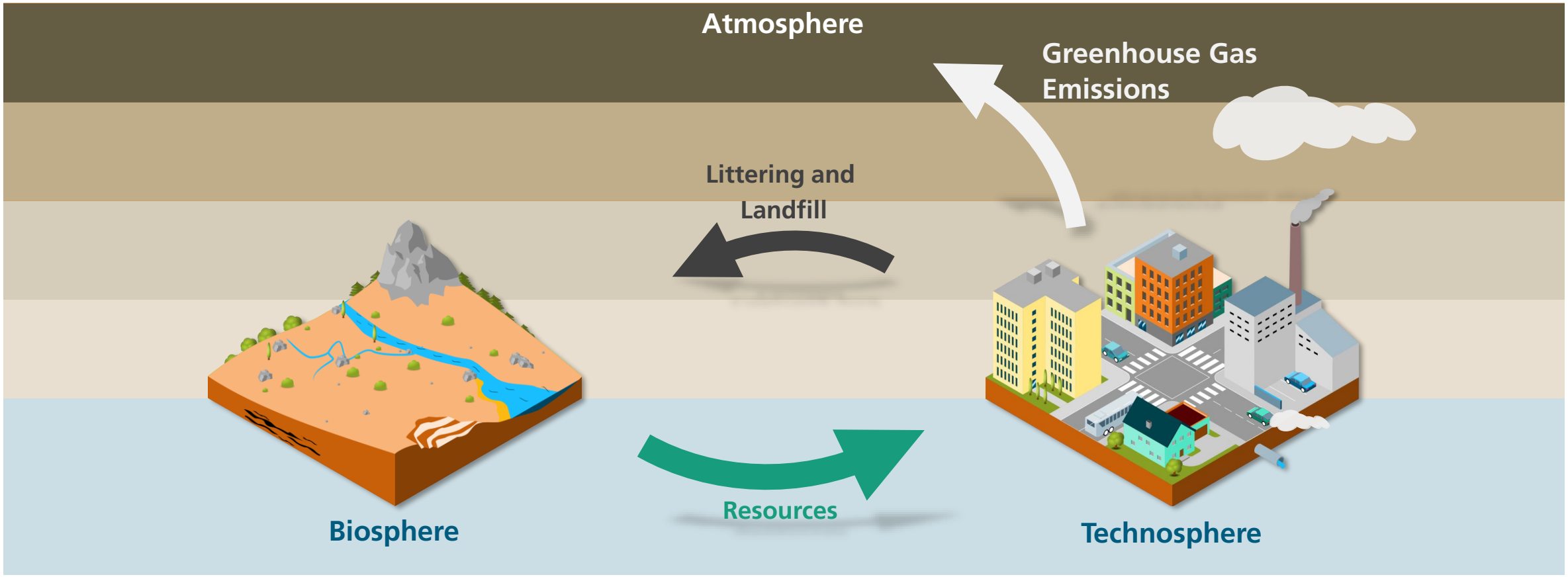
SPE AUTOMOTIVE COMPOSITES CONFERENCE & EXHIBITION 2025
Fraunhofer ICT | Sascha Kilian, M.Sc.; Anna Krueger, M.Sc.; Prof. Dr. Frank Henning |
Novi, MI – September 3-5, 2025

Morphology Lightweight Approach - Challenges of Processing Self-Reinforced Sandwich Structures

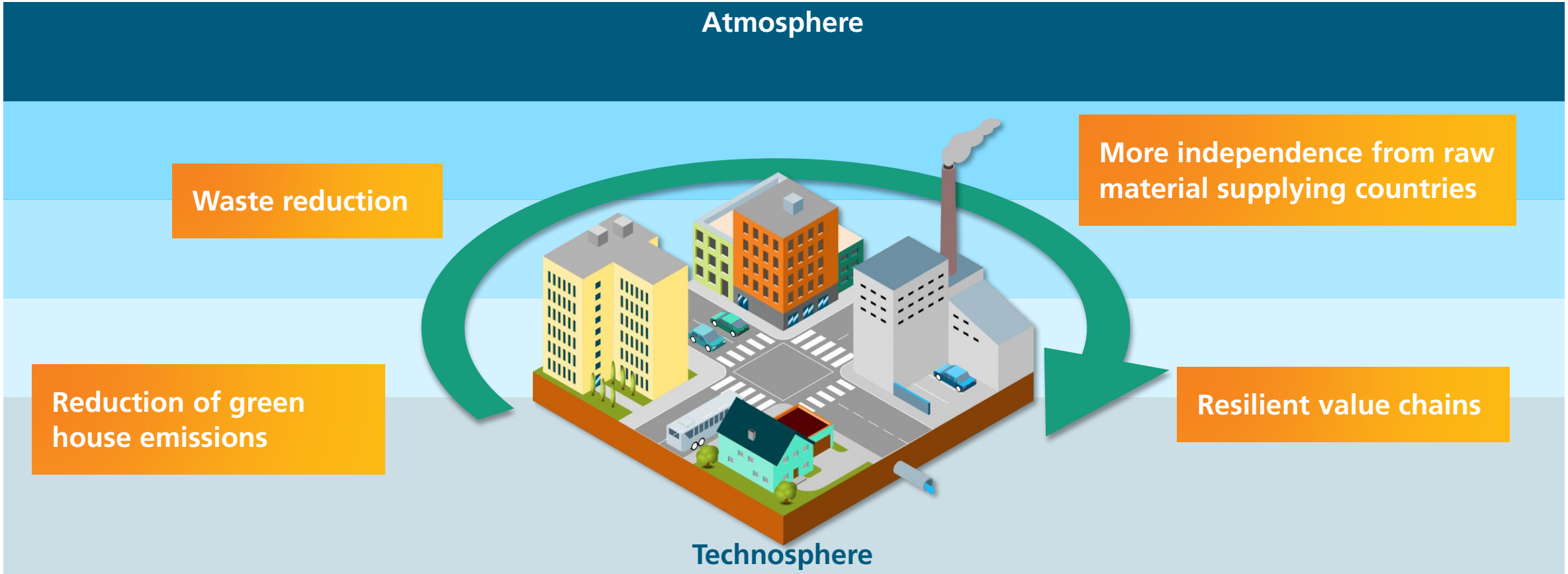
Motivation

Closing the Loop



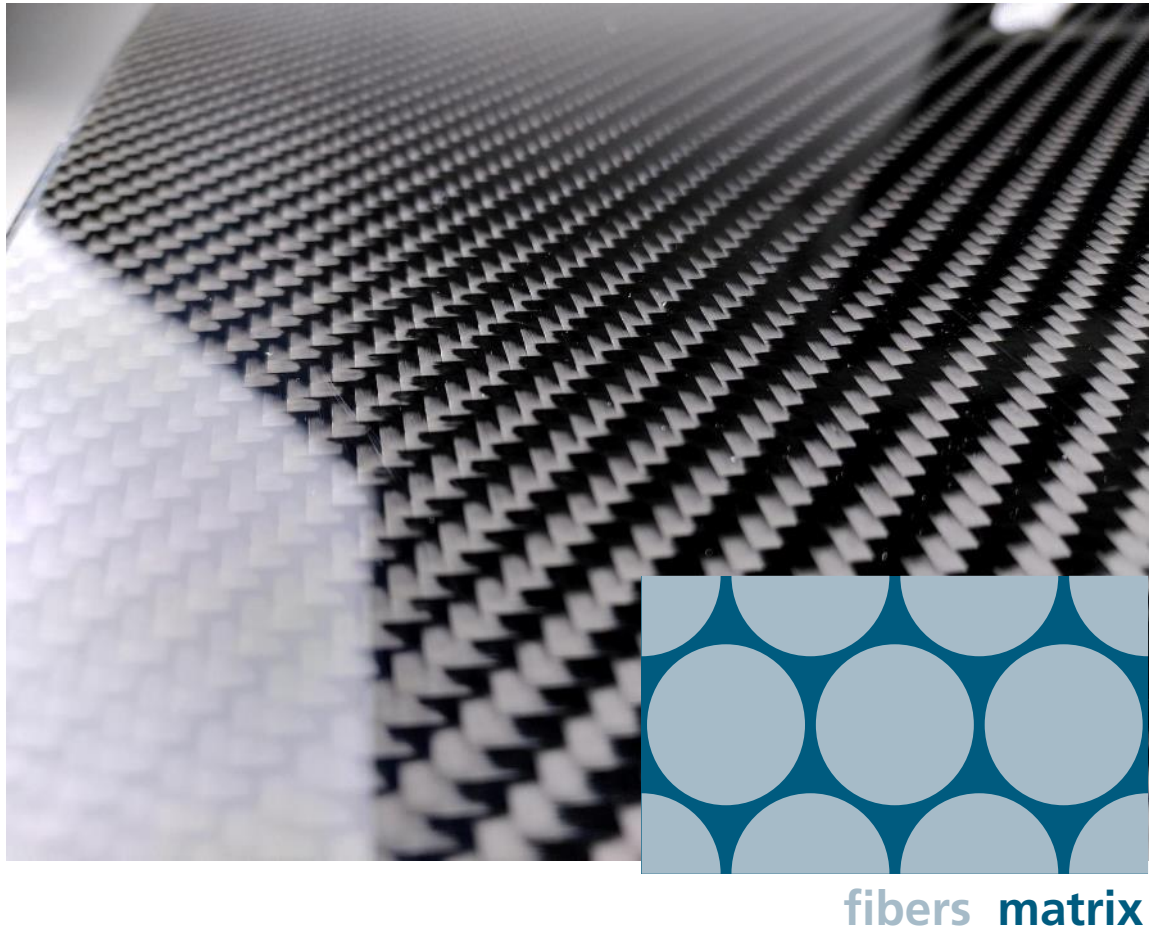
Motivation

Closing the Loop

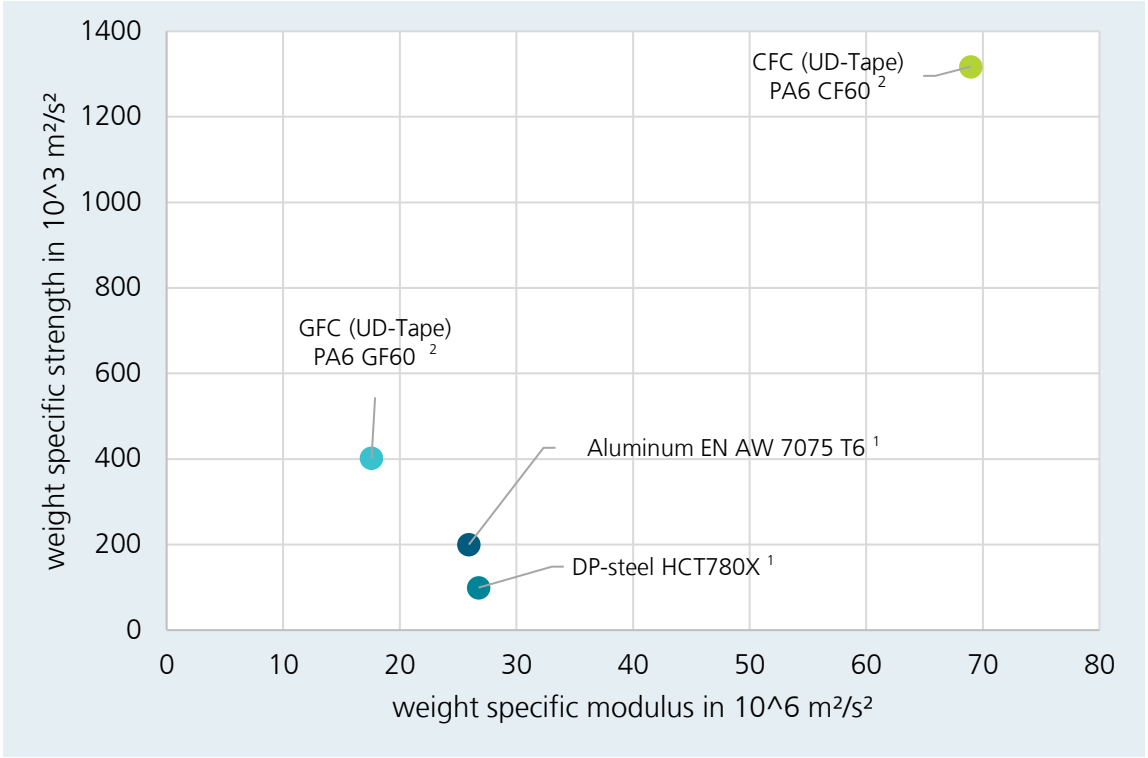


Cutting down Secondary Energy Demand - Use-Phase

Lightweighting using of fiber-reinforced plastics



Selection of weight specific tensional properties of different materials

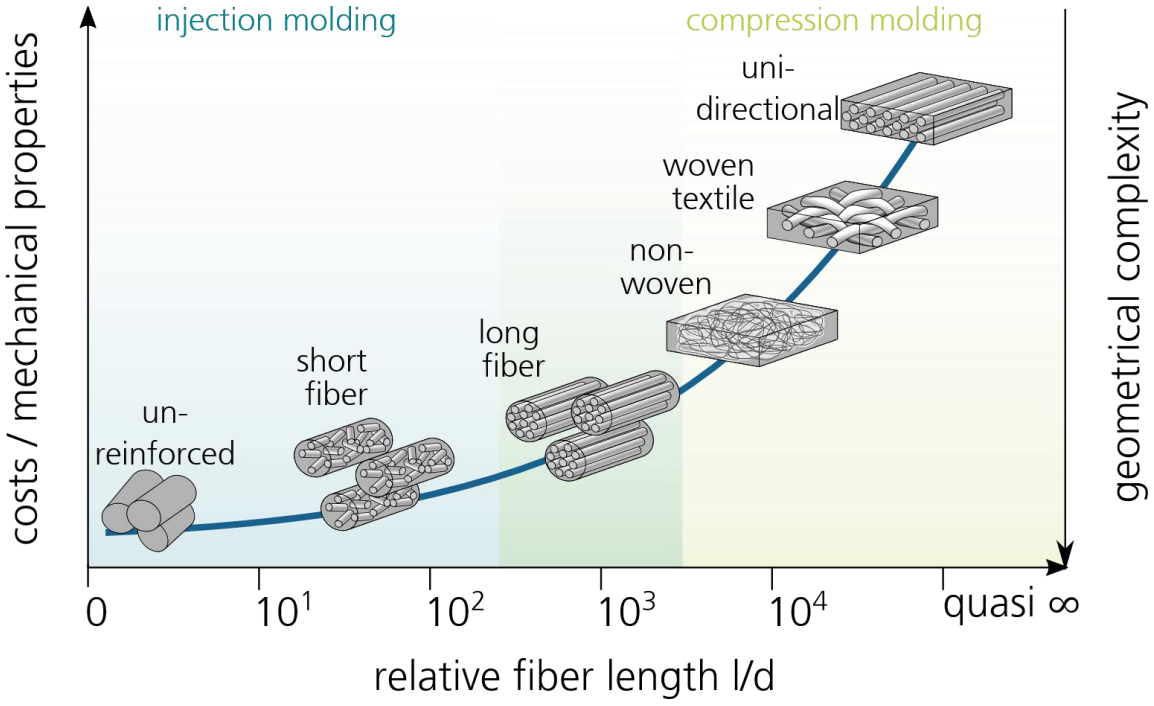


Own representation; Data base; [1] ThyssenKrupp [1;2]; [2] Celanese [3;4]

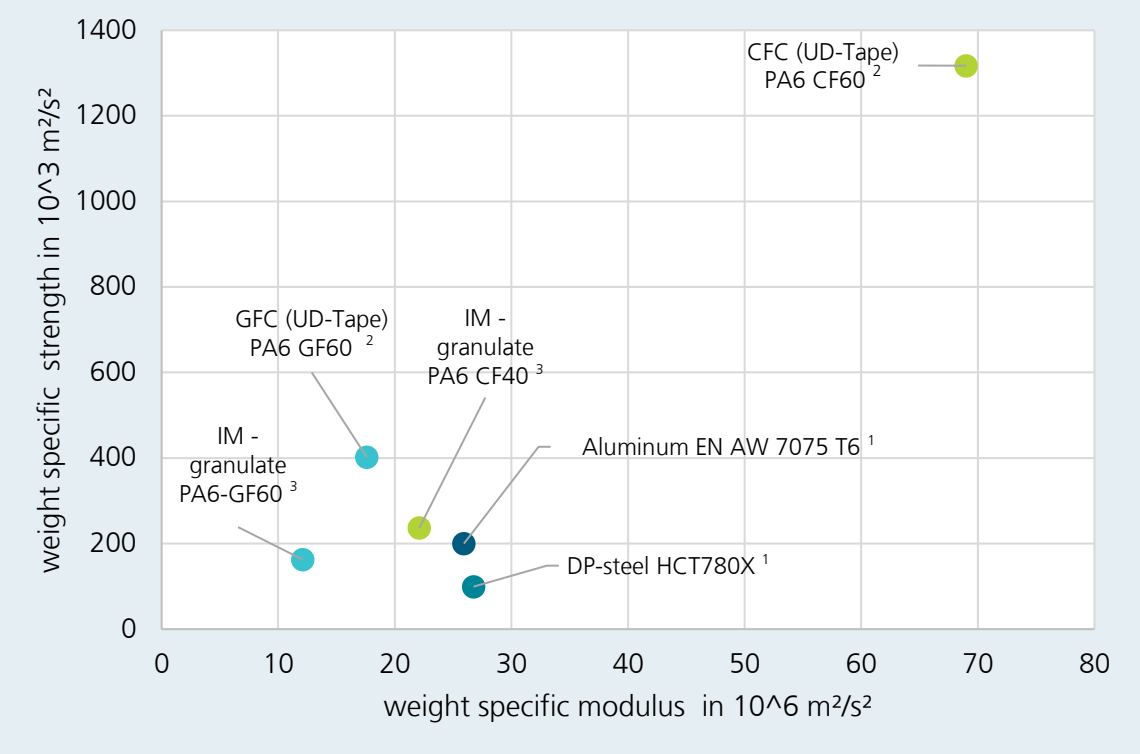
Mechanical Recycling - End-of-Life

Lightweighting using of fiber-reinforced plastics

Mechanical properties of FRPs vs. fiber length



Selection of weight specific tensional properties of different materials

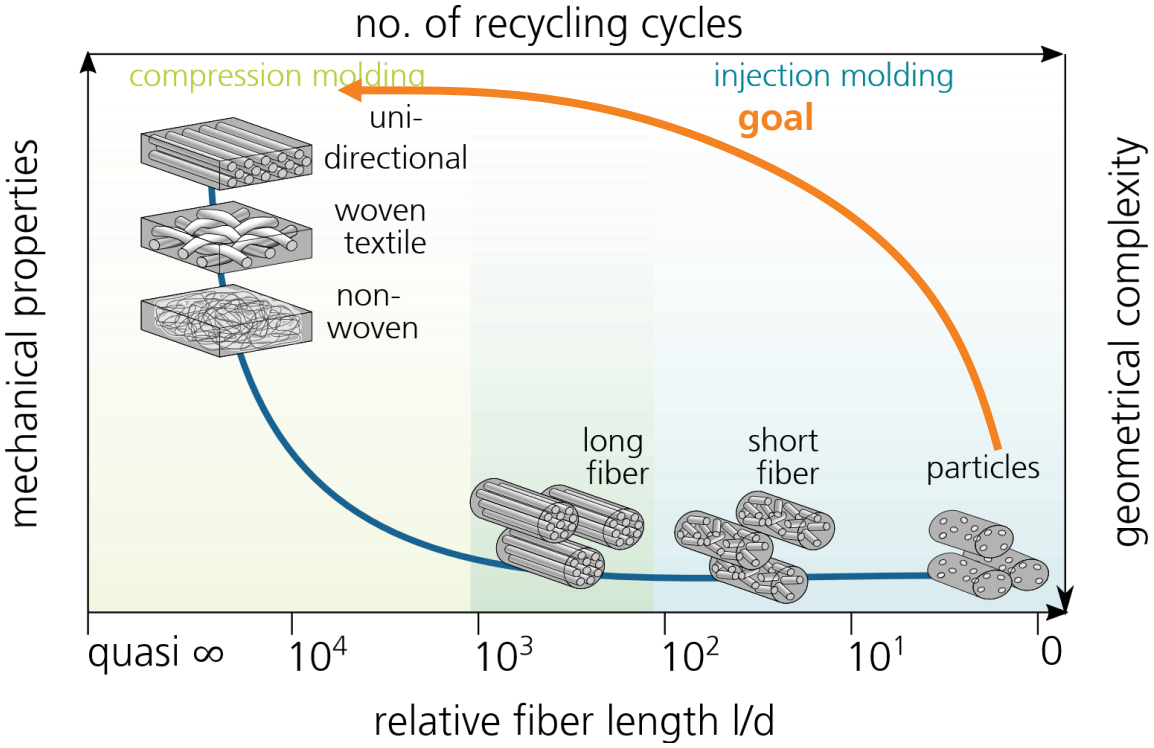


Own representation; Data base; [1]ThyssenKrupp [1;2]; [2]Celanese[3;4;5;6];

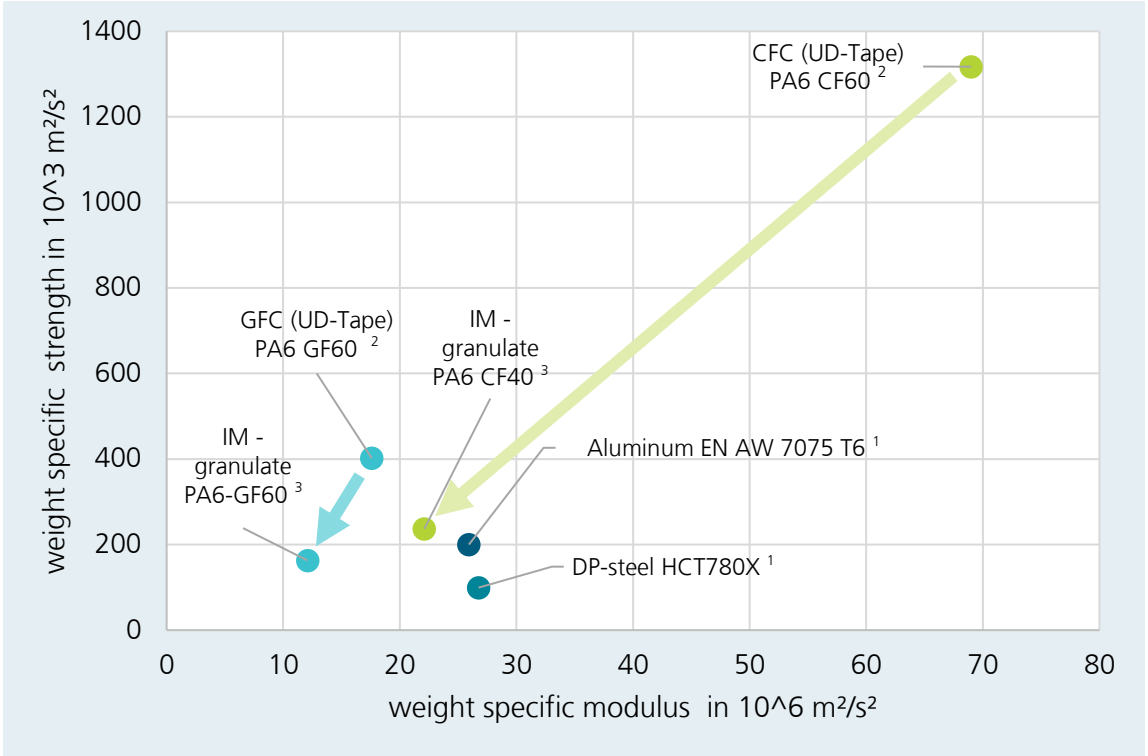
Mechanical Recycling - End-of-Life

Lightweighting using fiber-reinforced plastics

Mechanical properties of FRPs vs. fiber length



Selection of weight specific tensional properties of different materials



Own representation; Data base; [1]ThyssenKrupp [1;2]; [2]Celanese[3;4;5;6];

Imagine, there would be one material that could be shaped in different morphologies to enhance its specific performance.

One Material → Different Morphologies → Circular-Ready Lightweight Design

Morphology Lightweight Approach

Polymer granule

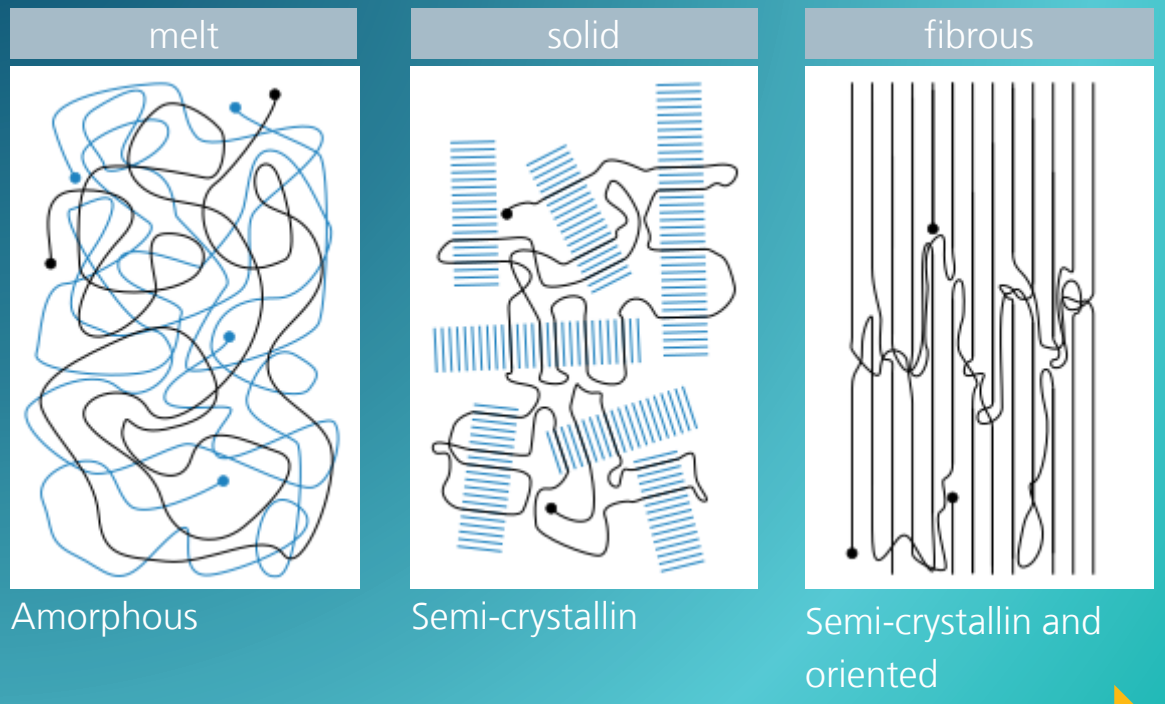
Fibers

Textiles

Solution Approach – Self-Reinforced Plastics (srP)

Working Principle

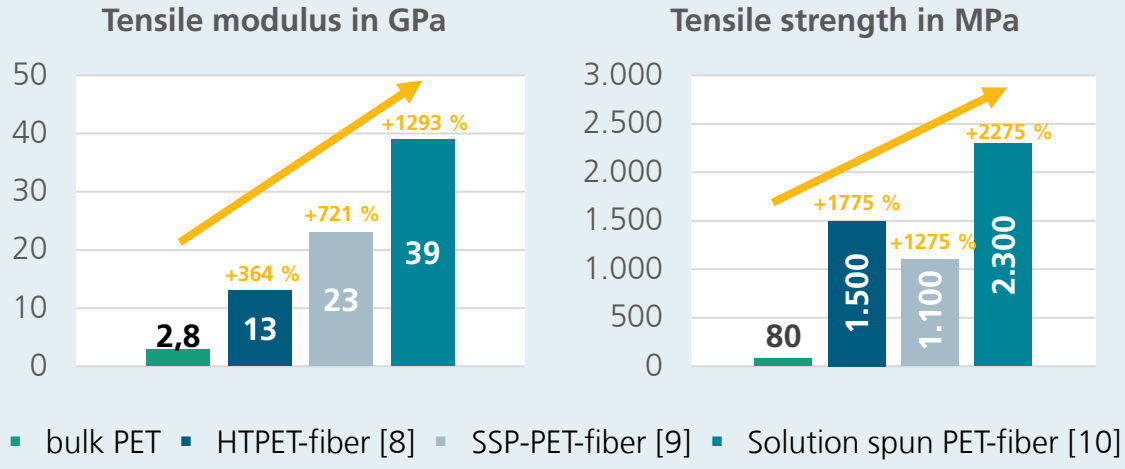
Orientation of polymeric molecules



Bond-dissociation energies

- Covalent bond (C-C aliphatic): ≈350 kJ/mol
- Hydrogen bridge bond: 10-50 kJ/mol
- Van-der-Walls-bond: 0,1-10 kJ/mol

Comparison of tensile properties of bulk and fibrous PET [2]



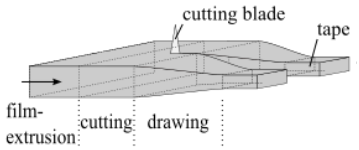
Fraunhofer ICT

Solution Approach – Self-Reinforced Plastics (srP)

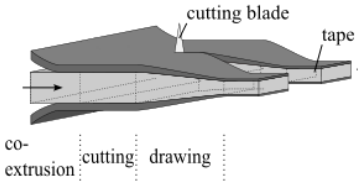
Manufacturing Technologies

precursor processing

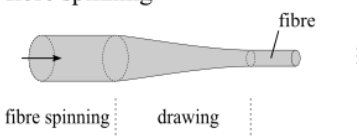
single-component tape



bi-component tape



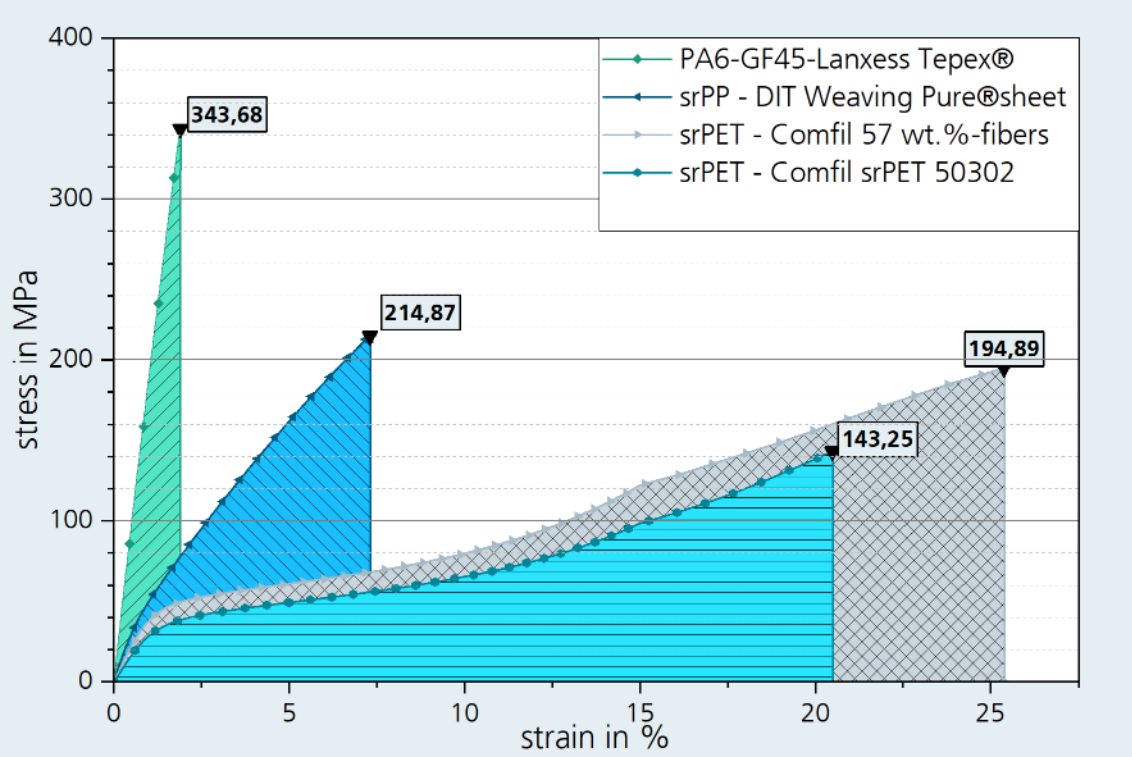
fibre spinning



Properties of Self-Reinforced Polymers

Comparison of different organo-sheets under tensional loads

Tensional properties



Weight-specific properties

Tensional properties according to DIN EN ISO 527-1

Property	unit	PA6-GF47[1]	srPP[2]	srPET 50%[3]	srPET 57%[4]
density	$\frac{g}{cm^3}$	1.8	0.78	1.38	1.38
Tensional modulus	GPa	19,9	6,4	3.5	4.6
Weight spec. tensional modulus	$10^6 \frac{m^2}{s^2}$	**11.06**	**8.21**	**2.54**	**3.33**
Tensional strength	MPa	343	215	143	195
Weight-spec. tensional strength	$10^3 \frac{m^2}{s^2}$	**190.56**	**275.6**	**103.6**	**141.30**
Elongation at break	%	1.9	7.7	22.8	24.7

[1]PA6-GF47 Lanxess Tepex®; [2]srPP DIT Weaving Pure®sheet; [3]srPET 50% Comfil srPET 50302;

[4]srPET 57% Comfil srPET 57 wt.%;

Low stiffness inhibits potential use of self-reinforced polymers in many applications

One Material → Different Morphologies → Circular-Ready Lightweight Design

Morphology Lightweight Approach

Polymer granule

Fibers

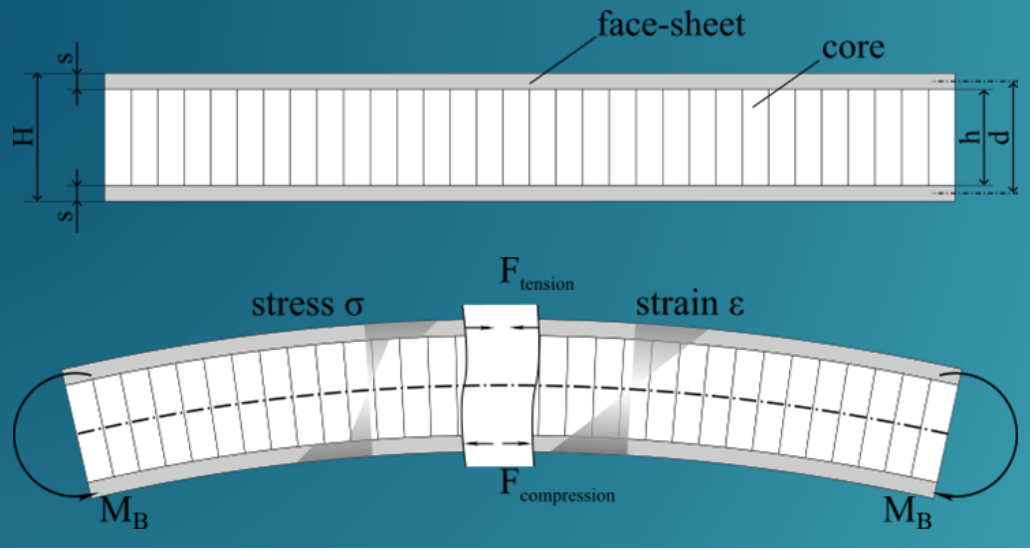
Textiles

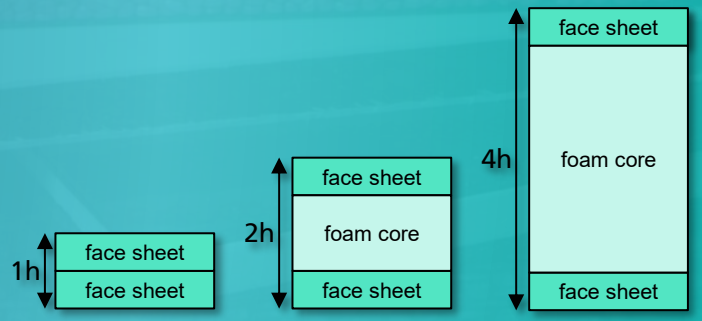
Foam

Sandwich-Structures

Multi-Morphology Design

- **increase in geometrical moment of inertia** while avoiding linear increase in mass
- two thin, stiff and rigid face-sheets separated by a **shear-resistant and light core**
- **optimized for bending loads** and impact performance



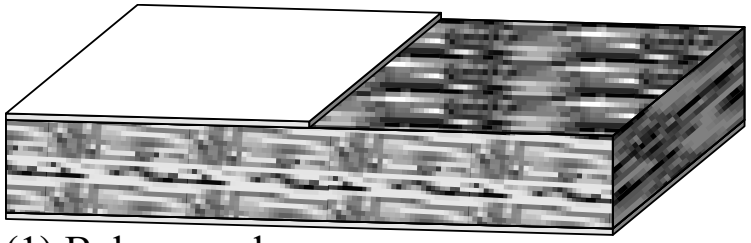


Mass	1	1.07 (+7%)	1.22 (+22%)
stiffness	1	7 (+600%)	37 (+3600%)

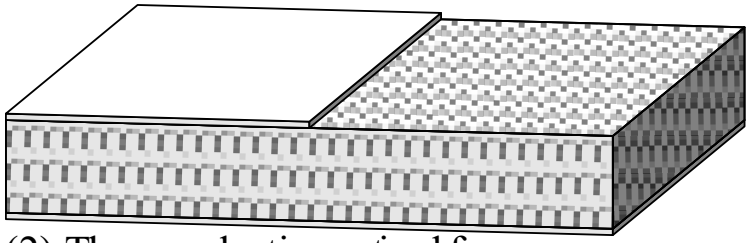
Fraunhofer ICT

Sandwich-Structures

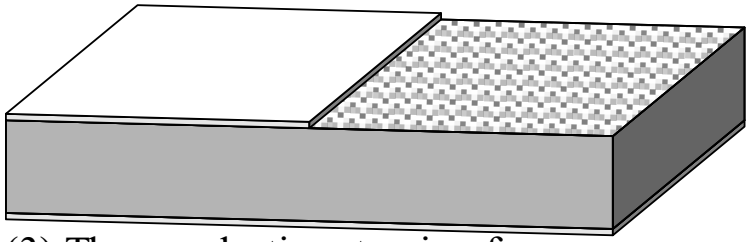
Multi-Morphology Design



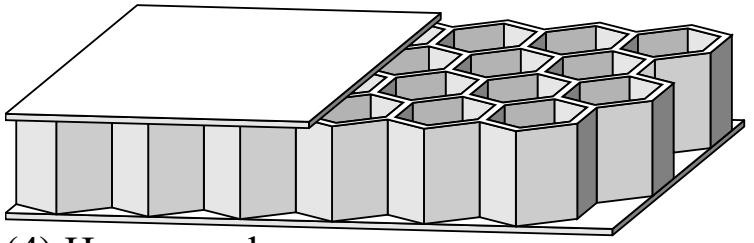
(1) Balsa wood



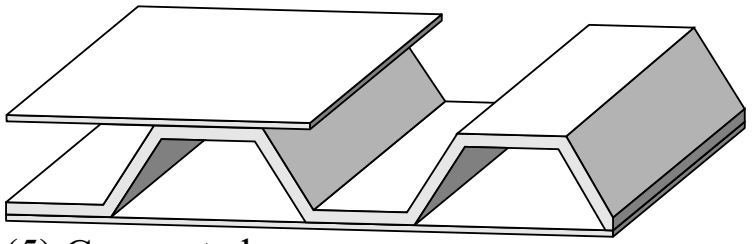
(2) Thermoplastic partical foams



(3) Thermoplastic extrusion foams



(4) Honeycomb cores



(5) Corrugated cores

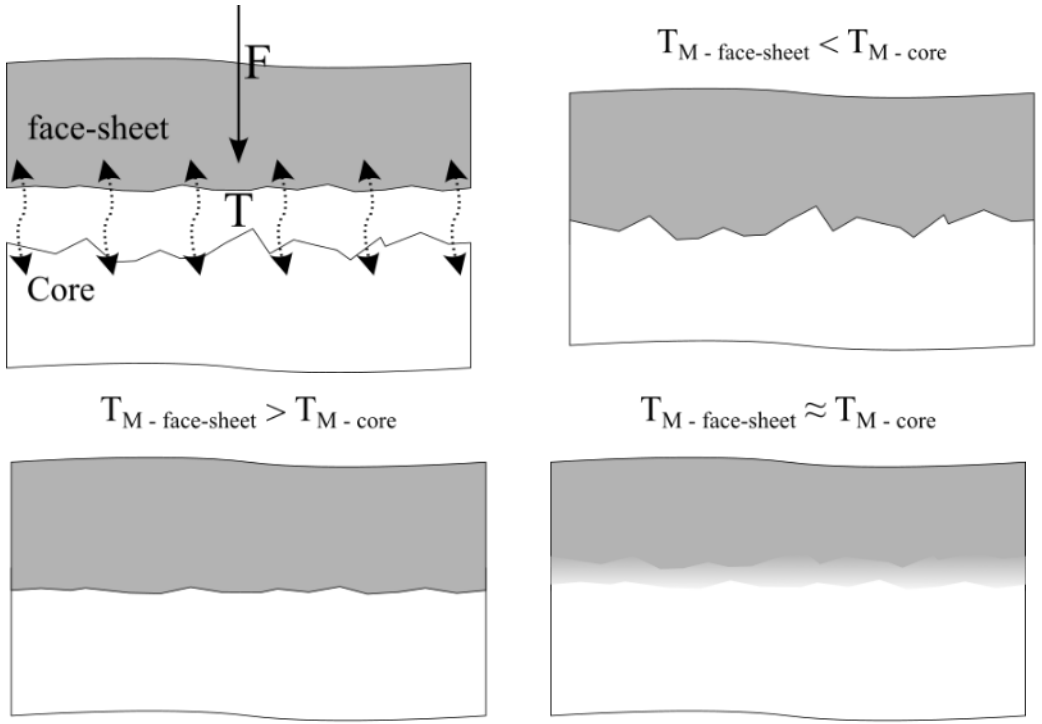
Suitable for MMSS

Challenges of Fusion Bonding

Achieving a cohesive bond between face-sheet and core using melt joining

Goal:

- Achieving an intimate contact without the use of adhesives through **application of temperature and pressure**

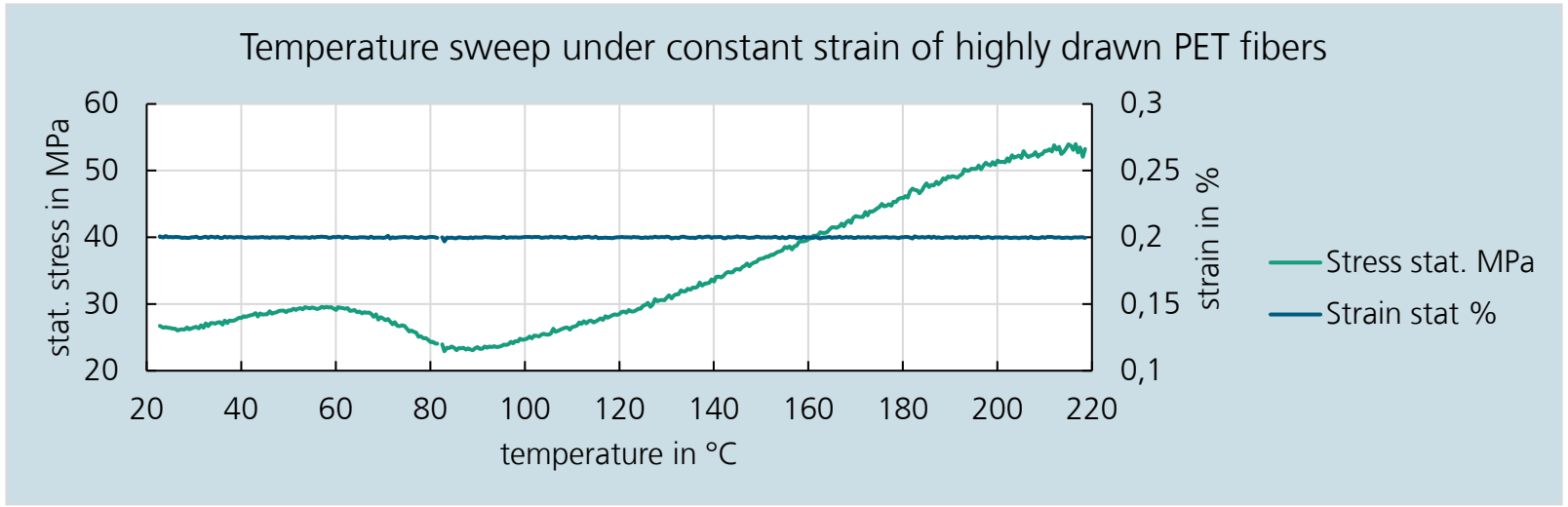


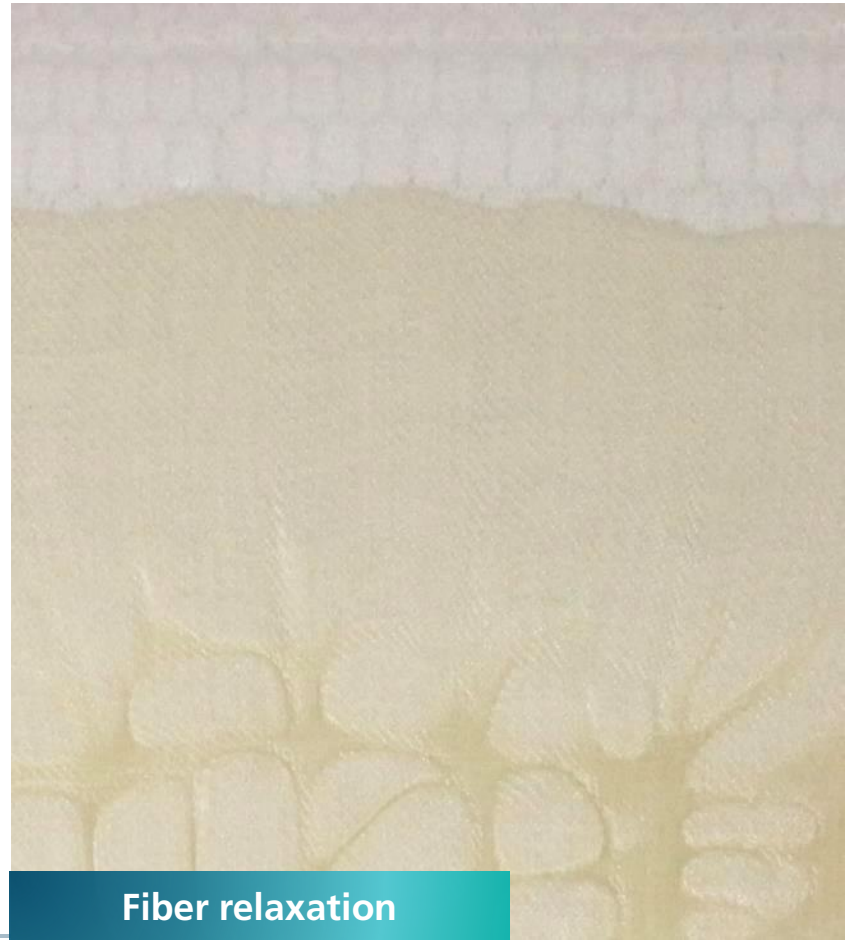

srPET sandwich

Challenges of Fusion Bonding

Fiber shrinkage due to relaxation effects

- In a drawn state, thermoplastic fibers have a **high potential energy.**
- At elevated temperature (processing temperature) the tendency for **entropy to increase** promotes fiber shrinkage.
- **High forces** in longitudinal direction.
- **Loss of mechanical performance.**
- **Crystallinity** plays a major role in the tendency for fiber relaxation.





Challenges of Fusion Bonding

Foam collapse

- Thermoplastic foams are **sensitive to compression loads** at elevated temperatures.
- **Coalescence of cells** near the melting temperature can lead to fatale failure of foam integrity.
- **Crystallinity** plays a major role

Thermal and pressure management is key for successful processing

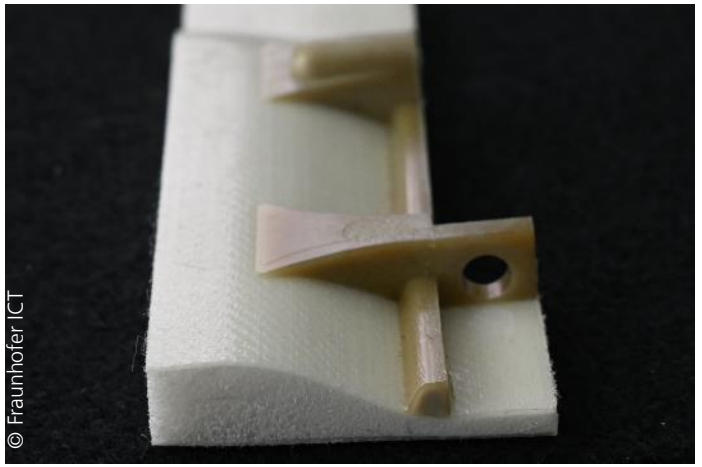
Foam collapse

Further Potential through Functionalization

Example: srPET-Sandwich

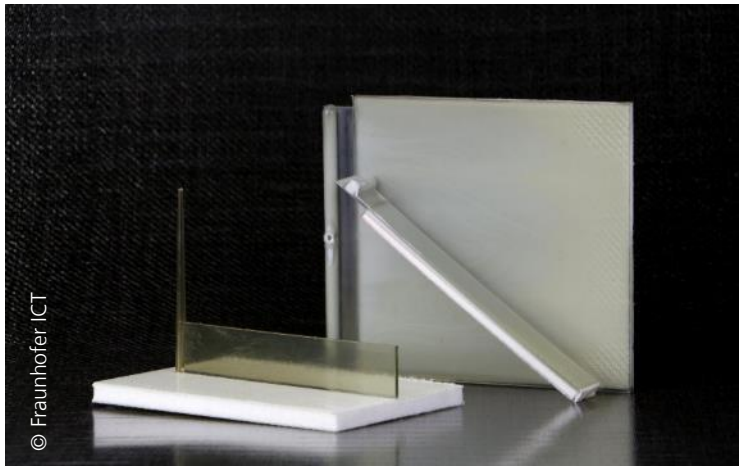
Thermo-forming

Compared to thermoset sandwich materials, thermoplastic show the advantage to be thermo-formed, which allows to use high-volume production semi-finished products



Core compaction

For thermoplastic foam sandwich cores a compaction step is applicable, which enables to achieve a gradual foam density and therefore optimized load transmission



Co-injection molding

Adding Ribs or functional elements like clips using co-injection and over-molding techniques

One Material → Different Morphologies → Circular-Ready Lightweight Design

Morphology Lightweight Approach

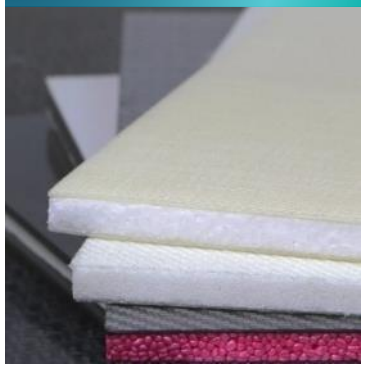
Polymer granule

Fibers

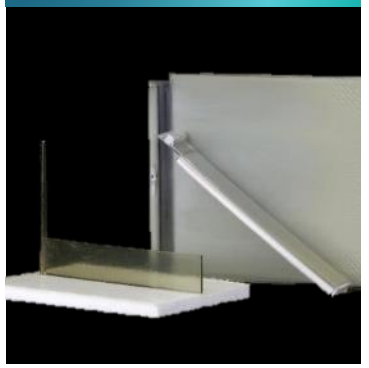
Textiles

Foam

Sandwich



Bulk



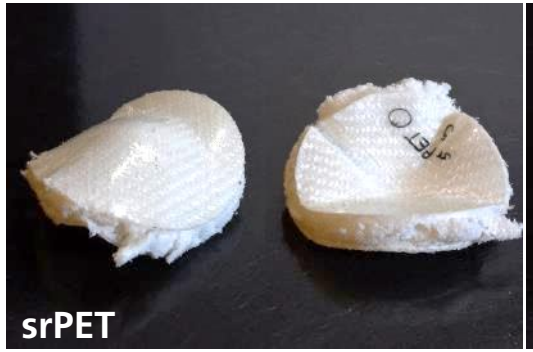
Surface

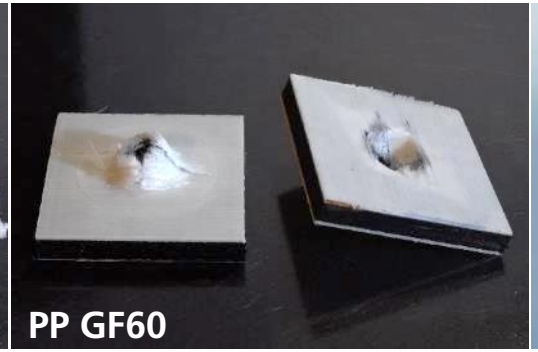
Potentials

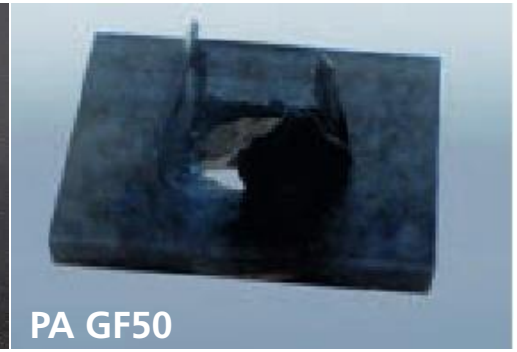
Impact properties (DIN EN ISO 6603-2)

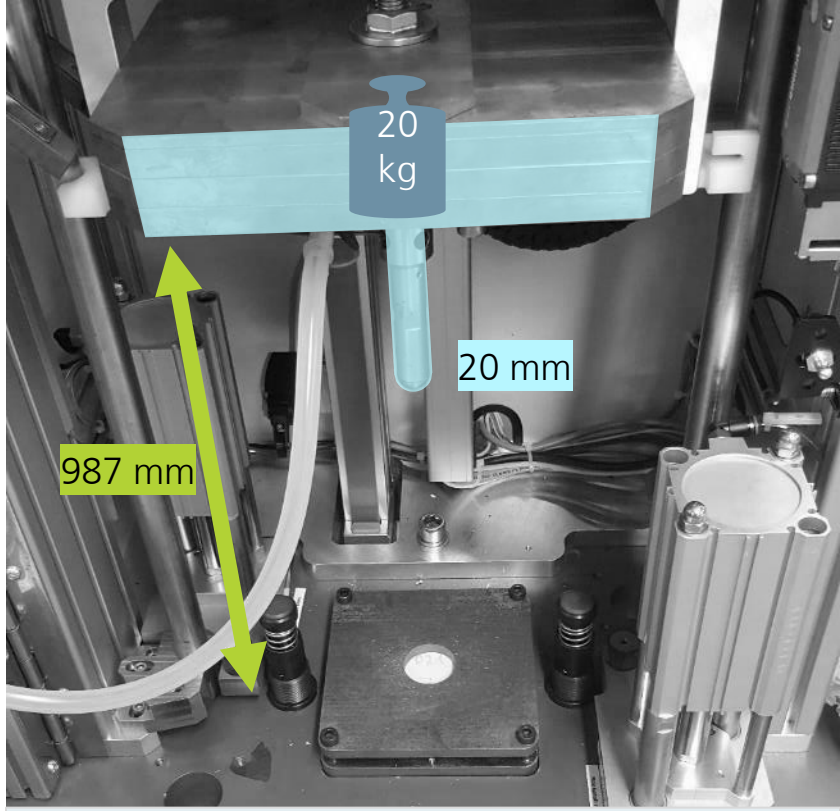
Comparison of different materials DIN EN ISO 6603-2

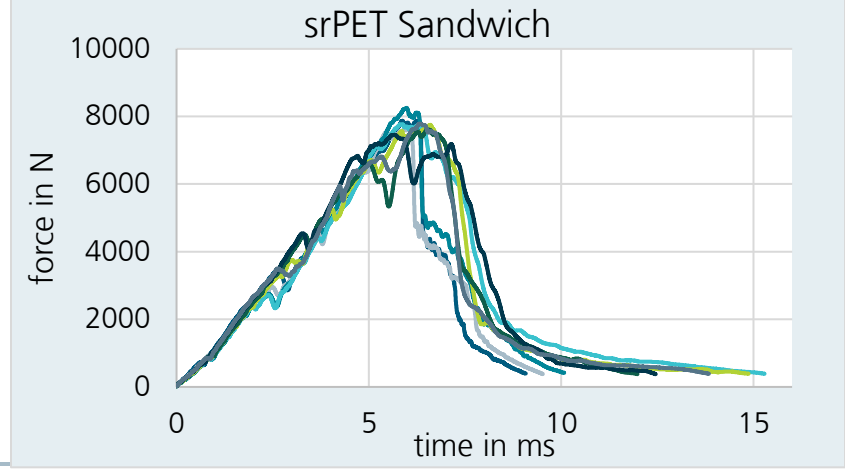
Material	areal weight in kg/m²	thickness in mm	max. force in kN	puncture energy in J	deflection in mm
Sandwich **srPET**	4.02	12	7.85	**115.8**	28.15
Sandwich **PPGF60**-UD-Tape EPP	6.09	12,6	6.73	**68.7**	19.4
Injection molding **PA6 GF 50** (Ultramid B3WG10)	6.20	4	3.80	**14.6**	n.d.











One Material → Different Morphologies → Circular-Ready Lightweight Design

Morphology Lightweight Approach

Polymer granule

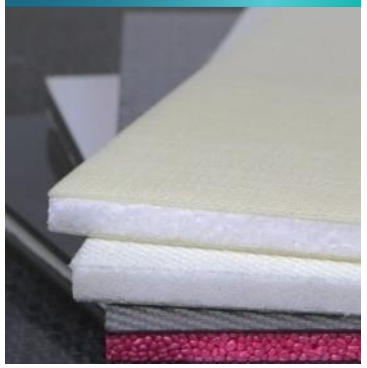
Application

Fibers

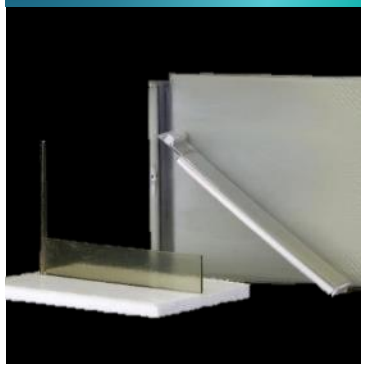
Textiles

Foam

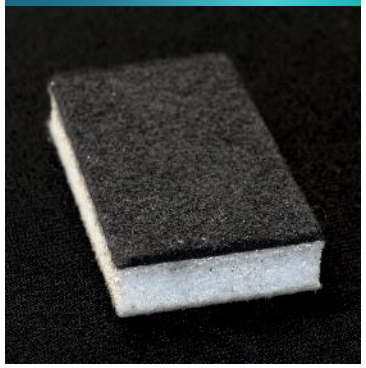
Sandwich



Bulk



Surface

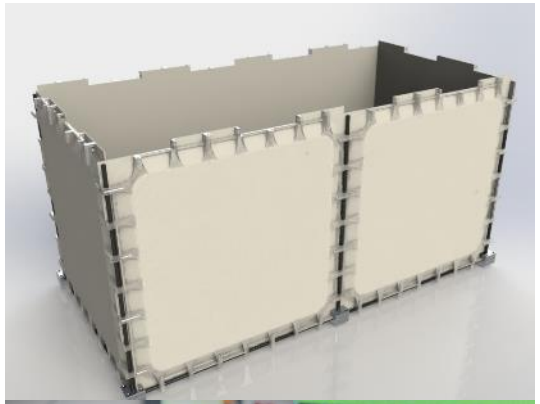


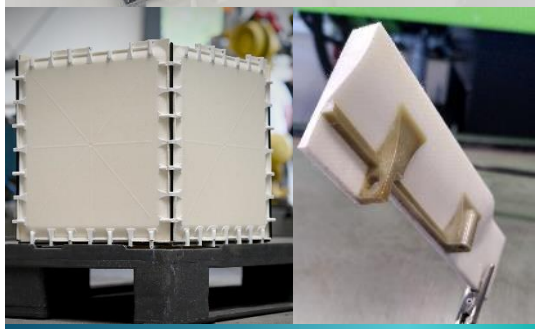
Exemplary application areas

Automotive

PA-based seat structure

UAV





PET-based modular transport container

Sports

PLA-based bike helmet

PLA-based surfboard

More to come…

One Material → Different Morphologies → Circular-Ready Lightweight Design

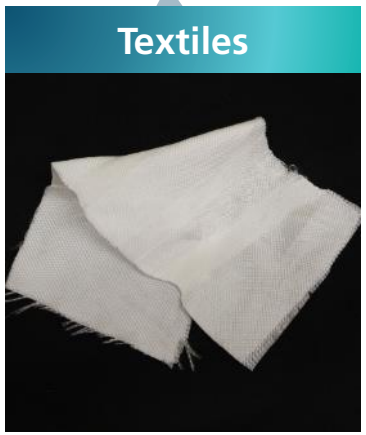
Morphology Lightweight Approach

Polymer granule

Recycle

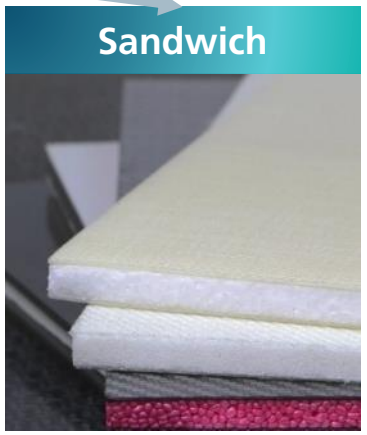
Application

Fibers



Textiles

Foam



Sandwich

Bulk

Surface

CONCLUSION

- **High lightweight potential,** due to low density
- **Necessity to re-design and re-shape products**
- **Characteristic profile of mono-material sandwich structures** enables the use in many applications like:
  - automotive,
  - aerospace,
  - sports&leisure,
  - etc.
- **Promising supplement** to conventional FRTPs
- Apart from PP, PA, PLA, PET morphology lightweight approach could be **adapted to other polymers**
- High potential to **close the loop**

Contact

Sascha Kilian, M.Sc.
Fraunhofer ICT | Polymer Engineering | Structural Composites
Tel. +49 721 4640-448
Fax +49 721 4640-800 448
sascha.kilian@ict.fraunhofer.de

Fraunhofer ICT
Joseph-von-Fraunhofer Str. 7
76327 Pfinztal
www.ict.fraunhofer.de

doi:10.24406/publica-5909

References

[1] European Commission - REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on circularity requirements for vehicle design and on management of end-of-life vehicles, amending Regulations (EU) 2018/858 and 2019/1020 and repealing Directives
[2] thyssenkrupp – DP-W® und DP-K® Produktinformation für Dualphasen-Stähle. - https://www.thyssenkrupp-steel.com/media/content_1/publikationen/produktinformationen/dp_w_dp_k/thyssenkrupp_dp-w_dp-k_produktinformation_steel_de.pdf , accessed on 24.01.2024
[2] thyssenkrupp - EN AW 7075 | Al Zn5,5MgCu - https://www.thyssenkrupp-materials-processing-europe.com/de/aluminium/legierungsgruppe-7000-or-en-aw-7020-or-en-aw-7075/en-aw-7075-or-al-zn55mgcu, accessed on 24.01.2024
[3] Celanese - CELSTRAN® CFR-TP PA6 CF60-03 - https://materials.celanese.com/products/datasheet/SI/CELSTRAN%C2%AE%20CFR-TP%20PA6%20CF60-03, accessed on 24.01.2024
[4] Celanese - CELSTRAN® CFR-TP PA6 GF60-03 - https://materials.celanese.com/products/datasheet/SI/CELSTRAN%C2%AE%20CFR-TP%20PA6%20GF60-03, accessed on 24.01.2024
2000/53/EC and 2005/64/ECCircular economy: improving design and end-of-life management of cars for more resource-efficient automotive sector; press release; Brussels; 13 July 2023
[6] Celanese - CELSTRAN® PA6-GF60-01 AF3001 NATURAL - https://materials.celanese.com/products/datasheet/SI/CELSTRAN%C2%AE%20PA6-GF60-01%20AF3001%20NATURAL, accessed on 24.01.2024
[7] Celanese - CELSTRAN® PA6-CF40-01 - https://materials.celanese.com/products/datasheet/SI/CELSTRAN%C2%AE%20PA6-CF40-01, accessed on 24.01.2024
[8] Santos, R.A.M.; Gorbatikh, L.; Swolfs, Y. (2021): Commercial self-reinforced composites: A comparative study. In: Composites Part B: Engineering 223, S. 109108. DOI: 10.1016/j.compositesb.2021.109108
[9] Nitta, S.; Yamaguchi, T.; Ito, M. (2007): Solid-state polymerization of melt-spun poly(ethylene terephthalate) fibers and their tensile properties. In: J. Appl. Polym. Sci. 103 (3), S. 1791–1797. DOI: 10.1002/app.25340.Ward, I. M.; Hine, P. J. (2004): The science and technology of hot compaction. In: Polymer 45 (5), S. 1413–1427. DOI: 10.1016/j.polymer.2003.11.050
[10] Huang, B.; Ito, M.; Kanamoto, T. (1994): Effects of draw conditions on deformability and draw efficiency of high molecular weight poly(ethylene terephthalate) fibres. In: Polymer 35 (6), S. 1329–1331. DOI: 10.1016/0032-3861(94)90033-7.
[11] Ward, I. M.; Hine, P. J. (2004): The science and technology of hot compaction. In: Polymer 45 (5), S. 1413–1427. DOI: 10.1016/j.polymer.2003.11.050
[12] Loos, J.; Schimanski, T.; Hofman, J.; Peijs, T.; Lemstra, P.J (2001): Morphological investigations of polypropylene single-fibre reinforced polypropylene model composites. In: Polymer 42 (8), S. 3827–3834. DOI: 10.1016/S0032-3861(00)00660-1.

.