Determination of strength of interface in packages based on an approach using coupling of experimental and modelling results

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Purpose

- Modelling is commonly used to predict lifetime of packages (component & assembly), but encounters some difficulties & issues :
  - Predictive reliability mostly dedicated to solder joints, and failure of interfaces (links between 2 materials) is often neglected
  - Parameters (material, manufacturing steps …) are sometimes unknown, and thus difficult to implement in models
  - In most cases, mechanical stresses induced by manufacturing process are not taken into account

Outline

- Introduction and Objectives
- Sample selection and preparation
- Experimental approach
- Modelling approach
- Conclusion

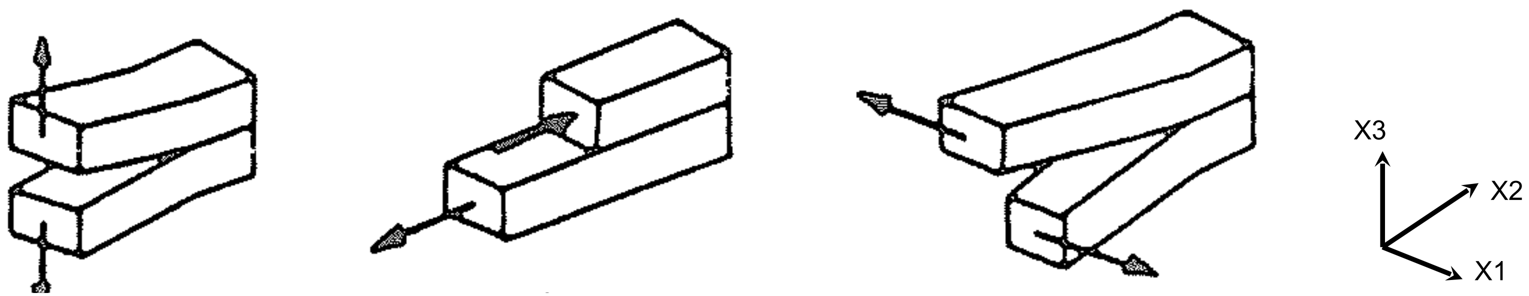
Introduction

- **Improve modelling calculation accuracy to have the more realistic prediction of electronic assemblies lifetime behavior**

- **The idea is to use real measurement results (real stressed states) to adjust, implement, and verify models.**

Sample selection and preparation

- Crack driven by two parameters
  - σ_t: traction (normal to interface crack)
  - τ_r : shear (in plane of interface crack)



Mode I
Tensile

Mode II
Shear

Mode II
Shear

Sample selection and preparation

- **Criteria for initiation of debonding :**
  - **Allows to take into account all the modes of stress of the crack**

$$(\sigma/\sigma_c)^2 = (\sigma_{33}\,|\sigma_{33}| / \sigma_t^2 + (\sigma_{12}^2 + \sigma_{23}^2)/\tau_r^2)$$

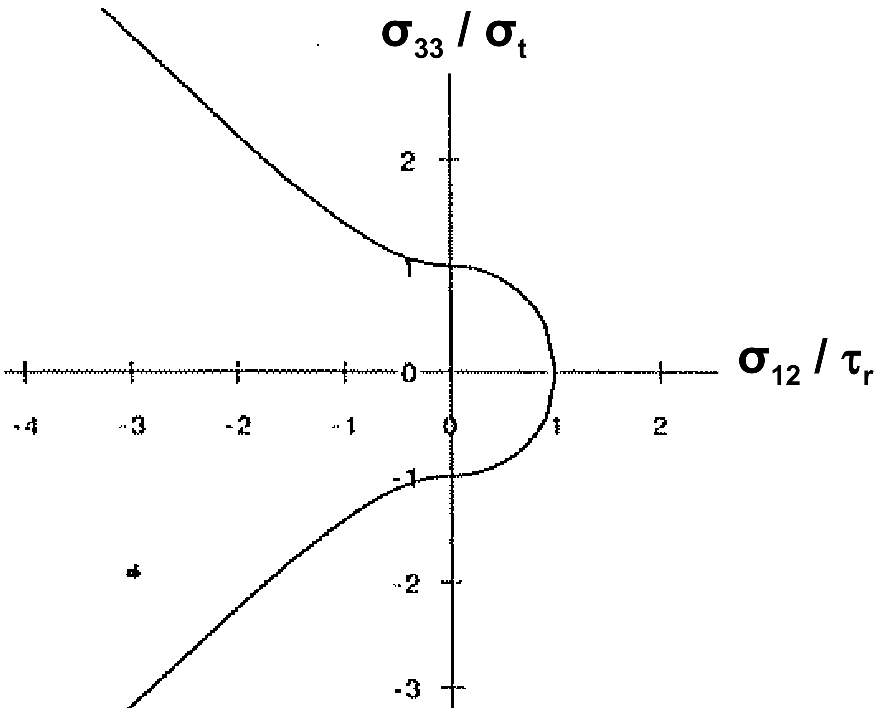
σ_t = **traction stress**

τ_r = **shear stress**

$\sigma_{ij\ \text{for } i,j=1 \text{ to } 3}$ = **stress tensor**

σ_C = **critical stress**

σ = **maximal stress**



Crack criteria curve

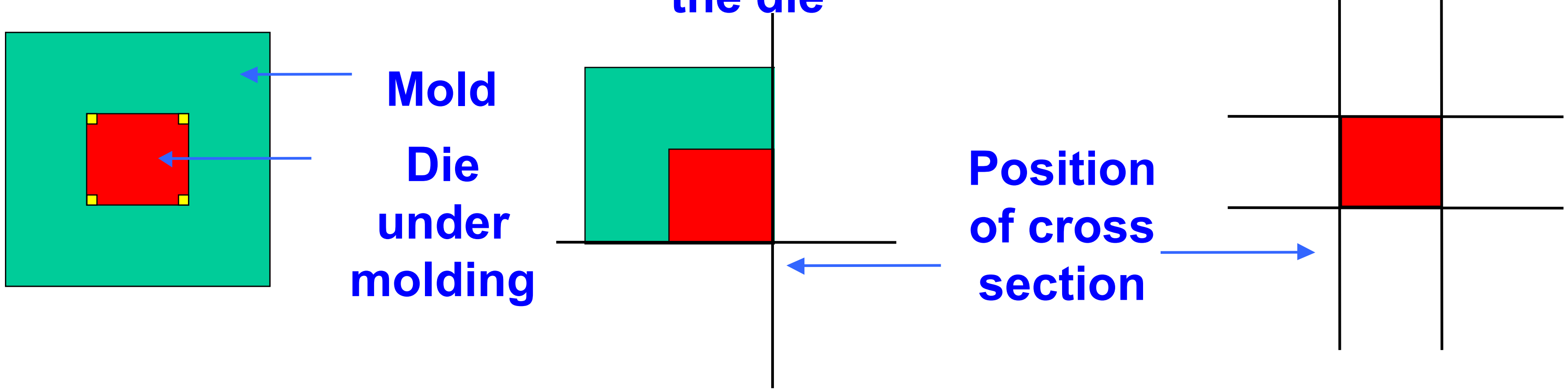
Sample selection and preparation

- It has been decided to work on the basis of real, but simple, components : BGA with one die, with specific preparation.
- Two types of cutting have been realized through the component in order to amplify and differentiate stresses and debonding in the component.

Whole BGA type samples

Same BGA with 2 cuts out around 2 perpendicular sides of the die

Same BGA with 4 cuts out around the die



Experimental results

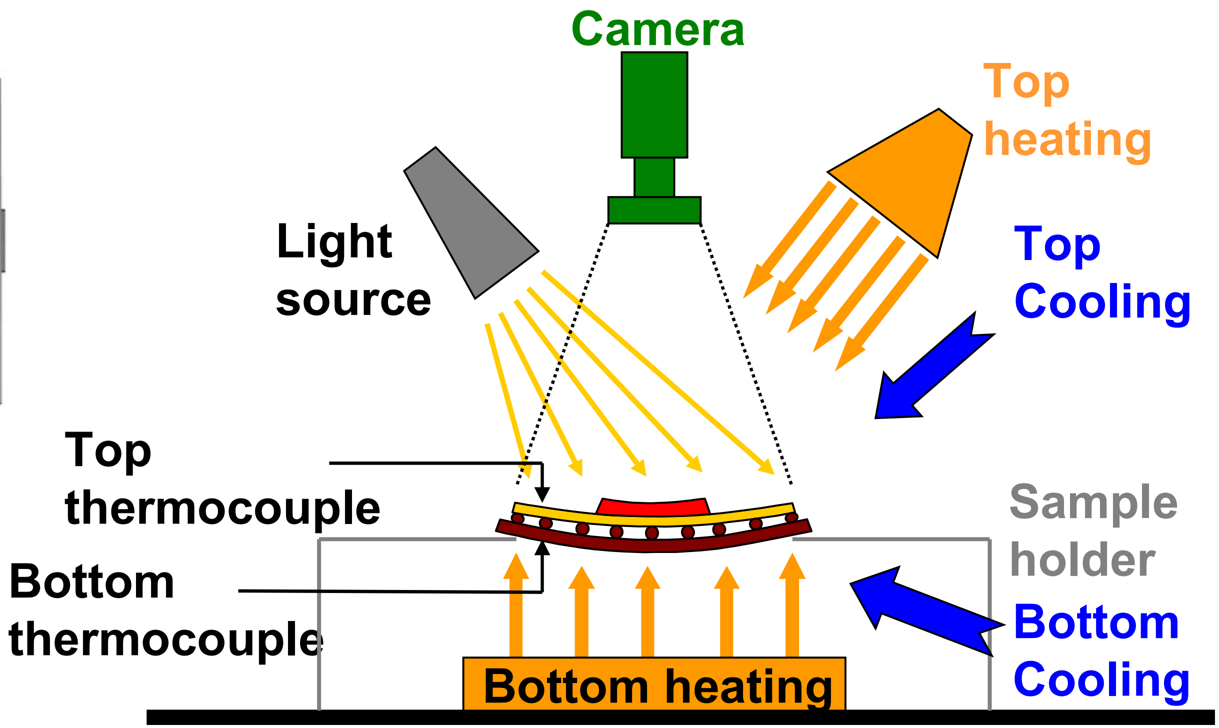
- **Measurement Techniques**

  - **Inspection using scanning acoustic microscopy is the only non destructive method to detect delamination in electronics components: BGA, Flip chip, SOI, Mems…**

  - **TDM is a tool developed by Insidix able to measure sample topography and deformation at the same time as a thermal stress is applied. Thus, one can have a “live” overview of samples behaviour during reflow or gluing process, during aging tests, …**

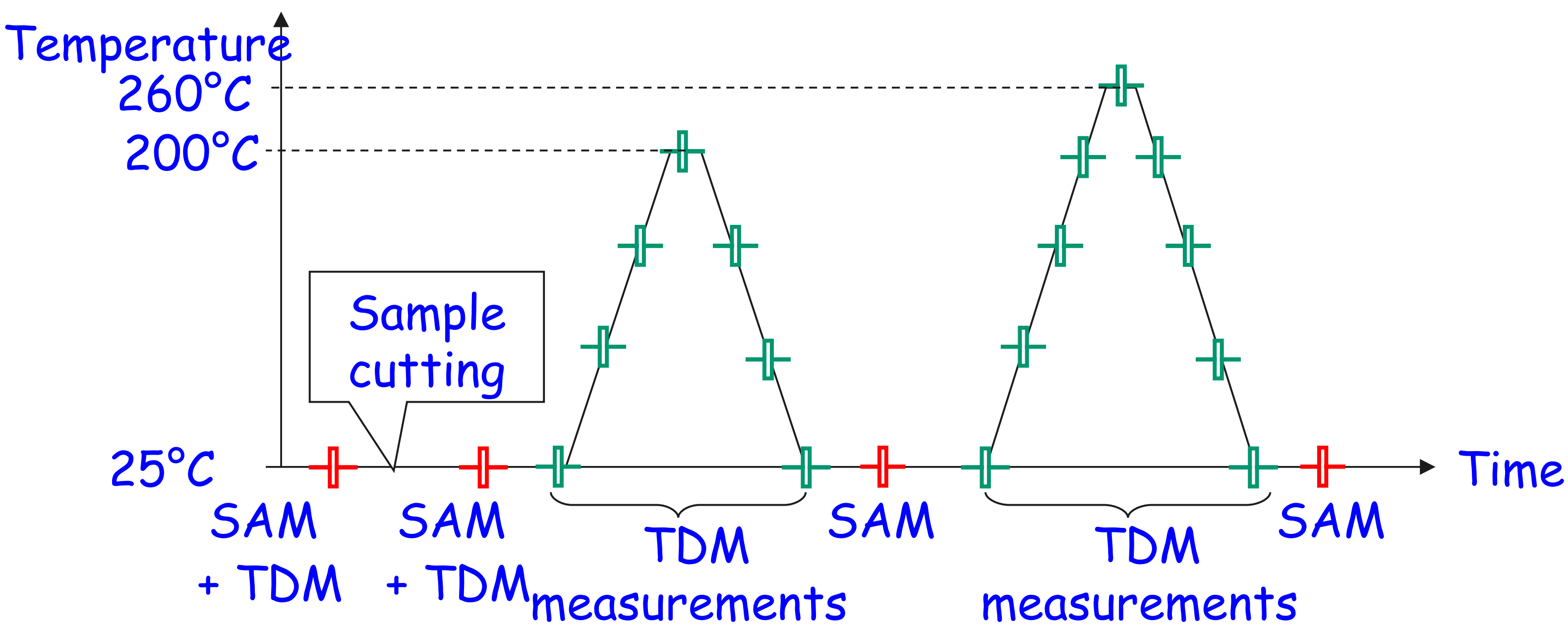
Experimental results

– High resolution and fast full field optical measurement (absolute and relative)
– Stable and manageable oven
– As representative as possible to real samples thermo-mechanical stress (Jedec profiles, etc)



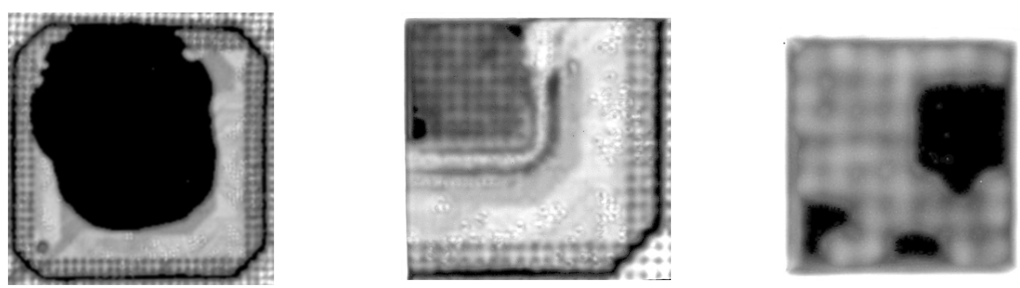
Experimental results

- Experiments
  - SAM of BGA before sample preparation,
  - SAM after sample preparation
  - Thermal stress, low speed :
    - TDM during heating up to 200°C + SAM back to 25°C
    - TDM during heating up to 260°C + SAM back to 25°C



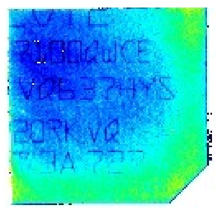
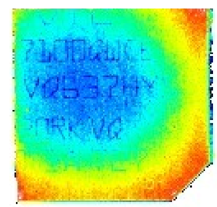
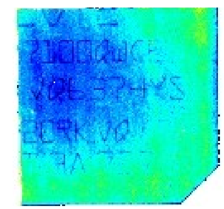
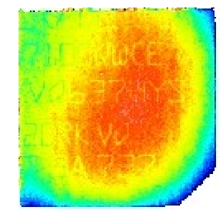
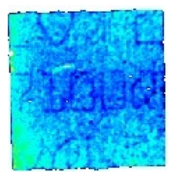
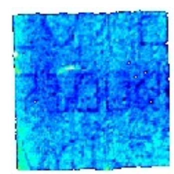
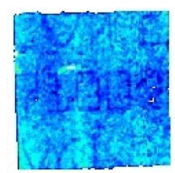
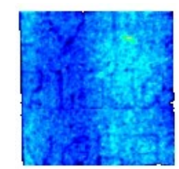
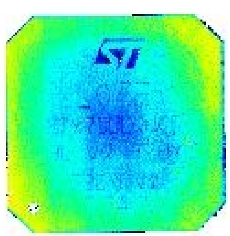
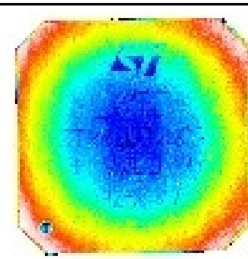
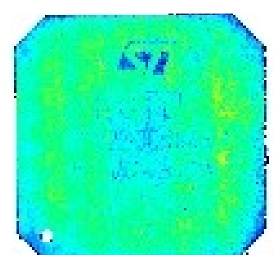
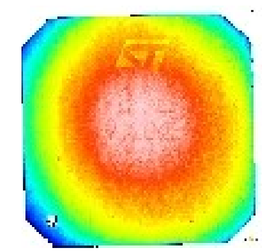
Experimental results

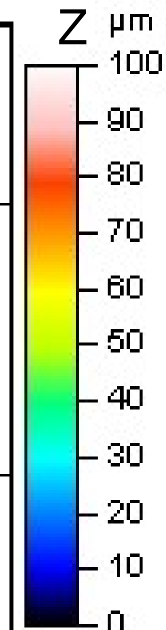
- **SAM**
  - No delamination or heterogeneity detected at initial state, after sample cut, and after heating up to 200°C
  - Delamination after the second thermal cycle, at die / substrate interface (die attach) for all samples, and also at molding compound/substrate for complete BGA.

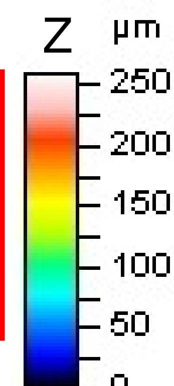


Through mode images after 260°C thermal cycle – black areas indicates delamination in the package. From left to right : whole BGA (large interface crack), BGA with 2 cuts along die, BGA with 4 cuts around the die

Experimental results

	25°C initial	25°C after cut	125°C	200°C	260°C
C1					
C3					
C5		**Not concerned**			





Topography images at 25°C, 125°C, 200°C and 260°C of 3 samples (BGA with 2 cuts along die, BGA with 4 cuts around the die, whole BGA)

Experimental results

- **The components were concave at initial state. The amplitude varies from -30µm to -50µm.**

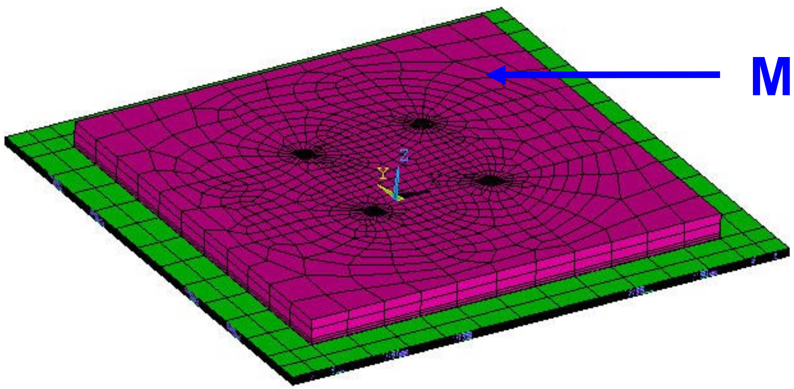
- **These surface geometries and the differences between one component to another one are due to residual stress after production.**

- **When the sample is cut, warpage variations are different, because strain at boundaries and also neutral fibre are not the same.**

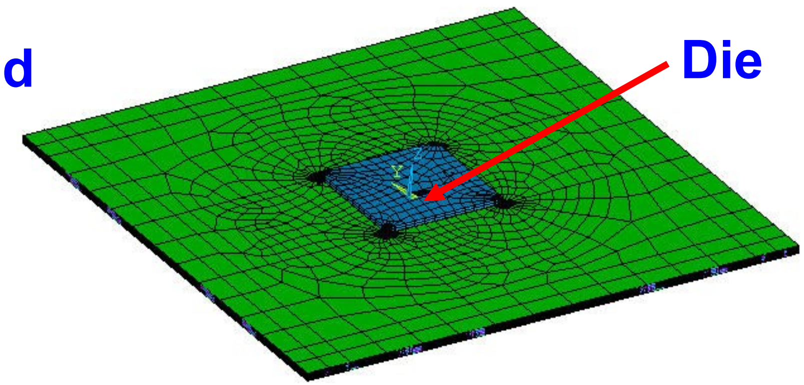
- **Warpage variations before and after glass transition (Tg) are often different – here it causes 4 increasing and decreasing of warpage between 25°C and 260°C, stressing then the interfaces.**

Modelling approach

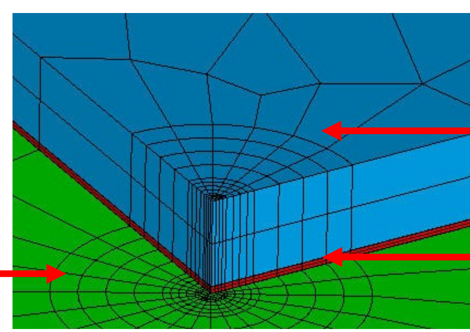
- The component has been represented fully in order to have a displacement profile with or without cutting it
- Materials properties are thermo-elastic



Finite elements model



Model without mold



Zoom at attach corner

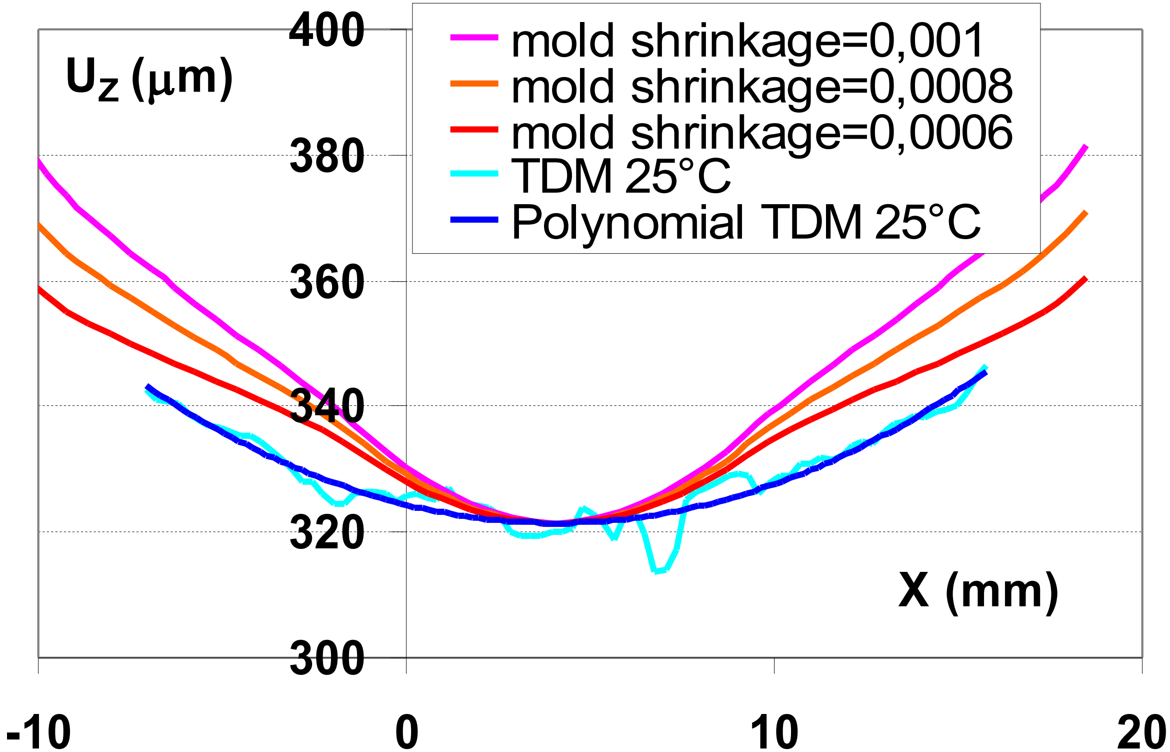
Modelling approach

Procedure steps

- Fab. process : die report on lead-frame (up to 275°C) & encapsulation (up to 180°C).
- Influence of 3 parameters (mold & glue shrinkage, CTE_{mold} with Topography measurements at 25°C
- Cutting of samples and thermal loads
- Calculation and adjustment of parameters on the whole component
- Calculations and checks of results on cut components

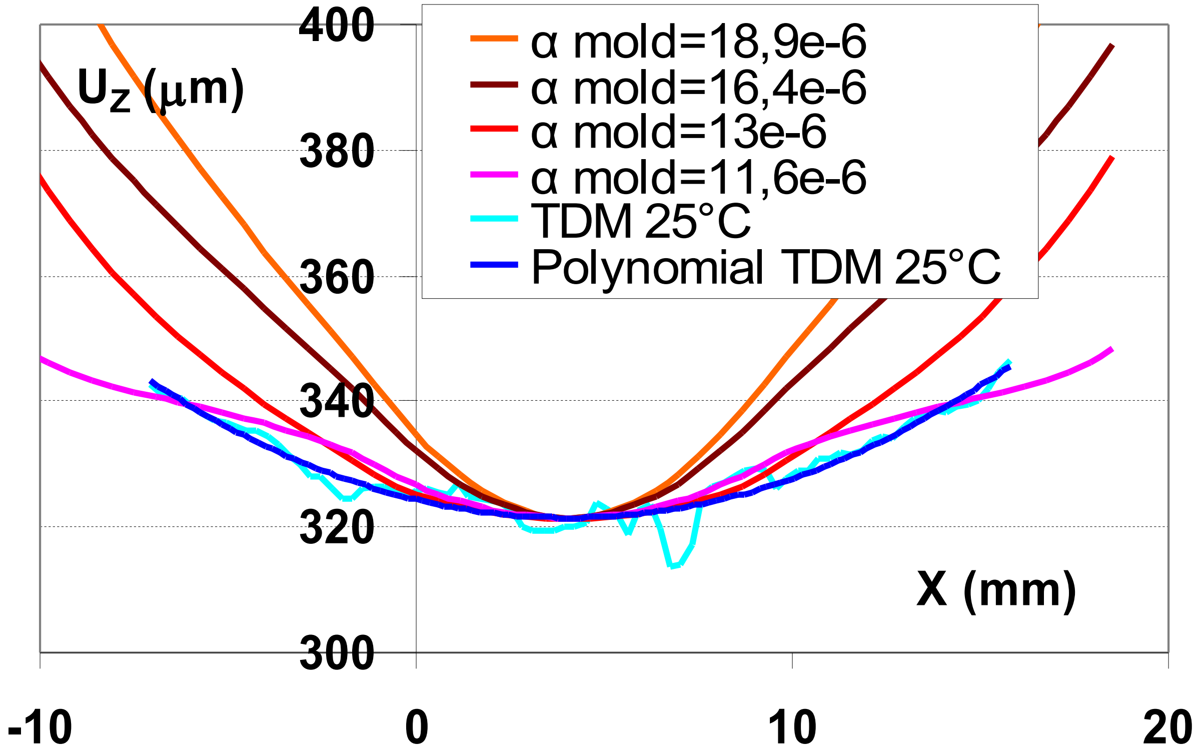
Influence of 3 parameters

- **Influence of the 3 parameters for the adjustment:**
  - **Mold shrinkage: large impact on mold deformation, curvatures increases with mold shrinkage**



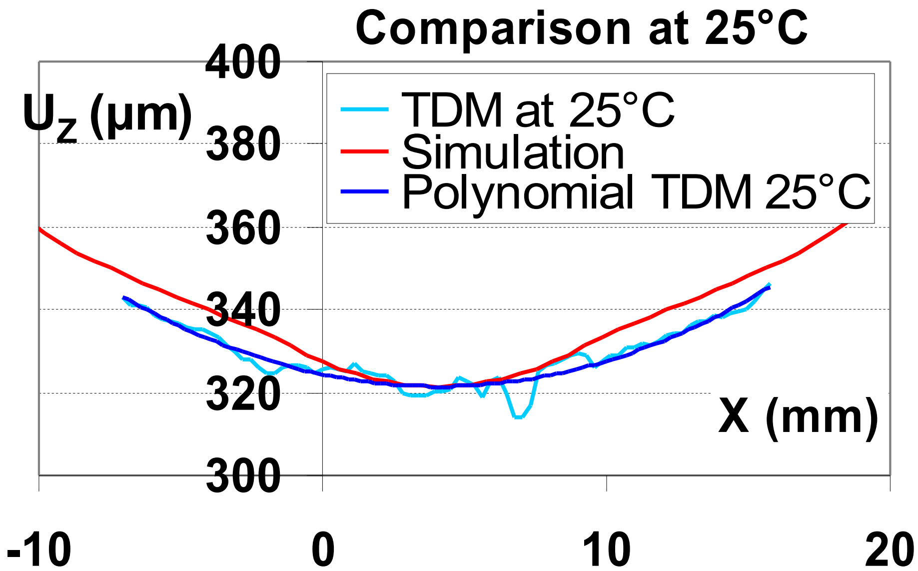
Influence of 3 parameters

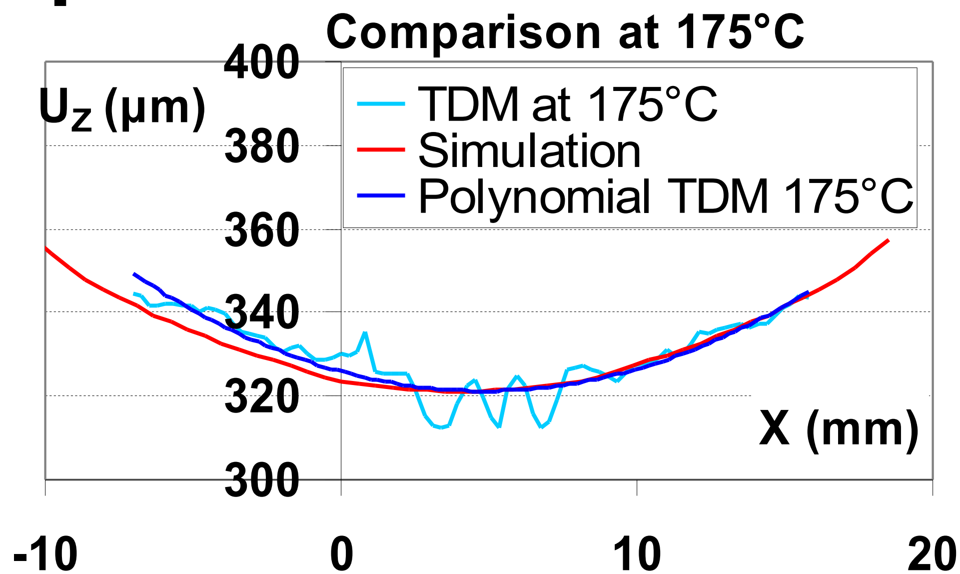
– **CTE_{Mold}: large impact on mold deformation, curvatures increases with the Coefficient of Thermal Expansion. Compared to mold shrinkage effect, CTE has wider effect.**



– **Glue shrinkage: the impact is negligible**

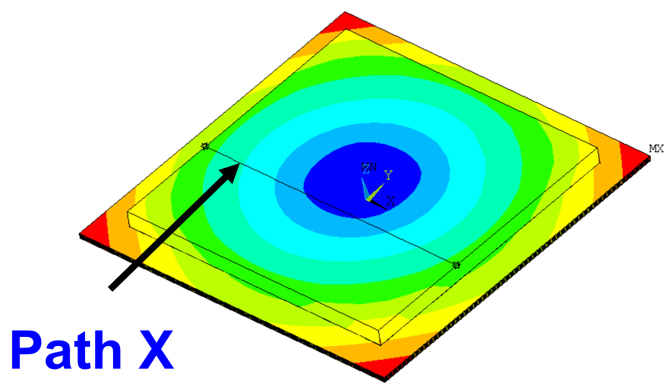
Calculations and adjustments on whole component





Final adjustment of displacement for the whole component

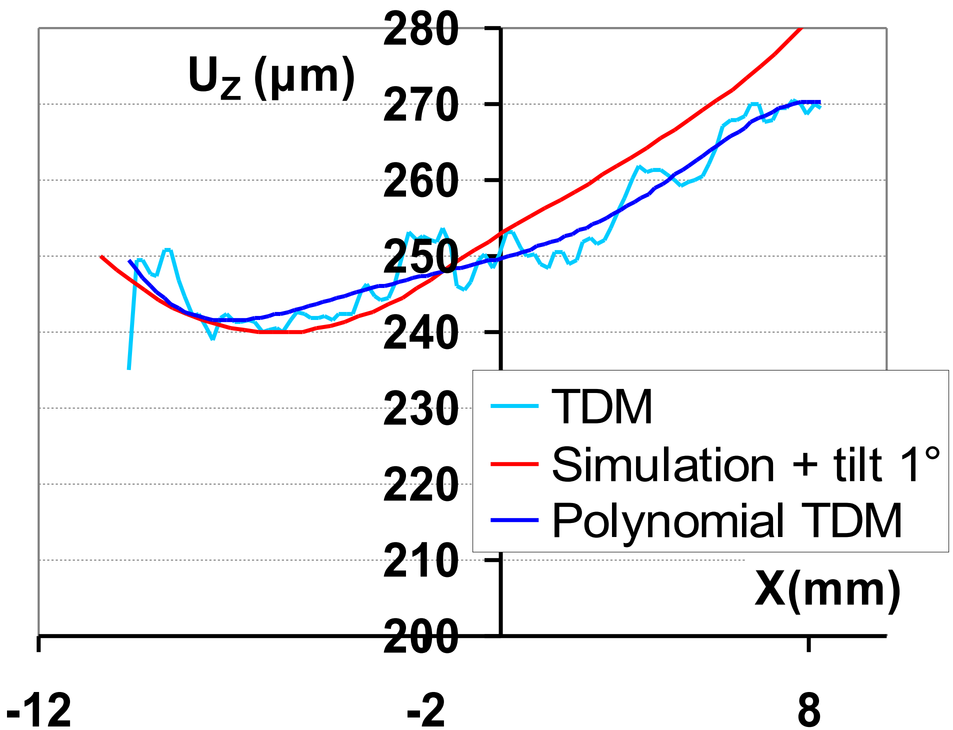
- **Simulation curves (in red) are fitted with the following parameters:**
  - **mold shrinkage: 0.05%**
  - **glue shrinkage: 0.3%**
  - **CTE_{Mold} at 25°C = 13 ppm**



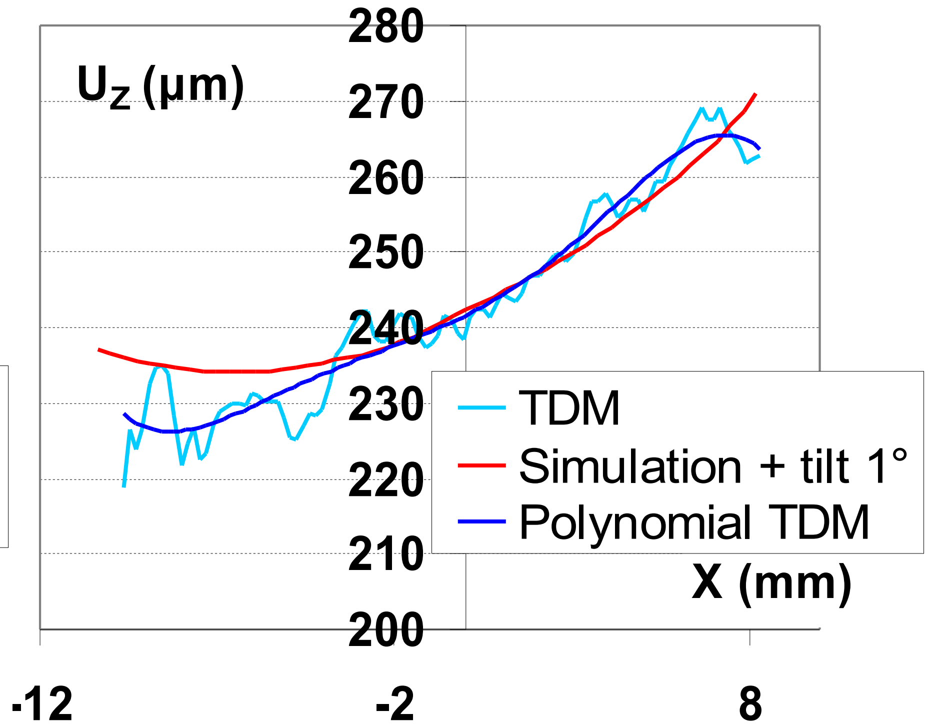
Check on cut component

- **Adjustments of shrinkage is checked after the cutting at 25°C and 175°C**

Comparison at 25°C



Comparison at 175°C

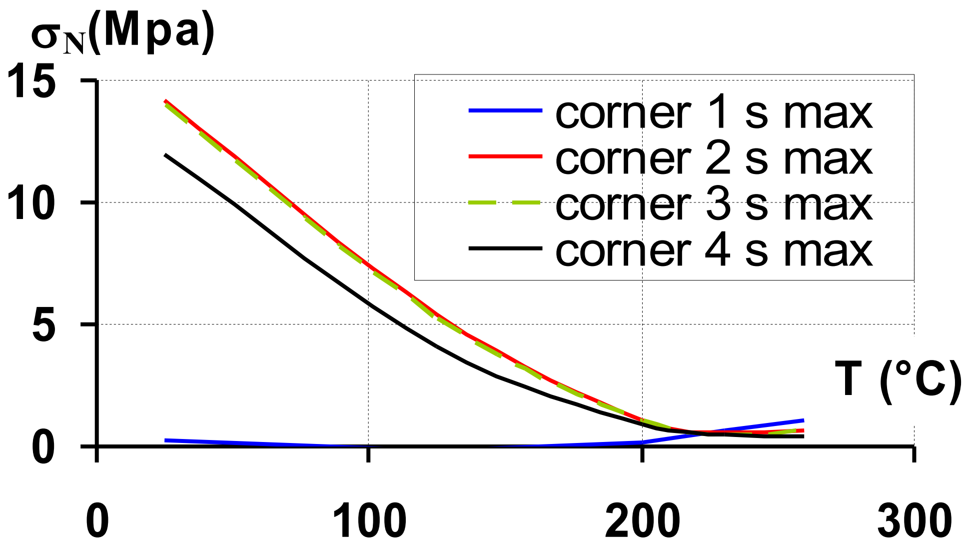


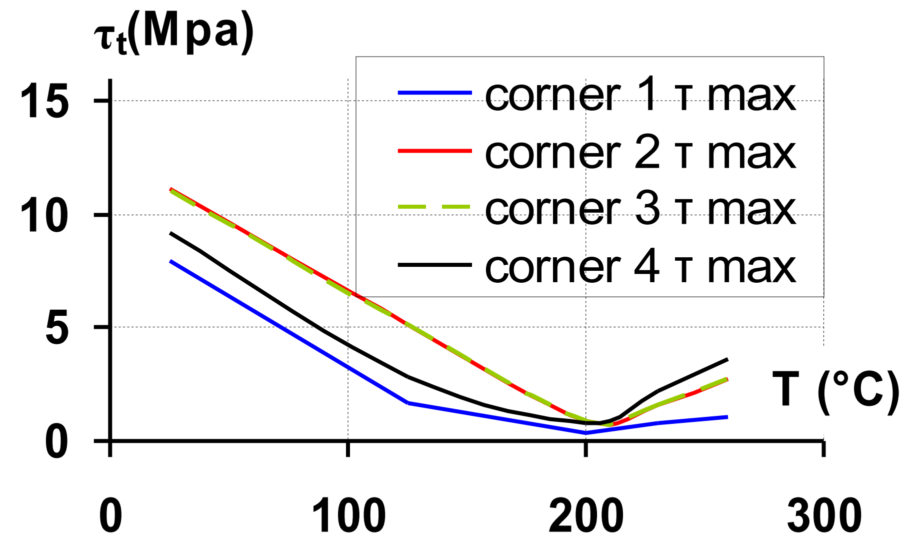
Adjustment of displacement for the cut component

- **Simulation curves rather fit measurements, with a small difference at the "free" corner.**

Stress values for cut component

- To compute failure behavior, maximum stresses at the interfaces have to be determined.

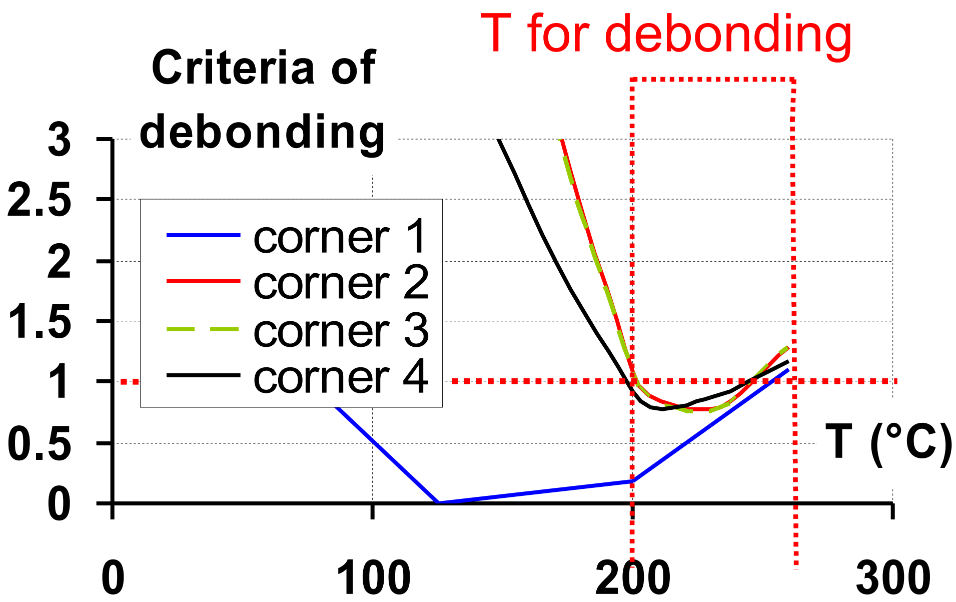


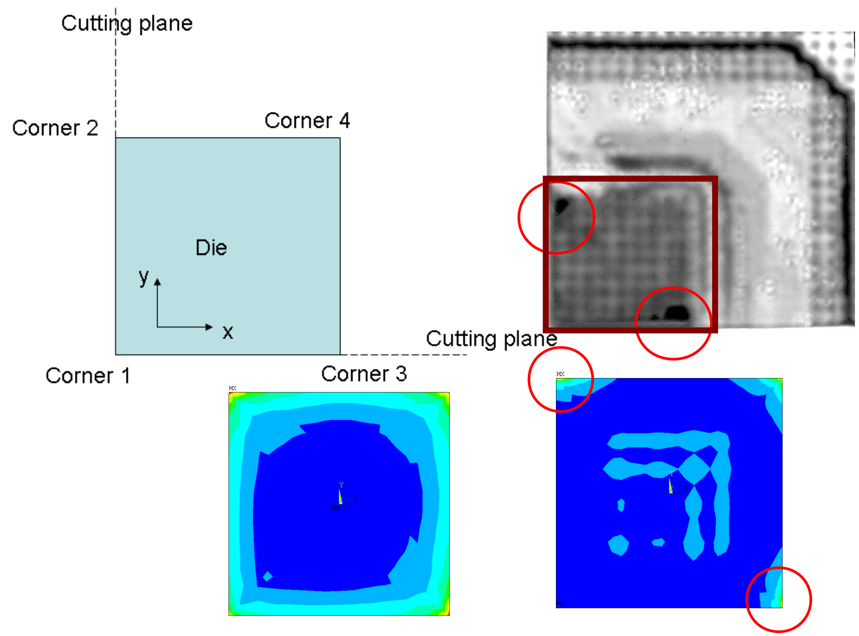


Variation of normal and tangential stresses at the 4 corners of die/glue interface during temperature cycling

- Same maximal stress values are observed at 25°C
- These graphs show that corners 2 and 3 are the most stressed.

Criteria of debonding

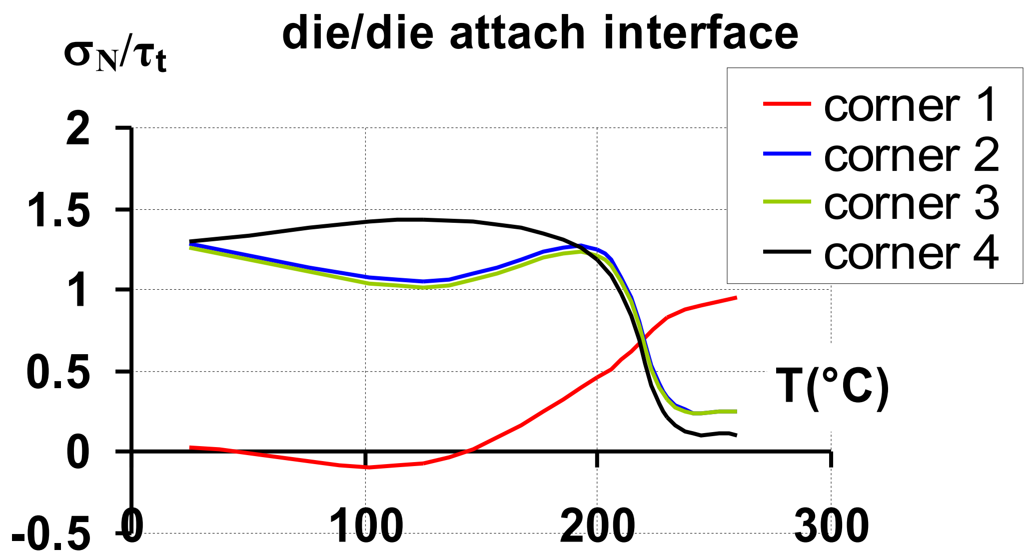




Criteria of debonding variation at the 4 corners of die/die attach interface during temperature cycling

- **Debonding observed with SAM measurements in corners 2 and 3 confirms the simulated behaviour.**
- **Measurements show that debonding occurs during the 2nd thermal cycle (260°C)**
- **➔ Consequently, the stress limit at interface debonding depends on temperature**

Criteria of debonding



σ/τ ratio variation at the 4 corners of die/glue interface during temperature cycling

- **Criteria of debonding is linked with σ/τ ratio, at 170°C this ratio is similar for corner 2, 3 and 4.**
- **Difficult to distinguish σ and τ effect in the criteria of debonding**

Conclusions

- **This study has permitted to improve modelling calculations by the use of experimental data.**
- **Simulation predicts starting location of debonding.**
- **It has been shown also that the stress limit at interface debonding depends on temperature.**
- **The method can be used at all levels (product development, reliability test, …), and for whatever component or assembly.**
- **With this methodology, save time and money with more realistic lifetime evaluation.**