Tailored Fiber Placement on Nonwovens made of Recycled Carbon Fibers

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Outline

CoDiCoFRP - Tailored Fiber Placement (TFP) on nonwovens made of recycled carbon fibers

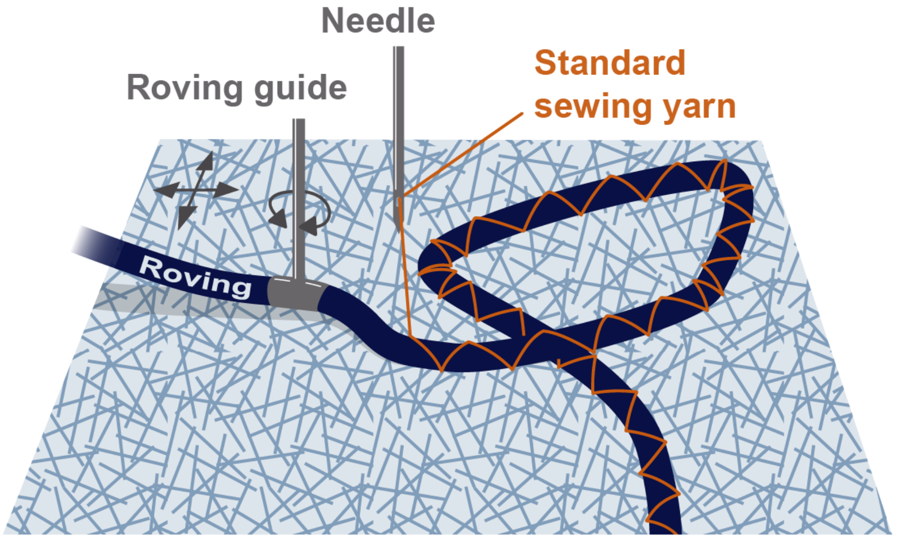
- Motivation and Approach
- Introduction Tailored Fiber Placement
- Requirements of rCF nonwovens for TFP application
- Mechanical properties of rCF/TFP pCF laminates with EP matrix
- Bolt tensile specimen – sub component
- Application of the technology on a complex part
- Conclusion and Outlook

CoDiCoFRP – TFP on nonwovens made of recycled carbon fibers (rCF)

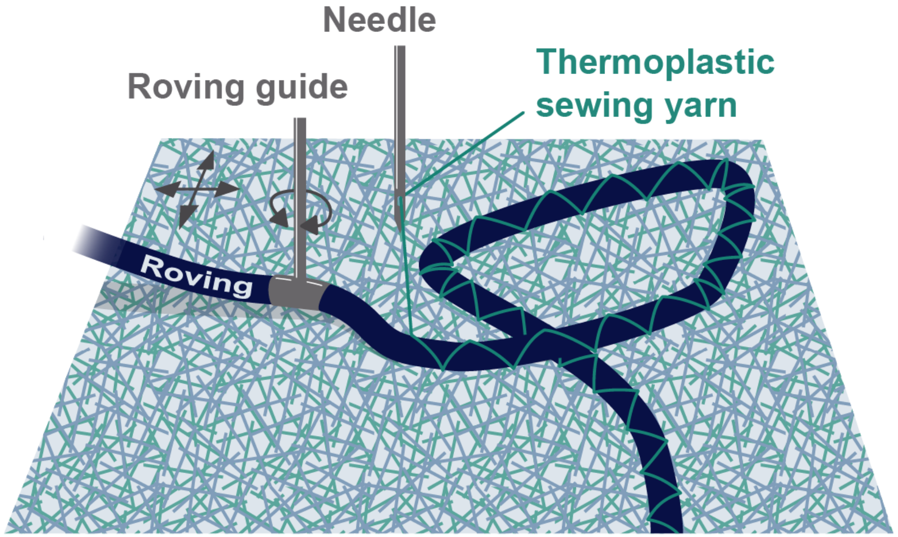
Motivation

- Enable the production of competitive CoDiCoFRP parts with at least 50 % rCF content and local continuous fiber reinforcements made of primary carbon fibers (pCF) using the TFP technology

Investigated approaches



Base material:
Nonwoven made of recycled carbon fibers
Roving: **Toho Tenax HTS 12K**
Matrix: **Epoxy (EPR L20 & EPH 161)**
Sewing yarn: Polyester

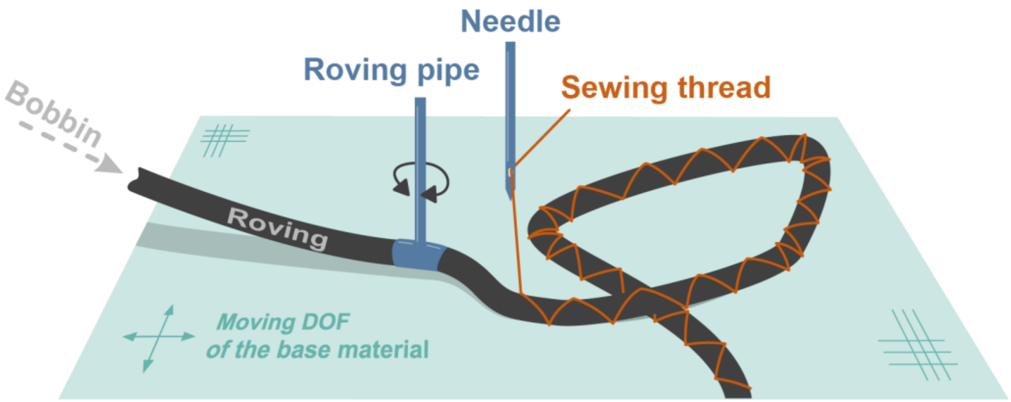


Base material:
Nonwoven made of recycled carbon fibers and PA6.6 thermoplastic fibers
Roving: **Toho Tenax HTS 12K**
Matrix: **PA6.6 (base material and the sewing yarn)**
Sewing yarn: specifically developed PA6.6

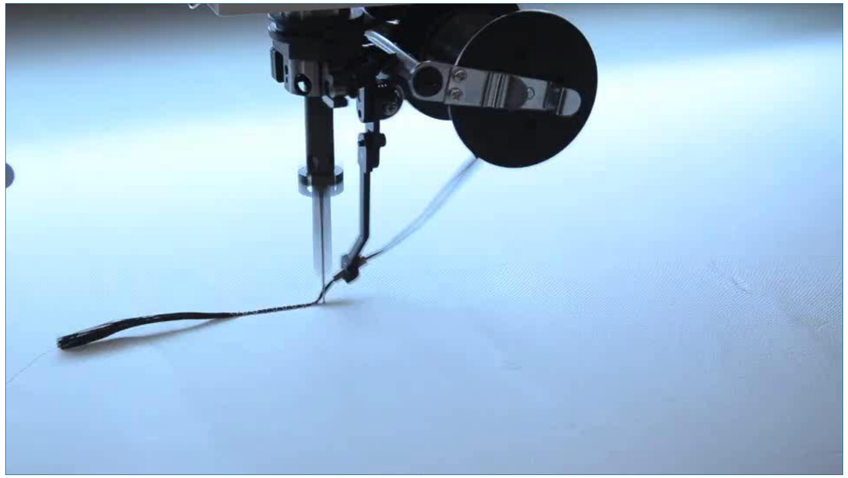
Tailored Fiber Placement (TFP)

Properties/Principle

- Development in the 1990s at IPF
- deposition speed up to 6 m/min per head
- productive textile, variable-axial and near net-shape preform technology
- arbitrary materials applicable, deposition radius r ≤ 5 mm
- (sub-)preform limited by bordure frame dimensions ≈ 1 m², t ≤ 6 mm



TFP-Principle

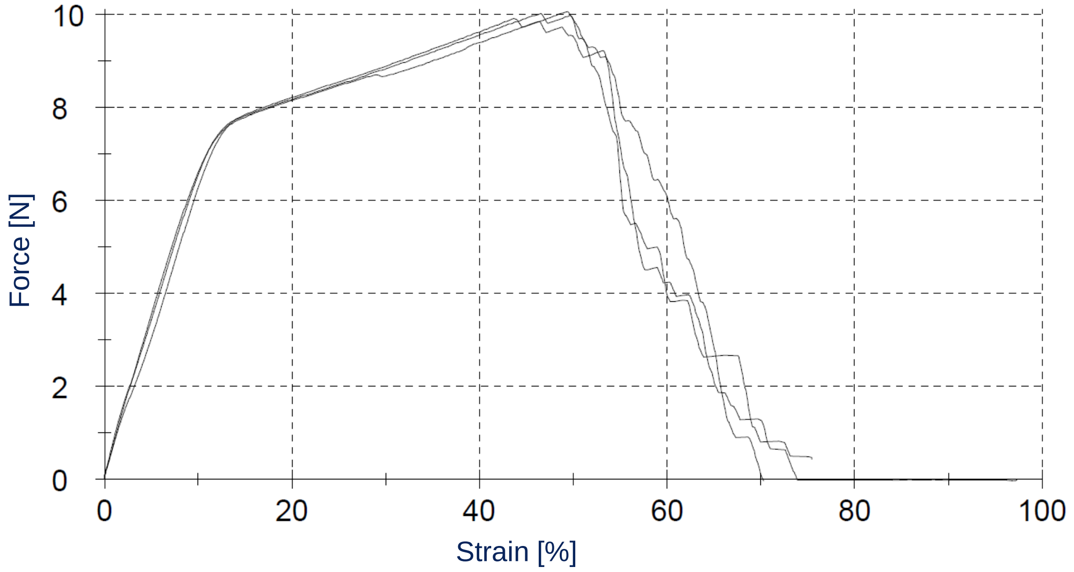


TFP-Process - Movie

Requirements of rCF nonwovens for TFP application

Sewing yarn for rCF/PA6.6 laminates

- commercially available PA6.6 sewing yarns contain silicone in the sizing
  → silicone reduces the fiber/matrix interphase strength drastically
- Development of a silicone free PA6.6 sewing yarn required
- IPF in house development, 24 tex PA6.6 sewing yarn with minimal sizing content (silicone free)



Force-strain behavior of the developed sewing yarn

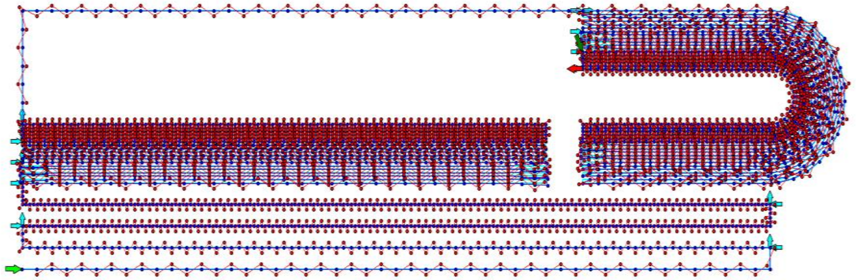
PA6.6 sewing yarn spool

Sewing yarn production line

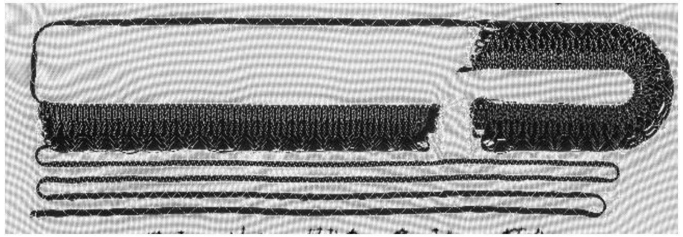
Requirements of rCF nonwovens for TFP application

TFP experiments

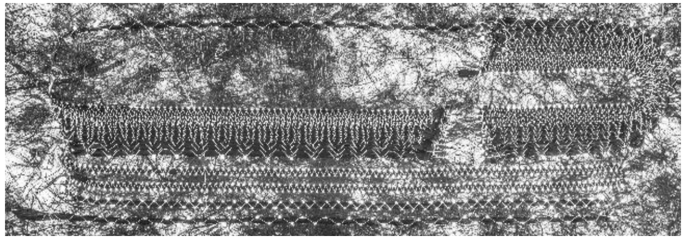
- Analysis of placement accuracy using a benchmark embroidery pattern
- At least 100 g/m² (gsm) are required for a stable TFP process when **pure rCF** is used
- Pure PA6.6 staple fiber base material – **no precise fiber placement possible**



Benchmark embroidery pattern (created with EDOpath)

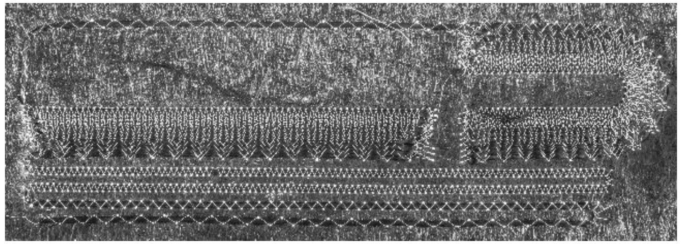


Reference (glas woven fabric 108 g/m²)

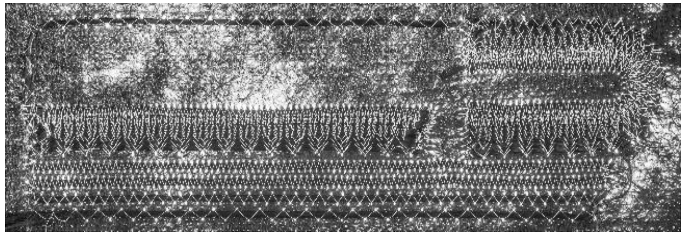


rCF 50 g/m², Krempel manufacturing process

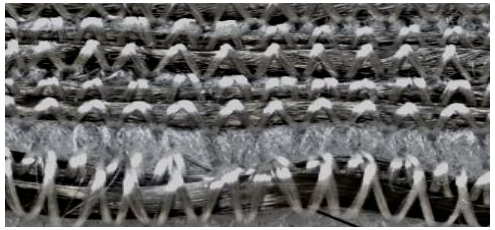
rCF/**PA6.6** – too high vertical compressibility of the PA6.6 nonwoven fabric



rCF 100 g/m², Krempel manufacturing process



rCF 100 g/m², Airlay manufacturing process



rCF/**PA6.6** – unsufficient placement accuracy

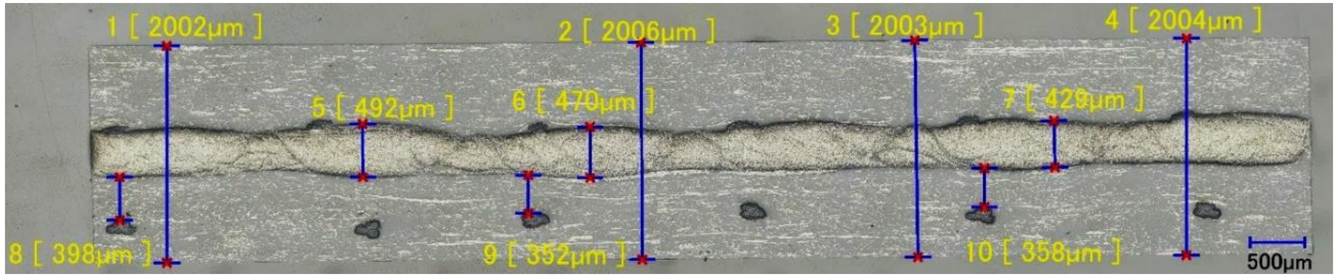
Manufacturing of rCF/TFP pCF laminates with EP matrix

Resin transfer molding (RTM) process

- 50/50 proportion pCF/rCF, TFP layer unidirectional, placed in the middle
- Reference laminate made of pCF NCF with quasiisotropic stacking, identical EP system and tooling
- Homogenous resin distribution due to rCF nonwoven layer, stable RTM process
- → low fiber volume content in rCF layer

Laminate stacking TFP pCF / rCF

RTM tool II



Laminate quality TFP pCF / rCF laminate

Mechanical properties of rCF/TFP pCF laminates with EP matrix

Tensile test results

- 50/50 proportion pCF/rCF, TFP layer unidirectional
- Reference laminate made of pCF NCF with quasiisotropic stacking, identical EP system and tooling
- → low fiber volume content in rCF layer limits the performance
- → when pCF are placed in load direction (added to the rCF nonwoven), performance increases significantly but the level of the pCF reference laminate cannot be reached

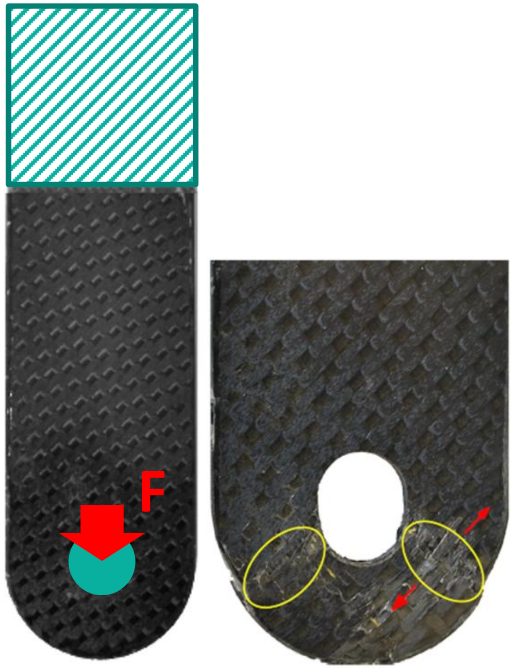
Zwick/Roell Tensile test rig with 20 kN load cell

Laminat-Configuration	**Laminate thickness**	$\bar{\varphi}^{1)}$	$\varphi_{rCF}^{1)}$	φ_{TFP} , φ_{NCF}	E ($E_{\parallel}$, $E_{\perp}$)$^{2)}$	R ($R_{\parallel}^{(+)}$, $R_{\perp}^{(+)}$)$^{2)}$
	[mm]		%	%	[N/mm²]	[N/mm²]
rCF – TFP pCF 50/50 ‖	2.22 ± 0.18	35,0	12.4 ± 0.3	57.6 ± 4.4	33526 ± 2322	392.0 ± 31.5
rCF – TFP pCF 50/50 ⊥	2.31 ± 0.18	33,25	11.8 ± 0.1	54.7 ± 2.1	18235 ± 1584	172.3 ± 24.6
pure rCF laminate	2.24 ± 0.01	15,0	15.0 ± 0.1	-	21385 ± 1447	250.4 ± 34.0
NCF QI laminate	1.04 ± 0.01	42,6	-	42.6	38760 ± 1245	592.0 ± 56.4

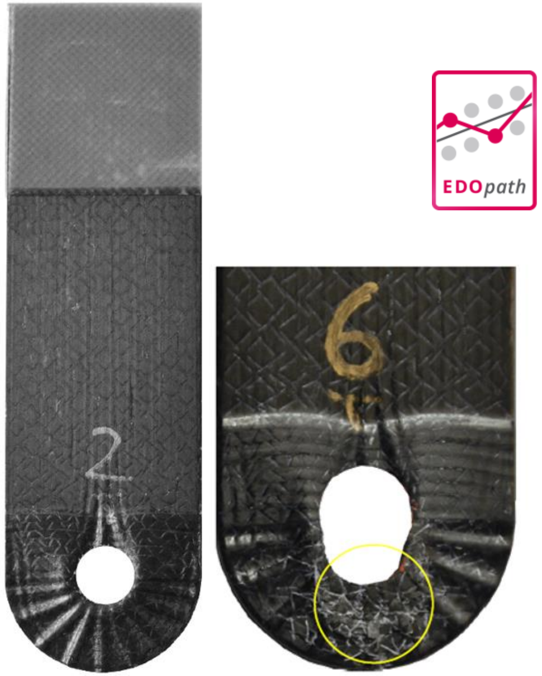
Bolt tensile specimen – sub component

Tensile test results

- 50/50 proportion pCF/rCF, TFP layer fiber layout according principal stress direction
- Reference laminate made of pCF woven fabric with quasi-isotropic stacking, identical EP system and tooling
- → low fiber volume content in rCF layer and lower fiber content in general limits the failure load
- → pCF/rCF TFP shows significantly increased displacement and provide a higher energy absorption capacity up to total failure
- → when normalized to the fiber volume content failure load is comparable to the pCF only reference laminate



pCF woven fabric bolt tensile specimen including failure image



rCF – pCF TFP 50/50 bolt tensile specimen including failure image

Bolt tensile specimen – sub component configuration	$\bar{\varphi}$	φ_{rCF} %	φ_{TFP} or φ_{NCF} %	Max load F_{max} [N]	Displacement till ultimate failure s [mm]
rCF – pCF TFP 50/50 - TFP fiber layout according to principal stress direction	33.0	ca. 12.5	ca. 55.0	31652 ± 1778	4.3
Woven fabric pCF – quasiisotropic stacking	52.0	-	52.0	50224 ± 2752	2.0

Application of the technology on a complex part – bike saddle

Results

- Excellent drapeability even on double curved surfaces
- Excellent wetting properties, stable resin infusion process
- competitive weight of the saddle shell (approximately 90 grams) due to optimized TFP pCF layout while still containing 50 % rCF

Demonstration part "bike saddle": TFP-CF on rCF nonwoven preform (top) and consolidated part (bottom), rCF content > 50 %, Embroidery pattern created with EDOpath

EDOpath

Summary

- The developed pure rCF nonwovens allow a reliable processing in the TFP process
- Due to the vertical compactibility of staple fiber based PA6.6 nonwovens no precise fiber placement is possible
- TFP preforms on rCF nonwovens exhibit a very good drapeability and a excellent wetting behavior
- The resulting material properties of the TFP based CoDiCoFRP are slightly limited by the low fiber volume content in the rCF nonwoven layer
- Due to the high degrees of freedom regarding the fiber orientation, competitive parts can be produced when the load case is known and the fiber layout is adapted accordingly

Outlook

- Combination of pCF TFP on PA6.6 foil and PA6.6 staple fibers with included rCF to enable the production of TFP based CoDiCoFRP with thermoplastic matrix materials and a substantial rCF content

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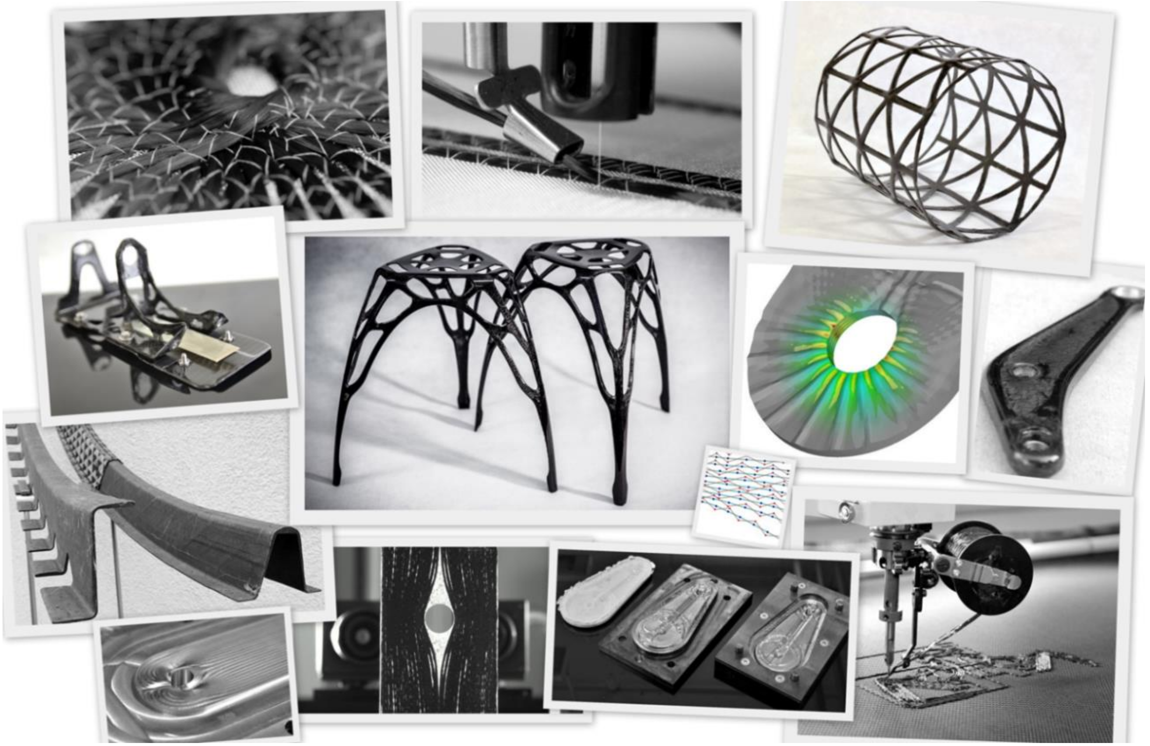

Thank you!

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