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Modeling Study on the Impact of Mold Thickness on Strip Warpage of a Molded Leadframe Package

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Short Research Article

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ABSTRACT

Strip warpage is a common problem in molded leadframe packages. When warpage becomes excessive, the strip could not be processed as it would result in the strip being stuck or damaged during loading to the handling machine loader. This study focuses on the impact of mold cap thickness on strip warpage of a molded Quad Flat No Lead (QFN) package to provide guidance in reducing the strip warpage to an acceptable level. Different mold thickness values were considered in the modeling using finite element analysis (FEA). Results showed that there is an optimum mold thickness, which is around 1.0 mm for 0.20 mm leadframe thickness and 0.65 mm for 0.125 mm leadframe thickness, that gives the lowest warpage in the case considered. The optimum mold cap thickness is lower for thinner leadframe. At mold thickness lower than the optimum value, warpage is in "frowning" mode and increases as the package gets thinner and this agrees with actual observations. This study shows that mold cap thickness has significant impact on molded strip warpage and could be assessed using FEA. Therefore, controlling the mold cap thickness could now be considered an option to reduce strip warpage in molded semiconductor packages as supported by modeling.

Keywords: Leadframe strip; mold thickness; molded package; strip warpage; warpage modeling.

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1. INTRODUCTION

Semiconductor packages are commonly molded in strip format or array and then singulated into individual units. However, the curing process of epoxy molding compound (EMC) and subsequent cooling down will introduce warpage due to polymerization shrinkage and coefficient of thermal expansion (CTE) difference of the materials [1]. The difference in the expansion rates of the different package component materials (EMC, leadframe, silicon die, die attach) during package assembly manufacturing results in warpage. Strip warpage becomes a challenging problem when it is excessive and strip handling would be difficult. Fig. 1 shows a molded leadframe strip package that has an excessive strip warpage encountered in this study.

A molded leadframe strip with high warpage can cause issues in the succeeding package assembly processes. During reflow at high temperature, the strip could get stuck in the conveyor of the reflow oven. It could also cause machine vacuum error as the molded strip would not stay flat on the strip holder when doing the package singulation. Strip handling would be very challenging when strip warpage is significantly high and goes beyond the acceptable warpage limit.

There are many studies [1-6] on strip warpage dealing with warpage problem in a molded package. They include warpage analysis considering the impact of design parameters and processing conditions, mold filling and curing steps, optimum combination of material properties, and the cure shrinkage of the mold compound. Wang et al. [7] studied strip warpage after molding process using bi-material strips (epoxy and copper). For laminate substrates, Lee et al. [8] suggested design optimization, mechanical/thermal treatment and low CTE material to reduce substrate warpage.

With the different factors affecting warpage response of a molded semiconductor package, this modeling study would only focus on the impact of mold cap thickness on strip warpage of a molded Quad Flat No Lead (QFN) strip to explore solutions to the warpage problem. Warpage modeling using finite element analysis (FEA) was used in studying the strip warpage with the different mold cap thickness values. The objective of this work was to understand how strip warpage would respond to changes in mold cap thickness. Knowing the expected warpage response would provide guidance in developing workable options to reduce strip warpage to an acceptable level.

2. WARPAGE MODELING OF THE MOLDED STRIP

Finite element analysis (FEA) has been used to do warpage modeling for molded strips in previous studies [1-5]. Some are using FEA techniques for improved prediction like the inclusion of cure shrinkage [4] or using the anisotropic viscoelastic shell modeling technique performed on the warpage simulations for a full microelectronic package with a multilayer PCB [9]. Other semiconductor package strip warpage studies use FEA in analyzing the effect of stress relief slots [10], mold compound fillers and die thickness [11], and the combination of mold cap thickness, substrate thickness and mold compound [12]. A simple and efficient image-based approach for simulating strip warpage as a function of temperature is also studied with FEA [13]. It can be seen that FEA is very useful in analyzing warpage response with different relevant factors or parameters.

In this study, linear elastic material properties of the package components were used in the warpage modeling of the molded leadframe strip. The material properties are shown in Table 1. For the die attach adhesive and the epoxy molding compound, there are two CTEs indicated. The first value (CTE1) is the CTE below the glass transition temperature (Tg) and the second value (CTE2) is the CTE above Tg. Fig. 2 shows the FEA model of a strip slice of the molded strip. Instead of modeling the whole molded leadframe strip, a strip slice model was analyzed to reduce the FEA computation time. This should be acceptable since the goal of the modeling is to have relative comparison in strip warpage with different mold cap thickness values. The stress free or zero warpage condition was set at 175^{o}C, which is the post-mold curing temperature of the epoxy mold compound considered. With different mold cap thickness values, two different leadframe thickness values (0.125 mm and 0.20 mm) were also used in the modeling implemented in ANSYS FEA software.

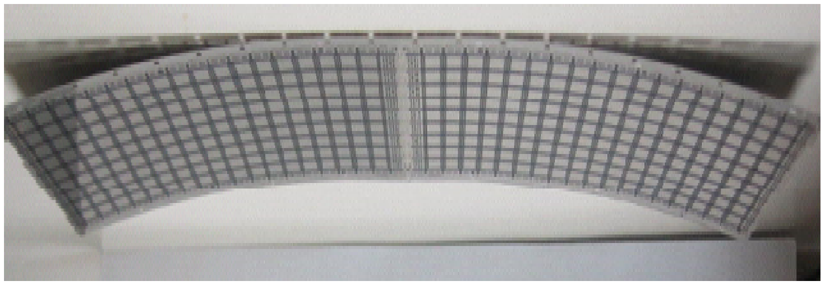


Fig. 1. A molded leadframe strip with excessive warpage in “frowning” mode

3. RESULTS AND DISCUSSION

The warpage modeling result for the baseline QFN package with 0.35 mm mold cap thickness and 0.20 mm leadframe thickness is shown in Fig. 3. This is the QFN package in which the actual problem in this study was encountered. As indicated in the warpage contour plot, the predicted warpage of the molded strip slice is in “frowning” mode. This agrees with the actual strip warpage in Fig. 1 that is also having a “frowning” warpage at room temperature after cooling down from the 175^{o}C post-mold curing temperature. The “frowning” warpage happens in this case because the leadframe shrinks faster than the other component materials during the cooling down of the strip from 175^{o}C post-mold curing temperature to room temperature. This is only a simplistic explanation because the mechanism is quite complex where warpage is not only governed by the CTE of materials but also the modulus and the package geometry. Thus, warpage modeling using FEA was used to capture such complex interactions.

For the 0.20 mm leadframe thickness, the optimum mold cap thickness was found to be around 1.0 mm as shown in Fig. 4. The strip warpage is in “frowning” mode for mold cap thickness below the optimum value. However, for mold cap thickness above the optimum value, the strip warpage reverses into “smiling” mode. This shows that as mold cap gets thicker, the influence of the epoxy molding compound to pull the strip into “smiling” mode increases after cooling down to room temperature. As mold cap gets thinner below the optimum value, the “frowning” warpage increases. This indicates that the influence of the leadframe to pull the strip into “frowning” mode increases when the mold cap thickness decreases. This is also why more strip warpage issues are encountered with thinner semiconductor packages as compared to thicker packages in actual package assembly manufacturing. The warpage trend from the modeling is also in agreement with observations from another related study [14] that warpage seems to be higher for thinner memory packages and larger package size as expected based on the fundamental structural mechanics and materials response principles.

With the thinner leadframe (0.125 mm), the optimum mold cap thickness changes to around 0.65 mm as indicated in Fig. 5. The optimum mold cap thickness for thinner leadframe is lower compared to the optimum value for thicker leadframe. So for a molded leadframe strip with a “frowning” warpage, using a thinner leadframe could help reduce the strip warpage. Looking at the 0.35 mm mold cap thickness, strip warpage has been reduced by 10% (Fig. 5) when using 0.125 mm leadframe compared to the 0.20 mm leadframe. Another option to reduce a “frowning” strip warpage is to use a thicker mold cap as clearly shown in Fig. 4 and Fig. 5. In terms of the epoxy molding compound, using one with higher CTE could also help reduce the “frowning” warpage.

The optimum mold cap thickness in this study is only applicable to the specific epoxy molding compound used and the specific leadframe thickness values considered. For different molding compound with different material properties, the optimum mold cap thickness would also be different. However, the optimum value could easily be determined using FEA warpage modeling. The results have shown that warpage can be reduced by controlling the mold cap thickness to a higher value within the specified range when there is an existing excessive “frowning” warpage. This approach is now being applied in single map large strip packages to achieve warpage reduction in actual package assembly.

Table 1. Material properties

Package Component	CTE (ppm/°C)	E-Modulus (GPa)	Poisson's Ratio
Leadframe	17.5	117	0.34
Die Attach Adhesive	40/ 140 (Tg = 75°C)	5.3	0.30
Silicon Die	3.0	169	0.23
Epoxy Molding Compound	7/ 33 (Tg = 125°C)	26.5/ 1.6	0.25

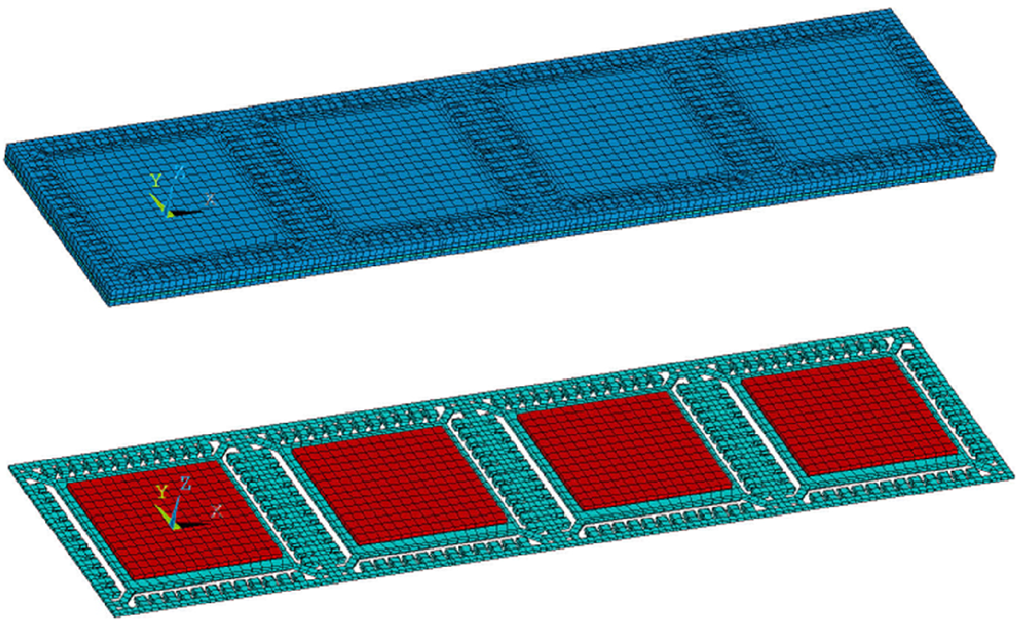


Fig. 2. FEA model of the molded leadframe strip

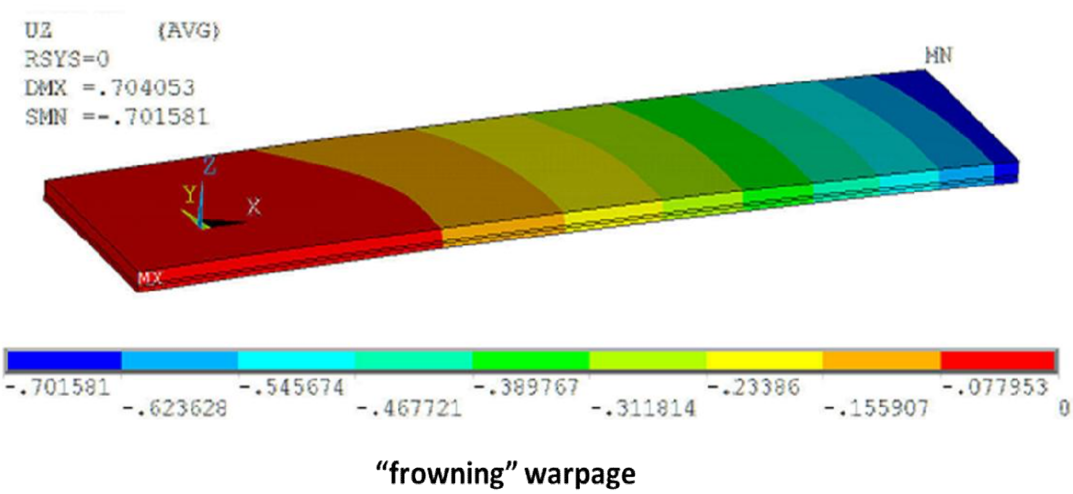
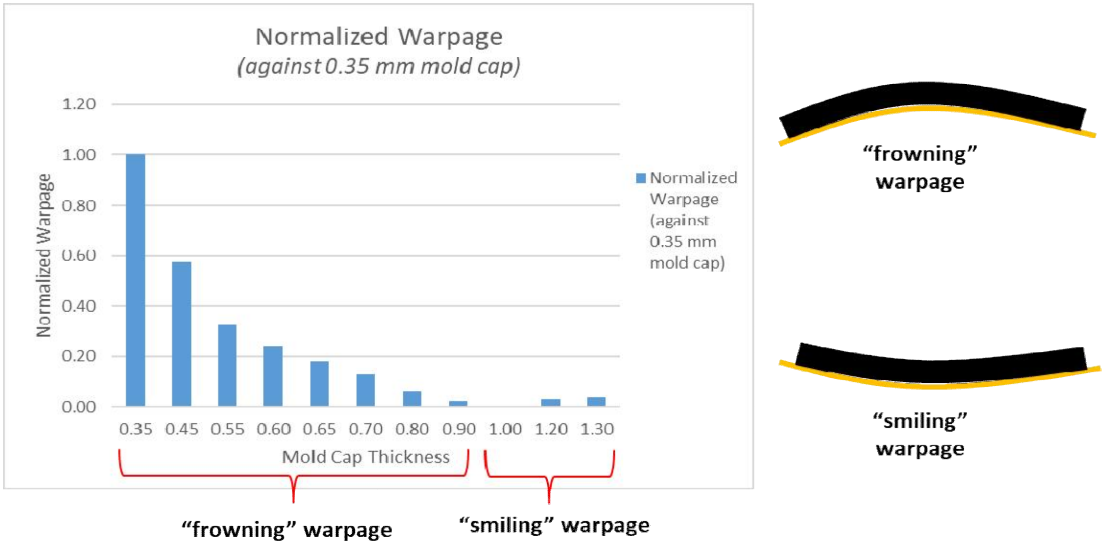
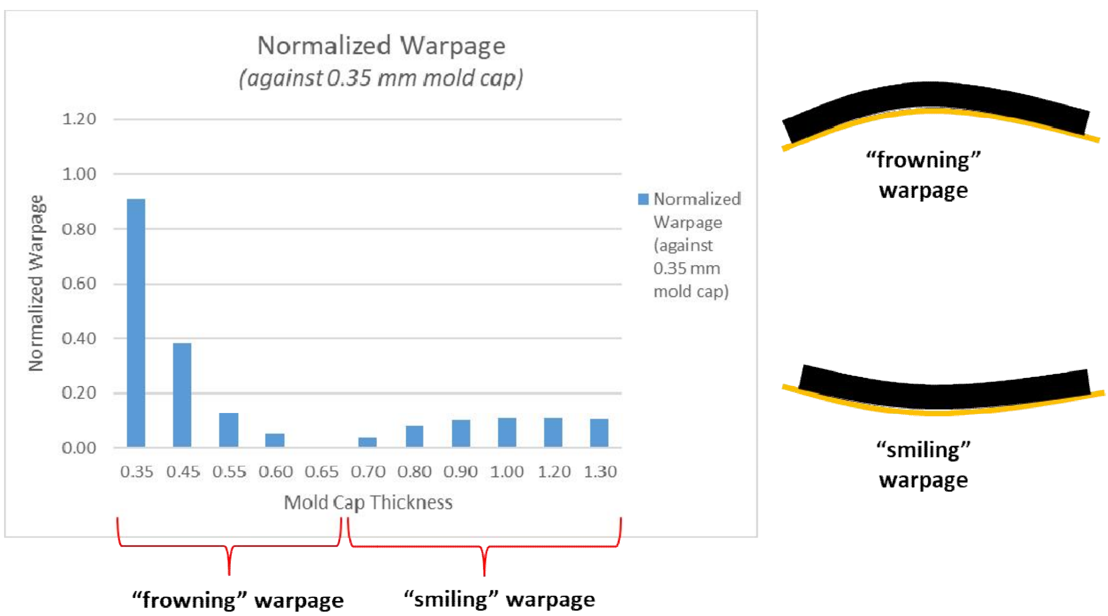


Fig. 3. Representative warpage contour plot result for the 0.35 mm mold cap thickness



a) b)

Fig. 4. a) Normalized molded strip warpage using 0.20 mm leadframe thickness; b) warpage direction



a) b)

Fig. 5. a) Normalized molded strip warpage using 0.125 mm leadframe thickness; b) warpage direction

4. CONCLUSION

Warpage modeling of the molded leadframe strip in this study showed that mold thickness significantly affects the strip warpage. For the specific case considered, the optimum mold cap thickness is around 1.0 mm for 0.20 mm leadframe thickness and 0.65 mm for 0.125 mm leadframe thickness. With mold cap thickness below the optimum value, strip warpage in “frowning” mode increases as the mold cap or package gets thinner. However, the strip warpage reverses into “smiling” mode with mold cap thickness above the optimum value. It has been shown that the optimum mold cap thickness is dependent on the leadframe thickness. This study has demonstrated that warpage modeling using FEA is a useful approach in understanding the impact of the different factors or package parameters on strip warpage of a molded leadframe package. It can also be concluded that the strip warpage of molded semiconductor packages can be reduced by controlling the mold cap thickness.

DISCLAIMER

The products used for this research are common and predominantly used in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because there is no intent to use these products as an avenue for any litigation but just for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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