low CTE DAF	-1.35	0.13	0.08	Smile to Cry
9	3-Up	200um	0.45mm	0.21mm	EMC A	Low CTE DAF	-10.32	0.12	0.04	Smile

Correlation between simulation and tests

Few tests were conducted with EMC A as shown in Table 2. The FEM simulation results for trip warpage are correlated with unit warpage in actual tests. For leg1, 2 and 3, the smile warpage trend of simulation results correlates well with actual test results. For leg 6 and 7, the cry warpage trend of simulation results correlates well with actual test results.

In leg 2, 3, 4 and 5, both simulation results and test results show that DAF has little effect on warpage. Leg 3 meets the 0.1mm unit warpage spec, so strip’s smile warpage limitation= (+)1.2 mm; leg 6 also meets the 0.1mm unit warpage spec, strip’s cry warpage limitation= (-)4.0 mm.

Full DoE simulation results

Based on actual tests and simulation results, three mold compounds (high CTE, middle CTE, low CTE), three mold cap thickness (0.6 mm, 0.55 mm and 0.5 mm) and two substrate thickness (0.21 mm and 0.26 mm) were selected to make full DoE simulation.

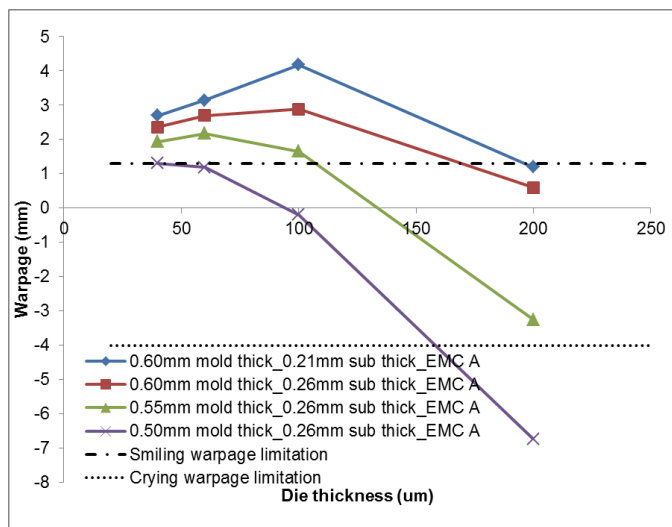


Figure 8. Simulation results for EMC A

Figure 8 shows that with EMC A, for the die thickness less than 150um, 0.5mm mold thickness with 0.26mm substrate thickness helps to control the warpage; for the die thickness between 120um and 200um, 0.55mm mold thickness with 0.26mm substrate thickness will control the warpage; for the die thickness more than 200um, 0.6mm mold thickness is better.

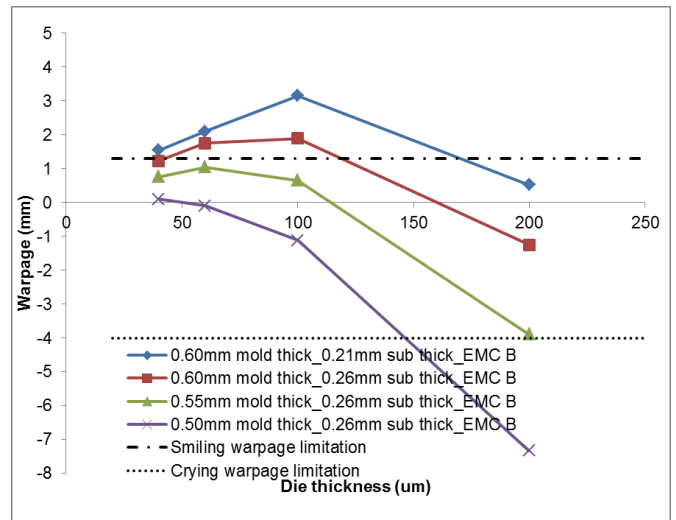


Figure 9. Simulation results for EMC B

Figure 9 shows that with EMC B, 0.55mm mold thickness with 0.26mm substrate thickness helps to control the warpage for die thickness less than 200um; for the die thickness more than 200um, 0.6mm mold thickness is better.

Figure 10 shows that with EMC C, 0.55mm mold thickness with 0.26mm sub thickness helps to control the warpage for die thickness more than 200um.

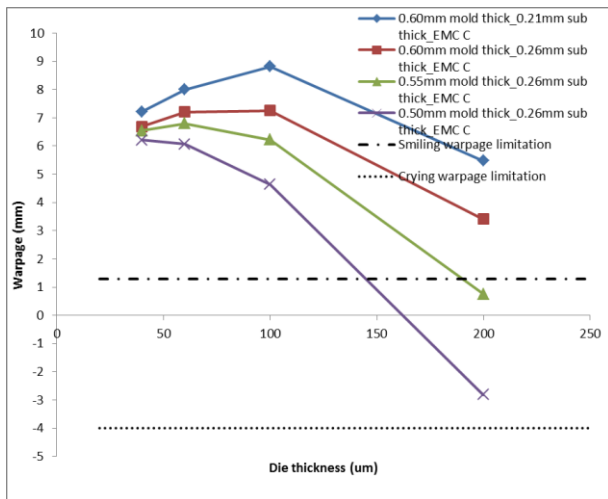


Figure 10. Simulation results for EMC C

Proposed solutions

According to the simulation results, several possible solutions are provided below.

Solution 1:

Based on Figure 8, fixed MC=EMC A, substrate thickness=0.26mm, for the die thickness below 150um, 0.5mm mold thickness can be used to control the warpage; for the die thickness between 120um and 200um, 0.55mm mold thickness with 0.26mm substrate thickness will control the warpage; for the die thickness more than 200um, 0.6mm mold thickness can be applied.

The risk is that for thin die around 50um, the margin is low. The advantage is that test results obtained already to correlate well with simulation results.

Solution 2:

Based on Figure 9, fixed MC= EMC B, substrate thickness=0.26mm, 0.55mm mold thickness helps to control the warpage for die thickness less than 200um; for the die thickness more than 200um, 0.6mm mold thickness can be used.

The risk is that there is no test results obtained to correlate yet; The advantage is that 0.55 mm mold thickness may help to control most part die thickness.

Solution 3:

Based on Figure 11 below, fixed substrate thickness=0.26mm, mold thickness=0.55mm, for the die thickness below 200um, EMC B can be used to control the warpage; for the die thickness more than 200 um, EMC C helps to control the warpage.

The risk is that no test results obtained to correlate for both EMC B and C. The advantage is that one mold thickness will control most die thickness range.

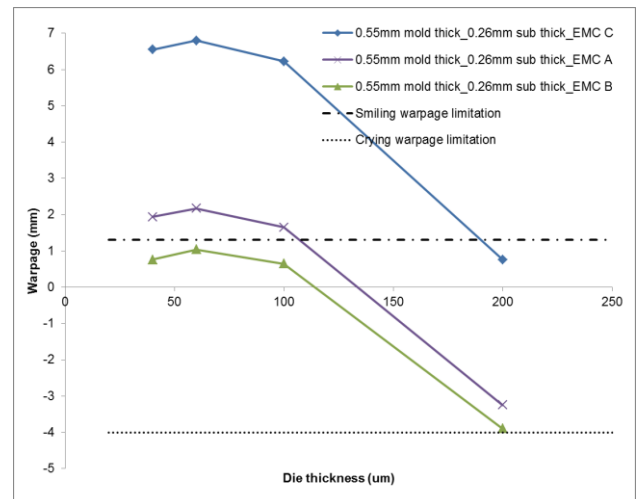


Figure 11. Fixed mold thk=0.55 mm, sub thk=0.26

Conclusions

This paper proposes a method to find solutions to unit warpage control with universal die thickness for the large FPBGA package. 3D quarter strip model is constructed for warpage study. The effect of each factor (mold cap thickness, substrate thickness, mold compound and die attach material) on warpage with these various die thickness was simulated and discussed. It found that die attach has little effect while others play important role. Few tests were conducted and the FEM simulation results were correlated with actual tests to determine the crying and smiling warpage boundary for satisfying warpage requirement in simulation. Based on actual tests and simulation results, three mold compounds (high CTE, middle CTE, low CTE), three mold cap thickness and two substrate thickness were selected to make full DoE simulation. Final simulation results showed that several combinations of mold cap thickness, substrate thickness and mold compound would be the solution to meeting the warpage requirements with universal die thickness. Only few actual tests are needed to be conducted to verify the final solution based on the simulation results.

References

1. Lin, W., et al, "Control of the Warpage For Package-on-Package (PoP) Design," SMTA International, 2006.
2. Lau, J. H., Ball Grid Array Technology, McGraw Hill Publications, 1995.
3. MyoungSu Chae ; Ouyang, E., "Strip warpage analysis of a flip chip package considering the mold compound processing parameters", Electronic Components and Technology Conference (ECTC), 2013 IEEE 63rd, Publication Year: 2013 , Page(s): 441 – 448.
4. Bingshou Xiong ; Lee, M.-J. ; Kao, T., "Warpage improvement for large die flip chip package", Electronics Packaging Technology Conference, 2009. EPTC '09. 11th, Publication Year: 2009 , Page(s): 40 – 43.
5. Ke Xue ; Jingshen Wu ; et al, "Warpage prediction of fine pitch BGA by finite element analysis and shadow moiré technique," 2009. ICEPT-HDP '09, Page(s): 317 - 321.