A Simple Method for an Appropriate Simulation of Short-Fiber-Reinforced Injection Molded Plastics

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Dr.-Ing. Wolfgang Korte, Dipl.-Ing. (FH) Sascha Pazour, Dr.-Ing. Marcus Stojek
PART Engineering GmbH
pazour@part-gmbh.de
0049 2204 30677 26
CAE Services & Software

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Elastomers
Metals

Converse

Plastics
Influence of Fiber Orientation onto Material Properties

Material: PA6+GF30

- **Stiffness**
  - Parallel: 6000 MPa
  - Perpendicular: 3000 MPa

- **Strength**
  - Parallel: 100 MPa
  - Perpendicular: 70 MPa

- **Thermal Elongation**
  - Parallel: 0.1
  - Perpendicular: 0.7
Fiber Orientations in Short-Fiber-Reinforced Plastics

S<sub>1</sub> Shear layer: Fibers oriented parallel to flow direction
S<sub>2</sub> Mid layer: Fibers oriented perpendicular to flow direction

Example Micrograph Pictures:

- Thick Mid Layer
- Thin Mid Layer
The yield function is defined as

\[ f = \overline{f'}(\sigma) - \left[ \sigma_0 + R(\varepsilon^p) \right] \]

where the equivalent stress \( \sigma_{eq} \) is defined as an anisotropic yield criterion

\[ \sigma_{eq} = \sqrt{F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + H(\sigma_{11} - \sigma_{22})^2 + 2L\sigma_{23}^2 + 2M\sigma_{31}^2 + 2N\sigma_{12}^2} \]

Where \( F, G, H, L, M \) and \( N \) are constants obtained by test of the material in different orientations. They are defined as

\[
\begin{align*}
F &= \frac{1}{2} \left( \frac{1}{R_{22}^2} + \frac{1}{R_{33}^2} - \frac{1}{R_{11}^2} \right) \\
G &= \frac{1}{2} \left( \frac{1}{R_{33}^2} + \frac{1}{R_{11}^2} - \frac{1}{R_{22}^2} \right) \\
H &= \frac{1}{2} \left( \frac{1}{R_{11}^2} + \frac{1}{R_{22}^2} - \frac{1}{R_{33}^2} \right) \\
L &= \frac{3}{2R_{23}^2} \\
M &= \frac{3}{2R_{13}^2} \\
N &= \frac{3}{2R_{31}^2}
\end{align*}
\]

(Source: Is-dyna-971-manual-k)
Degree of Orientation

- General case:
  \[
  \begin{pmatrix}
  a_{11} & a_{12} & a_{13} \\
  . & a_{22} & a_{23} \\
  . & . & a_{33}
  \end{pmatrix}
  \]

- Unidirectional:
  \[
  \begin{pmatrix}
  1 & 0 & 0 \\
  0 & 0 & 0 \\
  0 & 0 & 0
  \end{pmatrix}
  \]

- Quasi-isotropic:
  \[
  \begin{pmatrix}
  0.33 & 0 & 0 \\
  0 & 0.33 & 0 \\
  0 & 0 & 0.33
  \end{pmatrix}
  \]

Fig. 5
Example: Weld Lines
Isotropic Approach

Common Approach:
Isotropic

Radial Displacement
Example: Weld Lines
Anisotropic Approach

CONVERSE Approach: Anisotropic

Radial Displacement
Orientation and Degree of Orientation from Injection Molding Simulation
Fiber Orientation and Anisotropic Material

Converse Graphical User Interface

Fig. 9
Example: Tensile Bar Specimen

Layer 1

Layer 2

material type 108

*MAT_ORTHO_ELASTIC_PLASTIC
Converse Features and Interfaces

**Injection Moulding Solver**
- Moldflow
- Cadmould
- Sigma
- Moldex
- Fluent
- Simpoe
- 3D Timon

**Mechanical Solver**
- LS-Dyna
- Ansys
- Abaqus
- Optistruct
- Nastran
- Marc
- Samcef
- FEMFat
- Ncode
- Virtual.Lab

**Variables**
- Orientations
- Weld Lines
- Pressures
- Temperatures
- Wall Thicknesses
- Residual Stresses
- Shrinkage & Warpage
Part Geometry

Fiber Orientation in Converse

[Valeo Lighting Systems]

Lens Bracket Example

Fig. 12
Frequency correlation – simulation to Xp. modal analysis

<table>
<thead>
<tr>
<th>Mode</th>
<th>Experimental (Hz)</th>
<th>Isotropic (Hz)</th>
<th>Converse (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>44</td>
<td>76</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>56</td>
<td>77</td>
<td>62</td>
</tr>
<tr>
<td>3</td>
<td>91</td>
<td>114</td>
<td>94</td>
</tr>
<tr>
<td>4</td>
<td>224</td>
<td>270</td>
<td>218</td>
</tr>
</tbody>
</table>

[Insight: Average error – 4 Modes]

Lens Bracket Example

[Note: Valeo Lighting Systems]
Two suppliers but parts are geometrically up to 95% equal. Same material supplier, same machine settings, etc. Different gating location means two completely different engine components!

Moldflow results show different orientation.
1. distributed pressure on sealing contact surface

2. results evaluated on a path

3. displacements

Untolerable error if homogeneous isotropic material is used!

4. isotropic vs. anisotropic results
fiber orientation and material model by

Blue – Supplier 1
Red – Supplier 2
Dotted – Isotropic material

Δ - 62%

True distance along path

Influence Of Production on Anisotropic Part Stiffness

Fig. 15
Oil Filter Cover at Burst Pressure 87.5 bar (Test Result)

Fig. 16

[Isotropic]

[Scaled to Stress at Break (Campus)]

cross-section A

[Anisotropic (CONVERSE)]

[Scaled to Stress at Break of 90° Tensile Test Result]

cross-section A
Oil Filter Cover at Burst Pressure 87,5 bar (Test Result)

Test Result
Cracks

cross-section A

view on top of part
at cross-section A
Summary of the Procedure for Application in FEA

1. **FE-Molding Simulation**
   - orientation tensor
   - FE-mesh of part

2. **CONVERSE**
   - orientation mapping
   - orientation averaging
   - micromechanical model

3. **FE-Mechanical Simulation**
   - props. of fiber & matrix
   - FE-mesh of structure

4. Properties of anisotropic homogeneous composite

5. Implicit or Explicit Simulation

Fig. 18
Benefits

Easy-to-Use & Fast Learnable

Transparent Data-Handling

Multiple-Processor compatible

Permanent Data Access

No Subroutine needed

Floating License

Fig. 19