How the mold compound thermal expansion overrules the solder composition choice in board level reliability performance

B. Vandevelde[1], L. Degrendele[2], M. Cauwe[2], B. Allaert[3], R. Lauwaert[4], G. Willems[1]

[1] Imec, Leuven, Belgium
[2] Imec CMST, Gent, Belgium
[3] Connect Group, Ieper, Belgium
[4] Interflux Electronics, Gent, Belgium

***Abstract*— IC packages using mold compounds with low coefficient of thermal expansion (CTE) have been introduced in the last decade packages with basically no attention to its impact on board level reliability. In this study, the impact is shown for a large size QFN package. In this parameter sensitivity study, also the solder composition and the flank wettability of the QFN leads are varied. The QFN's soldered to a thick Printed Circuit Board (PCB) are tested under thermal cycling and the outcome is a Weibull failure distribution. Comparing the different results reveals which of the three parameters (mold CTE, solder composition, flank wettability) is the one dominating most the board level reliability. The work is supported by optical inspection on failed samples.**

***Keywords*— QFN; mold compound; CTE; Board Level Reliability; Thermal Cycling; Solder fatigue**

I. Introduction

The use of the low-CTE mold materials for IC packages was driven by the need to reduce the stress on the silicon chip, a lower moisture uptake and halogen-free "green" compounds. The RoHS directive gradually banned the halogen-based flame retardants material, so the molding compound transformed to SiO_2 based material. The SiO_2 based filler can reduce the amount of hygroscopic resin to decrease the MSL (moisture sensitivity level) and this is less expensive than resin filler. The amount of SiO_2 particles in the epoxy matrix increased up to a filler content of 85%. This leaded to mold compounds with CTE in the range of 6 to 9 ppm/°C. And for most packages, the mold compound easily takes 50% of the total volume of the package so it is obvious that the mold CTE has a huge impact on the average CTE of the component.

As a consequence of this change, the reduction of the CTE from 12-15 ppm/°C for conventional mold materials to 7-9 ppm/°C for these low-CTE materials substantially increases the thermal expansion mismatch with the printed circuit board (typically 15-18 ppm/°C), as indicated in Fig. 1. As electronics can be subjected to temperature cycling, the larger expansion/shrinkage mismatch between the board and component will increase the loading on the solder joint providing the electrical but also mechanical connection between package and board. The concern of the low-CTE mold compound packages has been first reported in 2011 [1]. Only few other references show some results on different mold compounds [2][3].

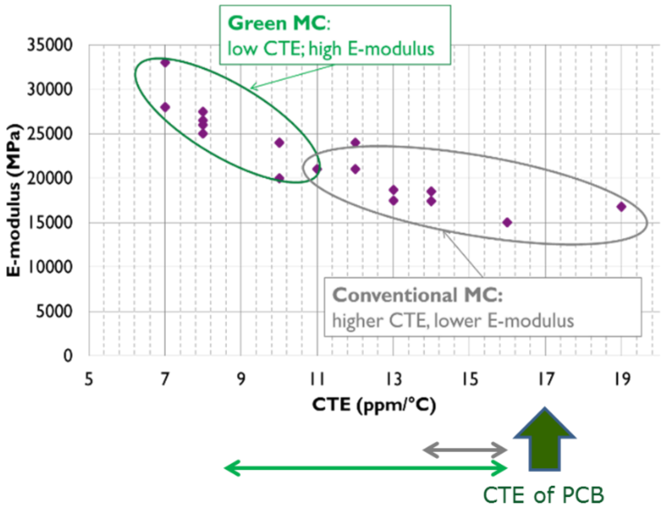

Fig. 1. Correlation between the mold CTE and mold stiffness for a wide range of commercially available mold compounds. The graph also indicates the larger gap between the CTE's of the PCB and the green mold compounds

Fig. 1 shows that there is a correlation between the stiffness (elastic or Young's modulus) and the CTE of the mold. This is also related to the content of SiO_2 content. Stiffer mold compounds also leads to higher stresses in the solder joints, which could be negative under shock loads.

Besides the impact on the solder joints, other phenomena were found that can be attributed to the low CTE compounds. One of them is the higher risk of fatigue failures of copper wire bonds which is also induced by the larger CTE mismatch between Cu (17.6 ppm/°C) and the low-CTE mold compounds [4]. Also more "head-in-pillow" process assembly issues are experienced which are related to the use of these new mold compound materials [5].

The objective of this work is to report on an experimental thermal test study which reveals the impact of low-CTE mold compounds on board level reliability.

II. EXPERIMENTAL SETUP

A. QFN package description

A 64 pins QFN with 9x9 mm size was selected for this study (Fig. 2). The solderable exposed pad is about half of the package size. The die size is roughly 4x4 mm^2, which makes that this package has a rather low die to package ratio.

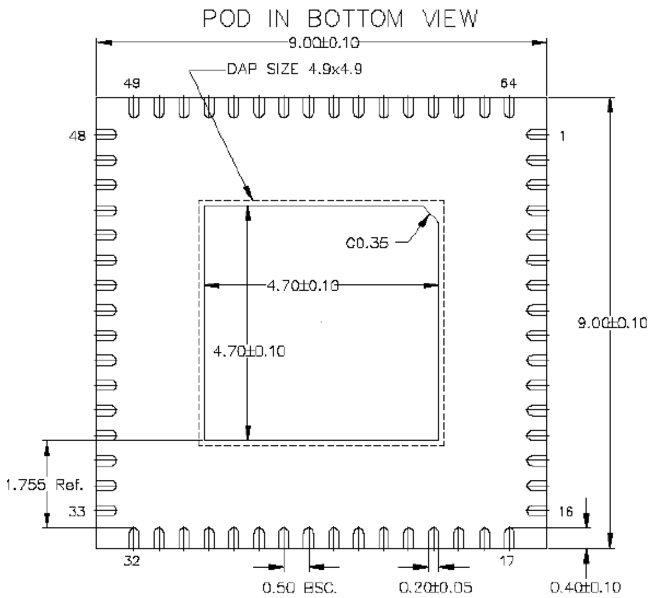

Fig. 2. Package outline drawing for the QFN package used in this BLR analysis

For this study, there are three packages produced, summarised in the Table 1 below.

TABLE I. THREE QFN VERSIONS

QFN #1	Mold CTE: 7 ppm/°C; non-wettable flank
QFN #2	Mold CTE: 7 ppm/°C; wettable flank
QFN #3	Mold CTE: 12 ppm/°C; non-wettable flank

B. PCB and board assembly

The boards are 8-layer boards with the 6 inner layers completely filled with copper in order to maximize the stiffness of the boards and obtain a CTE as close to that of Cu as possible. The total thickness is 2.4 mm.

The three different types of QFN's are soldered to the board with two different solder materials: SnPb and Sn3%Ag0.5%Cu. This makes that we have 6 different boards in test. An example of such assembly is shown in Fig. 3.

Fig. 3. Cross-section of QFN component soldered to a 2.4 mm thick PCB

C. Thermal Cycling test conditions

The IPC-9701 TC1 accelerated test condition for solder joint evaluation was selected as the most appropriate test.

- 0 to 100°C thermal cycling (air-to-air)
- Total cycling time = 1 hour
    - ramp up time = 10 minutes
    - dwell-time = 20 minutes
- In-situ measurement opens at all temperatures

III. RESULTS OF THE THERMAL CYCLING EXPERIMENT

Thermal cycling tests have been performed on six different configurations. For each configuration, 36 samples were taken for having sufficient statistics. A failure was detected when the resistance of the daisy chain, connecting all solder joints, increased with a critical value.

The results for the six configurations are plot as Weibull distributions, as shown in Fig. 4 and the Weibull parameters also summarized in Table 2.

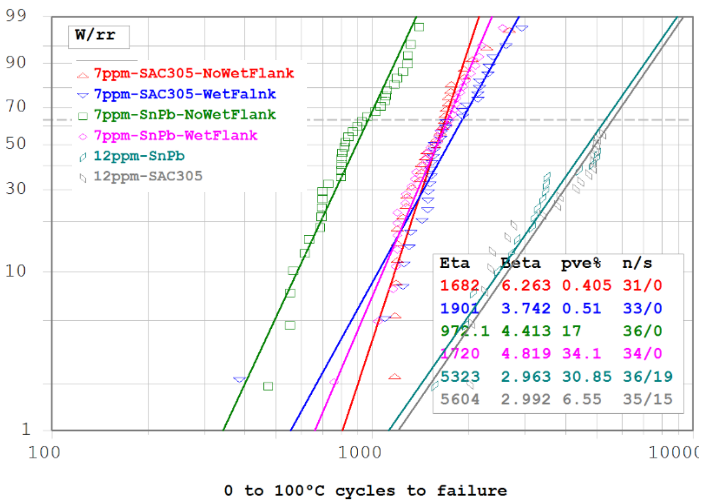

Fig. 4. Weibull distribution of 6 tested QFN64 solder assemblies.

TABLE II. CHARACTERISTIC LIFE AND BETA DISTRIBUTION PARAMETERS FOR THE SIX DIFFERENT CONFIGURATIONS

QFN type	Solder	N63%	β
QFN #1	SnPb	971	4.4
QFN #2	SnPb	1720	4.8
QFN #3	SnPb	5323	3.0
QFN #1	SAC305	1682	6.3
QFN #2	SAC305	1901	3.7
QFN #3	SAC305	5604	3.0

The results clearly reveal that the most dominant parameter is the CTE of the mold. For example for SAC305 assemblies, the difference between 7 ppm and 12 ppm/°C QFN's is a factor three. The other parameters have much less or even no impact on the BLR.

IV. Cross-Sectional Analysis

Cross-section have been made for the six different configurations in order to investigate the type of fracture.

Typically for all analyzed samples, one or even all four corner joints showed fractures leading to the daisy chain resistance increase. This confirms that the joint loads are related to the distance to neutral point, which is largest for the corner joints.

Another general conclusion was that the fracture was always inside the solder joint, and not at the intermetallic compounds nor the copper pad itself. The solder fractures are induced through low-cycle fatigue during the temperature cycling.

A. *QFN #1 + SnPb solder (failing after **971** cycles in average)*

This assembly showed the earliest failures. It can be related to the non-optimal wetting resulting in almost all solder at the side, however, not really functioning as a strong fillet. The rather thin stand-off height between the lead and pad, and without support from the fillet, results therefore in earlier solder fatigue fracturing.

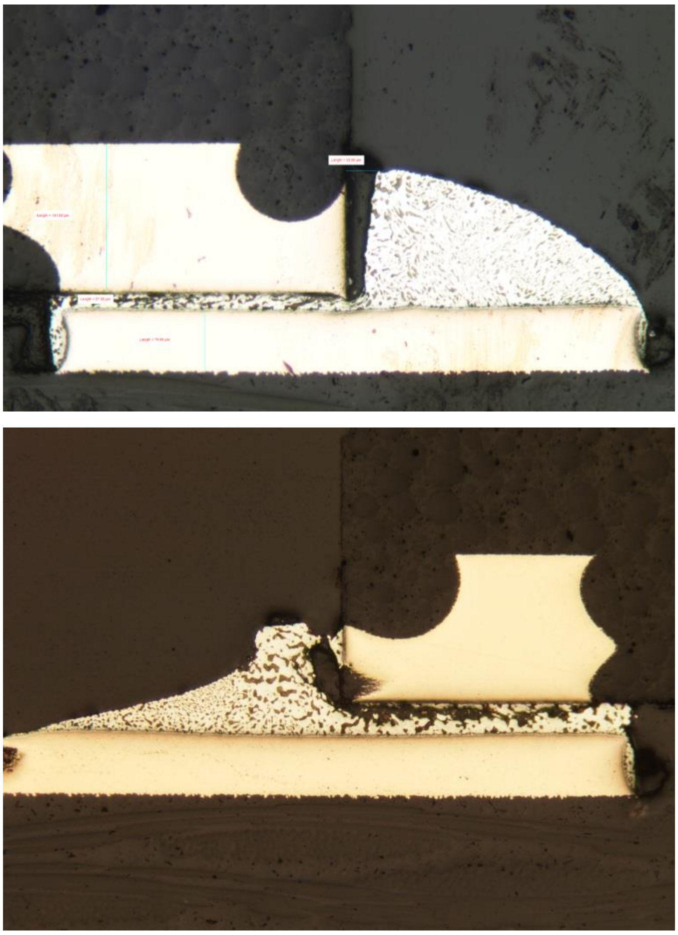

Fig. 5. Cross-section of SnPb soldered QFN component with 7 ppm/°C mold compound and non-wettable flanks

B. *QFN #2 + SnPb solder (failing after **1720** cycles in average)*

Thanks to the fillet, this solder joint can resist more cycle than the one above.

However, the cross-section shows strong damage which is due to the repeated large expansion mismatch between the component and board in each cycle, after it has already failed much earlier but while the test was still on going. This can only be explained by the low-CTE mold compound used in this QFN package.

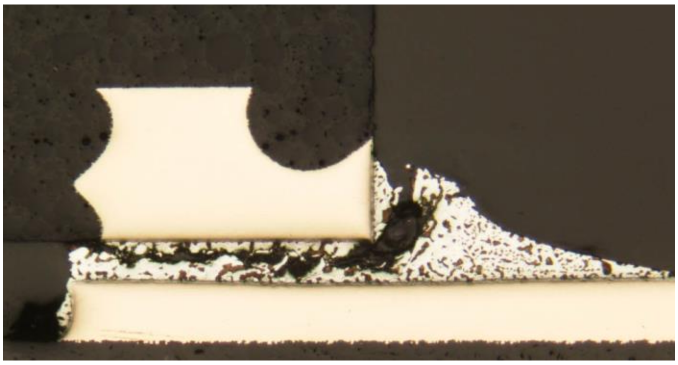

Fig. 6. Cross-section of SnPb soldered QFN component with 7 ppm/°C mold compound and wettable flanks

C. *QFN #3 + SnPb solder (failing after **5323** cycles in average)*

The QFN component with the 12 ppm/°C mold material survives about three time more temperature cycles. The fracture is visible, but there is not such a large damage as seen with the previous two cases.

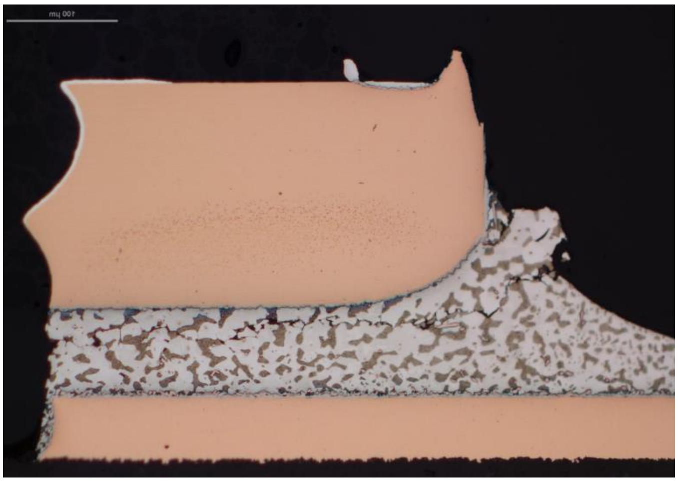

Fig. 7. Cross-section of SnPb soldered QFN component with 12 ppm/°C mold compound and non-wettable flanks

*D. QFN #1 + SAC305 solder (failing after **1682** cycles in average)*

While the SnPb soldered components showed very low stand-off heights, the same components soldered with SAC305 gave normal stand-off heights with even some side fillet, although the flanks were not be meant to be wettable.

The fractures are found near the interface with the lead of the component, however, still in the solder joint itself (no IMC failure).

Also here, we see quite some damage which is related to the large expansion mismatch between component and PCB.

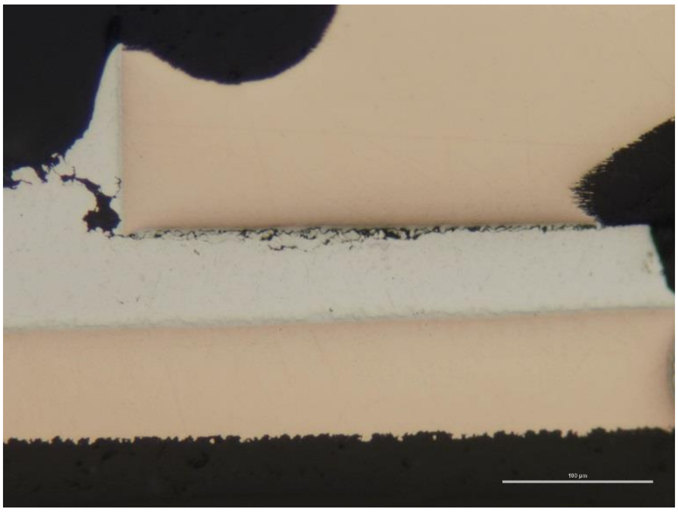

Fig. 8. Cross-section of SAC305 soldered QFN component with 7 ppm/°C mold compound and non-wettable flanks

*E. QFN #2 + SAC305 solder (failing after **1901** cycles in average)*

Similar conclusion as above. And as the solder joint shape is also similar to the non-wettable version, we indeed expect about the same life time.

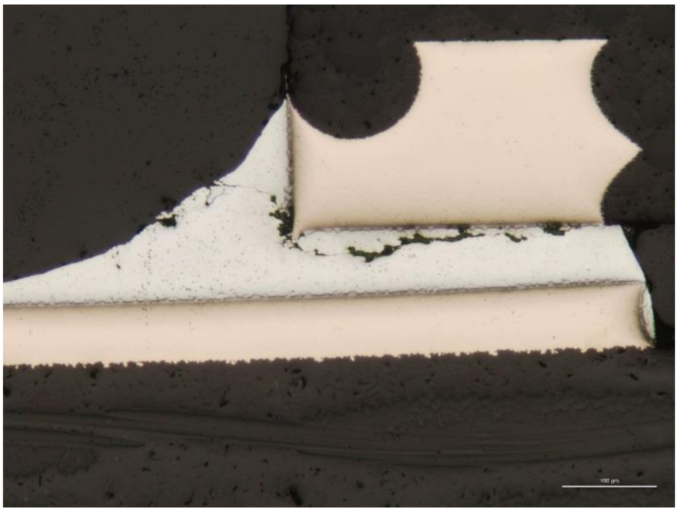

Fig. 9. Cross-section of SAC305 soldered QFN component with 7 ppm/°C mold compound and wettable flanks

*F. QFN #3 + SAC305 solder (failing after **5604** cycles in average)*

In the QFN component with 12 ppm/°C mold compound, we found a tiny crack over the whole length.

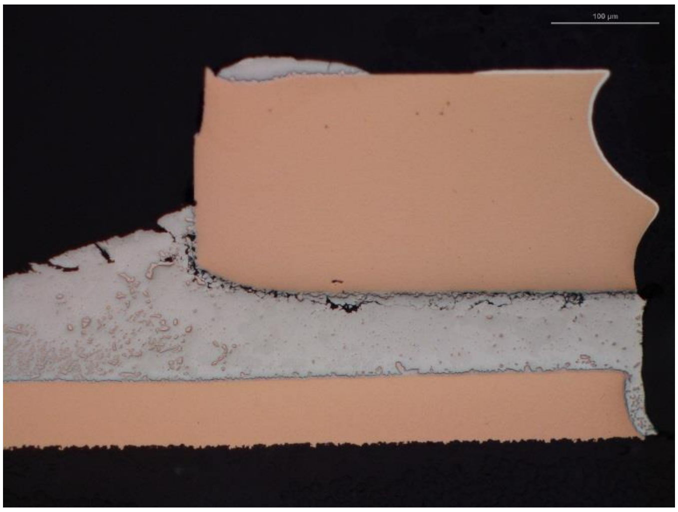

Fig. 10. Cross-section of SAC305 soldered QFN component with 12 ppm/°C mold compound and non-wettable flanks

Conclusions

In this work, BLR (board level reliability) tests have been performed on QFN 9x9 mm components with two mold compounds (7 ppm/°C, 12 ppm/°C), two solder materials (SnPb and SAC305) and two QFN lead finishes (wettable versus non-wettable flank). The samples have been tested under IPC9701-TC1 conditions (0 to 100°C) and the integrity of the solder joints were measured in situ.

The conclusion of the elaborated test was that the impact of the solder material and flank wettability was minimum (less than 20% of difference) while the mold compound had a high impact. The characteristic life time of the QFN's with 12 ppm/°C was 3 times higher than the QFN's with 7 ppm/°C.

For high reliability applications and electronics operating under severe conditions, this mold compound change creates a major reliability concern and requires thorough evaluation. The impact on electronics reliability is considerably greater than that of a change in solder alloy but as yet did not get a similar level of attention.

Acknowledgment

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