Virtual DoE → selection of molding compound based on FEM simulation

Przemyslaw Gromala

Motivation:
1) Complexity of the electronic control units is increasing
2) New materials in consideration
3) Shorten design cycle time
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Agenda

- Introduction
- Simulation driven design
- Virtual Design of Experiment
- Benefits of VDoE
- Validation of VDoE
- Summary
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Introduction

- New generation of vehicles → the amount of ECUs used is increasing.
- New solution must be cost effective.
- Multi-functionality within one robust package appears to be an interesting solution.
- Relative large size of the module leads to high stress at the integrated circuitry.
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Simulation driven design

Virtual DoE has a great potential here.
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Molded electronic control unit

- Entire integrated circuitry overmolded.
- Based on LTCC technology.
- Challenges:
  - Thermal – heat generation
  - Thermo-mechanical – temperature dependent deformation
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Design of experiment

Molding compound – composite material used for encapsulating of semiconductor devices and electronic control units

- Properties changes during the manufacturing process.
- Time/temperature dependent.
- Parameters of molding compound (DoE design):
  - CTE1 – 6 … 20 [ppm/K]
  - CTE2 – 25 … 50 [ppm/K]
  - Tg – 100 … 200 [°C]
  - Shrink – 0.0 … 0.4 [%]
  - E – 12500 … 30000 [MPa]

Covers wide range of available molding compounds
## Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

### Typical failure mode in semiconductor

<table>
<thead>
<tr>
<th>Crack in molding compound</th>
<th>Delamination</th>
<th>Wire bond lift off</th>
<th>Crack in silicon</th>
<th>Crack in substrate</th>
</tr>
</thead>
</table>

Can the prognosis be made for all possible failure modes?
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Optimization schemes

Understand the effect of the molding compound properties on the stress in molded control unit.

- Parameter identification – OptiSLang:
  - Sensitivity analysis.
  - Metamodel of optimal prognosis (MOP).
- Design of experiment – Cornerstone.
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Stress in the mold

**Reduce the risk of the molding compound fracture.**

- What influence the stress
  - Main parameter is Tg.
  - CTE and E are the second most important factor.
- **Recommendation:** high Tg, low CTE and low E.
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Stress in adhesive, ceramic, LTCC

Reduce the stress in the all other materials.

- What influence the stress:
  - Glass transition temperature is the most important parameter.
  - CTE plays second most important role.
  - Modulus of elasticity of molding compound doesn’t play significant role.

- Recommendation: Higher Tg and lower CTE.
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Warpage

**Deformation over the temperature should be low.**

- What influence the warpage
  - Main parameter is Tg.
  - CTE and curing shrinkage are the second most important factor.
  - Modulus of elasticity doesn’t play important role.
- **Recommendation:** high Tg, low CTE and curing shrinkage.
Validation

*W. Beveridge: “no one believes an hypothesis except its originator but everyone believes an experiment except the experimenter”.*
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Mold selection tool (Cornerstone → Excel)
## Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

### FEM vs. OptiSLang vs. Cornerstone

<table>
<thead>
<tr>
<th></th>
<th>FEM simulation REFERENCE</th>
<th>OptiSLang COI Quadratic</th>
<th>OptiSLang COP</th>
<th>Cornerstone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warpage [%]</td>
<td>100</td>
<td>99.9</td>
<td>98.0</td>
<td>101.6</td>
</tr>
<tr>
<td>Stress in mold [%]</td>
<td>100</td>
<td>104.1</td>
<td>101.6</td>
<td>96.9</td>
</tr>
<tr>
<td>Stress in adhesive [%]</td>
<td>100</td>
<td>101.5</td>
<td>101.0</td>
<td>103.2</td>
</tr>
<tr>
<td>Stress in LTCC [%]</td>
<td>100</td>
<td>100.5</td>
<td>99.7</td>
<td>101.0</td>
</tr>
<tr>
<td>Stress in ceramic [%]</td>
<td>100</td>
<td>99.8</td>
<td>103.5</td>
<td>96.5</td>
</tr>
</tbody>
</table>
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Process flow

Parametric geometry

Evaluation

Parametric geometry

Evaluation

Main parameters:

E, Tg, CTE1

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in DPAK's silicon die

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Evaluation

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in DPAK's copper finger

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in solder mask

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in molding compound

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in DPAK's copper finger

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in DPAK's silicon die

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in solder mask

EME-X86712

EME-X85939

EME-X85587

CEL-1700HF17E

Maximum tensile stress [MPa]

Temperature [°C]

EPM - stress in molding compound
Concept of the Virtual Design of Experiment for Development of the Molded Electronic Control Units

Potentials of Virtual DoE technique

- Virtual DoE technique can significantly accelerate the design process of the electronic control units → lower development costs.

- Selection of the molding compound can be supported by numerical simulation taking into account variation of the material properties of the mold.

- For specific application such as LTCC, PCB or DBC substrate BOM can be defined based on the internal stress distribution and deformation, long time before first samples are manufactured.

Is it possible to use the results MOP directly in excel?