Hidden Head-In-Pillow soldering failures

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Abstract

One of the upcoming reliability issues which is related to the lead-free solder introduction, are the head-in-pillow solderability problems, mainly for BGA packages. These problems are due to excessive package warpage at reflow temperature. Both convex and concave warpage at reflow temperature can lead to the head-in-pillow problem where the solder paste and solder ball are in mechanical contact but not forming one uniform joint. With the thermo-Moiré profile measurements, this paper explains for two flex BGA packages the head-in-pillow. Both local and global height differences higher than 100 µm have been measured at solder reflow temperature. This can be sufficient to have no contact between the molten solder ball and solder paste. Finally, the impact of package drying is measured.

1. Introduction to Head-in-Pillow soldering issues

As an IC package consists of different materials (silicon, mold compound, underfill, BT substrate, copper leadrame, etc.) having different coefficients of thermal expansion (CTE), the materials expand or shrink differently under temperature changes resulting in mechanical stresses and global package warpage.

Excessive package warpage at temperatures above solder reflow temperature can lead to solder process failures. Both convex warpage (corners bends downwards) and concave warpage (corners bends upwards) can happen but they can lead to different kind of soldering failures.

When the package has an excessive **convex** deformation at reflow temperature (Figure 1), the outer solder joints can collapse such that two or more joints form one shorted joint. After cooling down below solder reflow temperature, this joint is frozen in and the component will indicate an electrical failure after assembly [6].

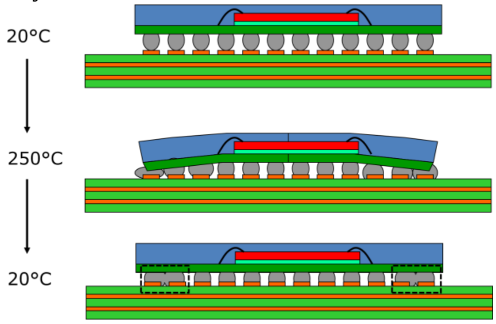

Figure 1: Schematic drawing indicating the impact of convex warpage at reflow temperature leading to shorts between balls

When the package has an excessive **concave** warpage, another soldering failure can be experienced. A too high concave warpage at solder solidification temperature can cause the so-called head-in-pillow where the solder paste deposit wets the pad, but does not fully wet the ball or the liquid solder connection gets disconnected without merging together again prior to solidification (Figure 2). This results in a solder joint with enough of a connection to provide temporary electrical interconnectivity but lacking sufficient mechanical strength (Figure 3). Due to the lack of joint strength, the joint will fail with little mechanical stress. This defect is usually not detected in electrical testing, and typically shows up as a field failure after the assembly has been exposed to some temperature increases where the BGA ball loses from the PCB solder pad due to package warpage.

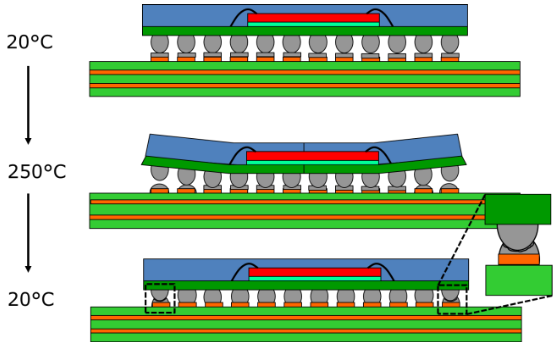

Figure 2: Schematic drawing depicting the consequences of concave warpage at reflow temperature leading to head-in-pillow failures.

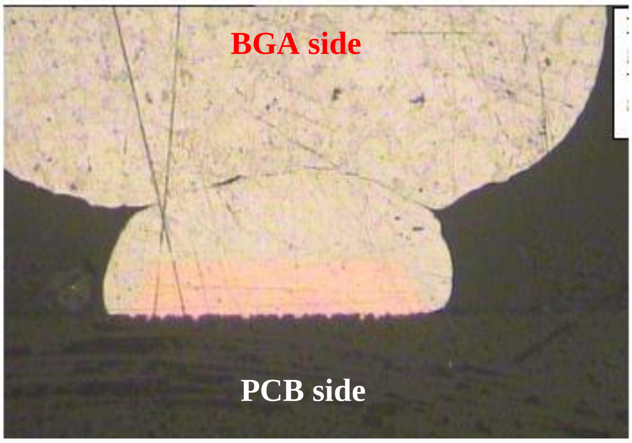

Figure 3: Cross-section visualising the head-in-pillow BGA joint seen after cooling down from soldering process. It actually looks like a head has pressed into a soft pillow.

Convex warpage can also lead to head-in-pillow in the center area: this depends a lot on the shape of the deformation, determining which solder joints can keep the package attached to the board.

The head-in-pillow failure mode gained a lot of importance since the transition to lead-free assembly [1, 2, 3]. About 30°C higher reflow temperature causes more absolute deformation. And the use of low-CTE (7 to 10 ppm/°C) mould compounds increasing the CTE mismatch with the PCB (14-18ppm/°C) and the BT substrate (14 ppm/°C) [3]. In particular the latter one brings back the head-in-pillow as critical process failure issue (which was basically non-existing in the pre-leadfree/green mould era). Moisture uptake of the package and/or PCB can also have an impact on the warping behaviour of the package, as it will also be revealed later in this paper. Baking of the packages can be one of the solutions.

While warpage is the main source of the head-in-pillow problem and therefore should be well controlled, improving the flux chemistry in combination with an optimised thermal profile can also reduce the issue. When the BGA solder ball is not in contact with the solder paste (including the fluxing agent), the ball oxidises and when the ball comes back to the solder paste, the fluxing agent can be gone. The addition of flux dipping, and/or N_2 gas reflow both reduces the HiP defect rate.

Increasing the paste volume is also recommended. This can be done by using square aperture vs. round opening, or by enlarging overall deposition volume without jeopardizing bridging.

2. Sample description and measurement setup

This paper reports the head-in-pillow soldering failures experienced with two flex BGA packages. The basic geometrical properties of these two packages are summarised in Table 1.

Table 1: Description of two flex BGA packages measured in this work

17mm FBGA	1 mm pitch, 0.5 mm ball size 256 pins (16x16 area array) 17x17x1.4 mm^3 
27 mm FBGA	1 mm pitch, 0.64 mm ball size 676 pins (26x26 area array) 27x27x2.25 mm^3 

In order to be able to explain the head-in-pillow soldering issues, measurements of the warpage during a solder reflow profile are measured using the INSIDIX measurement system [1]. The warpage is measured experimentally by means of a topography and deformation measurement (TDM) and is based on the Projection Moiré principle. A light projector illuminates the sample with a striped light pattern consisting of equidistant parallel lines, under an angle of about 45˚. The projected light pattern is recorded by a camera. If the sample surface is curved, there will be a variation in the recorded light pattern. By measuring the offset between the projected and recorded pattern, one can calculate the amount of curvature. In addition, the sample can be heated up and cooled down while performing TDM. This allows to simulate the temperature profile of manufacturing processes and to calculate the corresponding warpage evolution.

A typical reflow temperature profile has been applied to these packages, with a maximum of 245°C.

3. Hidden head-in-pillow solder failure for 17 mm flex BGA packages

As the 3D profile of the bottom side of the BGA is difficult to measure due to the balls, the warpage was measured at the top “mould” side of the package. The package was stored at room temperature and did not have any drying nor wetting process in advance. It is expected that the package took up some moisture.

Figure 4 shows the measured out-of-plane profiles of the 17 mm size packages at different temperature stages of the solder temperature profile. It can be seen that the package is rather flat at room temperature and a convex warpage is found in particular above 200°C, with a highest deformation at 245°C.

Figure 5 shows the difference between the topography profile at 245°C and at 23°C. The delta graph obviously indicates that this BGA package gets a convex deformation when it is at the highest temperature. The four corners are warping down. Figure 6 shows this out-of-plane deformation over the diagonal. The package warps almost **150 µm** and this explains why the inner balls are having a potential for having the head-in-pillow solder failure.

The JEITA ED7306 guideline sets that for package with 1 mm pitch and 0.5 mm ball height, the maximum permissable warpage is 220µm. Taking into account that the board itself also can warp and at room temperature, the flex side is already warped down several tens of microns, the measured warpage comes close this critical value.

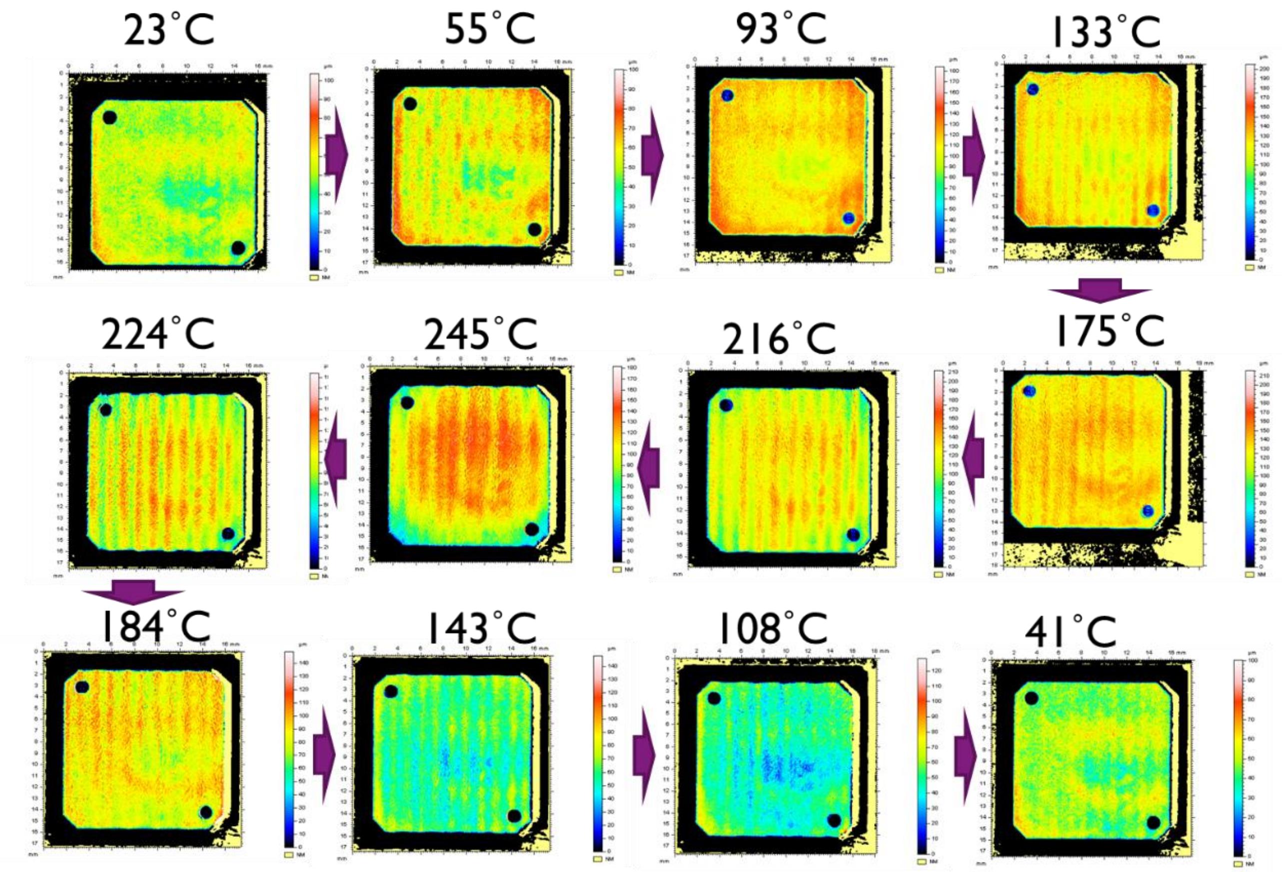

Figure 4: 3D profile of the 17 mm flexBGA package measured during a solder reflow profile. The package was stored at room temperature being able to take up some moisture

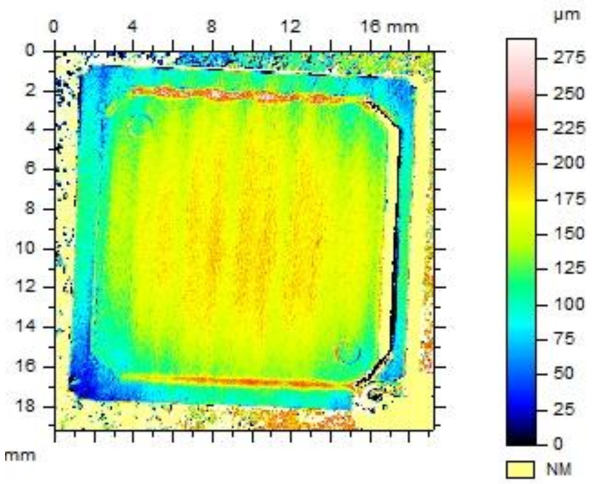

Figure 5: Difference in z-deformation between 245°C and 26°C. This plot indicates that the package has a convex deformation from room to reflow temperature (17 mm FBGA)

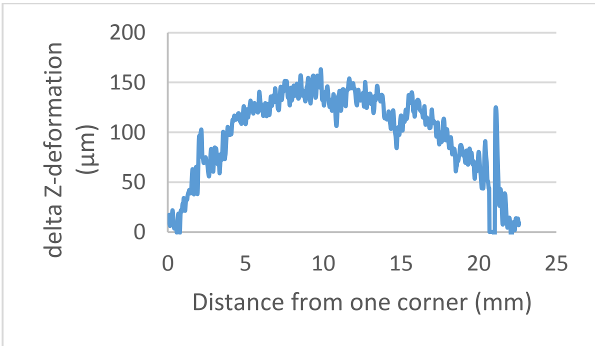

Figure 6: Delta warpage between 246°C and 26°C shown over one diagonal (17mm FBGA)

As shown in Figure 7, the convex warpage mainly occurs above 180°C. This is caused by the higher thermal expansion of the mould compound than the expansion of the laminate. The turning point around 110°C is probably related to the glass transition point Tg of the mould compound. Below this Tg, the CTE of the mould compound is lower than the one of the laminate.

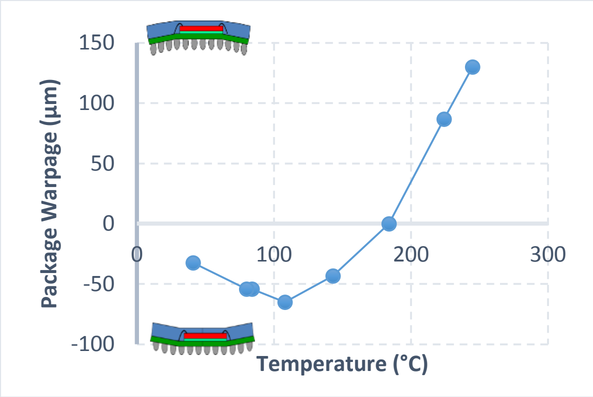

Figure 7: Warpage evolution of 17 mm FBGA as function of temperature

4. Hidden head-in-pillow solder failures for 27 mm flex BGA packages

For a 27x27 mm^2 flex BGA package with 1 mm ball pitch, another kind of "hidden" head-in-pillow was experienced. The non-wetted balls were not found in the inner area like with the 17 mm package, nor at the edge, however, they were found in the third and fourth outer row. Soldering issues for the same package type were also reported by reference [5].

In order to explain this result, the warpage versus temperature measurements were performed on this package with the same measurement approach. The topographies at different temperature stages are shown in Figure 8.

At room temperature, the package has some convex warpage. But at temperatures above solder reflow temperature, the package gets a concave shape. This is however only for the inner area. The edges and the four corners are still warping downward when the temperature rises, as it is indicated in the delta contour plot in Figure 9 and the z-deformation over the diagonal Figure 10.

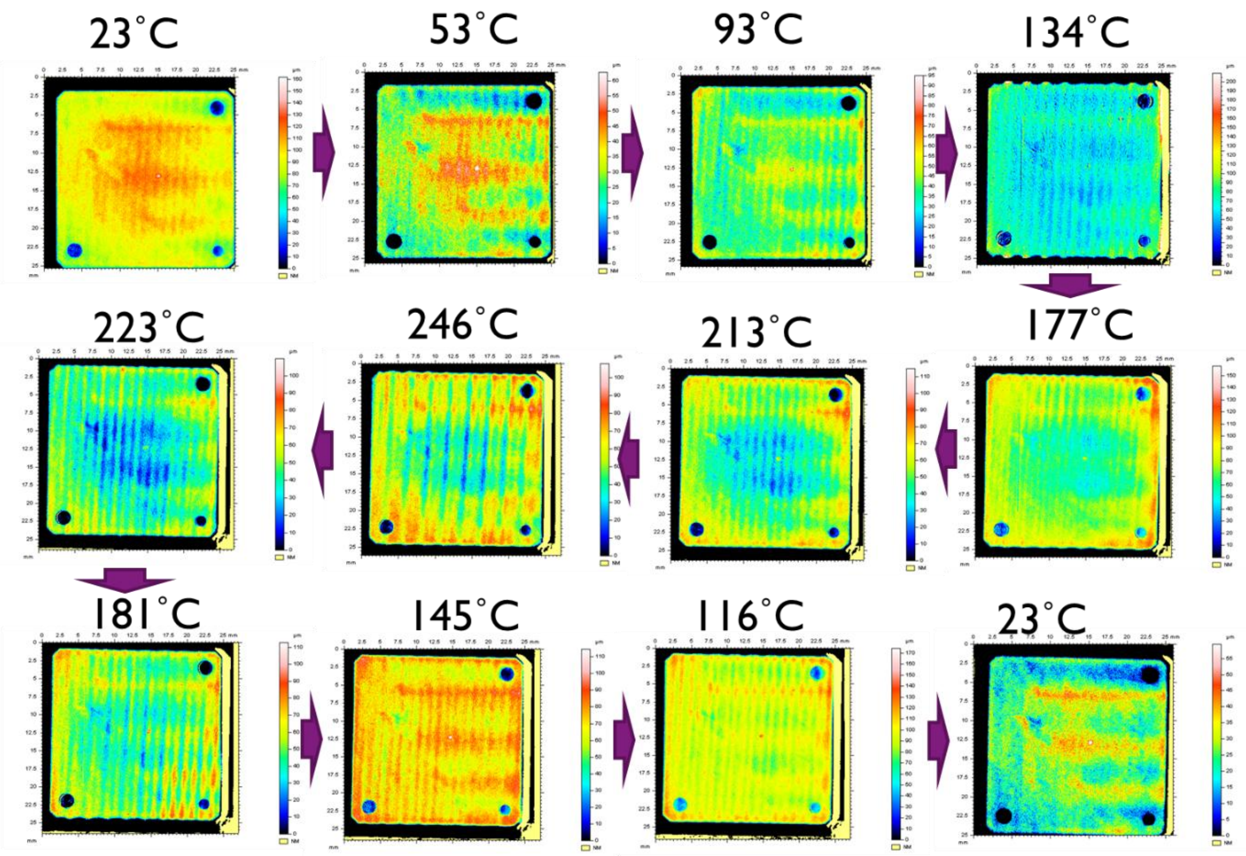

Figure 8: Warpage of the 27 mm FBGA package measured during a solder reflow profile.

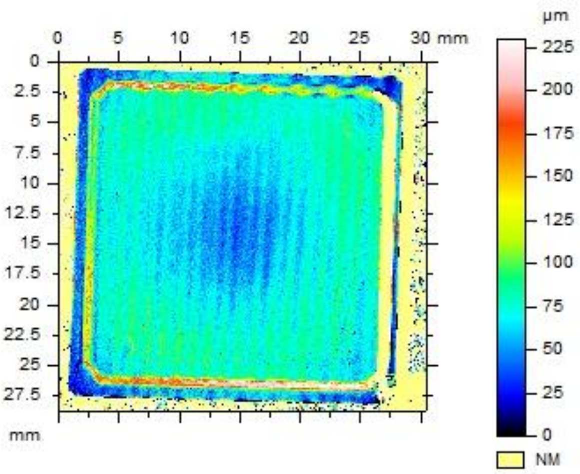

Figure 9: Difference in z-deformation between 245°C and 26°C for the 27 mm FBGA

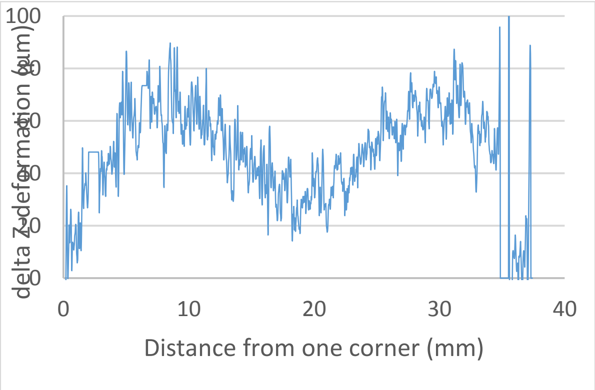

Figure 10: Delta warpage between 246°C and 26°C shown over one diagonal (for 27mm FBGA).

The consequence of such deformation profile at reflow temperature is that at about 3 to 4 mm from the edge, the package is at highest point. With a 1 mm pitch, this means that the third and fourth row of solder joints have the risk to have no contact with the printed circuit board leading to the head-in-pillow issue experienced with this package. This is schematically shown in Figure 11. Taking into account already some initial convex warpage of the package at room temperature and also the outer unmoulded flex substrate which is warping down, we can easily have a height difference of 100 µm between the third and the outer row of solder joints at reflow temperature. This can be sufficient to get the head-in-pillow issue.

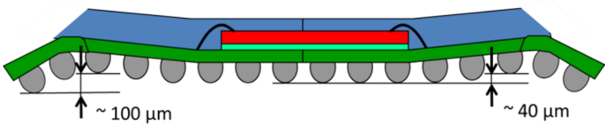

Figure 11: Schematic drawing showing the deformation of FBGA 27mm package at reflow temperature. Between the third and outer row of solder joints, about 100 µm height difference was measured.

5. Impact of moisture on risk for head-in-pillow

The warpage-temperature evolution has been measured for three 17mm FBGA packages with following pre-conditions:

- the package stored at room temperature: this is the one which has been presented in section 3
- the dried package which has been put for 5 days at 125°C
- the wetted sample which was put for 15 hours in the 85°C/85% oven

Figure 12 shows the warpage evolution for the three pre-conditions. As expected, the highest warpage was found for the wetted package, the lowest for the dried package. The difference is about a factor 4. The stored sample is lying in between the two curves. Drying these packages before the reflow process gives a reduction of about 2.5 in warpage and probably solves the head-in-pillow issue.

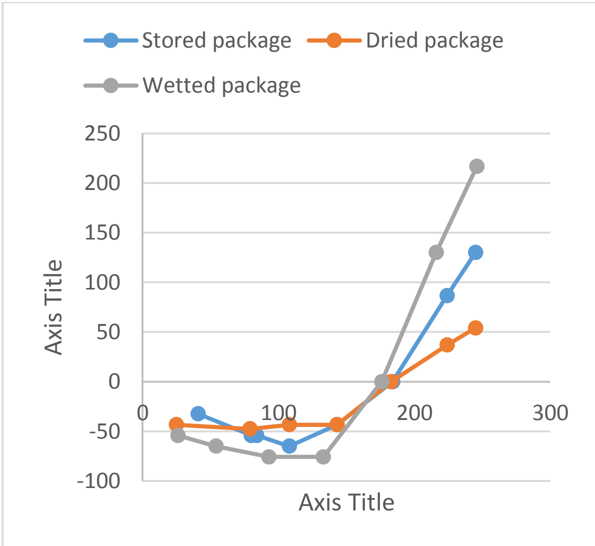

Figure 12: Warpage evolution of 17 mm FBGA as function of temperature.

6. Conclusions

Head-in-Pillow is a challenging and complex soldering problem with much risk for the OEM. A head-in-pillow defect is the incomplete coalescence of the solder joint between a BGA and the printed solder paste.

Following conclusions and recommendations are defined in this work:

- when head-in-pillow failures are experienced after soldering, Project Moiré measurements are very useful to visualise and quantify the warpage problem
- for two flex BGA packages, a high warpage at reflow temperature was measured which explains the head-in-pillow sensitivity of these package

- although both packages are flex BGA's, the HiP balls are found at different locations: the 17 mm has the highest problems in the center area, the 27 mm FBGA has the HiP balls in the third and fourth outer row
- besides improving solder paste and temperature profile conditions, drying the packages reduces the warpage and the risk for head-in-pillow. The reduction in warpage was a factor 2.5 for the 17 mm FBGA

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References

1. Scalzo, M., "Addressing the Challenge of Head-inPillow Defects in Electronics Assembly", Indium Corporation Technical Library, 2009.
2. Vandevelde, B. Excessive warpage of large packages during reflow soldering. In: The ELFNET Book on Failure Mechanisms, Testing Methods and Quality Issues of Lead Free Solder Interconnects. Springer; pp.283-296; 2011. (Chapter 13)
3. Vandevelde B., Deweerdt R., Duflos F., Gonzalez M., Vanderstraeten D., Blansaer E., Brizar G., Gillon R. (2009), Impact of Moisture Absorption on Warpage of Large BGA packages during a lead-free reflow process, pp. 162-165, Therminic Workshop, Leuven, Belgium.
4. M. Hertl, D. Weidmann, and J-C. Lecomte (2009), Process Optimization: Influence of Heating and Cooling Rate on the Thermo-Mechanical Stress Generated in Components, EMPC2009, Rimini, Italy.
5. A. Arazna, G. Koziol, W. Steplewski, K. Lipiec, Head on pillow defects in BGAs solder joints, ESTC conference, 13-16 Sept. 2010, Berlin, Germany.
6. B. Vandevelde, M. Lofrano and G. Willems, Green mold compounds: impact on second level interconnect reliability. In: Electronics Packaging Technology Conference - EPTC. ieee, 2011. (7-9 December 2011; Singapore, Singapore.)