Lightweight Product Design Using Long Fiber-Filled Polypropylene

Warden Schijve  SABIC
AU Moldflow Power track, December 2011, Las Vegas
Contents

- Short intro SABIC
- What is long fibre polypropylene?
- What defines the properties?
- What can we do with design?
- What can we do with simulation?
- Why light weight is so important to the automotive industry?
  ➔ Carbon footprint reduction
SABIC

Plastics, Chemicals, Polymers, Metals, Fertilizers

>33,000 Employees
130 million tons by 2020

Plastics from former DSM and GE-Plastics

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- **PE, PP, PC, PBT, ABS, PEI,** etc. and numerous blends.

**Automotive materials:**

- Lexan Glazing
- Noryl
- PP Compounds
- etc.

- **STAMAX® Long Glass Reinforced Polypropylene**
  + Verton long fibre materials
Typical STAMAX PP-LGF applications

- Instrument panel carrier
- Door module
- Front-end module
Long glass fibre reinforced Polypropylene

PP + additives

Glass fibres

STAMAX®
Pellet detail

- Glass filament
- Thermoplastic coating
- Silane coating
- PP matrix + additives

Contents
- Introduction
- Properties
- Design
- Simulation
- Sustainability
Specific advantages of Long glass PP

Low cost performance material (PP resin)

Good properties at low and high temperatures

Ease of processing (high flowability/thin wall design possible)

Low warpage
LGF-PP

What defines the properties?
What is specific for long glass materials?

1. Fiber orientation
2. Fiber length distribution
3. Fiber dispersion

Anisotropic Shrinkage
- Warpage

Anisotropic Properties
- Mechanical performance
Properties in real parts – heavily dependent on fibre orientation

0°

90°

"parallel"

"perpendicular"

"perp."

"parallel"

1. Fiber orientation
Common design practice – Use of Datasheets

Take E-modulus from datasheet. (Industry standard)

E.g.:
E = 6700 MPa for 30% LGF

"measurements on injection moulded samples"

=> High fibre alignment.
=> Much to high values.

Some use fixed knock-down factors.
Isotropic method EATC

Measure 3 directions, then calculate Isotropic properties

Method description and automatic calculation tools for download on: www.eatc-online.org
Example 40% LGF part

Strength (MPa)

Modulus (MPa)

More orientation

European Alliance for Thermoplastic Composites
Example 40% LGF part

**Strength (MPa)**

- Real part
- Datasheet
- EATC isotropic result

**Modulus (MPa)**

- 0 2000 4000 6000 8000 10000

More orientation

European Alliance for Thermoplastic Composites
Fibre length dependent on process

2. Fiber length
Effect fibre length on properties

\[ E_I = \eta V_f E_f + (1 - V_f) E_m \]

Fibre effectivity \( \eta \)

- Stiffness
- Strength
- Impact

Source: Schijve, AVK Tagung 2002
Effect fibre length at higher temperatures

**Fibre effectivity** $\eta$ **stiffness**

- At higher temperatures, longer fibres are needed for the same effect.
- Similar effect also for strength.

2. Fiber length

Fibre length (mm)

23°C

80°C

23ºC

80ºC

23ºC

80ºC

Fibres

Short fibres

Long fibres

73ºF

180ºF

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Isotropic properties as function of fibre length

- **E-Modulus (MPa)**
- **Tensile strength (MPa)**
- **Penetration Energy (J/mm)**

At $t=3.0$ mm

Indirect measurement of fibre length and properties

Fibre length acc. Owens Corning measurement method. Other methods yield different results.
Competition between dispersion and length

- **Start length:** 12 mm
- **Dispersion:** 100%
- **Fibre length:** < 1 mm
- **Amount of shear during process**

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**3. Fiber dispersion**
Dispersion examples - X-Ray pictures

**course**

- length > 10 mm
- 0.4"

**fine**

- length ~ 2 mm
- 0.08"
Effect of bundles on mechanical properties

Ashed sample with bundles: Undispersed cut rovings

16x

ca. 1 mm

0.04"
Effect of bundles on mechanical properties

\[ \eta = 1 - \frac{L}{D} \sqrt{\frac{2G_m}{E_f \ln(R/r)}} \]

\[ \tanh \left( \frac{L}{D} \sqrt{\frac{2G_m}{E_f \ln(R/r)}} \right) \]

=> equal performance as with relative short, well dispersed fibres
Tensile specimens from front-end

Strength (MPa)

- Fine dispersed (STAMAX 40% LGPP)
- Other material with bundles

Average:
- fine $\varepsilon_f = 2.20\%$
- bundles $\varepsilon_f = 1.04\%$

Modulus (MPa)
Conclusion for effectivity graph

Fibre effectivity $\eta$

- Stiffness
- Strength

Fibre length (mm)
Conclusion for effectivity graph

Fibre effectivity $\eta$

- **Stiffness**
- **Strength**

**Fibre length (mm)**

- **bundle effect**

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3. Fiber dispersion
Light weight design

What can we do with design?
Example hybrid front-end with little space

5.15 kg
front-end +
insert
Redesign in same space - full plastic

old design

5.15 kg

Calculations:
- same properties (STAMAX 30YM240)
- minimum same component stiffness
e.g. Lock stiffness 471 N/mm

full plastic redesign
3.29 kg -36%

+ without 4 extra attachment points
Effect clever design – Same loading/boundary conditions

**Clever design**

**Standard design**

**STAMAX-Full Plastic**

**Original**

*Factor 4 difference, just by design*
Example radiator support stiffness X-direction

<table>
<thead>
<tr>
<th>XSGABICystle05853_VW_Passat_B6_rigid_hypermesh</th>
<th>DADCDesign</th>
<th>DADCDesign_stiffnesses</th>
<th>Loadcase 1: SS - Radiator Force X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loadcase 1: SS - Radiator Force X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.20E+02</td>
<td>-3.67E+02</td>
<td>-5.14E+02</td>
<td></td>
</tr>
<tr>
<td>2.61E+02</td>
<td>-2.01E+02</td>
<td>-1.50E+02</td>
<td></td>
</tr>
<tr>
<td>1.02E+02</td>
<td>-1.04E-03</td>
<td>-3.87E-04</td>
<td></td>
</tr>
</tbody>
</table>

**Difference in stiffness factor 2.5**

STAMAX-Full Plastic

great potential for pedestrian lower leg support
Light weight design

What can we do with simulation?
Isotropic material data not OK for front-ends.
Isotropic material data not OK for front-ends.

One directional flow  ➔  Higher fibre alignment
Resulting orientation and properties

example fibre orientation core layer  example E-modulus distribution
Isotropic vs. Anisotropic simulation result

**Calculated lock stiffness (N/mm)**

- **Isotropic**
- **Anisotropic**

Measured stiffness at 2000 N

→ Anisotropic 20% higher stiffness in this case.
Isotropic versus anisotropic simulation options (used at SABIC)

1. Isotropic

2. Anisotropic
   a) Moldflow → Abaqus
   b) Moldflow → Digimat → Abaqus

1. fibre orientation
2. micro-mechanics
3. mechanical simulation
Prediction of the fiber orientation for LGF-PP

**Default Moldflow version**
- Folgar-Tucker short glass model
  - Highly aligned orientation as typically found for short fibre.
- Recent: ARD/RSC long glass model
  - Slow orientation development, less aligned.

**SABIC expertise**
- Special method and data for long glass fibres
- Correct orientation development all flow types.
- Includes: Effect different fibre lengths, concentrations, dispersion.
Predicted versus measured properties – medium fibre length

**E-modulus (MPa)**

- **Moldflow Folgar-Tucker**
- **Moldflow ARD/RSC**
- **SABIC Moldflow**
- **Measurement**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Flow Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-0°</td>
<td>31mm 107mm 183mm</td>
</tr>
<tr>
<td>E-0°</td>
<td>31mm 107mm 183mm</td>
</tr>
<tr>
<td>E-90°</td>
<td>31mm 107mm 183mm</td>
</tr>
<tr>
<td>E-90°</td>
<td>31mm 107mm 183mm</td>
</tr>
</tbody>
</table>

**E-modulus (MPa)**

- **Flow length**: 75mm 100mm 125mm 150mm 175mm 200mm
- **Orientation**: E-0° E-0° E-0° E-0° E-0° E-0° E-0° E-90°

**Parallel**

**Perpendicular**

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Isotropic versus anisotropic simulation options

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1. fibre orientation
2. micro-mechanics
3. mechanical simulation
What is micromechanics?

Use matrix + fibre mechanical data to predict composite properties:

matrix  

volume%  length  orientation  dispersion

fibre

composite
Micromechanics results – example 40% LFT

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**Input:**
- Orientation
- Fibre length
- Matrix properties
- Fibre properties
and adaption for long fibre

LFT adapted Moldflow results similar to Digimat but ca. 3% higher, less consistent.

**Graph Description:**
- Graph showing the variation of Young's modulus (E1, E2), shear modulus (G12), and Poisson's ratio (nu12) with orientation level.
- Orientation level ranges from isotropic to fully aligned.
- E, G (MPa) values are plotted against orientation level.
- a_{22} = 1 - a_{11} is shown for orientation levels.
Isotropic versus anisotropic simulation options

1. Isotropic
2. Anisotropic

a) Moldflow → Abaqus

b) Moldflow → Digimat → Abaqus

1. fibre orientation
2. micro-mechanics
3. mechanical simulation
Calculated lock stiffness
(N/mm)

- isotropic
- Moldflow Abaqus
- Moldflow Digimat Abaqus

Various errors in direct Moldflow Abaqus, most important: use of too stiff linear tri elements
Conclusions effect anisotropic simulations

Anisotropic simulations

20% weight saving + cost saving

But need to know!:

- Fibre orientation
- Fibre length
- Fibre dispersion
- Micro-mechanics

Reliable long fibre simulation

LFT Process knowledge

Long fibre adapted
Why is light weight so important to the automotive industry?

→ Carbon footprint reduction
**Number 1 benefit**: Lower weight cars $\Rightarrow$ Lower CO$_2$-emissions

Reduction Fuel/CO$_2$:
- Rolling resistance (exhausted)
- Engine alternative fuels / hybrids
- Weight hybrid battery compensation

Roughly: $-100$ kg $\rightarrow$ $-10$ g CO$_2$/km$^*$

$\Rightarrow$ Already for European car fleet alone: $-100$kg/car

= $-40$ million MT CO$_2$/yr

= Same CO$_2$ reduction as 33000 MW on Windmills!$^{**}$

$^*$From VW study (PSA: $-9$g)
$^{**}$ www.ewea.org

Europeon car fleet is $\sim$ 20% of world fleet
So it's good for our planet.

But does the OEM really care?
And all in all, is it the better alternative?
The pain of the OEM: CO₂ emission legislations

Example

Europe, start 2015:

Average car fleet emission < 130 g/km CO₂

Penalties for too high emission*

*Regulation (EC) 443/2009
Problem with weight based criteria

CO₂ Emission (g/km)

Average car weight (kg)

Weight saving to achieve desired CO₂ reduction still gives a penalty

Emission Regulations all over the world

- **European CO₂ Regulations 443/2009: 2015 and up**
- **Rest of the world comparable regulations**

Historical fleet CO₂ emissions performance and current or proposed standards

Source: European Aluminium Association
The pain of the OEM: CO₂ emission legislations

Example: Emission = 140 g/km:

\[ = +10 \text{ g/km CO}_2 = 710 \text{ € Penalty per car}* \]

Can be solved with 100 kg weight reduction

\[-100 \text{ kg} \rightarrow -0.4 \text{ liter/100 km} \rightarrow -10 \text{ g/km CO}_2 \]

⇒ Value of weight reduction = 7.1 €/kg to the OEM

*Regulation (EC) 443/2009 penalty in 2015, in 2018 it will be 950€
Penalties for electric vehicles unlikely. But range and battery are problems:

**Electric vehicles:**
Reduction on battery cost for same driving range:

⇒ Value of weight reduction = 11.5 €/kg to the OEM*

~$7/lb

*RWTH Aachen 2010*
The value for the consumer

Value of a car that is 100 kg lighter:

-100 kg → -0.4 liter/100 km → -

-760 liter petrol over lifetime car ~ 1040 €*  

⇒ Value of weight reduction = 10.4 €/kg by fuel saving for the consumer

⇒ Plus tax benefits for low emission cars. 1.5-5 €/kg**

~$1400

~$6/lb

~$1-3/lb

*Net present value, 190000 km, current European fuel prices  
**Country dependent, complex table systems
## Summary  Value of weight reduction

<table>
<thead>
<tr>
<th></th>
<th>Value (Euros / kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value to the OEM</td>
<td></td>
</tr>
<tr>
<td>CO₂ Penalties</td>
<td>7.1*</td>
</tr>
<tr>
<td>Value to the consumer</td>
<td></td>
</tr>
<tr>
<td>Fuel savings</td>
<td>10.4</td>
</tr>
<tr>
<td>Tax benefits</td>
<td>2.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>20 €/kg</strong></td>
</tr>
</tbody>
</table>

For gasoline based engine
And likely even better picture for electric vehicles.

* 9.5 €/kg in future
So far about the car use.

All in all, is LGF-PP light weight the better alternative?

⇒ LCA
Life Cycle Assessment

LCA is a mass and energy balance over a product life cycle
LCA measures potential environmental impact of a product life cycle

All the Inputs from Natural World

Product Life Phases

Cradle → Gate → Use → Grave → Cradle

All the Outputs to Natural World

LCA Details

Typical measurements from LCA are
- CO₂eq Emissions (e.g. Greenhouse Gases)
- CO₂ equivalents
- Non-renewable Resource Use (e.g. fossil fuels)
- Mega Joules
- Land Use (e.g. “food vs. fuel vs. nature)

Measurement for: how good is a product/component?:
- Comparison with state of the art solution.
Different light weighting options:

1. LEXAN* Glazing
2. **NORYL*** GTX Fenders
3. STAMAX* PP Tailgate Inner
4. XENOY* Tailgate Outer
5. STAMAX Door Modules
6. LEXAN* EXL Steering Wheel
7. Flex NORYL* Wire Coating
8. STAMAX* Front End Module
9. XENOY* Energy Absorbers
10. ULTEM* Headlamp Reflectors
Noryl* GTX resin

NORYL GTX* Resin – a compatibilized blend of PPE with PA for Body Panels

Poly (2,6-dimethylphenylene) ether (PPE)

On line paintable – conductive
Low CLTE
Freedom of design
Fender life cycle carbon footprint

Noryl* GTX has up to 50% lower footprint vs Steel

Kg CO₂ / 2 fenders

Materials  Fabrication  Use  End-of-Life  Total

Steel  Aluminum  GTX

based on our internal life cycle assessment, peer review in progress
Example Automotive front-end structure

Reference, state of the art:
Steel/PA6 hybrid

3 steel inserts
3.3 kg steel +
2.7 kg PA6/30%SG

STAMAX full plastic
3.5 kg LGF-PP 40%

LCA Study is ongoing.
Includes sensitivities.
Outcome to be published
LCA expected outcome (simplified)

- **CO₂ emission (kg)**
  - Material manufacture
  - Part manufacture
  - Part use
  - Recycle
  - Total

- **High importance use phase**

- **The alternative is "green"!**

"green" actually means here: significant lower CO₂-emission
And what about "green" materials then?

Example: Renewable or bio based material which has lower foot print in production due to CO₂ as absorption from growing plants...
Example of potential false "green washing"

"Green" material, taking CO₂ out of the air, e.g. Natural fibres: low density, but also low properties

Depending on properties may end up higher!

➜ "Green" materials may not be green!

Actually: Renewable/bio based materials may not be sustainable for total LCA.
+ Impact on water / land use also to be made.
General conclusions on LCA

- Material with best properties specific for the application (e.g. high stiffness over weight) will score best in use phase.
- Light weighting very important for automotive applications
- Good design, and making use of good anisotropic simulations will add to this.

Good design + Proper simulation → Weight saving = Sustainable!

-30% to -50%

≈ -20%

Energy/CO₂ LCA

Reference optimal design LGF-PP

Material part use recycle
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