EADS Innovation Works

Development of Flexible Matrix Composites (FMC) for Fluidic Actuators in Morphing Systems

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Outline

SADE- Project description

- Main ideas

Droop nose - concepts

- Actuation System
  - Material properties

Flexible Matrix Composites (FMC)

- Definition
- Combinations
- Production Process

Experiments

Tensile tests

Simulation

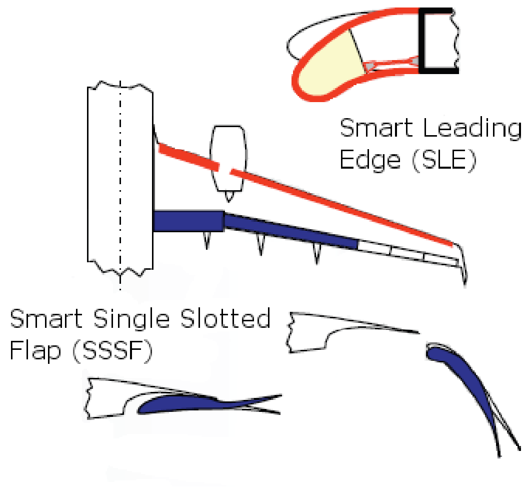
Conclusion

SADE (Smart High Lift Devices for Next Generation Wings)

The project's aim is to create a seamless and gapless high lift device at the wing's leading and trailing edge with the goal to reduce the airframe's noise and drag and enable laminar wing flow.

Two points of focus:

- **leading edge**
- **trailing edge**



SADE smart high lift configurations
(Source: DLR)

This lecture: focus on leading edge in form of droop nose.

Droop Nose – Requirements

Enable laminar flow

Reduce noise ← less turbulence

- the droop nose as to be a seam- and gapless device → enabler for a smooth surface (necessary for laminar flow)

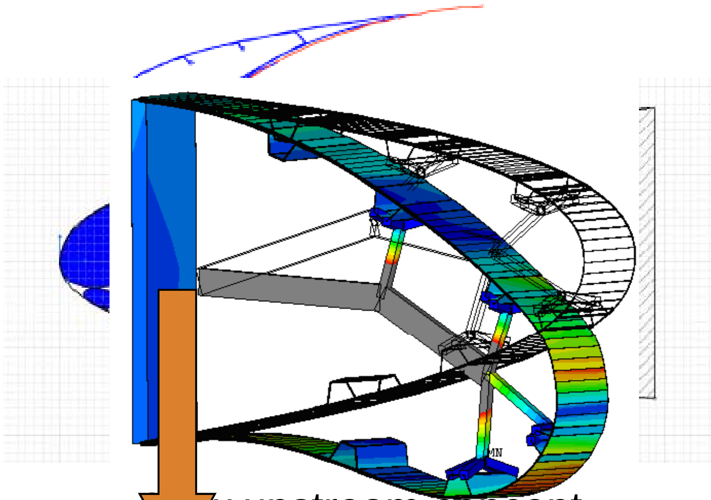
Nose material has to be

- flexible to allow the required deformation (at start and landing) and at the same time
- stiff enough to keep the needed shape.

The actuation-mechanism has to support the skin (same requirements as above)

→ to achieve good support of the skin a pneumatic actuation systems is being developed which will continuously support the skin

Droop Nose



New upstream concept
Pneumatically actuated

SADE concept
mechanically actuated

Actuation Tubes

Even greater flexibility (than skin) needed, but also stiffness

- Material-requirement: flexible but also stiff

→ **Flexible matrix composites** (FMC)

Flexible matrix composites are flexible matrix materials reinforced with continuous (stiff) fibers

Goal of this study: development of a production process for FMC at “large” scale (not laboratory setting)

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Flexible matrix composites

Possible material combinations:

Rubber, **silicone** and **thermoplastic elastomers** with carbon or glass fibers

Table 1: Material Combinations

Fiber Material		**Matrix Material**		
		TPE	Rubber	Silicone
Carbon fibers	Single rovings	X	X	
	UD-Tape	X	X	
	UD-non crimp fabric	X		
	Multiaxial-weave	X		X
Glass fibers	Multiaxial-weave	X		X

Flexible matrix composites

Production techniques:

Pressure moulding, Injection moulding, Hand lamination, VAP, pultrusion

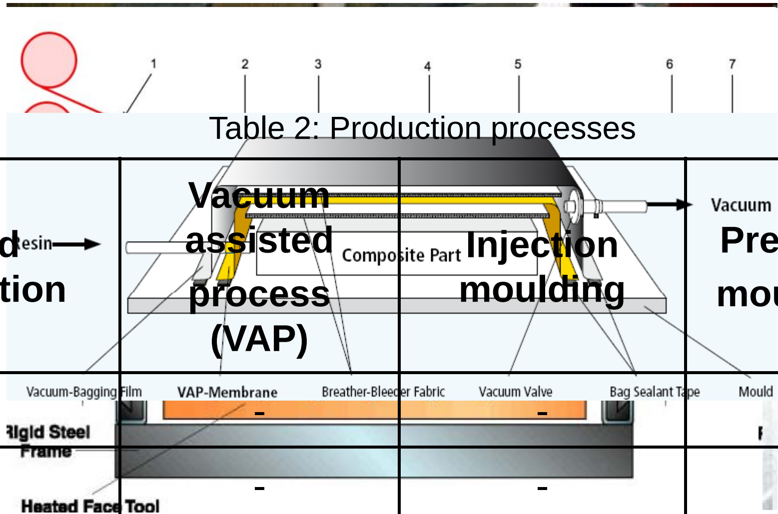


Table 2: Production processes

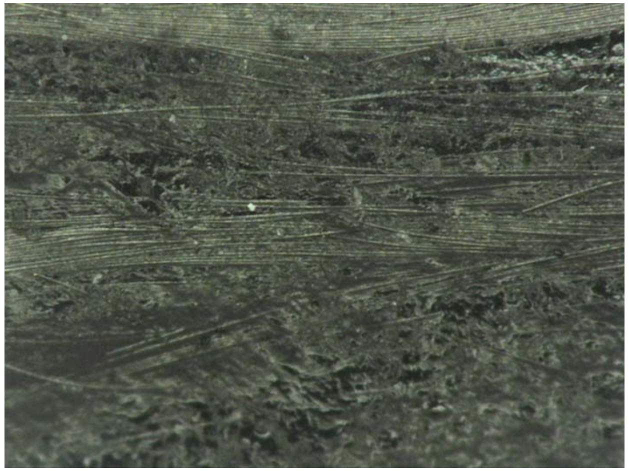
Production method Material	Hand lamination	Vacuum assisted process (VAP)	Injection moulding	Pressure moulding	Pultrusion
Rubber	-	-	-	+	-
Silicone	+	-	-	-	-
TPE	-	+	+	+	+

Experiments with rubber

Material-tests with rubber

- Production process: **pressure moulding**

Tested Material: Dynanotex HS 15/50SL (UD-tape) with rubber mixture SAA1052/70



Rubber pressed with 250-400 bar at 120°C (at Kraiburg Gummiwerke)

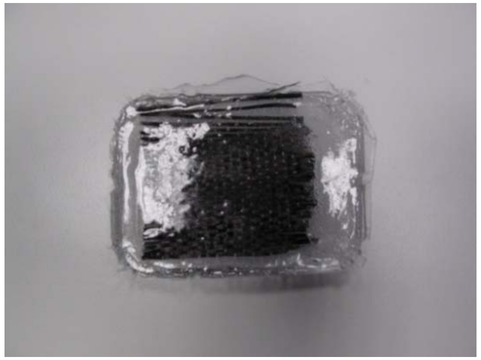
Conclusion: Good distribution of rubber in the fibers, but highly distorted fibers through rubber flow

Experiments silicone rubber

Material-tests with silicone-rubber

- Production process: **hand lamination**

Tested Material: Torayca T300B 6k Biax-fabric with Wacker Elastosil LR 7665



Conclusion: Silicones have a too high viscosity to infiltrate the fibers, infiltration only possible when the silicone is diluted with e.g. benzine

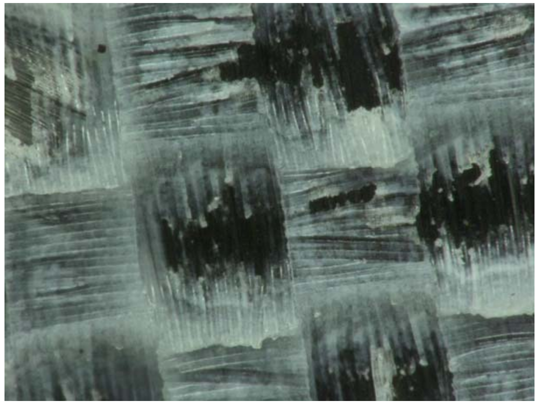
Experiments with TPE

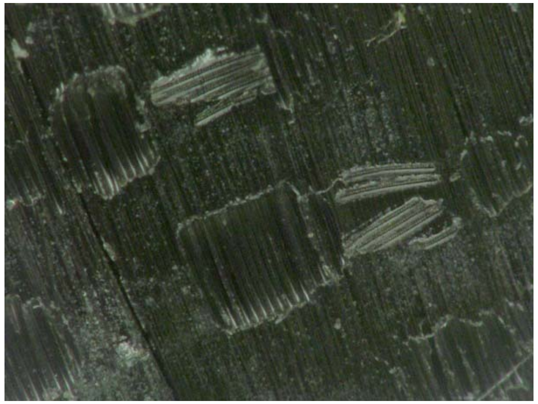
Material-tests with TPE

- Production process: **VAP**

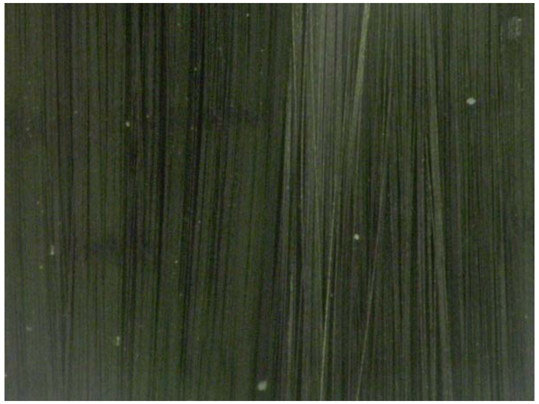
Tested Material: Torayca FT 300B 6k 50B with TPE Patch HTC 8533/49

Duration: 3h at 180°C





TPE/C-Fiber laminat after VAP-process



Dry fibers (comparison)

Conclusion: TPE to viscous for VAP, very slow process, shear-forces not high enough

Experiments with TPE

Material-tests with TPE

- Production process: **injection moulding**

Tested Material: Torayca FT 300B 6k 50B with TPE Patch HTC 8533/49

TPE/C-Fiber laminat after injection-moulding
at 190°C into a cold cast

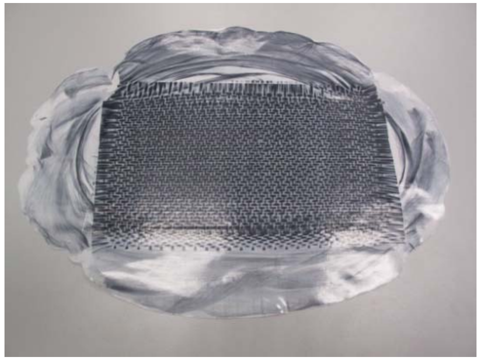
Conclusion: shear-forces in the nozzle reduce the viscosity, flow of the liquid TPE pushes fibers away but good through-layer infiltration, cold cast reduced spread of the TPE

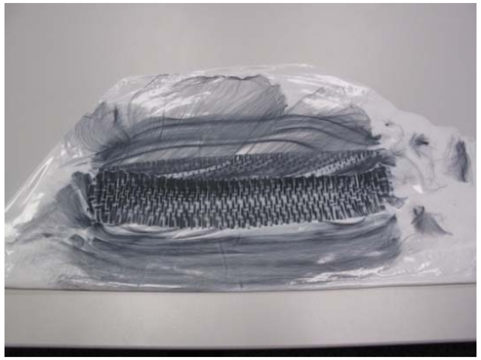
Experiments with TPE

Material-tests with TPE

- Production process: pressure moulding

Tested Material: Torayca T300B-6000 Bi-ax fabric with TPE Patch HTC 8533/49


1-layered


2-layered

TPE pressed into a biax carbon fabric at 180°C and 2.5 bar

Conclusion: Viscosity of TPEs in general low enough, pressure moulding effective but the “flow” of the TPE leads to high fiber distortions, necessary to restrict the fiber movement.

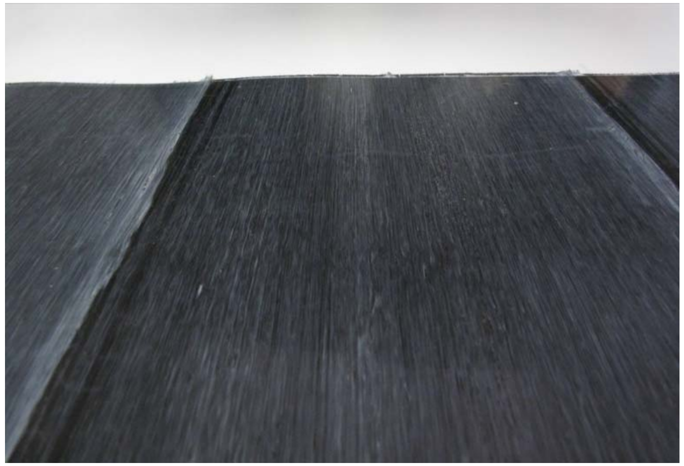
Experiments with TPE

Material-tests with TPE

- Production process: **pultrusion**

Tested Material: Torayca FT 300B 6k 50B with TPE Patch HTC 8533/49

TPE/C-prepreg-Tape



4-layered TPE/C-laminat

Conclusion: Viscosity of TPEs in general low enough, pultrusion effective but the fiber-volume fraction needs to be lower in future trials

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Summary of material and production trials

Continuous Fibers				Matrix Material		
Base Material	**Fiber type**	**Fabric type**	**Area weight**	**TPE***	**Rubber****	**Silicone*****
Carbon Fibers	Torayca T300B-6000	6k-Roving	396 tex	X+	X-	
	Dynanotex HS 15/50SL	UD-tape	50 g/m²		X+	
	Torayca T700S	UD-tape	100 g/m²	X+		
	Torayca FT 300B 6k 50B	6k-UD-fabric	120 g/m²	X+		
	Toho Tenax IMS65 E13 24k 830tex	24k UD-fabric	208g/m²	X-		
	Torayca T300B-6000	6k Biax-fabric	317 g/m²	X+		X-
	Torayca T700S-12000	12k biax-NCF	578 g/m²	X-		X-
Glass Fibers	Interglas technologies	Biax fabric	288g/m²	X-		X(+)
*TPE-SEBS Patch HTC 8533/49 Kraiburg TPE / **Rubber SAA1052/70 Kraiburg Gummiwerke / ***Silicone: MVQ-silicone (FSU-50-83 by MG Silikon)/ Wacker Elastosil LR 7665						

Preparation for Tensile Tests with FMC (C/TPE)

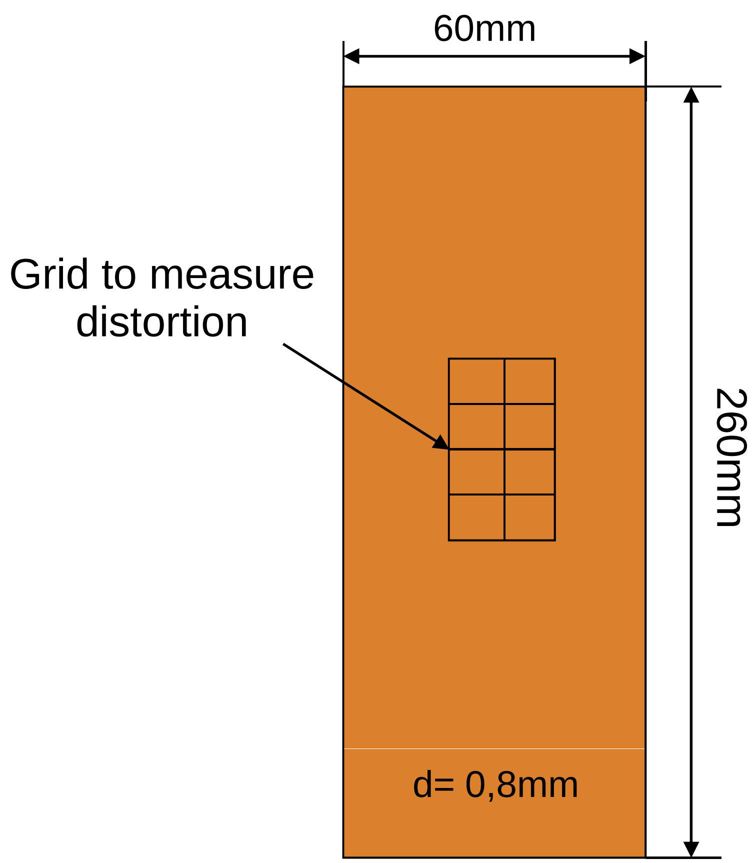
Tensile tests in 0°/ 90° and ±45° direction

8- tests/specimen each

Strain measurement with optical sensor

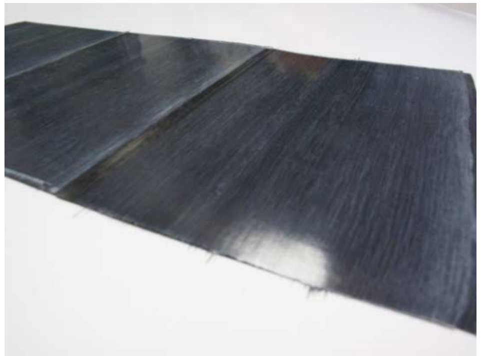
- Only one direction possible
- For other directions: grid-deformation (recorded with video camera)

Goal: Definition of the mechanical properties for hyperelastic-anisotropic material model

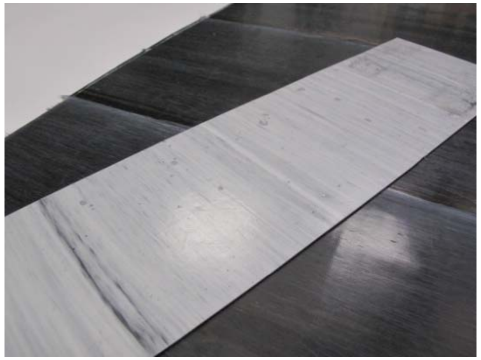


Geometry of test-specimen

Preparation for Tensile Tests with FMC (C/TPE)



4-layered 90° laminat

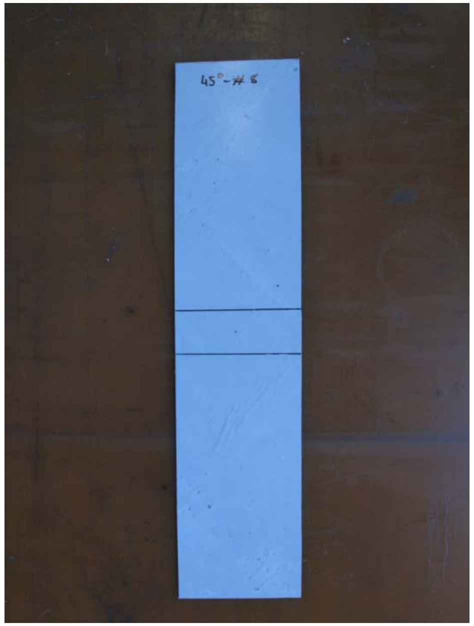


4-layered 90° laminat cut into specimen shape with an added TPE layer

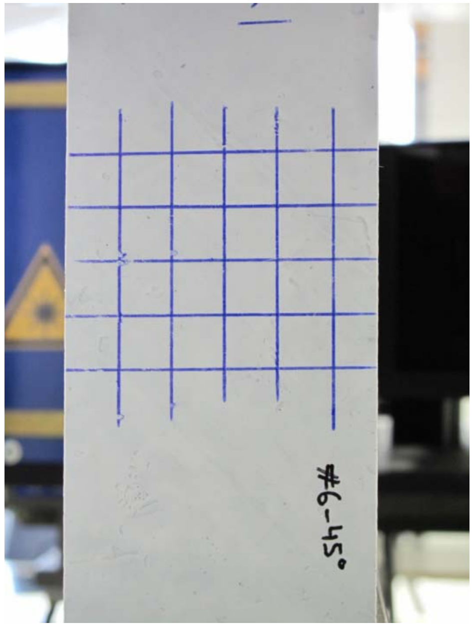
90°- specimen before cutting

The material from the pultrusion was used like prepreg material and stacked to create a 4 layer-thick laminat with the needed fiber-angles.

Test-setup for Tensile Tests with FMC (C/TPE)



Test-sample

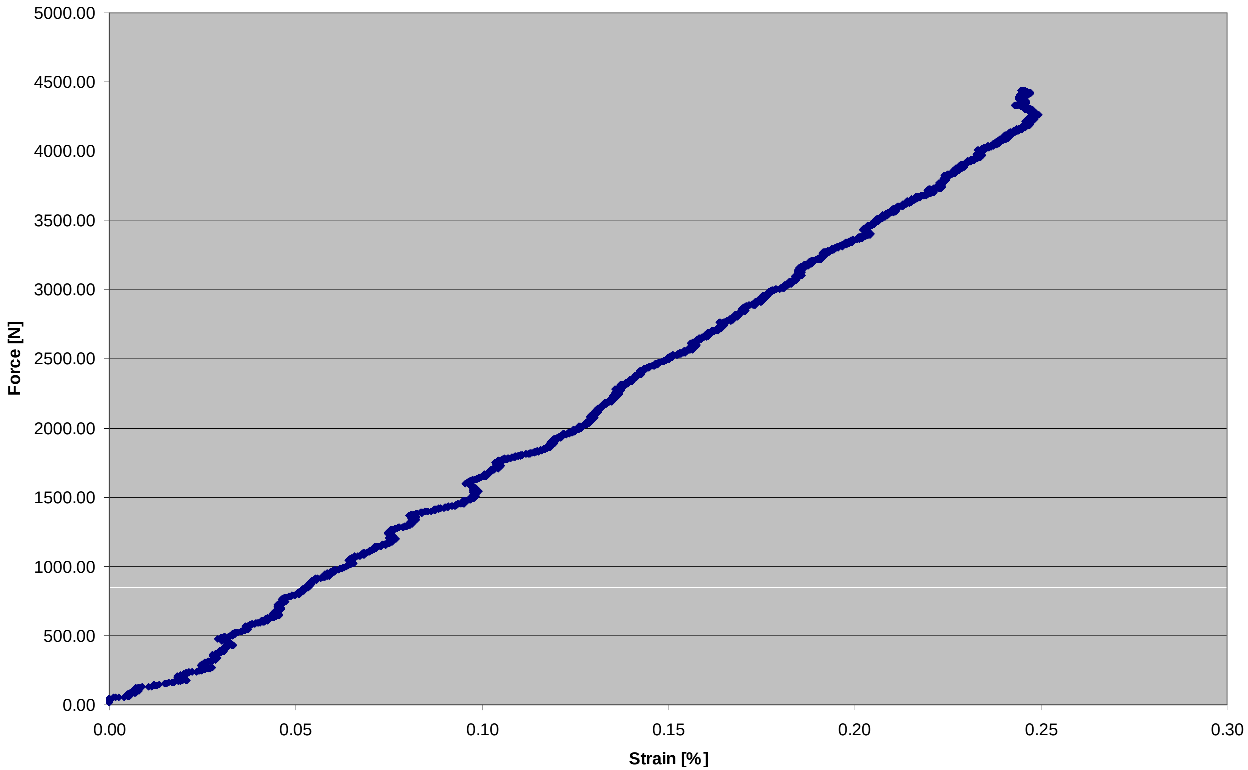


Distortion grid

Optical strain measurement

Tensile Tests

0°-Results



E_{11}=48.12 kN/mm²

In comparison to calculated value from rule of mixture at a fiber-volume-fraction of 28%
E_{11calc}=65kN/mm²

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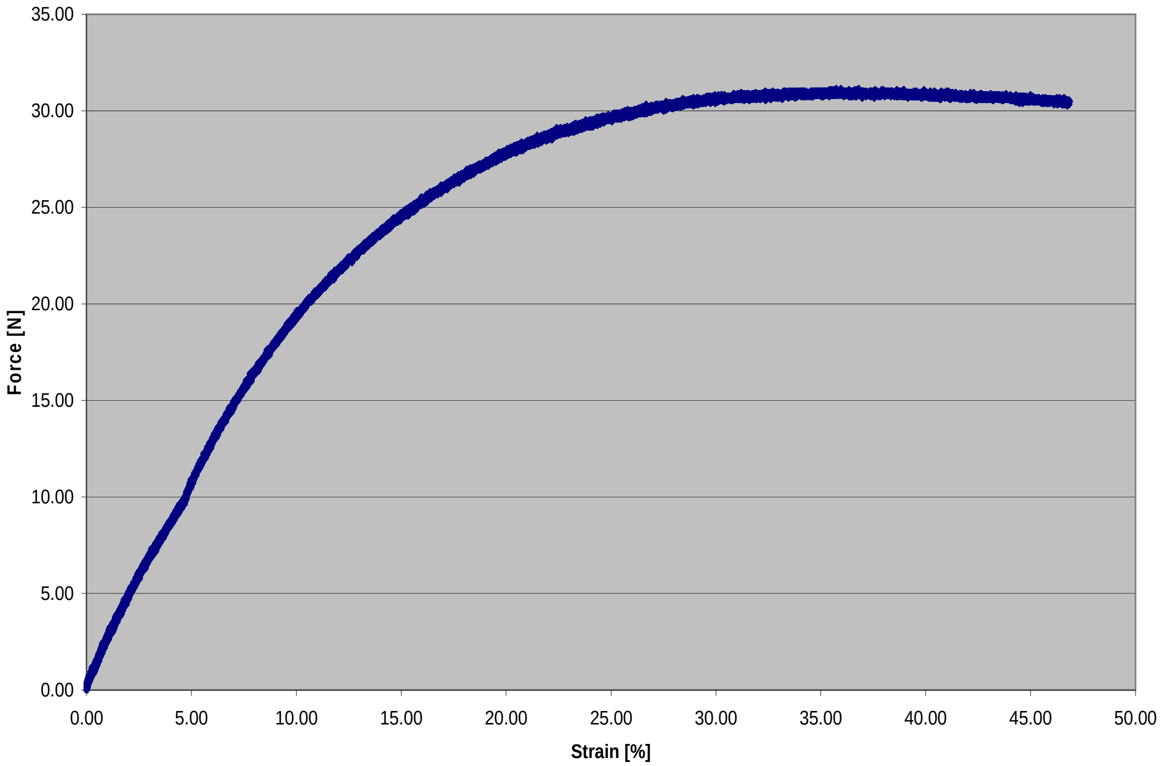
Tensile Tests

90°-Results



E_{22}=6.81 N/mm²
In comparison to calculated value from rule of mixture at a fiber-volume-fraction of 28%
E_{11calc}=9.25N/mm²

only valid for strain less than 3%

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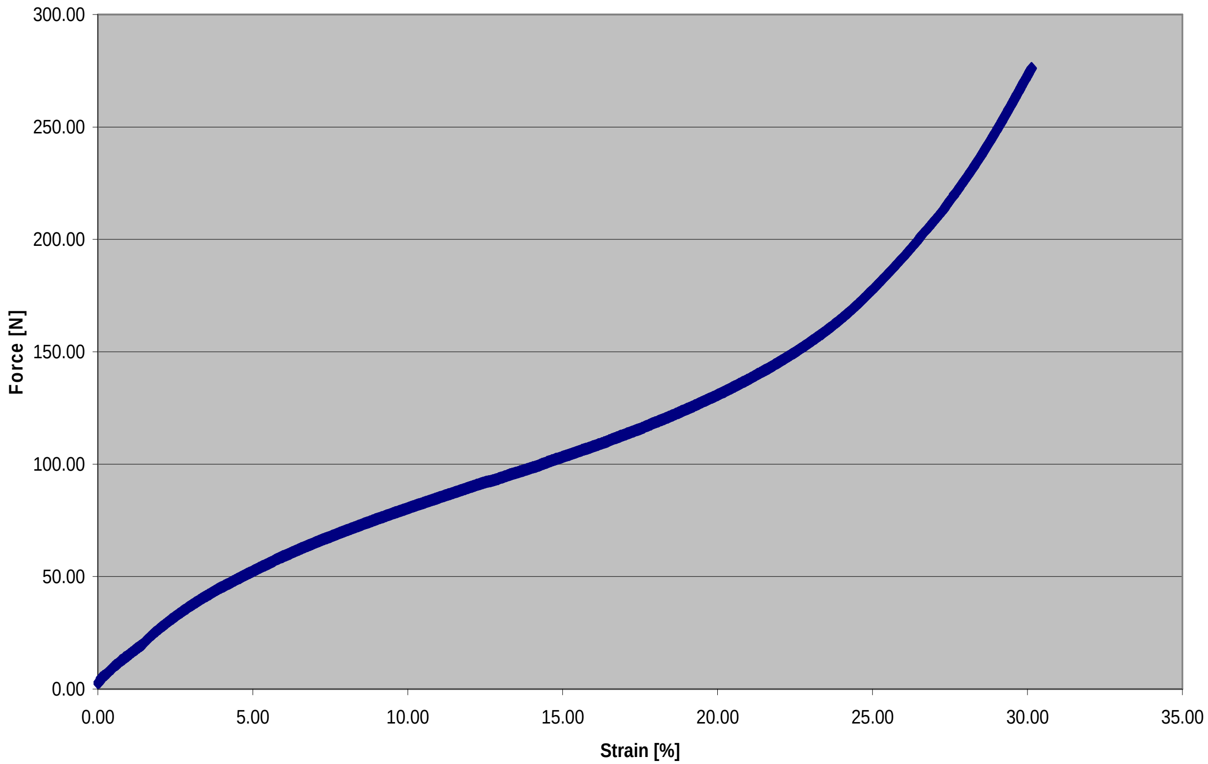
Tensile Tests

±45°-Results



G_{12}=17,52 N/mm²
only valid for strain less than 3%

At large strains (above 25%) delaminations could be seen to occur on the edges of the specimen

Tensile Tests-Results

The tests showed:

- Method for 0° -testing has to be changed.
- the different stiffness in the different directions (as expected)

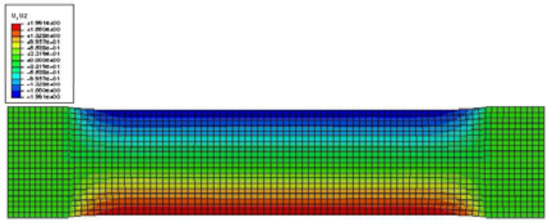
The Tensile tests are being used to calculate the material-properties of the developed material. For a range up to 3-5% strain standard methods can be used (approx. linear) e.g. rule of mixture / Hook’s law

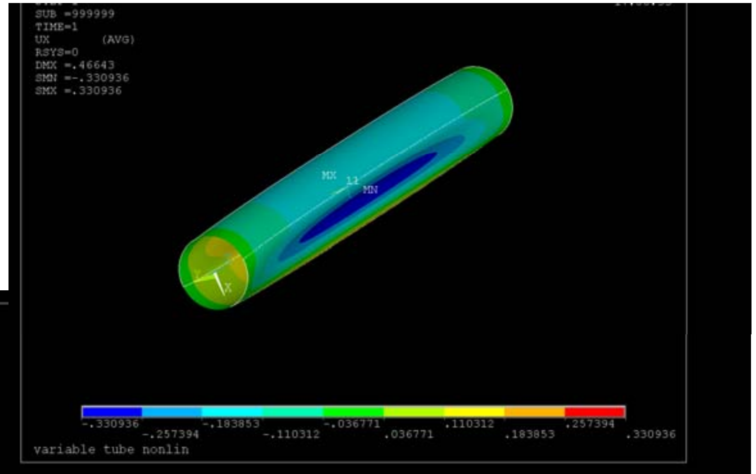
For strains above 5% different material-models are necessary: Fung, Holzapfel-Gasser-Ogden (Hyperelastic; anisotropic)

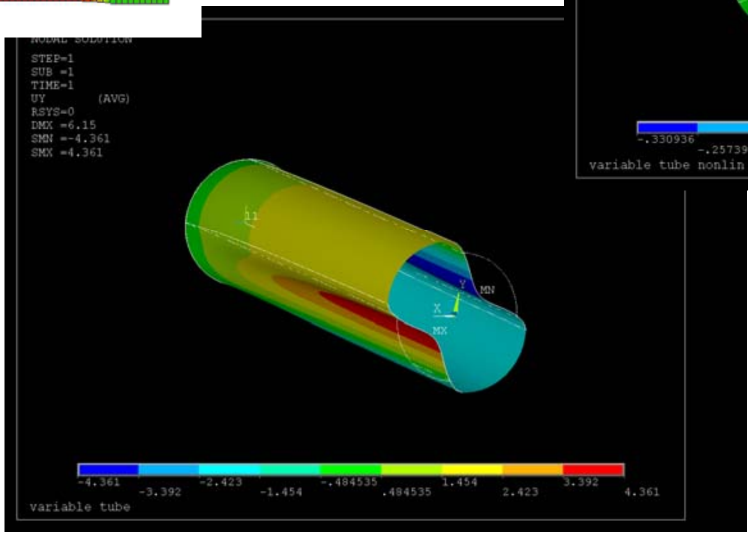
Simulation

The calculated material-constants are used to simulate various geometries with Abaqus and Ansys using the Fung and Ogden models.

- Same geometry as the tensile-tests (verification)
- Tube-shaped (actuator-design)







Conclusion / Outlook

Material- and production trials concluded a combination of pressure moulding and pultrusion with a TPE/Carbon material mix as the most suitable production process

Different TPE's should be tested with pultrusion to gauge range of mechanical properties

- Tests planned with Kraiburg TPE's Hipex®-material

Tensile tests showed expected results but also the necessity to improve the test methods

- further test are needed at different angles (to improve the data-base)
- tests in 0°-direction need to be improved
- Fatigue tests are needed

Simulation needs more refinement of the material-model

Thank you for your attention!

Questions?