Study of the Effect of Gravity Weight on Strip Warpage

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Abstract

Strip level warpage control is critical for the manufacturing and assembly of advanced packages. Unfortunately, it is very challenging to simulate strip level warpage accurately. One of the challenges is the strip gravity weight effect. In this paper, nonlinear simulations were performed using Ansys Workbench to observe the effect of gravity on strip warpage. The model consisted of the strip on top of a supporting surface, or table, to more closely resemble how the warpage was actually measured. To account for the gravity effect in simulations with various warpage shapes, contact conditions were included to capture the interactions between the strip and the supporting surface. Simulation results show the weight effect greatly reduced warpage on pre-mold strips, resulting in more accurate warpage simulation results when correlating to actual strip warpage measurement data. There was a significant difference in the weight effect at the chip-attach stage compared to the post-mold stage, with the post-mold stage showing less of a reduction in warpage. Other strip configurations and geometry effects were also studied in this paper, such as: strip size, number of blocks, a slot placed between blocks, and a cored vs. coreless substrate.

Key words

Contact, finite element analysis, strip warpage, gravity weight effect

I. Introduction

The mechanical behavior of electronic packages is an important consideration at each stage of the assembly process. Many packages are assembled in strip format, making strip warpage a critical challenge for manufacturability and yield. Accurate simulations for strip warpage are an effective tool to determine what factors cause large warpages and to explore solutions before assembly. In these simulations, it is common to neglect the weight of a package or strip. However, this assumption is only valid if the simulated object does not deflect due to its own weight when it rests on a table post-assembly for warpage measurement. This can result in simulations calculating large warpages that are unrealistic when compared to the actual measurements. To address this gap between the warpage measurements and simulation, gravity was included in the simulations to create more accurate predictions. Previous simulation efforts involving gravity have been performed on panel warpage and found that including gravity in the simulation reduced the warpage, especially for large panels [1, 2]. It was also found that gravity was not a significant factor for panels after molding, due to the increase in thickness and stiffness. When including a table support into the panel warpage model with gravity, a greater reduction in warpage occurred compared to other supporting conditions [2].

This paper continues to close the gap between the actual process and the simulation for strip warpage measurements. Gravity and potential parameters that can influence the effect of gravity were investigated to see their effect on warpage. The Process of Record (POR) model was calibrated using actual warpage data for both pre- and post-mold strips. The main parameters observed involve the substrate or strip geometry, since many factors may contribute to a change of stiffness in the X/Y directions and have different reactions to gravity.

II. Simulation Set-Up and Validation

A. Simulation Set-Up

Simulations were performed using Ansys Workbench. A quarter symmetric model was used and consisted of the strip on top of the table, as shown in Fig. 1. The strip is grouped as a multi-body part and the table as a separate body, this way contact conditions can be applied between the bottom of the strip and top of the table. To correlate the simulation results to the actual warpage measurements, the materials used in the simulation matched those in the actual strip. Density also needed to be included in each of the material properties for the simulation to incorporate the weight of the strip when gravity is applied.

Once this initial setup is completed, meshing and contact can be set up in Workbench. For the mesh, a 0.3-mm mesh size was used for the strip, and 0.8 mm was used for the table. After meshing was complete, contact conditions were established between the strip and the table. The elements on the bottom of the strip were selected as the contact, while the tabletop was selected as the target element. The contact type was set to frictionless, which avoids over-constraining the system and allows the strip to slide along the tabletop. It is assumed that friction can be neglected and still reasonably approximate the static position of a strip after it is placed on top of the measuring table. As this study was focused on the weight effect, for simplicity, neither the measurement nor the simulation considered the time effect. Nonlinear material effects such as viscoelastic properties were also not considered in the simulation. All materials were assumed to be elastic.

Asymmetric contact behavior was chosen so that one side is the contact, and the other side is the target. The formulation was set to Augmented Lagrange for its high accuracy and faster computation time compared to the other methods. The contact detection was set to nodal-normal to target, which allows for contact to be detected on a nodal point perpendicular to the target surface. This detection method was able to capture the contact on the edges of the strip as the center lifts off the table. Lastly, since a nonlinear analysis was used, the stiffness matrix was set to update each iteration.

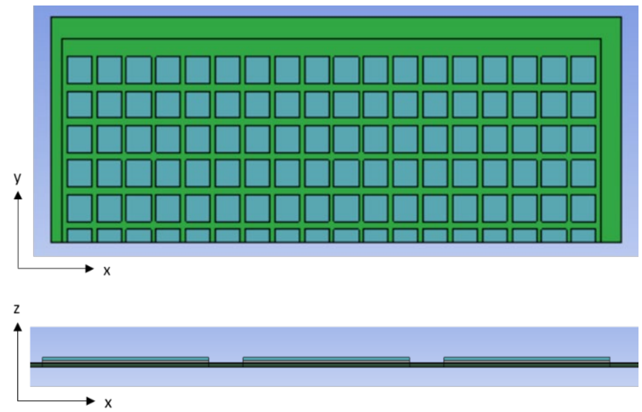

Fig.1: Overview of the quarter symmetric, 2 block, CA95 strip geometry without epoxy molding compound (EMC).

For the strip and table, symmetric boundary conditions were applied. Since standard Earth gravity was applied to the entire model, in addition to the symmetry boundary conditions, the table was fixed and only the strip would be affected by gravity to match the actual process. The analysis was set to nonlinear with a direct solver type with four load steps over which temperature was ramped down to 25°C.Once the simulation was complete, warpage was obtained by viewing the strip displacement in the Z direction.

B. Simulation Geometry

The baseline geometry used in the simulations was a 2 block CA95 (240 x 95 mm) strip. The unit was a Flip Chip Chip Scale Package (FCCSP) with a 3-layer, coreless substrate, a die size of 5.6 x 5.1 mm, and package size of 7 x 6 mm as shown in Fig. 2. The two large gray rectangles on the strip indicate a block.

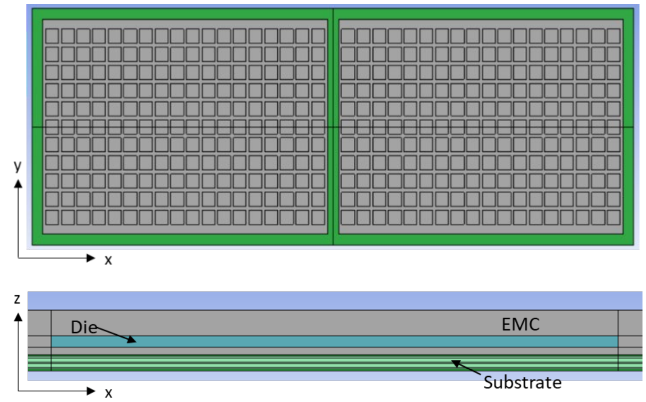

Fig. 2: Baseline geometry showing 2 blocks of EMC (top) and a cross section showing one unit with each component labeled (bottom).

The different strip configurations observed in this study are outlined in Table I. The die and package size remained the same across all strips. When a core was included, an additional layer was added to the substrate to make it four layers.

Table I: Strip configurations

Strip	Description
A	CA 95, coreless, 2 block, no slot
B	CA74, coreless, 3 block, no slot
C	CA95, coreless, 1 block, no slot
D	CA95, cored, 2 block, no slot
E	CA74, cored, 3 block, no slot
F	CA95, coreless, 2 block, slot
G	CA95, cored, 2 block, slot

C. *Simulation Validation*

Actual strip warpage measurements were obtained at room temperature by measuring the displacement of the strip from the measuring table using a caliper. The measurements were obtained after flip chip attach (FCA) and post mold cure (PMC), so the simulation was able to be validated at both stages. From the comparison between the actual and simulation measurements in Table II, the simulation results with gravity agree well with the actual warpage measurement at both FCA and PMC.

Table II: Validation results

	After FCA (mm)	After PMC (mm)
Actual measurement	7.5	3.1
Strip A, no gravity	47.7	5.8
Strip A, gravity	7.9	4.5

The results show that gravity has a large effect on warpage for FCA, and a much smaller impact on PMC warpage. For FCA, the result with gravity was off by 5% compared to the actual, while not including gravity has the simulation result off by an order of magnitude compared to the actual measurement. The difference in the warpage magnitude between the two strips can be seen in Fig. 3. The large warpage produced in in the FCA result without gravity, is not typical of actual warpage measurements from Table II. From this, including gravity in the simulation can produce a much more realistic warpage result. This can then provide a better aid in predicting the warpage at each step before the manufacturing process begins.

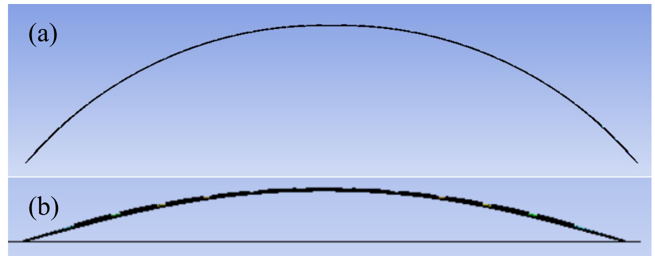

Fig. 3: Warpage after FCA, (a) without gravity and (b) with gravity.

III. Strip Configuration Effect Studies and Results Discussion

A. *Effect of EMC*

Including EMC in the simulations reduced warpage in all cases. As the results show from Table II, FCA warpage is much higher when compared to the PMC results. Adding EMC to the strip results in a smaller gap in the CTE between the top half of the strip, the die and EMC, and the bottom half of the strip, the substrate. The CTE of silicon is very low at 2.6 ppm/K, while the substrate CTE can be close to 20 ppm/K. This large mismatch can result in a large warpage, as seen in strip A after FCA, with no EMC. However, once EMC is included in the strip, the top portion CTE can become much closer to the substrate CTE and produce a smaller warpage, as shown in the PMC results.

As far as the gravity effect difference between FCA and PMC stage, the simulation results show, when gravity is included, the FCA warpage drops significantly, while the PMC warpage only drops slightly. This could be due to the EMC strengthening the strip, resulting in gravity having less of an effect on warpage. In addition to the strip thickness increase by the EMC layer, the EMC material also connects all the die together, making the whole strip much stiffer to counter the gravity effect.

B. *Effect of Strip Size*

Studies are conducted to find out if the gravity effect is strip size dependent. CA95 and CA74 are two commonly used strip types with different sizes. Fig. 4 shows the dimensions and configurations of these two types of strips.

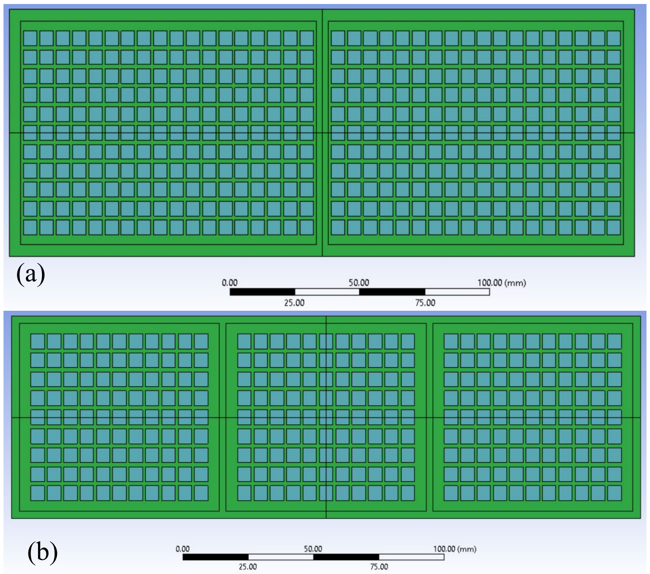

Fig. 4: (a) CA95 strip, (b) CA74 strip.

The warpage results comparing the CA95 and CA74 strip sizes are in Table III. The effect of gravity does not differ for the smaller CA74 strip size compared to the larger CA95 strip and should be included in FCA simulations for both strip sizes.

Table III: Strip size results

	After FCA (mm)	After PMC (mm)
Strip A, CA95 no gravity	47.7	5.8
Strip A, CA95 gravity	7.9	4.5
Strip B, CA74 no gravity	44.6	5.0
Strip B, CA74 gravity	5.2	3.8

C. *Effect of Strip Blocks*

Typically, a strip layout can be configurated as single block, two blocks, or three blocks. Simulations were performed on a CA95 strip with 2 blocks and a CA95 strip with a single block (as shown in Fig. 5) to see if the strip set up influenced the gravity effect.

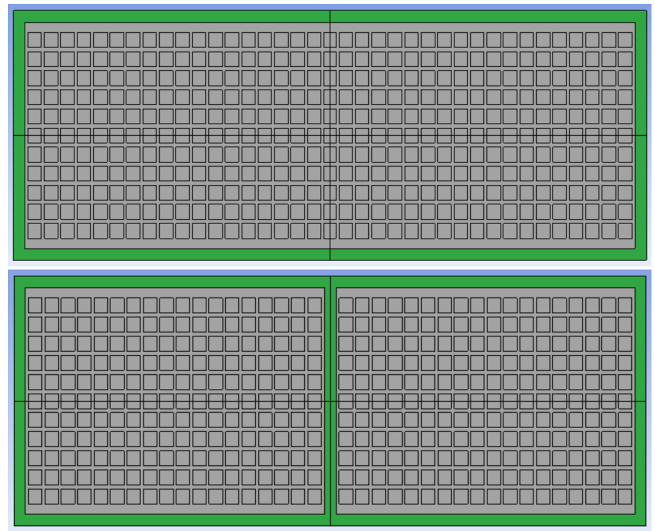

Fig. 5: Single block CA95 strip (top) and a 2 block CA95 strip (bottom) layout.

The results, shown in Table IV, indicate that the number of blocks in the strip does not change the gravity impact on the warpage results for this strip at FCA or PMC.

Table IV: Strip block results

	After FCA (mm)	After PMC (mm)
Strip A, 2 blocks, no gravity	47.7	5.8
Strip A, 2 blocks, gravity	7.9	4.5
Strip C, 1 block, no gravity	50.0	8.1
Strip C, 1 block, no gravity	7.0	5.3

D. *Effect of Cored Strip vs Coreless Strip*

Another important factor in strip warpage is whether the substrate is cored or coreless. Simulations were performed to understand how gravity affects differently on a cored strip vs a coreless strip. Table V shows the results comparing a coreless and cored substrate for both CA95 and CA74 strip sizes. Comparing strips, A and D and strips B and E for both FCA and PMC warpage, the inclusion of a core in the substrate had a great impact on reducing the strip warpage. When gravity was included, there was a smaller reduction in warpage for the strips with a core for both FCA and PMC. The gravity effect is more significant for a coreless strip than a cored strip as shown in Fig. 6 for FCA. This is likely due to the increase in thickness and stiffness of the cored substrate causing gravity to have less of an effect on reducing warpage. Since a stiffer substrate can make the strip more resistant to warpage, the same effect applies to gravity.

Table V: Core effect results

	After FCA (mm)	After PMC (mm)
Strip A, CA95, coreless, no gravity	47.7	5.8
Strip A, CA95, coreless, gravity	7.9	4.5
Strip D, CA95, cored, no gravity	5.1	1.8
Strip D, CA95, cored, gravity	3.7	0.4
Strip B, CA74, coreless, no gravity	44.6	5.0
Strip B, CA74, coreless, gravity	5.2	3.8
Strip E, CA74, cored, no gravity	3.5	0.3
Strip E, CA74, cored, gravity	3.2	0.3

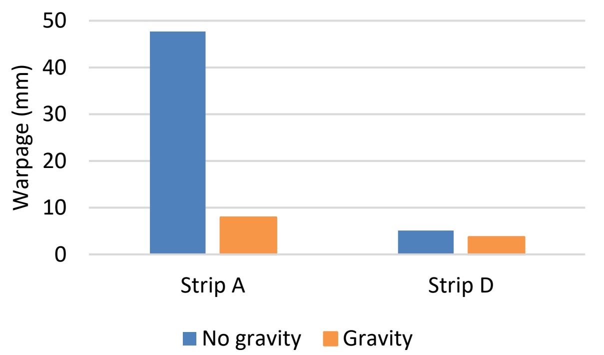

Fig. 6: After FCA warpage comparison between strip A (coreless) and strip D (cored).

E. *Effect of Slot*

In strip design, usually there are slots between each block on the strip. Simulations were also conducted to help understand the interaction of slots with the gravity effect. As shown in Fig. 7, a slot was placed between blocks on the substrate of the CA95 2 block strip to compare respective cases without the slots. The comparison results are shown in Table VI.

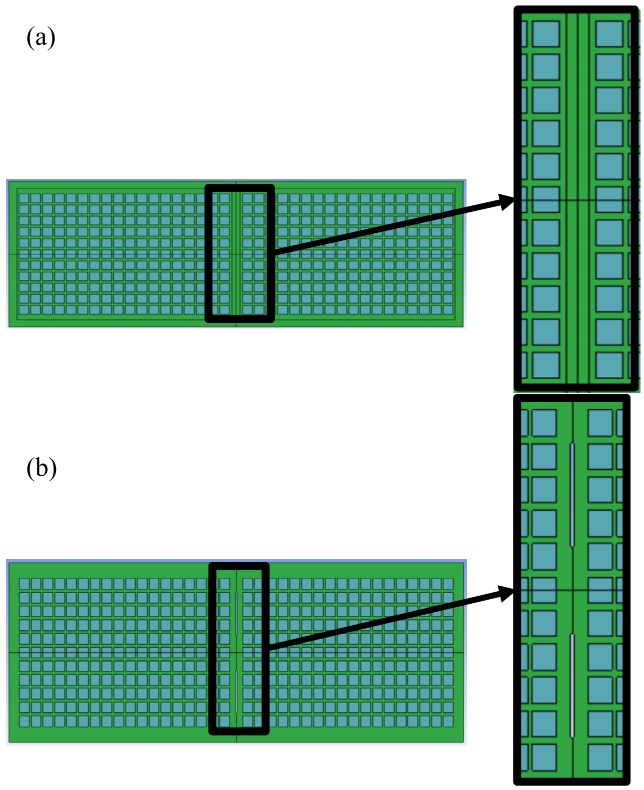

Fig. 7: Comparison of blocks (a) with no slot and (b) with slot.

Looking at the slot only results, there was little difference in the warpage between the no slot and the slot versions of the model at FCA. For PMC, the slot lowered the warpage when gravity was included. Without gravity, the PMC warpage was very similar, however with gravity, the warpage is much lower with a slot. This can be seen in Fig. 8 comparing the PMC warpage for the slot and no slot strips. From this comparison, a slot is recommended to be included in PMC simulations when using gravity. However, when a core was included, as in strip G, warpage was reduced at both process stages and with and without gravity.

Table VI: Slot results

	After FCA (mm)	After PMC (mm)
Strip A, coreless, no slot, no gravity	47.7	5.8
Strip A, coreless, no slot gravity	7.9	4.5
Strip F, coreless, slot, no gravity	47.4	5.3
Strip F, coreless, slot, gravity	8.0	1.7
Strip G, cored, slot, no gravity	3.8	1.7
Strip G, cored, slot, gravity	3.6	0.01

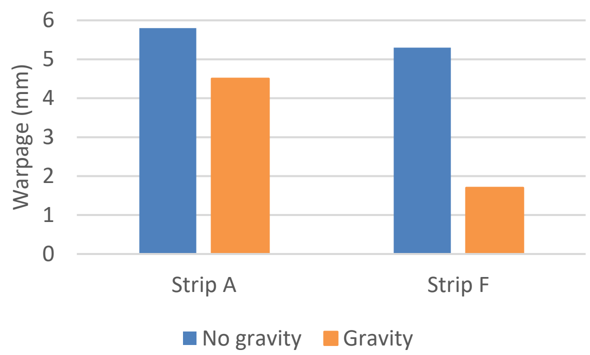

Fig. 8: After PMC results comparing the effect of gravity for strip A (no slot) and strip F (slot).

IV. Conclusion

The inclusion of gravity in simulations was able to better match warpage at both FCA and PMC process steps, making the simulation results closer to actual measurement data. Warpage was reduced substantially more when gravity was included after FCA strips compared to after PMC strips, likely due to the inclusion of the EMC in PMC strips. Strip size and the number of blocks did not change the gravity effect on the strip. However, gravity has a more significant effect on a coreless substrate strip. If the substrate contains a core, gravity had less effect on reducing warpage at both FCA and PMC, mostly due to the increase in stiffness of the substrate reducing its flexibility. The inclusion of slots between strip blocks does not impact the gravity effect at the FCA stage, but it makes the gravity effect much more significant at the PMC stage.

Acknowledgment

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References

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