UNDERSTANDING THE MECHANICAL BEHAVIOR OF THIN PACKAGES DURING DIE ATTACH CURING PROCESS

Amor Zapanta
Jefferson Talledo
Bernie Chrisanto Ang

Corporate Packaging and Automation
STMicroelectronics, Incorporated. Calamba, Laguna, Philippines
amor.b.zapanta@st.com, jefferson.talledo@st.com, bernie.ang@st.com

ABSTRACT

In this paper, the authors would like to quantify the warpage effect of the cure profile on a very thin carrier with very thin die that uses die attach film to permanently place it on the die paddle. The quantification is both done using mathematical computation with simulation software available in the market today and the other one is by measuring the actual warpage as the whole curing process is continuously taking place on both the snap and box oven curing with different temperatures used as suggested in the Dynamic Scanning Calorimetry (DSC) degree of curing.

Through the DSC, the degree of curing optimization where the optimum time to cure the die attach film (DAF) and the minimum time to cure the material will become the baseline of the temperature setting for the snap and box oven cure and the lapse time requirement.

Using simulation software, the warpage of the carrier with DAF and die, in this paper is called the system, is calculated with different cure profile using both the snap and the box oven curing with different temperature settings as suggested in the DSC characterization.

The system is then exposed to a pre-determined temperature and time of exposure as dictated by the DSC. It is loaded to the Thermo-Mechanical Analyzer (TMA) machine to quantify the warpage experienced at room temperature until the system has experienced the cooling down process.

This paper brings interesting data for those design engineers and package development individuals dealing with thinner package as it requires very thin mold cap that is very prone to exposed wire at molding process if the warpage of the system is not considered in the process development.

In this paper also, the usual thinking that at higher temperature the warpage would be higher than during the cooling process is refuted and explanation to it is provided by the authors as the part of the learning.

1. 0 INTRODUCTION

Semiconductor packages are getting thinner and smaller nowadays as this is driven by the application requirements specially defined by the consumer electronics. In order to have a thinner package, most of the strategy is to reduce the leadframe thickness and this will be complimented by the thickness reduction of the die and the mold cap.

There are several problems that will be encountered by the process development engineers in achieving these changes just to cater the customer requirements. One of which is the wire exposure on the top of the die due to thinner mold cap. Commonly, design engineers control the loop height and the loop profile for the wires to prevent the wires to be exposed after molding process.

Little interest was put on controlling the warpage to prevent wire exposure. Warpage is contributed by the shrinkage of the different materials inside the package during and after the heating process. As the materials have different Coefficient of Thermal Expansion (CTE), the materials at elevated temperature will experience different linear expansion and shrink again during the cooling down process.

There is another shrinkage that will contribute to the warpage of the package especially for thin packages, which is the chemical shrinkage contributed by the different polymers used inside the package with different purposes yet very vital materials like the die attach glue or film, mold compound and underfill. During the curing process these polymers will encounter not just mechanical shrinkage but also chemical shrinkage due to the reaction of the components inside the polymers reacting at elevated temperature.

Understanding the mechanical and chemical shrinkage of these materials both due to the curing process or related to the manufacturing of these raw materials are very important in order to know how to control the warpage of the system. Through this, the event of trial and error will be eliminated with time lapsed on different evaluation and cost will be avoided or minimized for the new product development as well as on the process improvement.

1.1 Objectives

One of the objectives in this paper, as well as of the team, is to determine the temperature where the DAF will start to cure. These temperatures will be set as a temperature to be used for snap cure setting and for box oven cure temperature setting. This can be done using the Dynamic Scanning Calorimetry (DSC) by performing the dynamic scanning at 10°C/min ramp rate. The next action is to determine the number of minutes at these temperatures that will make the DAF fully cured.

The second objective of the paper is to understand the mechanical and chemical expansion and contraction of the system, with very thin components, reactions on the different curing profile that these would undergo during the die attach curing. This would give us a clear understanding on the whole process that the system experience as it will undergo from heating up, isothermal condition and to cooling down by measuring it using the simulation software with warpage as the output response that will be quantified and compared.

The third objective is to quantify the warpage of the system using the Thermo-Mechanical Analyzer (TMA) by measuring the warpage during the expansion and contraction of the system at different cure profile as set or used in the simulation software. The data gathered will then be compared to the theoretical computation to assess the error percentage compared to the actual simulation.

At the end of the paper, the authors recommend the best condition to get lesser warpage of the system to be used in the qualification phase.

1.2 Boundary Conditions

The study is based on one batch of sample provided to the authors. There is no repeatability of this study on the different condition of the materials and with different properties of materials. This will also reduce the variability on the study as this will focus more on the effect of the heat to the materials and block the materials set as constant in the whole experiment either on the simulation or on the actual measurement.

The software used in the simulation is ANSYS and the assumptions on the material properties were based on the technical datasheet provided by the different suppliers except on the evaluation done on the DSC. The result may vary depending on these inputs in the simulation software and the results will be compared to the actual results of the TMA. There will be some errors due to process related variability that may affect the outcome of the output variable under observation.

The study does not cover the modulus of the material but focus only on the expansion and contraction of the material during the heating and cooling process of the system. In the TMA, a pre-load force is applied to the material to prevent any slip and this may affect the material property of the DAF but since all samples were subjected to the same condition it may become negligible to the simulation as to evaluation.

2. 0 REVIEW OF RELATED LITERATURE

In the system, which we identify as the leadframe with die attach film and die, has two type of expansion and contraction during the heating and cooling condition on a die attach film curing. One is the mechanical part which is contributed by the CTE of the die and the leadframe and the other one is the chemical reaction of the DAF during curing.

On the mechanical expansion and contraction, the leadframe and the die have a linear expansion when the temperature is ramped up from room temperature to the desired temperature setting for the DAF curing. The faster the ramp rate that will be set, the rate of change of length of the leadframe and die will also increase. During cooling, the shrinkage of the material is dependent also on the rate of cooling down as this is dependent on the change of temperature.

In processing the carriers like leadframe, there is a stamping and etching process to create the leadframe topography. In the stamping process, since this is a mechanical forming process, stress is induced on the leadframe due to the shearing of metals to create the leads and paddle and this will have an impact on warpage once the material is heated to an elevated temperature.

The other expansion or shrinkage is caused by the chemical reaction contributed by the cross-linking of the different polymers inside the system. This type of reaction is dependent on the formulation used for these polymers and the reaction rate varies depending on the type and quantity of accelerators and resin used. But the reaction rate will be affected also by the other factors and other raw materials used as these must be considered also.

The temperature setting for the curing profile will impact also the speed of reaction rate as the raw materials and formulation will be dependent on this setting also. The higher the setting the faster the rate will be. As temperature is also impacted by the mechanical side of the expansion, it is considered as the very significant factor on the warpage.

3.0 EXPERIMENTAL SECTION

In this paper, the experimental section is divided into two parts. One is the simulation of the different DAF curing profile with warpage as the output response. The other one is the actual quantitative observation of the warpage at different DAF cure profiles. Through this, correlation between the two can be made to see if there is a significant difference and if what is observed in actual measurement could be explained by the simulation result. And also, it could be determined if there is significant difference between the snap curing and the box oven curing profile in terms of the warpage.

In the simulation process, the properties of the materials were logged into the program and this could be seen in Table 1 showing the Elastic Modulus and Poisson's Ratio of the materials. These values were given by the suppliers and were not taken from the batch of materials used in the experiments.

Table 1: Material Properties

Item	**CTE** (ppm/°C)	**E-Modulus** (GPa)	**Poisson Ratio**
Die	3.0	169	0.23
Carrier	17.5	117	0.34
DAF	α 1 = 18 α 2 = 95 Tg = 165°C	15	0.35

After the simulation of the system using ANSYS software, a sample of the DAF material was loaded to the DSC pan to determine the Onset Temperature and the Peak Temperature of the curing for the purpose of determining the cure profile. Units were assembled until die attach process and these units would be cured in the TMA machine. Each unit was loaded to the TMA machine as shown in Figure 1 with different curing profiles determined in the DSC with a pre-load of 0.005N.

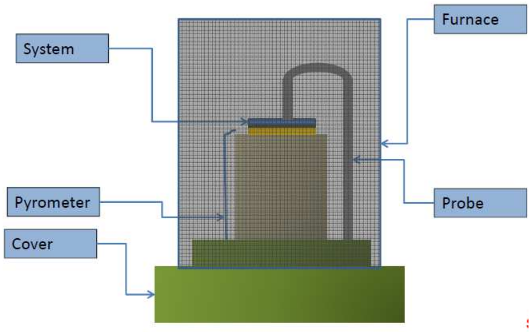

Figure I: TMA Set Up for this experiment.

The flow of the evaluation is illustrated in Figure 2 and the derived temperature after the DSC activities is shown in Table 2 where snap and box oven cure temperatures were determined.

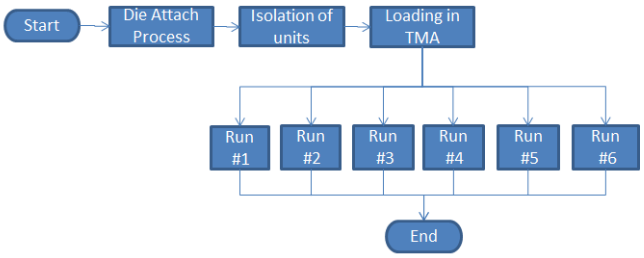

Figure II: TMA Experiment Flow

After determining the minimum and the maximum temperature requirements to cure the DAF material at snap cure setting and in the box oven cure setting at a given time, these temperatures were used for the TMA experiment. Since this was done already and was documented only for this technical paper purposes, the determined temperatures were set already as shown in Table II.

Table II: Evaluation Runs TMA settings.

Run #	**Snap /Box**	**Setting**
1	Snap	120°C - 200°C
2	Snap	200°C
3	Box	150°C - 200°C
4	Box	200°C
5	Box	160°C
6	Box	150°C

For the purpose of DAF voids inspection, the units were mechanically decapsulated to separate the die from the carrier to check the presence of voids but would not be presented in this technical paper.

4.0 RESULTS AND DISCUSSION

As shown in Table II above, the minimum and the maximum temperature setting that can be used for snap curing and oven curing were determined using the DSC machine using the Dynamic Scanning at 10°C/min ramp rate. In Figure IV, it showed different temperatures to cure the DAF material and the percent cured at a given time to determine the snap and box oven setting.

In the Dynamic Scanning Result as shown in Figure III, that the DAF Material has an Onset Temperature of 150°C and a peak temperature of 190°C. This means that the reaction rate of the DAF material will start to become faster at 150°C and the reaction will be at maximum rate at 190°C.

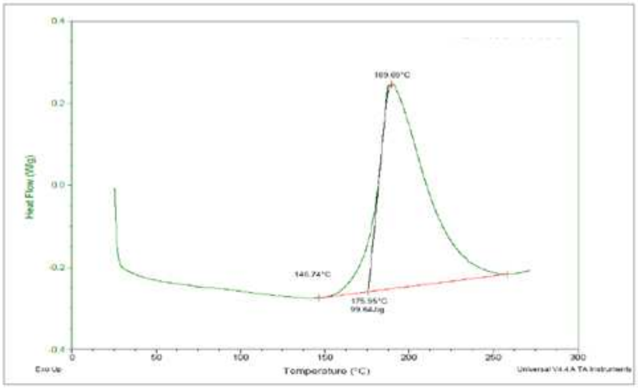

Figure III: Dynamic Scanning of DAF Material

In Figure IV, at 120°C and 130°C cure temperature setting showed that two hours curing have never reached 50% reaction rate. This means that at these settings, the DAF material is not yet 50% cured and may create workability problem in the succeeding processes especially at wirebond as this DAF may induce very low modulus during bonding.

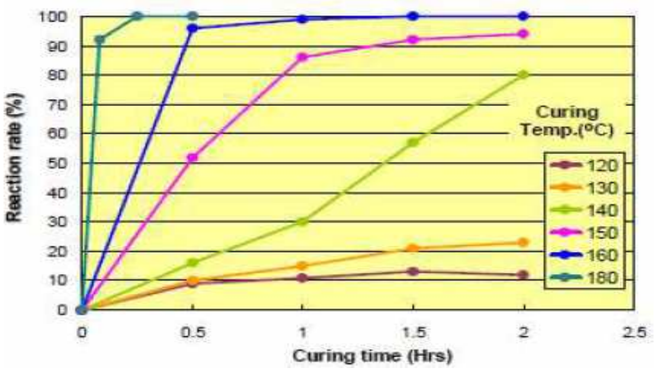

Figure IV: DAF Material Cure Profile

The 150°C and the 160°C cure setting showed that it can reach 90% cured after 60minutes of curing. On the 160°C setting at 30 minutes, the DAF material is more than 90% cured already at this setting. In Fig. IV also, showed that at 180°C setting, the curing will be very fast and will be done within a few minutes.

Through the DSC Data shown above, the Box Oven Temperature setting could be set at 150-160°C for 60 minutes and the Snap Cure Oven Setting at 200°C setting as to incorporate the cure time requirement of less than 10minutes and the material variability.

After determining the temperature settings for the Snap Cure and the Box Oven Curing, these temperatures will be used in the simulation software to assess the warpage response from heating to cooling of the system. It will be more difficult for the simulation and the experimentation if the optimum temperatures were not determined and this would make it a trial and error evaluation.

In the simulation modeling, as shown in Figure V, at 200°C reference temperature (Tref) there is a 76µm warpage. While at 160°C, a 59µm warpage reading is predicted and at 120°C the warpage is at 42µm warpage. The modeling showed higher warpage result for higher zero-warpage temperature or Tref. Tref is assumed close to the curing temperature and so the results show that the higher temperature would result in higher warpage.

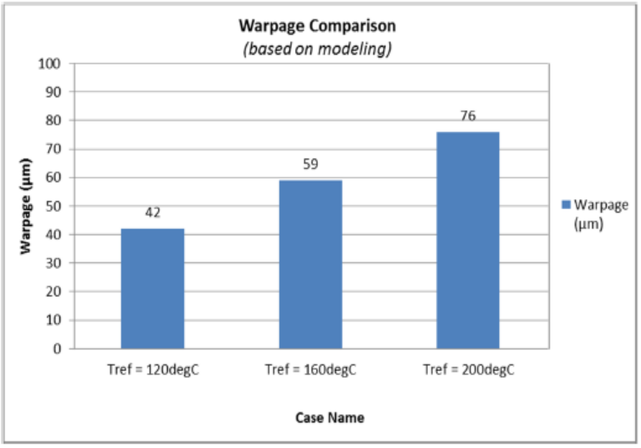

Figure V: Warpage Comparison at different temperature

In the modeling assumption of zero-warpage temperature at 160°C, at 200°C condition of the system the warpage reading is at 18µm as shown in the Figure VI.

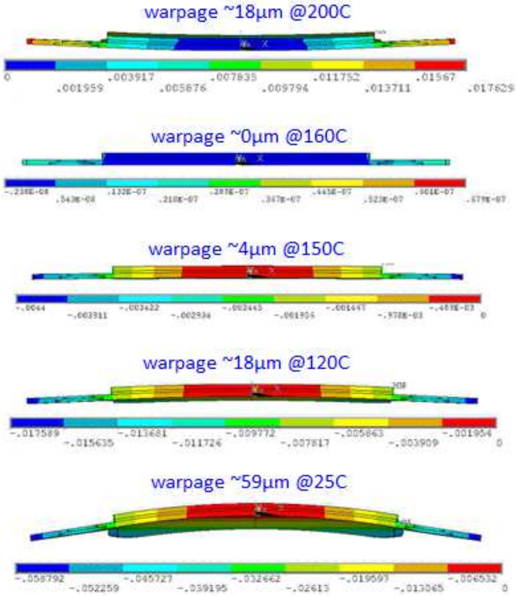

Figure VI: Modeling Results of Warpage at different temperatures

In the simulation results, as shown in Fig. VI, it can be seen that at 200°C, 18µm warpage is in a “smiling” mode. As the system cools down to 160°C the warpage is approximately at 0µm as the Tref is at 160°C. As the system is cooled to 120°C, the warpage reverses to a “frowning” mode as it increases to 18µm and then increases further as it cools down to room temperature at 59µm warpage.

In the TMA evaluation of the system, with the maximum temperature setting of 200°C for snap curing and box oven curing showed high warpage after the curing and reached the room temperature as shown in Fig. VII. For run #1, it shows that the warpage at 24°C is at 58µm while for run #2 the warpage is at 51µm. For box oven curing with maximum temperature of 200°C, for run #3, the warpage is at 56µm and run #4 is at 56.31µm. These data including the box oven at lower temperature are tabulated in Table III.

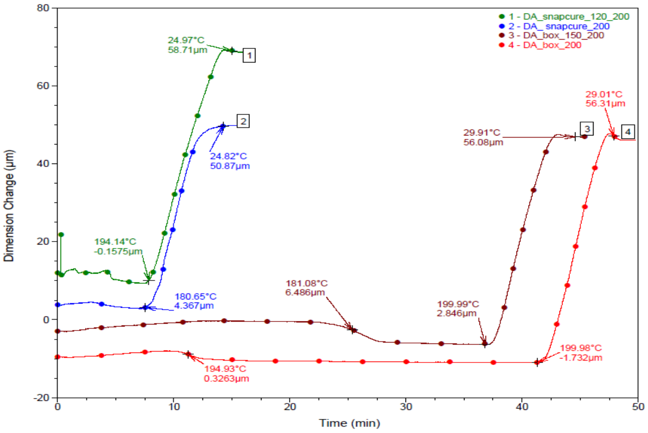

Figure VII: Warpage Result of Snap Cure and Box Oven curing with maximum temperature of 200°C.

The other evaluation is to compare the warpage output response of box oven with different temperature setting. The result as shown in Fig. VIII shows that with maximum temperature setting of 200°C, the system will have higher warpage reading compared to box oven curing with lower temperature setting of 150°C and 160°C. The graphs of runs while curing profile setting at 200°C as shown in Fig. VIII, showed at run # 3, warpage is at 56µm while run # 2 has 51µm. Comparing it to those runs with curing profile with temperatures 150°C and 160°C, system has negligible warpage readings and almost flat surface after the DAF curing.

As assumed in the simulation, the zero-warpage temperature was set at 160°C. It has correlated to the TMA results that at 150°C and 160°C maximum curing temperature profiles will have approximately zero warpage at these temperatures and will also have almost zero warpage as the system will be cooled down to room temperature. The data also shows that regardless of the method of curing as long as the maximum temperature setting of the cure profile is set not higher than 160°C.

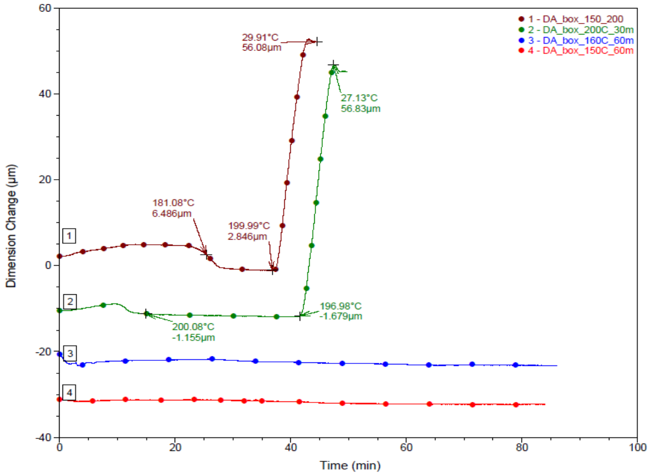

Figure VIII: Warpage Result of Box Oven curing with maximum temperature of 150°C, 160° and 200°C.

For easy comparison between the different runs and settings, the results of the TMA evaluation are tabulated in Table III. Since the maximum temperature setting for each run differs, it is better to compare the warpage at room temperature after the curing process of the system to get the correct state of the system.

Table III: Runs of TMA Evaluations and Results

Run	Snap /Box	Setting	RT Warpage (µm)
1	Snap	120°C - 200°C	58.71µm
2	Snap	200°C	50.87 µm
3	Box	150°C - 200°C	56.08 µm
4	Box	200°C	56.83 µm
5	Box	160°C	-1.12 µm
6	Box	150°C	9.36 µm

In the study, it shows that at room temperature the system has initial state of warpage already contributed by the processing of the raw material. The raw materials especially the carrier, like leadframe, has a stamping process that creates initial stress or deformation on the dimension. During the temperature ramp up as experienced by the system during the curing process, the system is initially shrinking as this makes all of the components in the system to expand and normalize. After the curing the process where the temperature starts to cool down, the graph shows that the warpage also increases and even greater than the initial state of the system when the ramp up of the temperature has started.

In this study also, the temperature at which the DAF material starts to cure coincides with the temperature where the warpage is very minimal as shown in the simulation and on the TMA evaluations. For this material combination, the minimal warpage in order to prevent any wire exposure for a thin package is achieved and eliminated with the optimization of the cure temperature and setting used in the die attach.

5.0 CONCLUSION

In this study, it has been shown through actual experiment and also modeling and simulation that the higher the curing temperature, the higher the warpage that will be encountered and that implies more problems like exposed wire after molding. So in terms of warpage of the thin package system after die bond, curing at lower temperature would be better but there is also a need to consider the mechanical stability at the succeeding wire bonding process.

The study also reveals that in developing very thin package that is prone to warpage, appropriate characterization method like the use of DSC and TMA is needed to fully understand the warpage behavior of the package as it undergoes different processes with different high processing temperatures.

Modeling and simulation was also able to explain the mechanism that refutes the usual thinking that at higher temperature condition the warpage would be higher than during the cooling process. On the contrary, modeling and actual experiment reveal that as the die bonded package cools down, the warpage increases.

6.0 RECOMMENDATIONS

Based on this study, it is recommended to use appropriate material characterization method (e.g. DSC, TMA) coupled with modeling and simulation to fully understand the actual warpage behavior of thin packages at different temperatures in order to come up with the right approach to eliminate warpage related processing problems.

Further detailed studies on the impact of different curing profiles on DAF void formation are also recommended.

7.0 ACKNOWLEDGMENT

The authors would like to thank the leadership of the Corporate Packaging and Automation (CPA) of STMicroelectronics Calamba for the support provided in this study and for empowering the team to understand the behavior of the very thin packages.

The authors are also grateful to the members of the STMicroelectronics Corporate Packaging Automation who in one way or another provided some additional help and to the Assembly Manufacturing Team for providing us samples for the Material Characterization Team to analyze at different settings.

8.0 REFERENCES

1. Chiu, T.C. (2011). Effect of Chemical Aging on Warpage for Encapsulated Packages - Characterization and Simulation. Electronics Components and Technology Conference. Pp 1894 – 1900.
2. Ernst, L.J. (2007). Polymer Materials Characterization, Modeling and Application. Micro and Opto-Electronics Materials and Structures: Physics, Mechanics, Design, Reliability, Packaging. pp A3-A63
3. Yang, Daoguo (2005). Micromechanical Modelling of Stress Evolution Induced During Cure in a Particle-Filled Electronics Packaging Polymer. IEEE Components and Packaging Technology. 676 – 683
4. Nawab, Y. (2013). Chemical Shrinkage Characterization Techniques for Thermoset Resins and Associated Composites. Journal of Material Science. 5387 – 5409.
5. Parameswaranpillai, J. (2013). Investigation of Cure Reaction, Rheology, Volume Shrinkage and Thermomechanical Properties of Nano-TiO2 Filler Epoxy / DDS Composites. Journal of Polymers
6. Teng, S. Y. (2007). Predicting the Process Induced Warpage of Electronics Packages Using the P-V-T-C Equation and the Taguchi Method. Microelectronics Reliability. Pp2232 – 2241.

9.0 ABOUT THE AUTHORS

Jefferson S. Talledo has a mechanical engineering background (MS at UP-Diliman and BS at MSU-IIT). He is currently working on package mechanical modeling and simulation at STMicroelectronics. He has more than 12 years of semiconductor R&D and design experience gained at Intel, Delta Design and lately STMicroelectronics.

Amor B. Zapanta is currently working on different areas of materials characterization at STMicroelectronics Inc. Calamba under Corporate Packaging and Automation Department. She has 19 years of experience in the industry working previously in Philips Semiconductors and NXP Semiconductors. She is a graduate of Bachelor of Science in Secondary Education, Major in Mathematics at Pamantasan ng Lungsod Ng Maynila, Intramuros, Manila.

Bernie Chrisanto M. Ang is a graduate of Xavier University-Ateneo de Cagayan with a degree of Bachelor of Science in Mechanical Engineering with a Master Degree in Engineering Management at Colegio de San Juan de Letran Calamba. He works on different material characterization and developing new techniques to predict the behavior of different materials on high temperatures. He also works on the development of mold equipment and process.