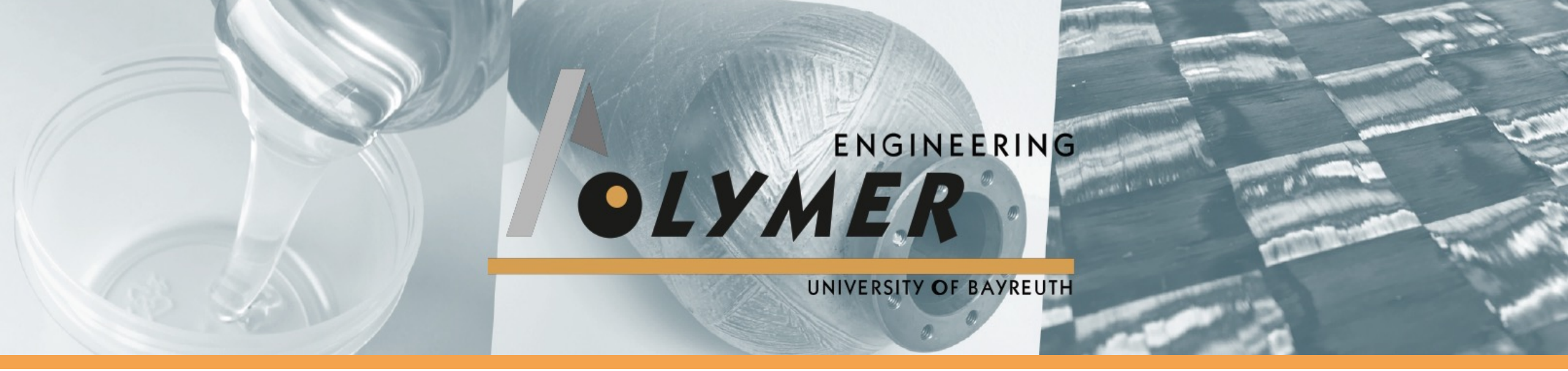


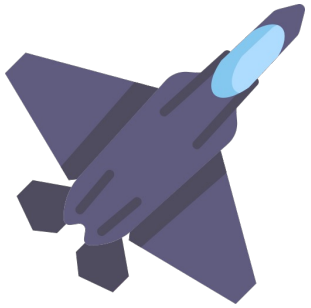
THE EFFECT OF GRAPHENE AS A MULTIFUNCTIONAL ADDITIVE FOR CARBON-FIBER COMPOSITES IN CRYOGENIC ENVIRONMENTS

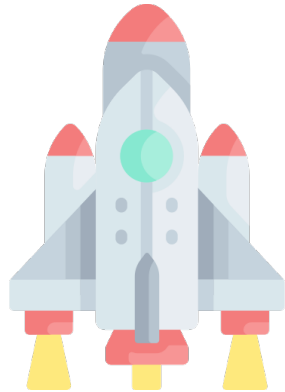
ICCM 23 | **30 July – 04 August** |
Eduardo Szpoganicz[1], Fabian Hübner[2], Uwe Beier[2], Matthias Geistbeck[2], Maximilian Korff[3], Andreas Scherer[3], Martin Demleitner[1], Holger Ruckdäschel[1]

[1] Polymer Engineering Department, University of Bayreuth, Bayreuth, Germany
[2] Airbus Central Research and Technology, Munich, Germany
[3] Mechanical Engineering Department, Bundeswehr University Munich, Munich, Germany

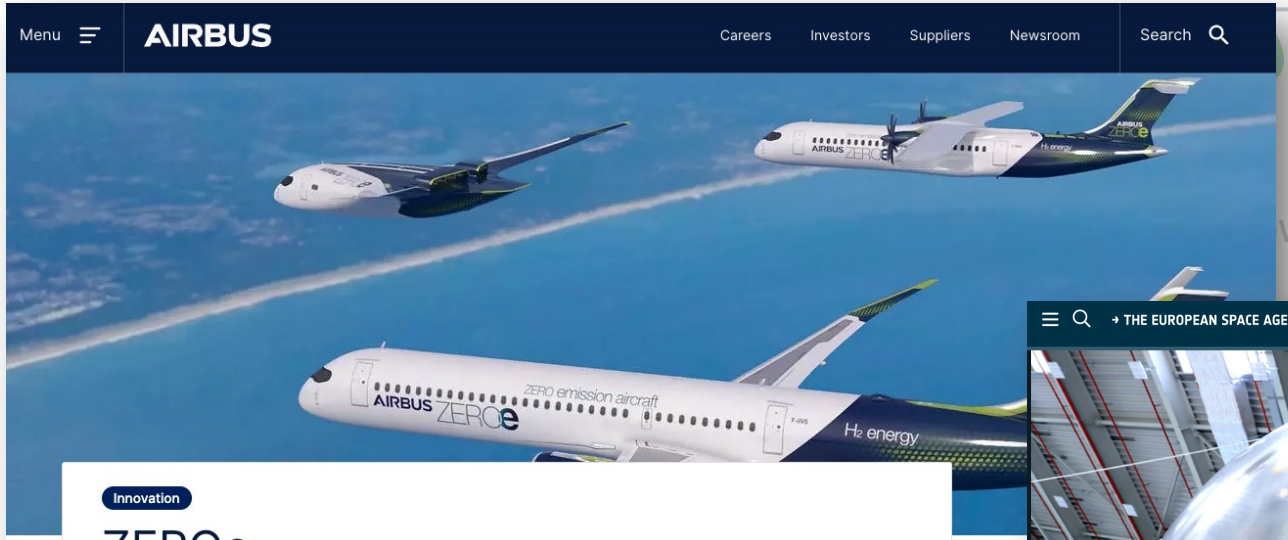
ICCM 23 INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS BELFAST 2021 1 - 6 AUGUST 2021

Hydrogen – Towards zero-emission technologies





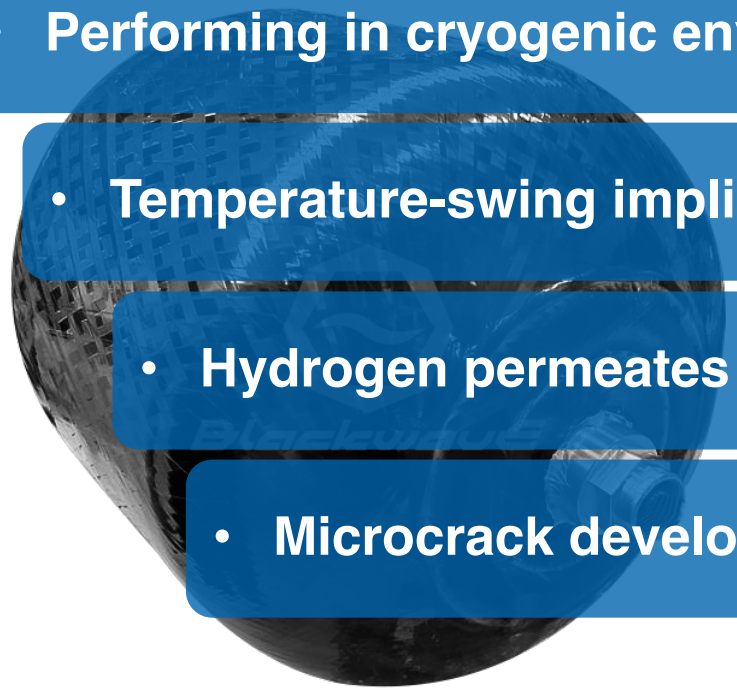
Hydrogen – Towards zero-emission technologies



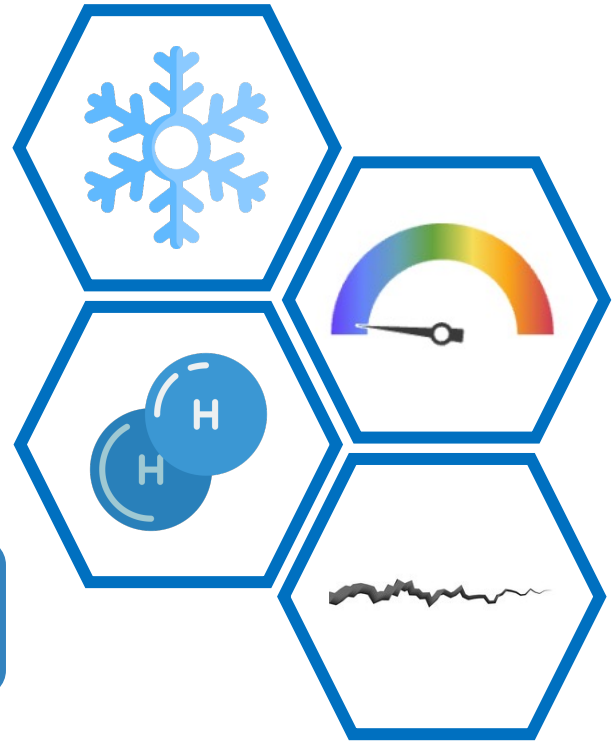
Hydrogen – Towards zero-emission technologies

Ultra-light weight hydrogen tanks promises to make jet fuel out of date

Hydrogen – Towards zero-emission technologies

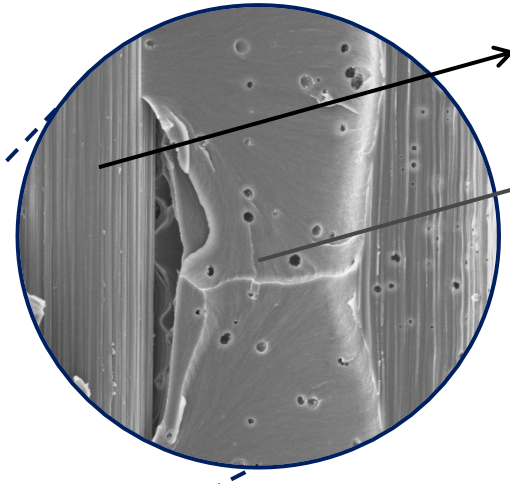


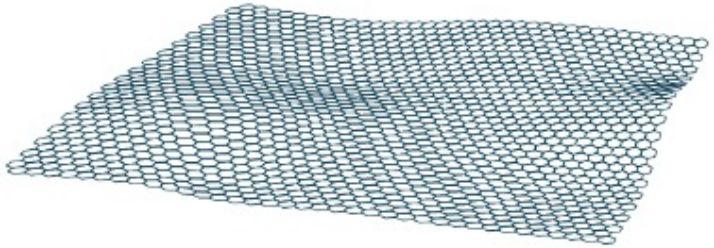
- Performing in cryogenic environments (20 K)
- Temperature-swing implies critical thermal stress
- Hydrogen permeates through the CFRP layer
- Microcrack development



CFRP – Carbon-fiber reinforced plastic

Hydrogen storage vessel technology

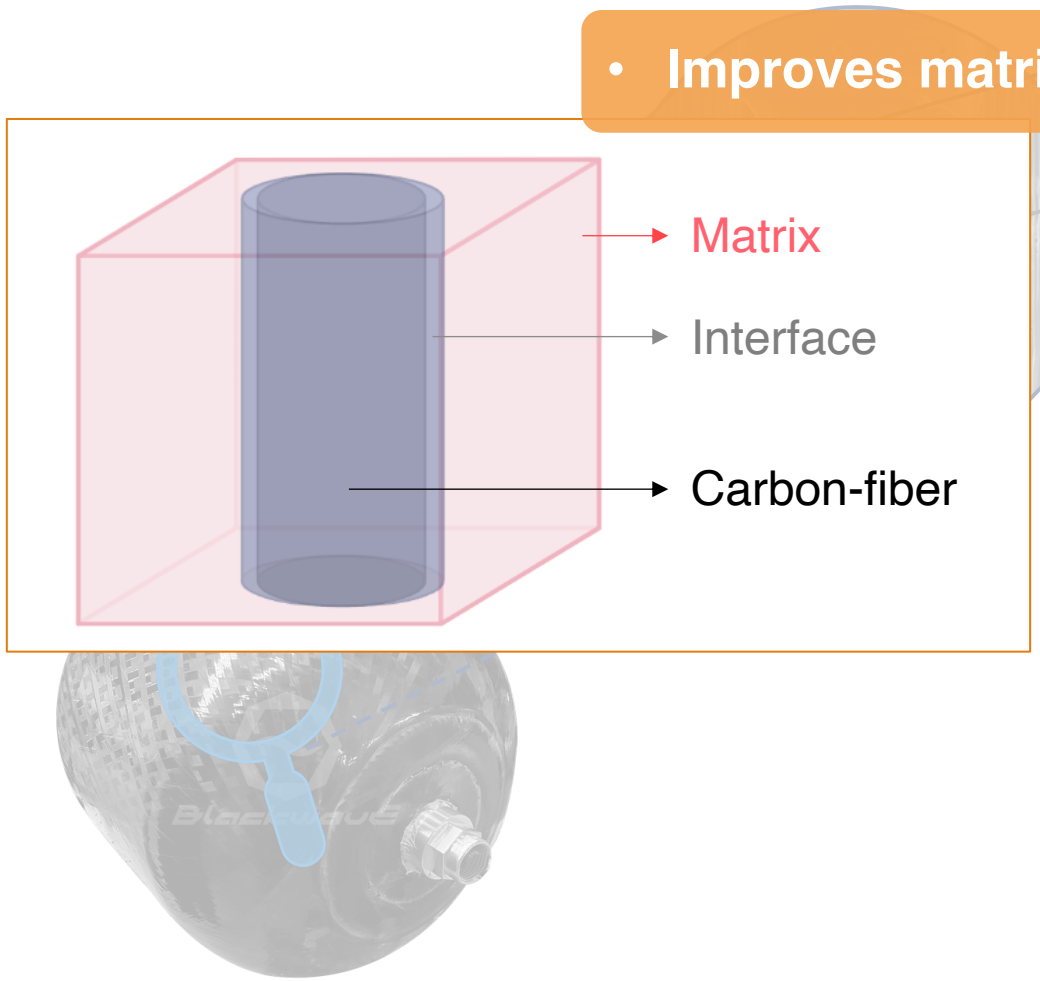


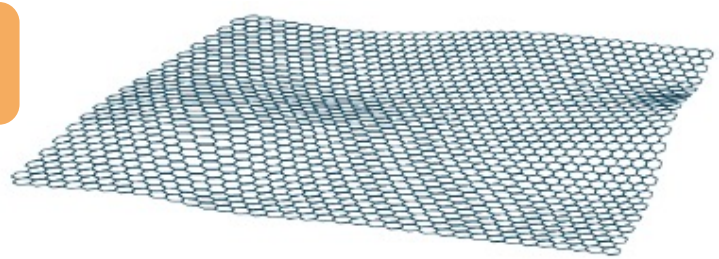


Incorporation of Graphene as a multifunctional additive

Hydrogen storage vessel technology

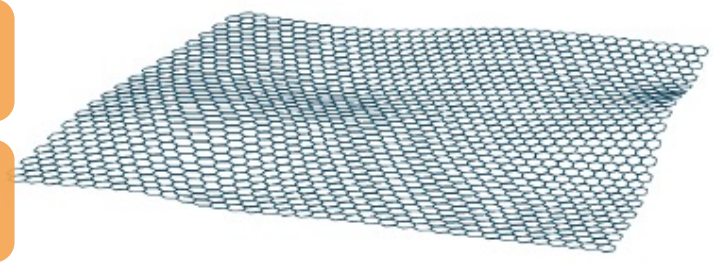
- **Improves matrix-fiber interaction**

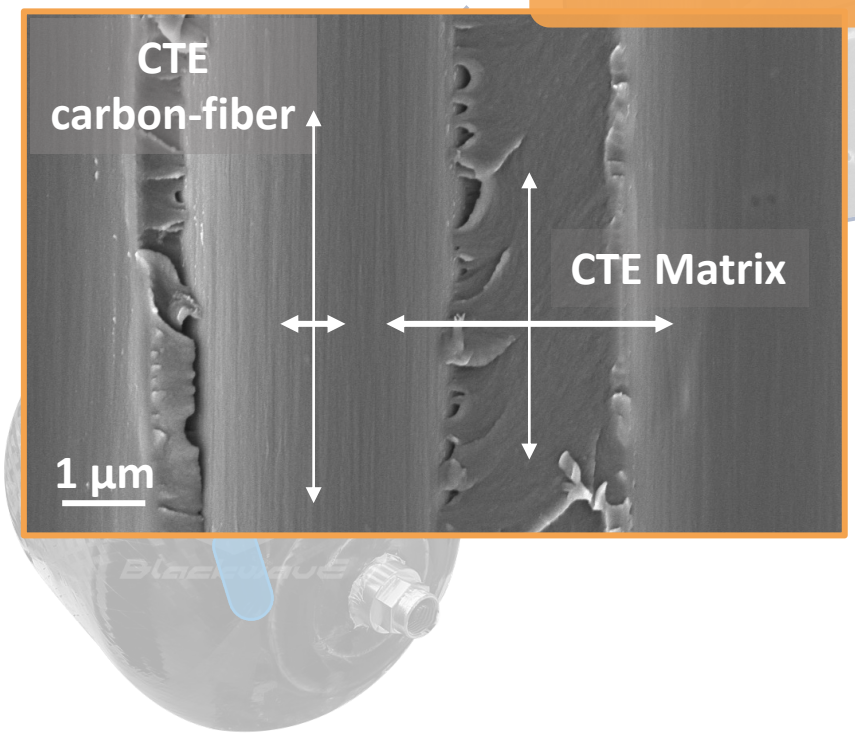




Hydrogen storage vessel technology

- Improves matrix-fiber interaction
- Reduce matrix-fiber CTE difference





Hydrogen storage vessel technology

- Improves matrix-fiber interaction
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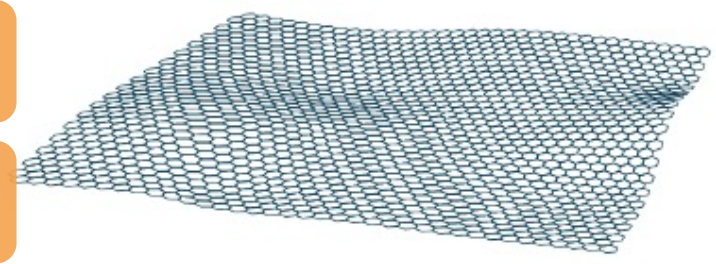
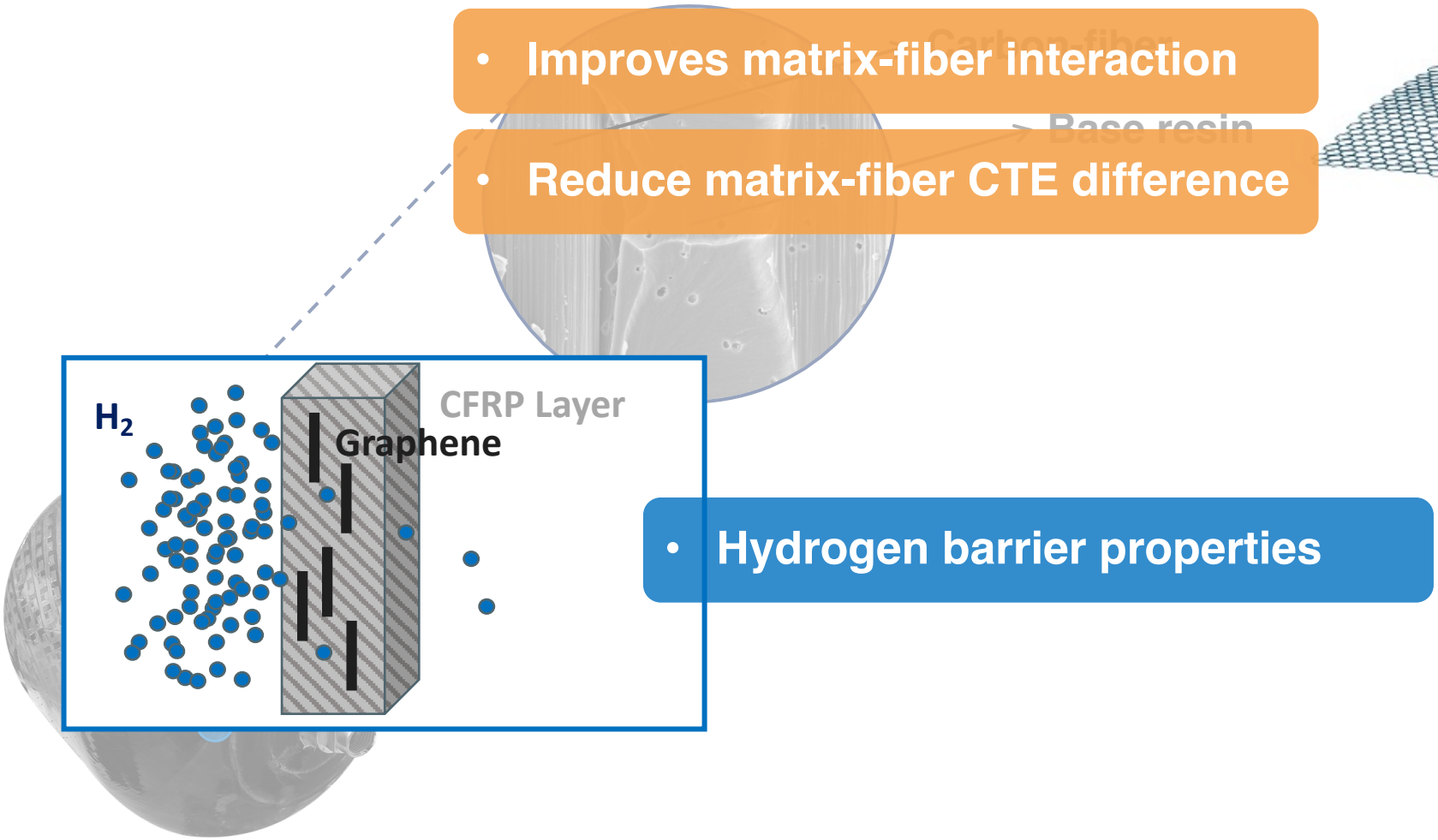
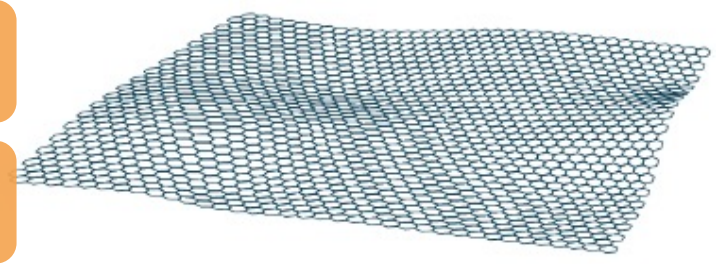


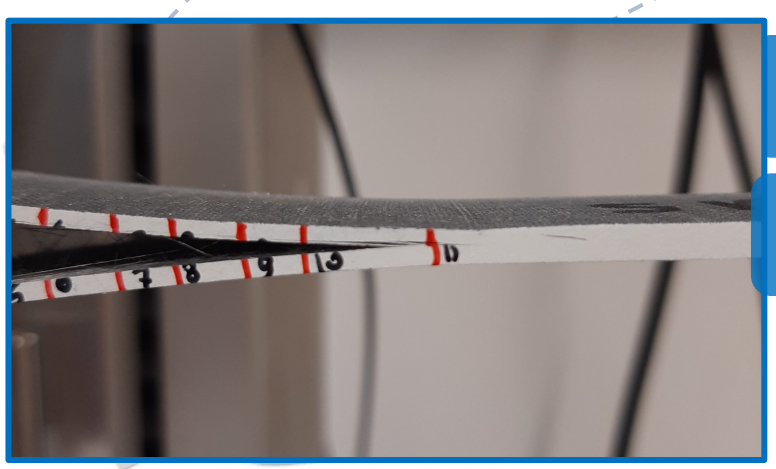


- Hydrogen barrier properties

Hydrogen storage vessel technology

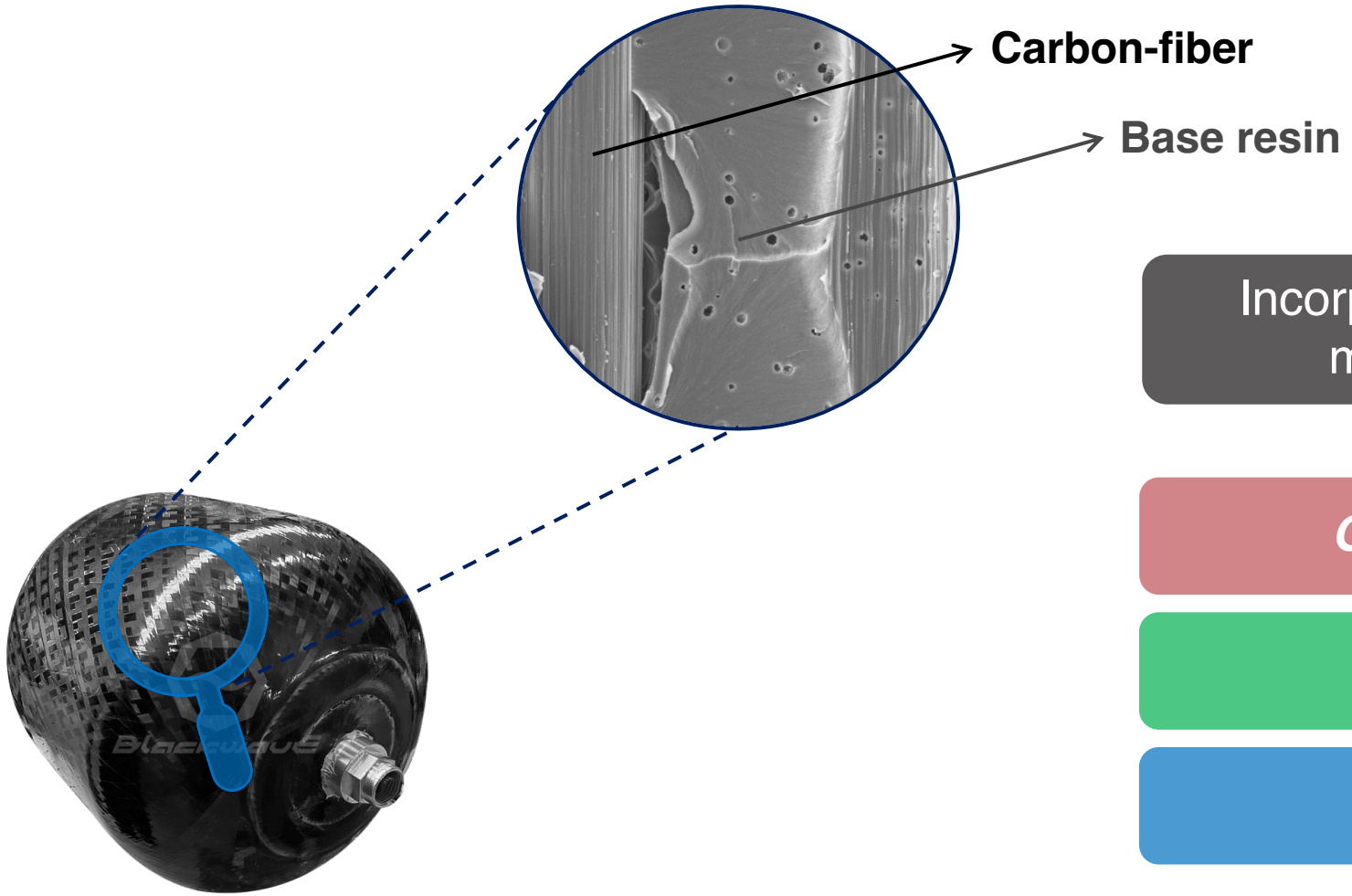
- Improves matrix-fiber interaction
- Reduce matrix-fiber CTE difference

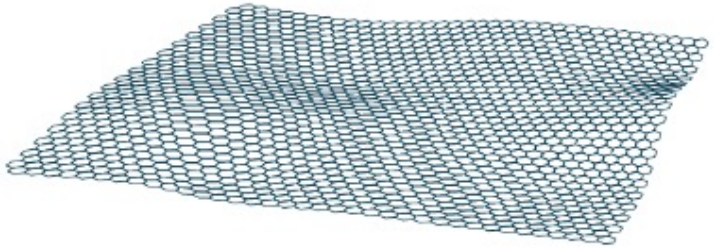




- Hydrogen barrier properties
- Stiffening of the matrix

Hydrogen storage vessel technology





Incorporation of Graphene as a multifunctional additive

Genable ® X1400

Genable ® 1000

Genable ® 1200

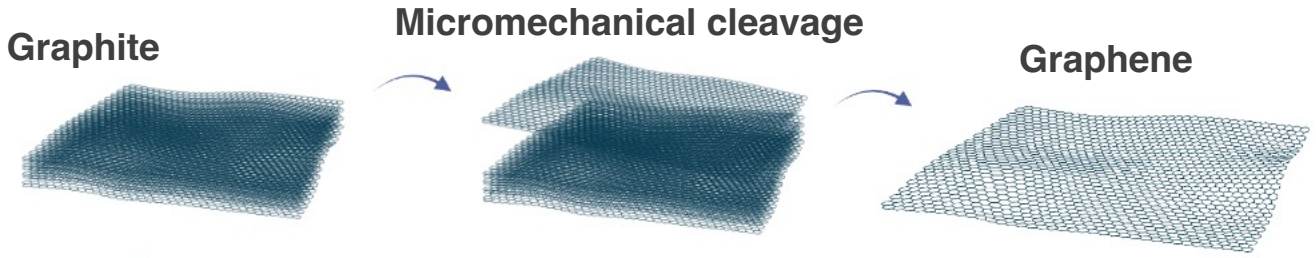
Hydrogen storage vessel technology

UNIVERSAL MATTER ADVANCED MATERIALS

APPLIED GRAPHENE MATERIALS

Genable ® X1400

Top-down / Exfoliation



Genable ® 1000

Top-down / Exfoliation
+ oxidized function

Genable ® 1200

Bottom-up / Deposition

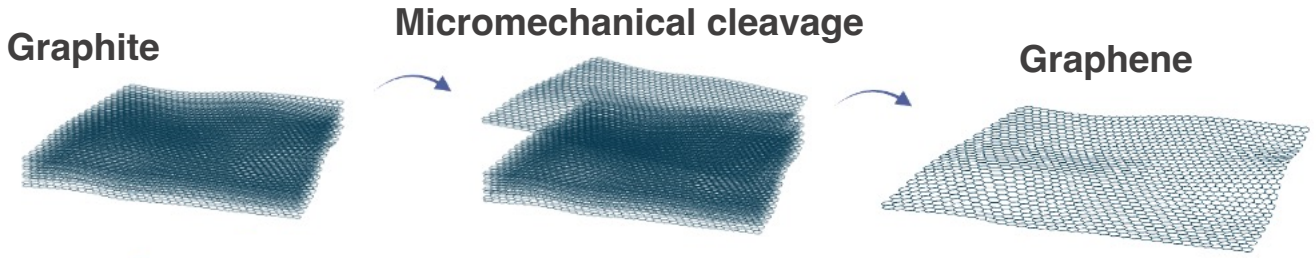
Hydrogen storage vessel technology

UNIVERSAL MATTER ADVANCED MATERIALS

APPLIED GRAPHENE MATERIALS

Genable ® X1400

Top-down / Exfoliation

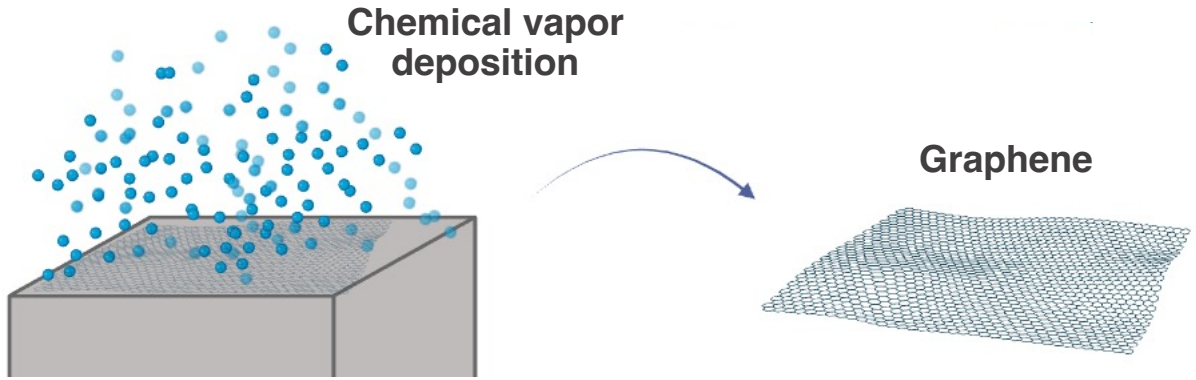


Genable ® 1000

Top-down / Exfoliation
+ oxidized function

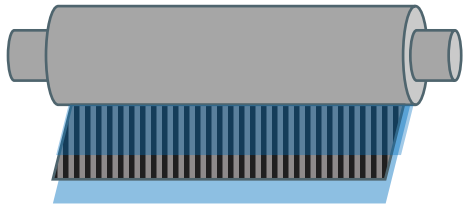
Genable ® 1200

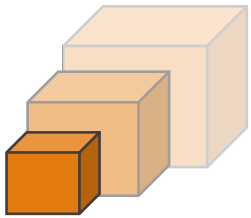
Bottom-up / Deposition



Effect of graphene as a multifunctional additive

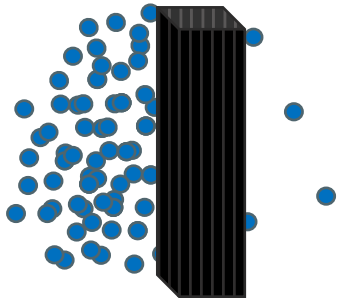
What is the influence of **graphene** on the **manufacturing process of the composite?**





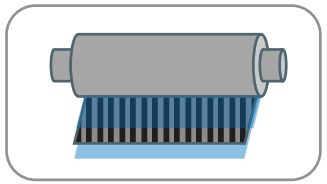
Can **graphene** suppress the **CTE property** of the CFRP laminate?

Does **graphene** act as a barrier towards **hydrogen permeation?**



How will the **graphene** effect the **delamination process** of the CFRP composite

Prepreg Line – Manufacturing of the composite prepregs

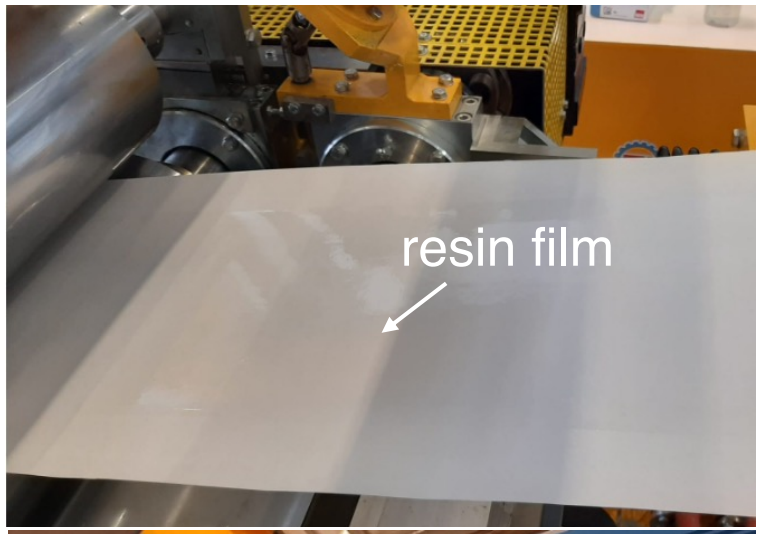


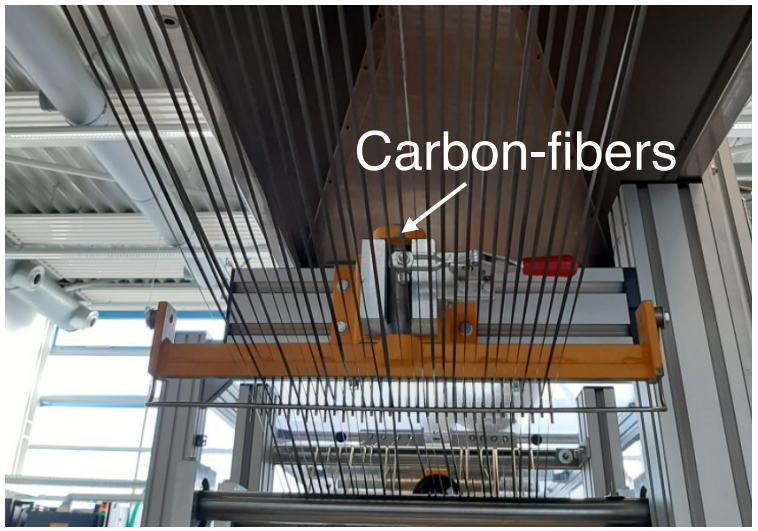
Reference

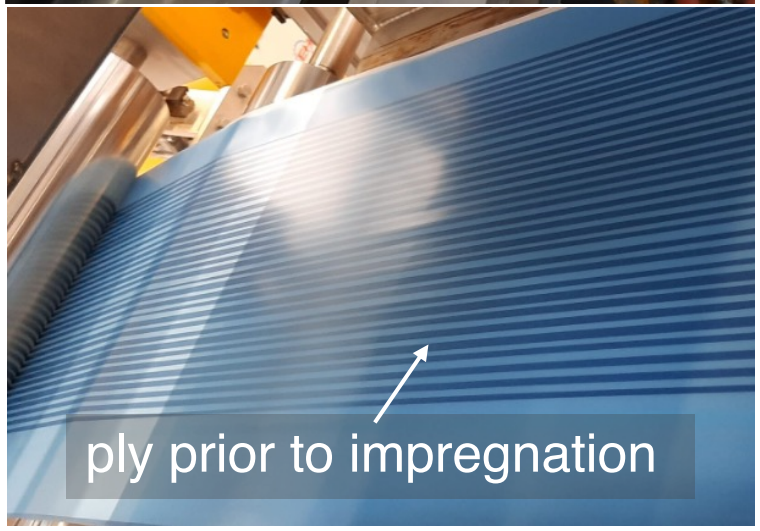
Genable® X1400: 0.1wt

Genable® 1000: 0.1wt

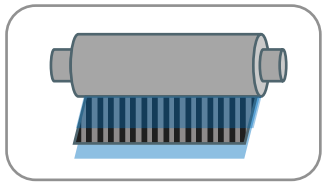
Genable® 1200: 0.1wt







Prepreg Line – Manufacturing of the composite prepregs



Reference

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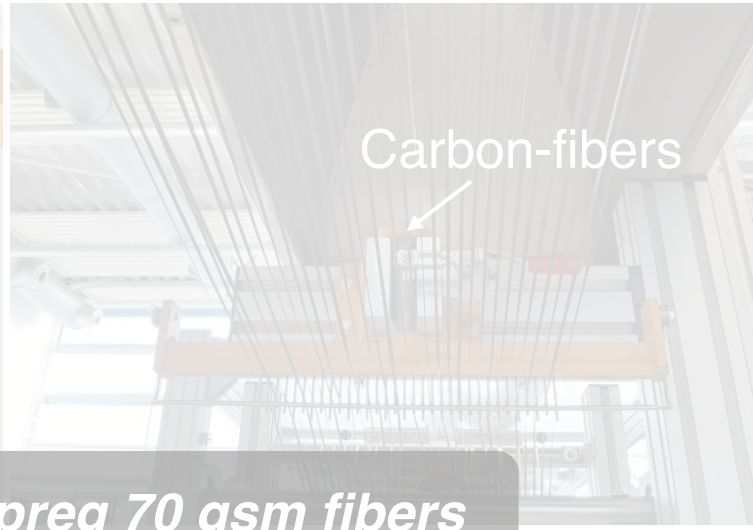
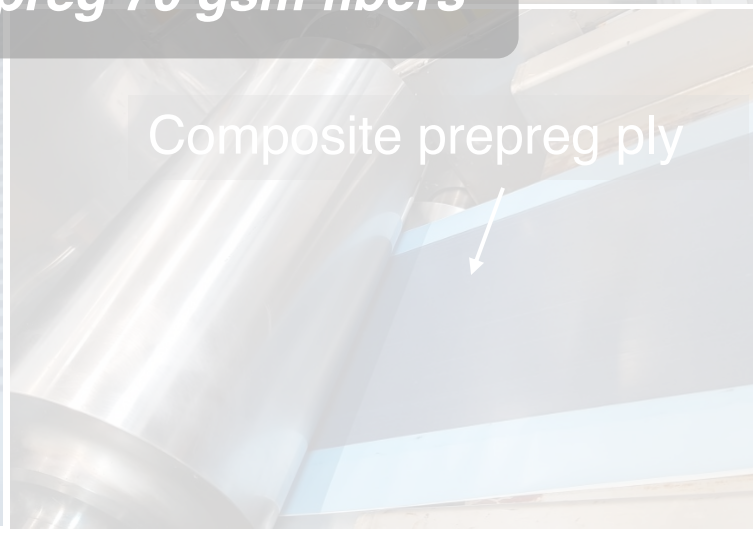
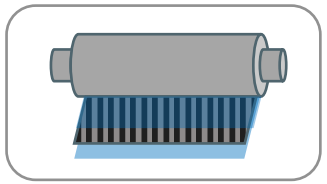
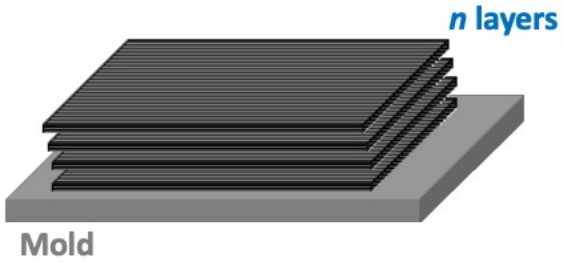


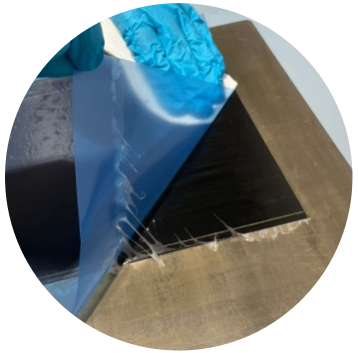
IM7/EP prepreg 70 gsm fibers

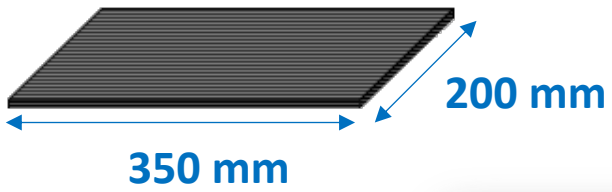


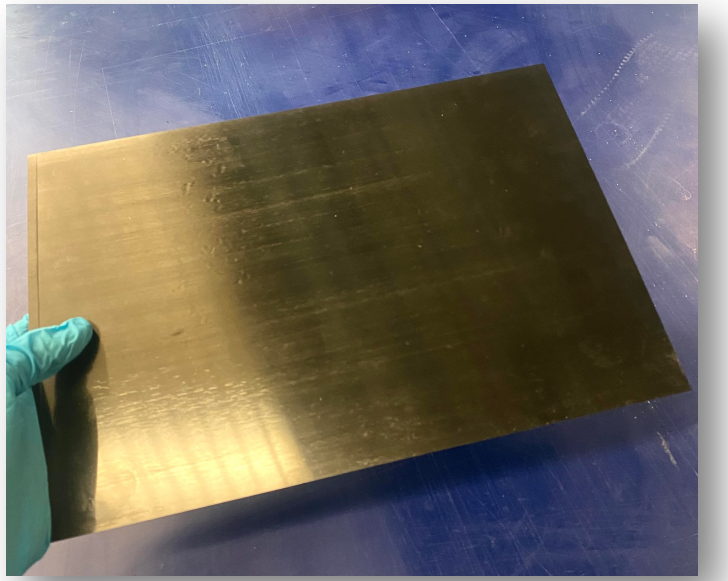
Manufacturing of prepreg laminates



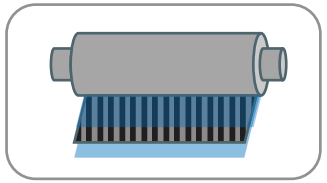


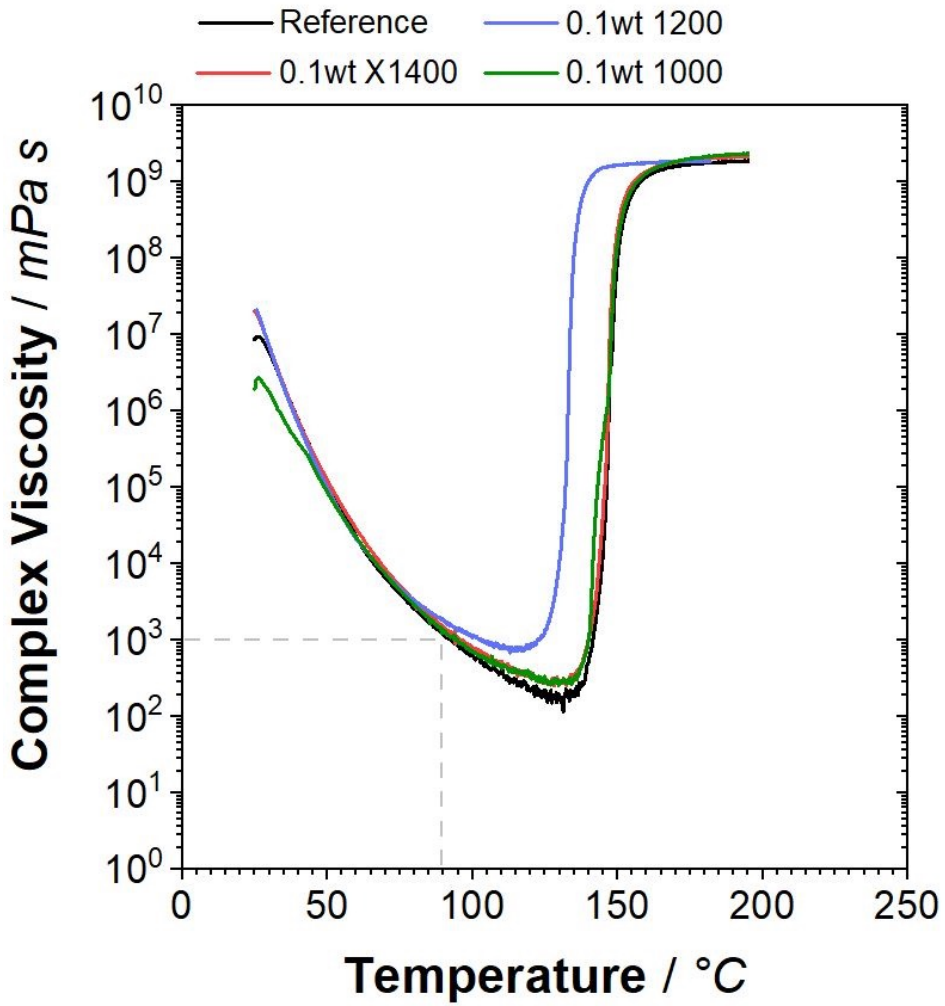






Viscosity measurements of the Base Resin



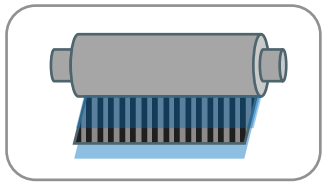


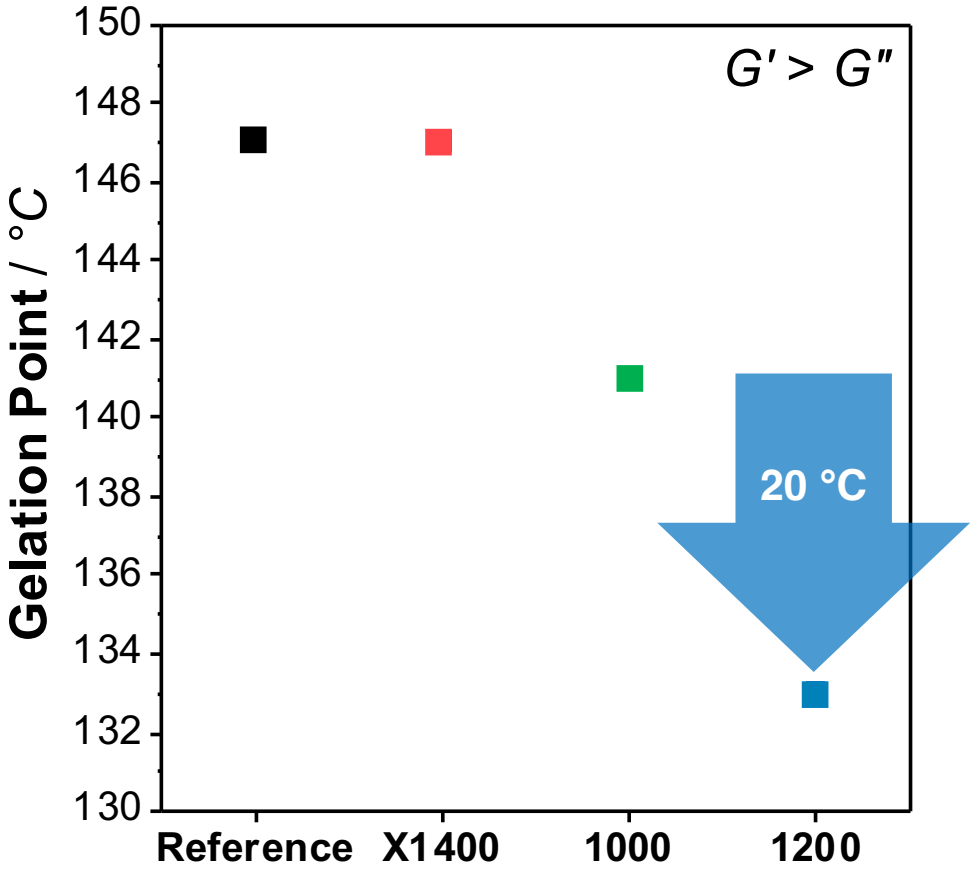
***Genable X1400: Minor effect** on the resin viscosity with 0.1wt% content*

***Genable 1000: Minor effect** on the resin viscosity with 0.1wt% content*

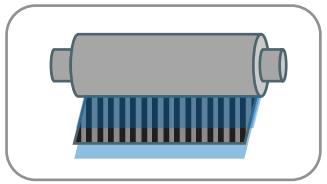
***Genable 1200: Signigicant effect** on resin viscosity with 0.1wt% content*

Viscosity measurements of the Base Resin



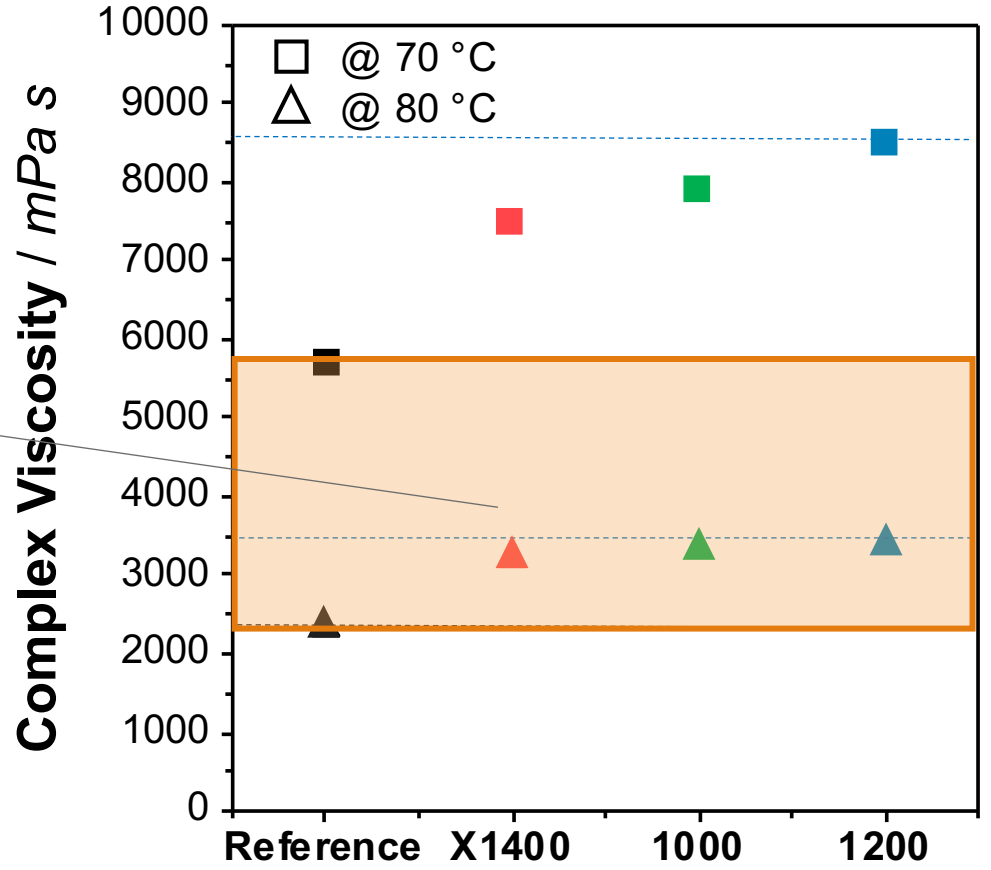


Viscosity measurements of the Base Resin

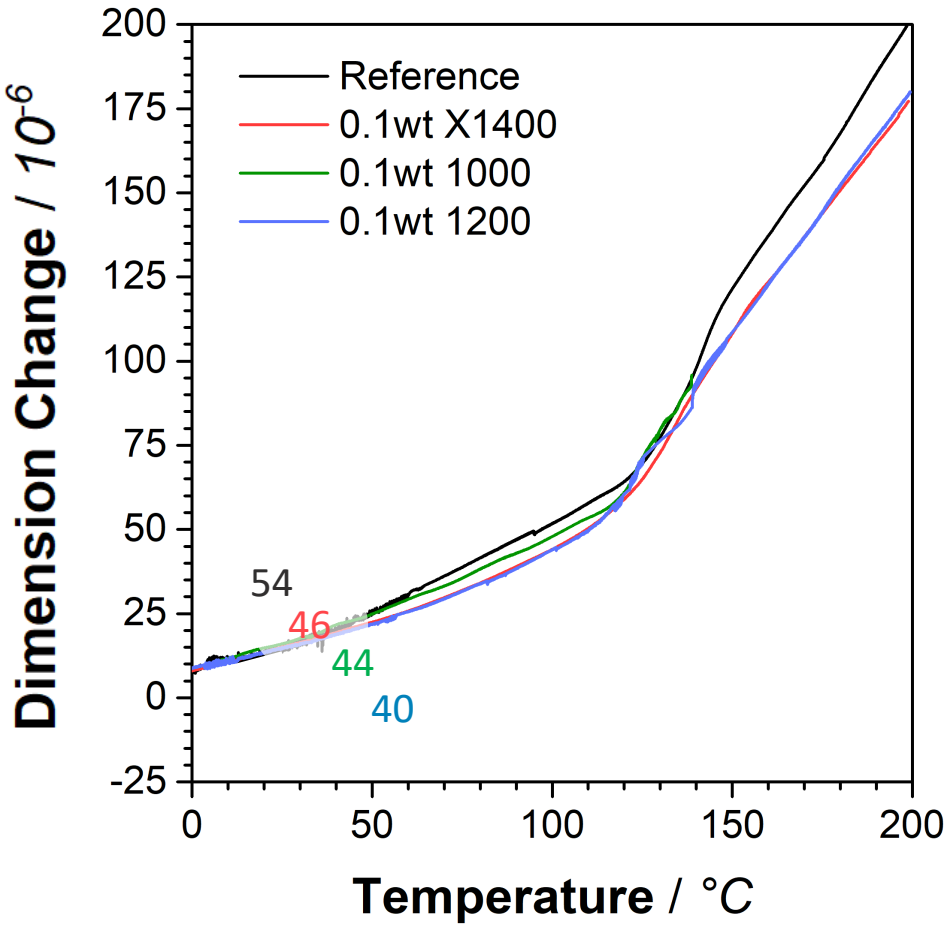


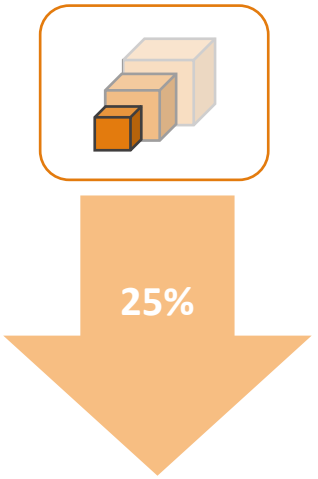
Suitable viscosity *and* ***pot-life*** *for Hot-melt prepreg processing →* ***70-80 °C***

Thin ply prepregs possible

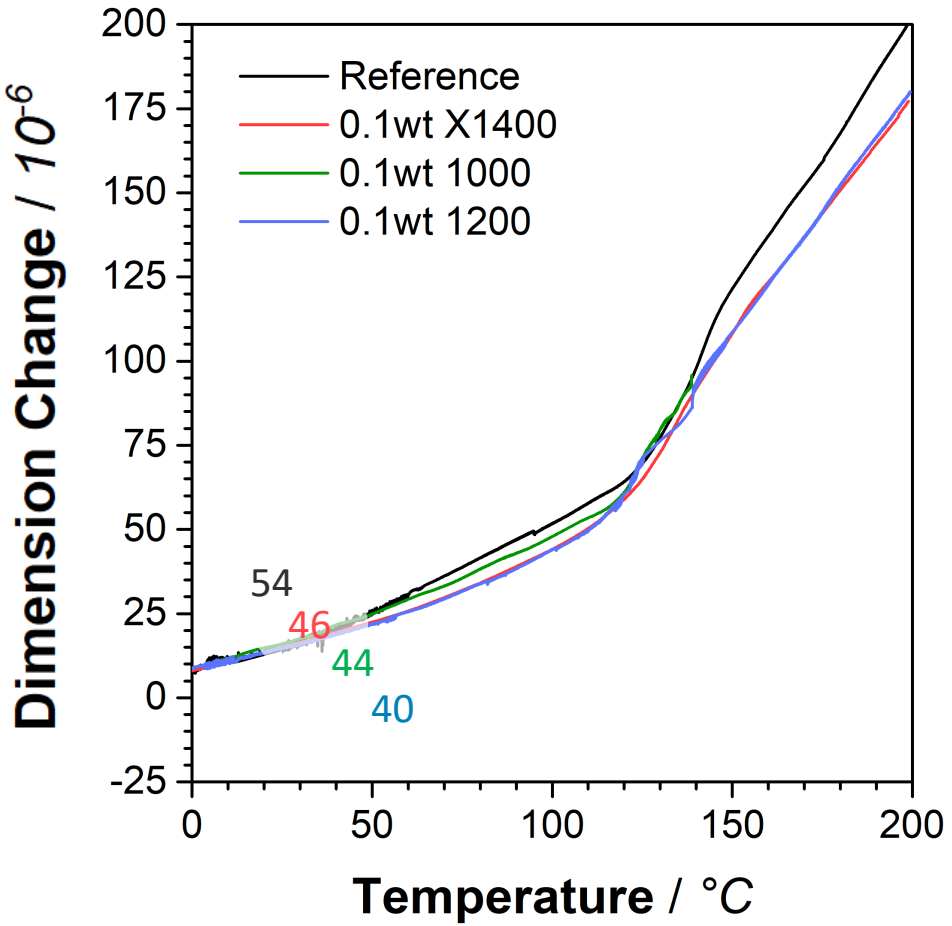


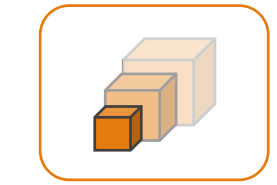
Coefficient of thermal expansion CTE



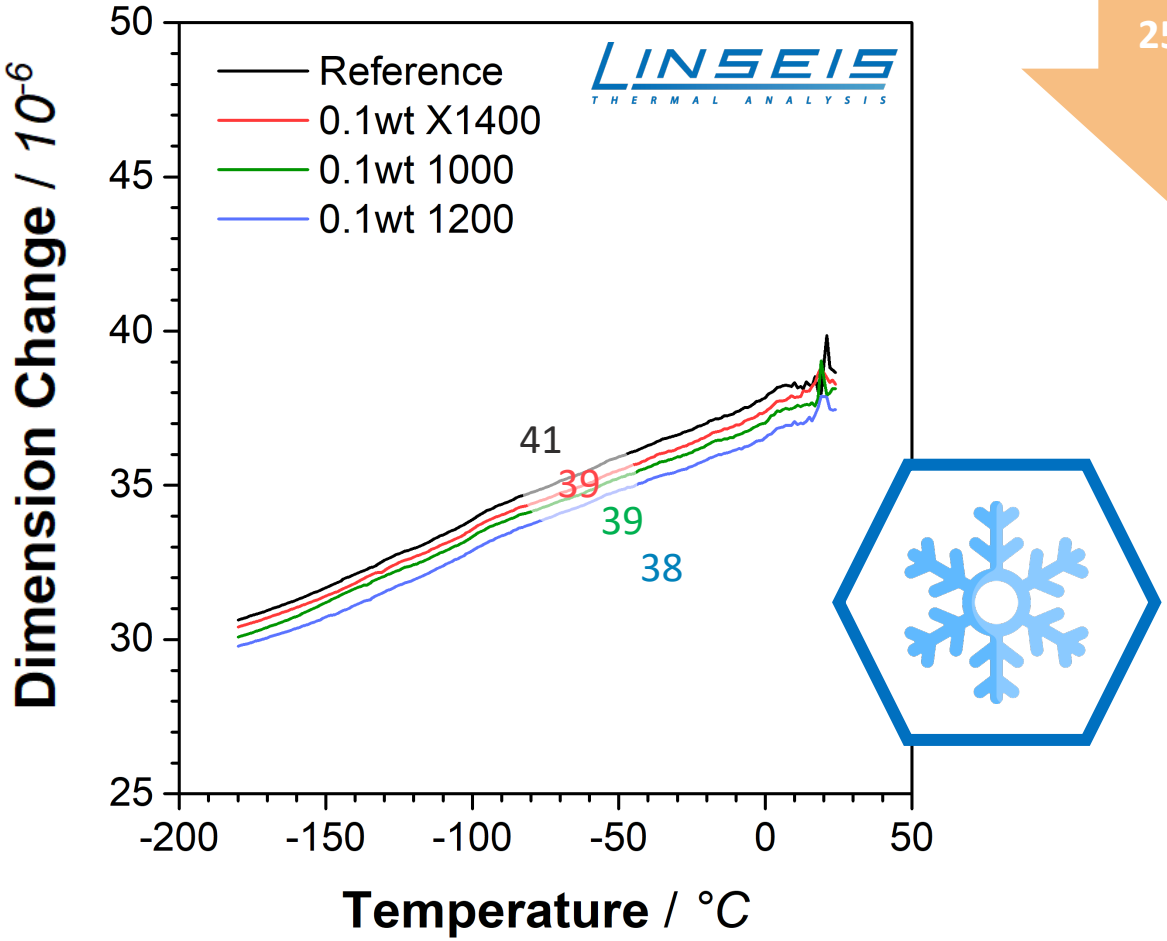


Coefficient of thermal expansion CTE

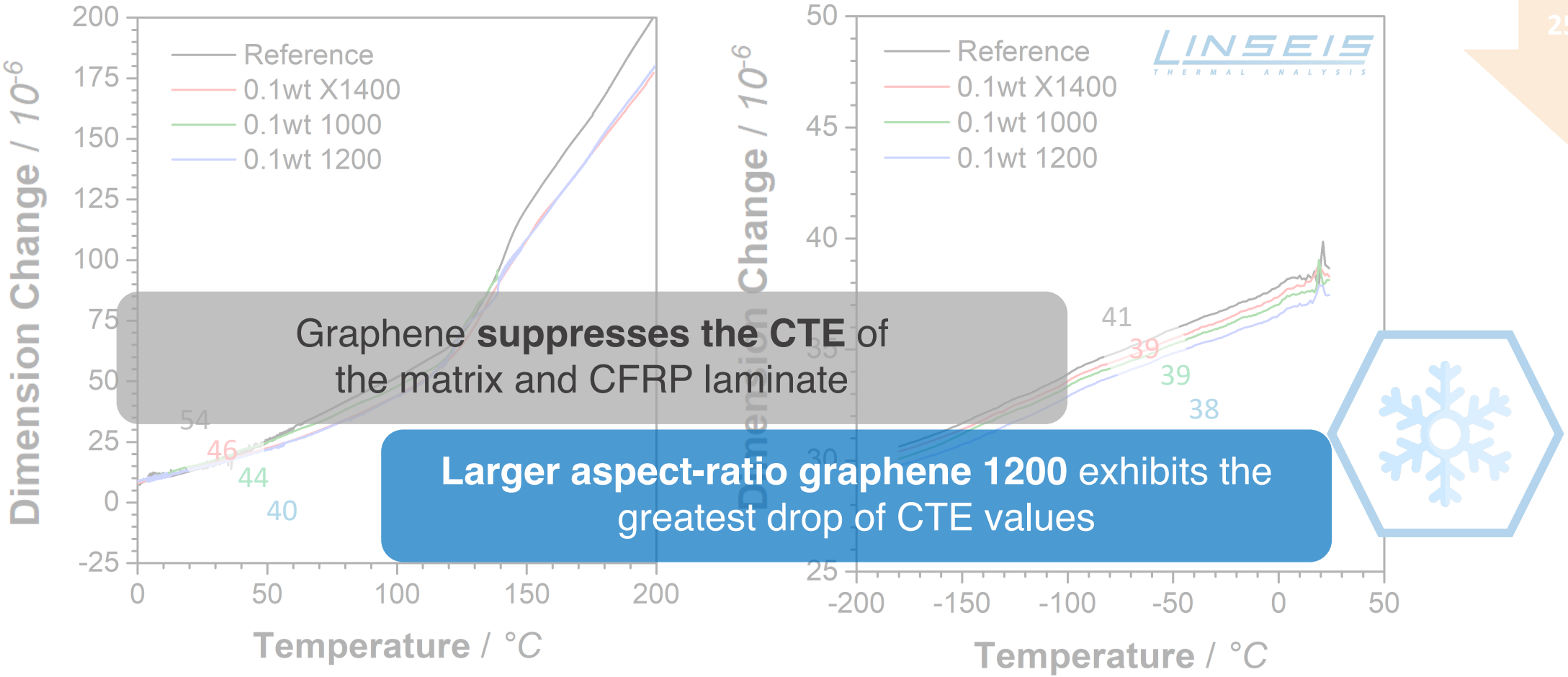




25%



Coefficient of thermal expansion CTE



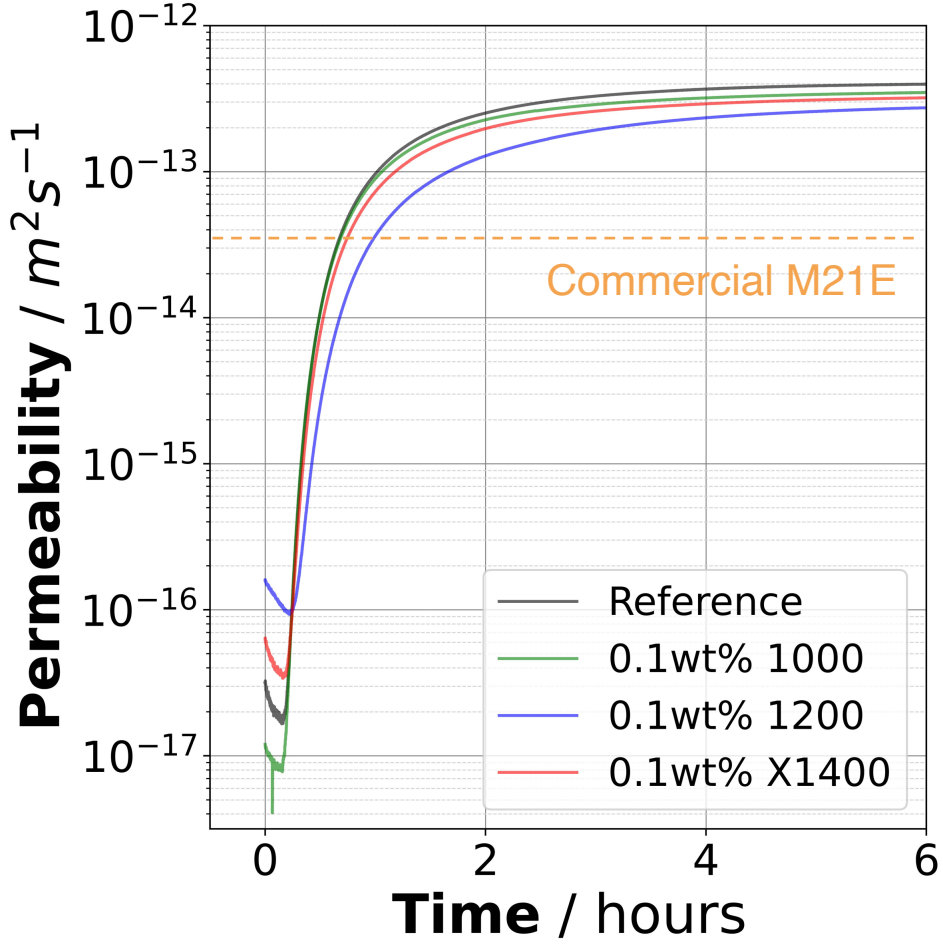
25%

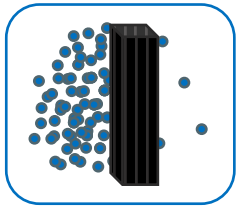
Graphene **suppresses the CTE** of the matrix and CFRP laminate

Larger aspect-ratio graphene 1200 exhibits the greatest drop of CTE values

Hydrogen permeation

der Bundeswehr
Universität München

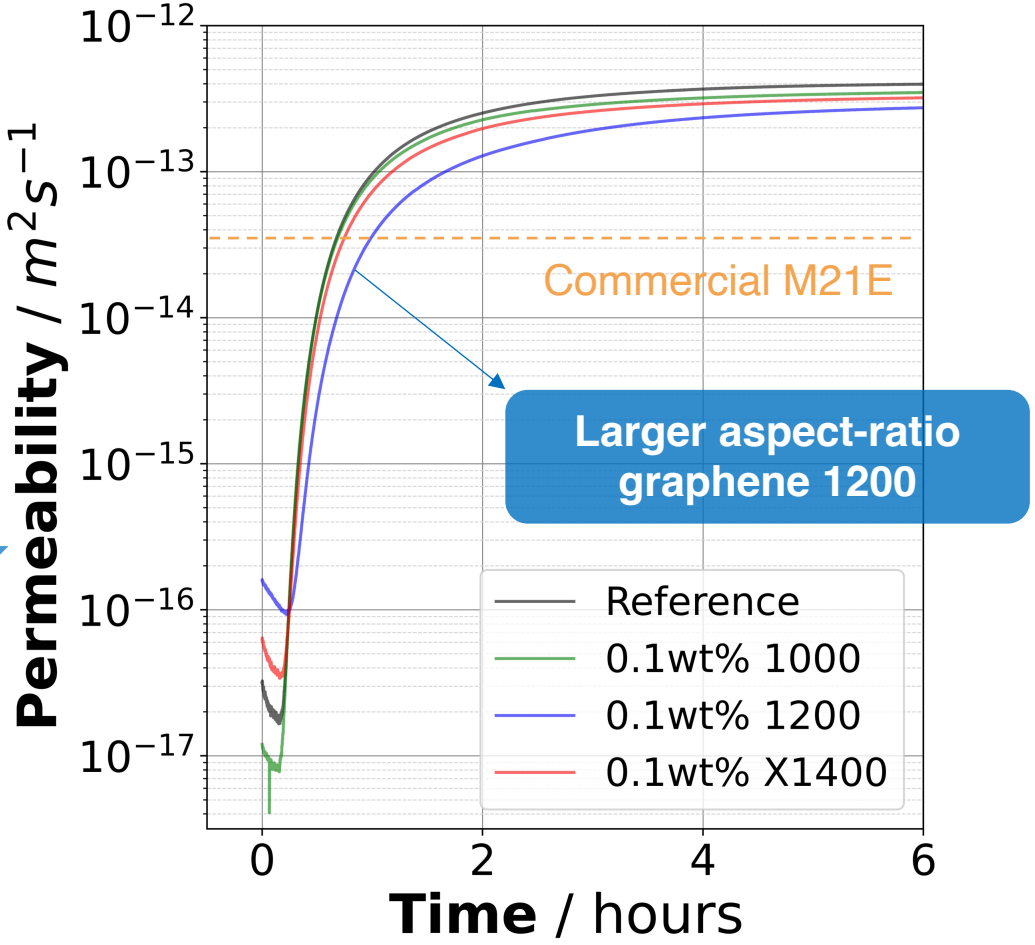


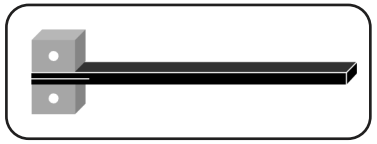


Hydrogen permeation

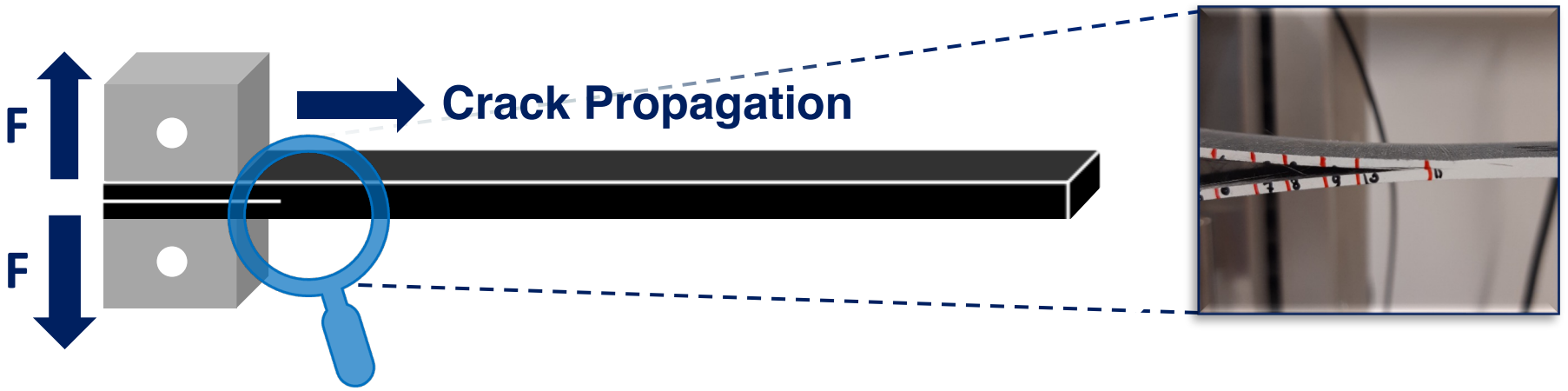
System	Leakage (mbar l s^{-1})
Reference	1.1E-6
0.1wt% 1000	9.7E-7
0.1wt% X1400	9.5E-7
0.1wt% 1200	7.5E-7
Commercial M21E	7.7E-8

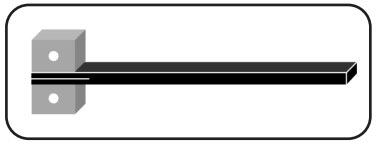
30%





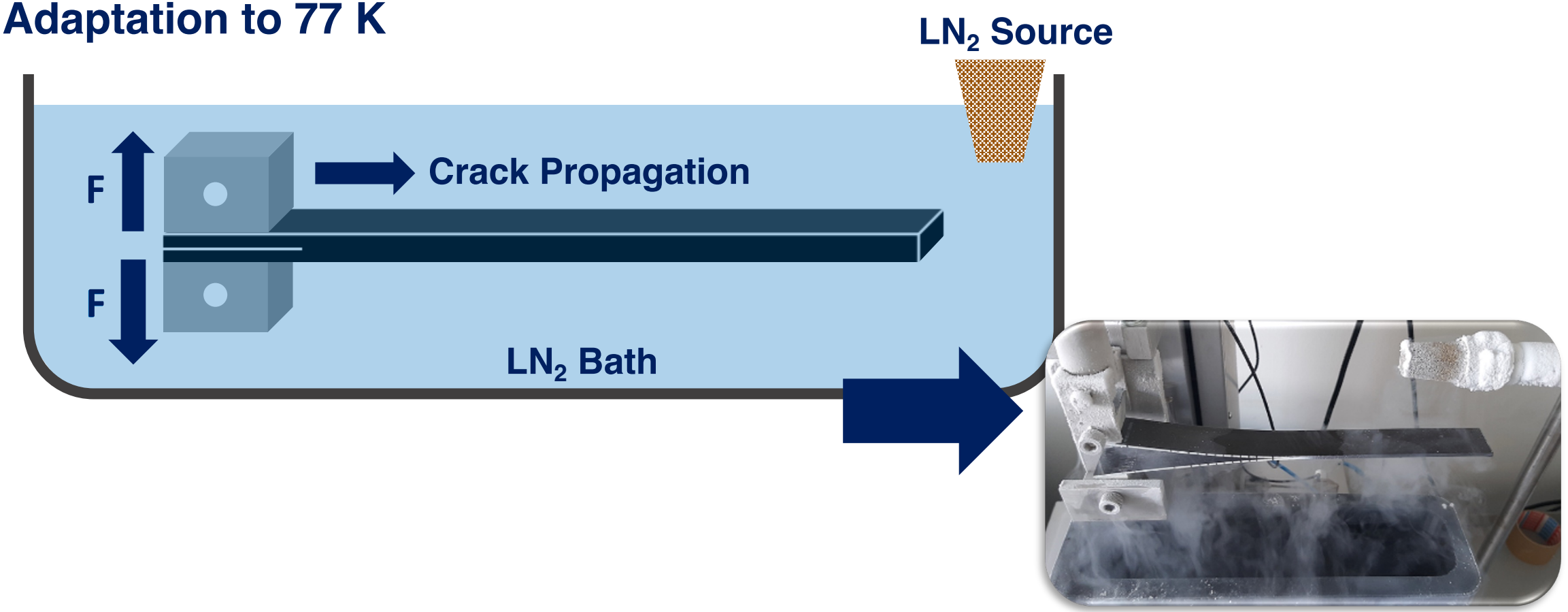
Interlaminar Energy Release Rate G_{IC}

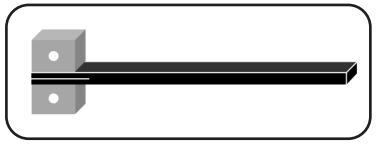




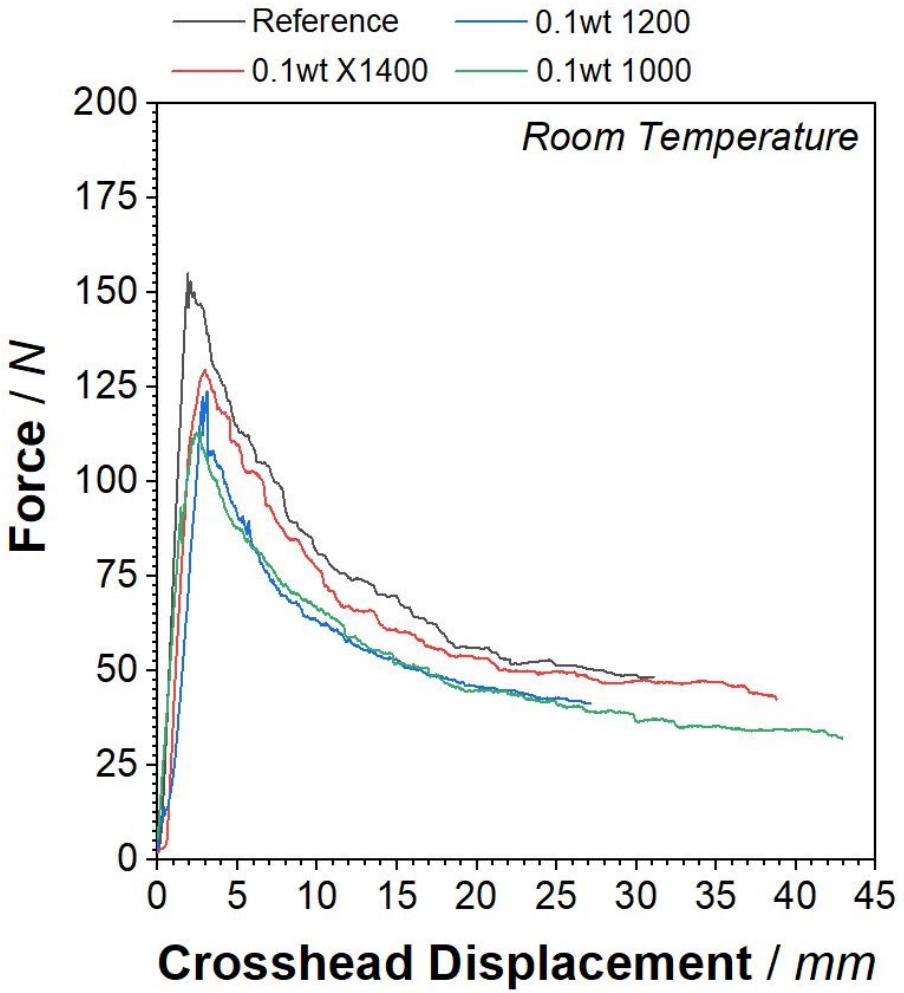
Interlaminar Energy Release Rate G_{IC}

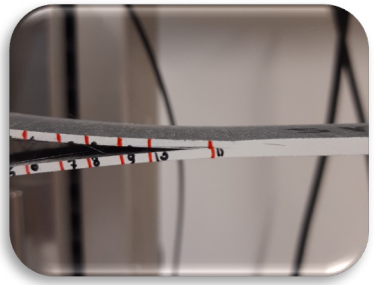
Adaptation to 77 K





Interlaminar Energy Release Rate G_{IC}

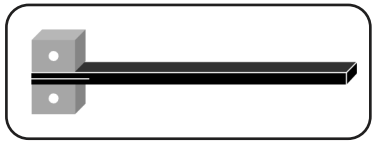




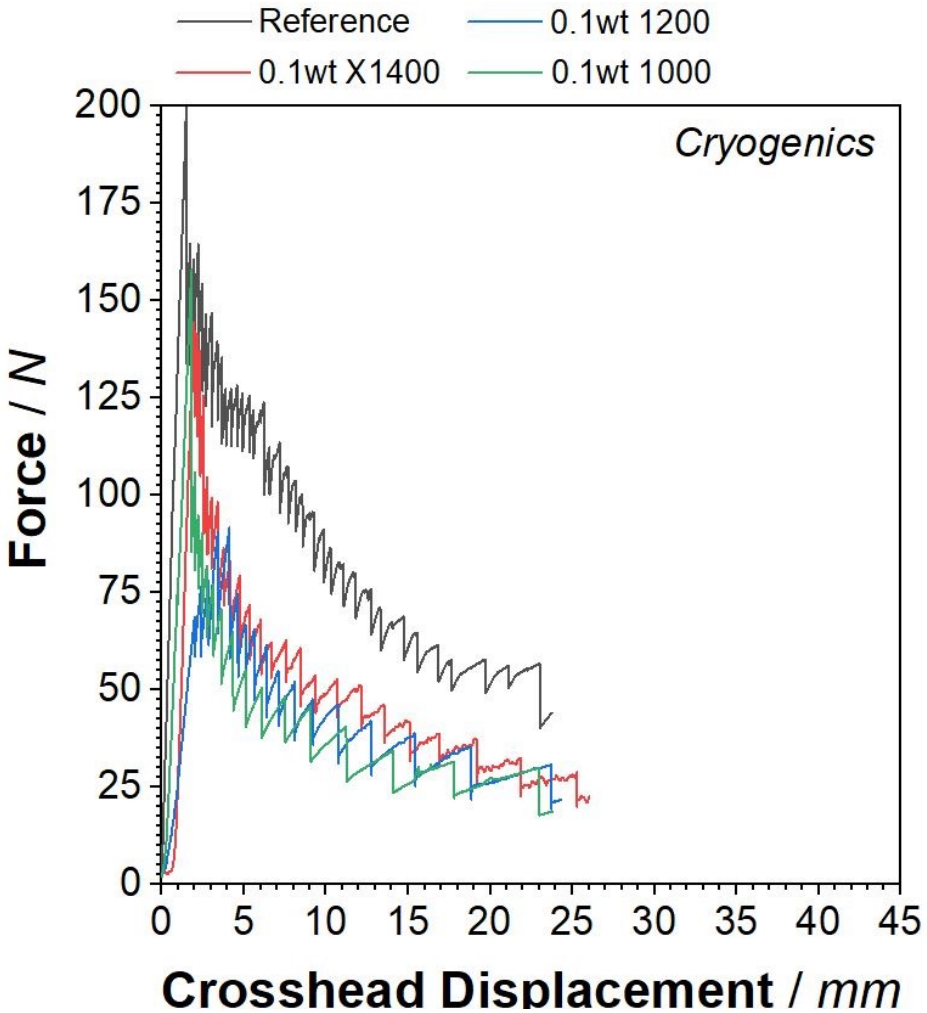
857 J m^{-2}
783 J m^{-2}
775 J m^{-2}
734 J m^{-2}

Decrease in matrix ductility

DIN EN ISO 6033
Load cell: **500 N**
Displacement rate: **10 mm min^{-1}**
N. of specimens: **5**
Carbon-fiber volume content: **56-58vol%**



Interlaminar Energy Release Rate G_{IC}



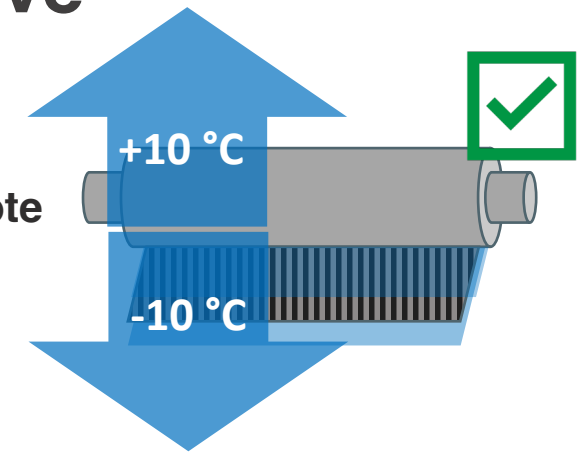
DIN EN ISO 6033
Load cell: **500 N**
Displacement rate: **10 mm min^{-1}**
N. of specimens: **5**
Carbon-fiber volume content: **56-58vol%**

647 J m^{-2}
527 J m^{-2}
496 J m^{-2}
466 J m^{-2}

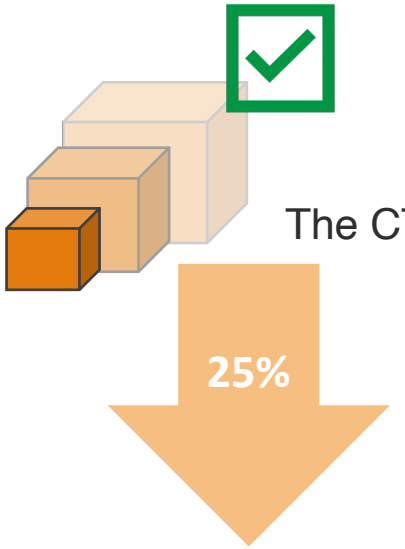
Decrease in matrix ductility

Effect of graphene as a multifunctional additive

The use of graphene additives in the base resin **does not promote significant effect** on the manufacturing of the composites

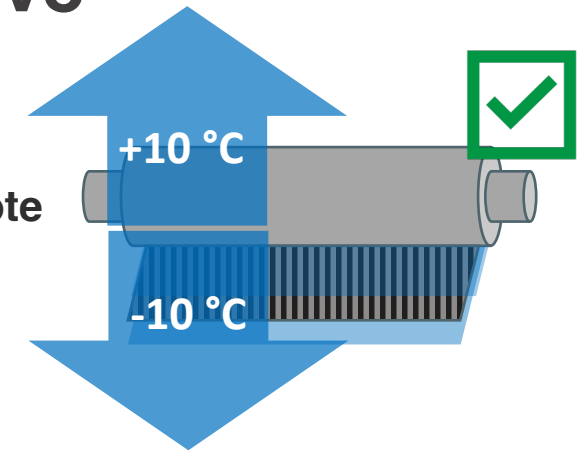


Effect of graphene as a multifunctional additive



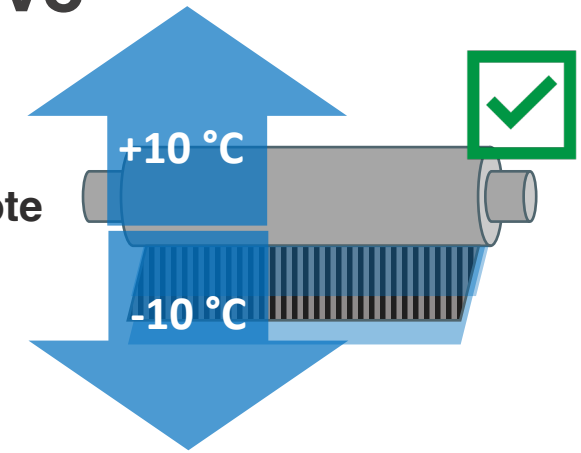
The use of graphene additives in the base resin **does not promote significant effect** on the manufacturing of the composites

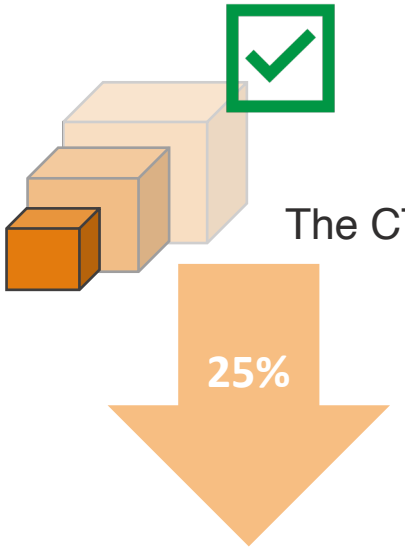
The CTE of the CFRP laminate **is reduced** by the use of graphene additives



Effect of graphene as a multifunctional additive

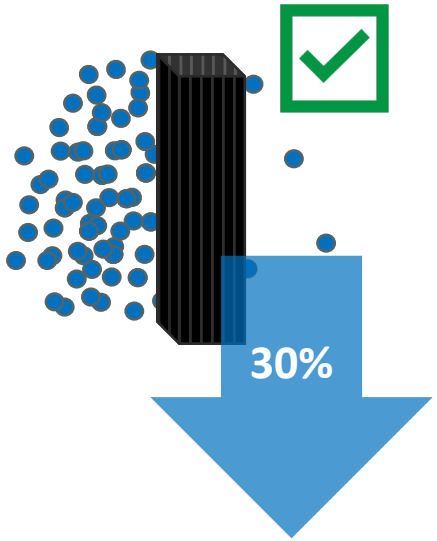
The use of graphene additives in the base resin **does not promote significant effect** on the manufacturing of the composites



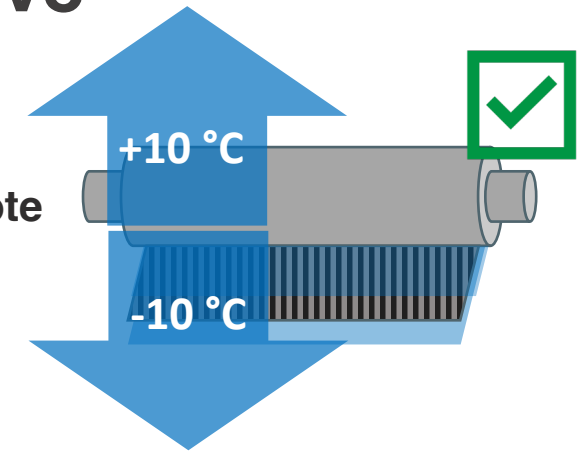


The CTE of the CFRP laminate **is reduced** by the use of graphene additives

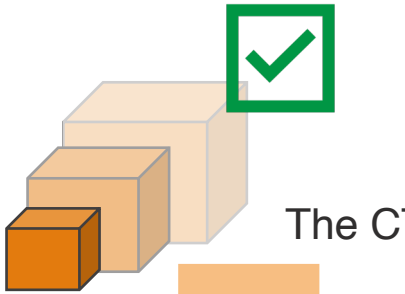
The hydrogen permeation of the CFRP laminate **is reduced** by the use of graphene additives



Effect of graphene as a multifunctional additive

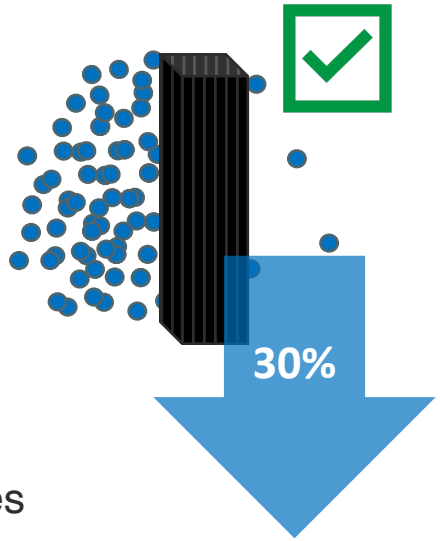


The use of graphene additives in the base resin **does not promote significant effect** on the manufacturing of the composites

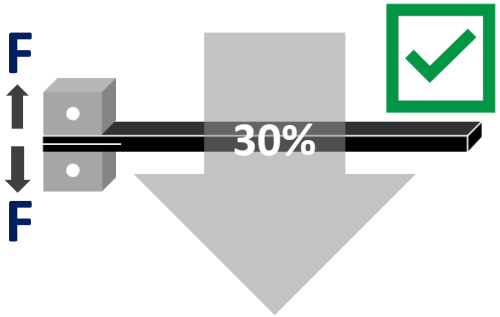


The CTE of the CFRP laminate **is reduced** by the use of graphene additives

25%

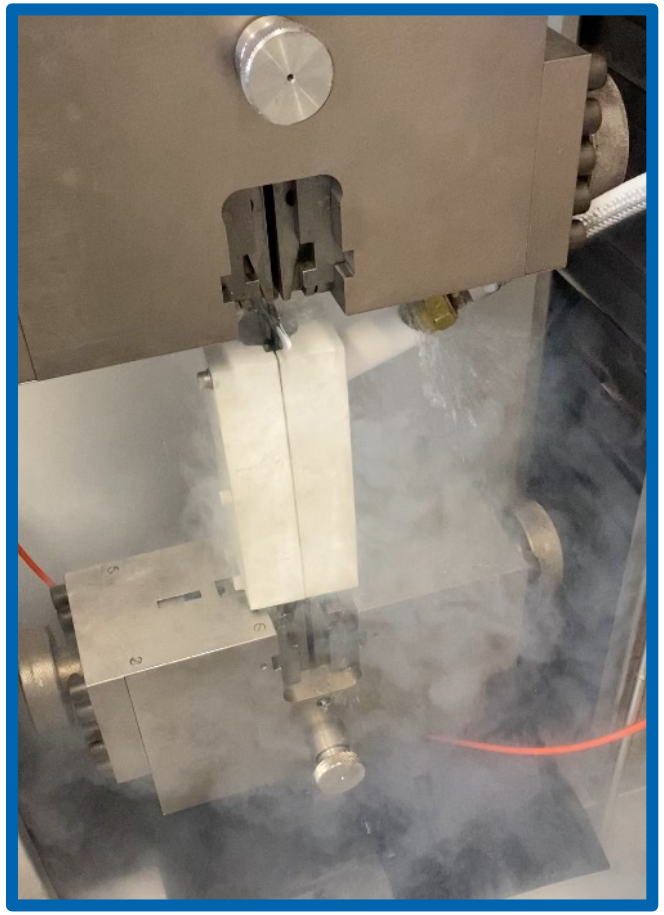


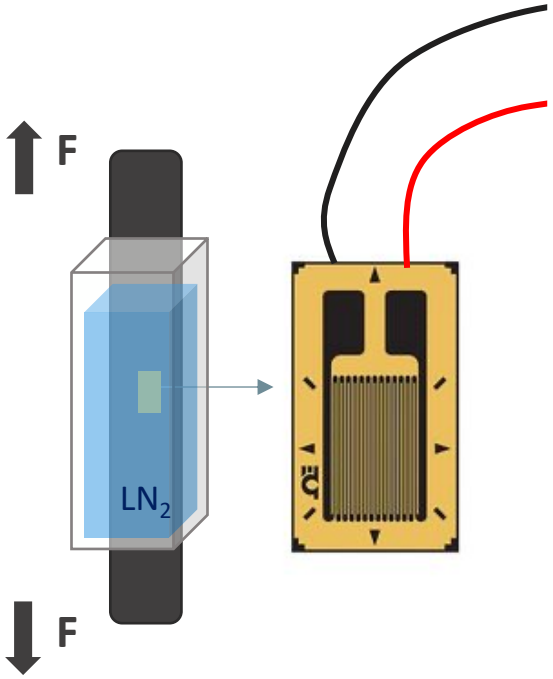
The hydrogen permeation of the CFRP laminate **is reduced** by the use of graphene additives

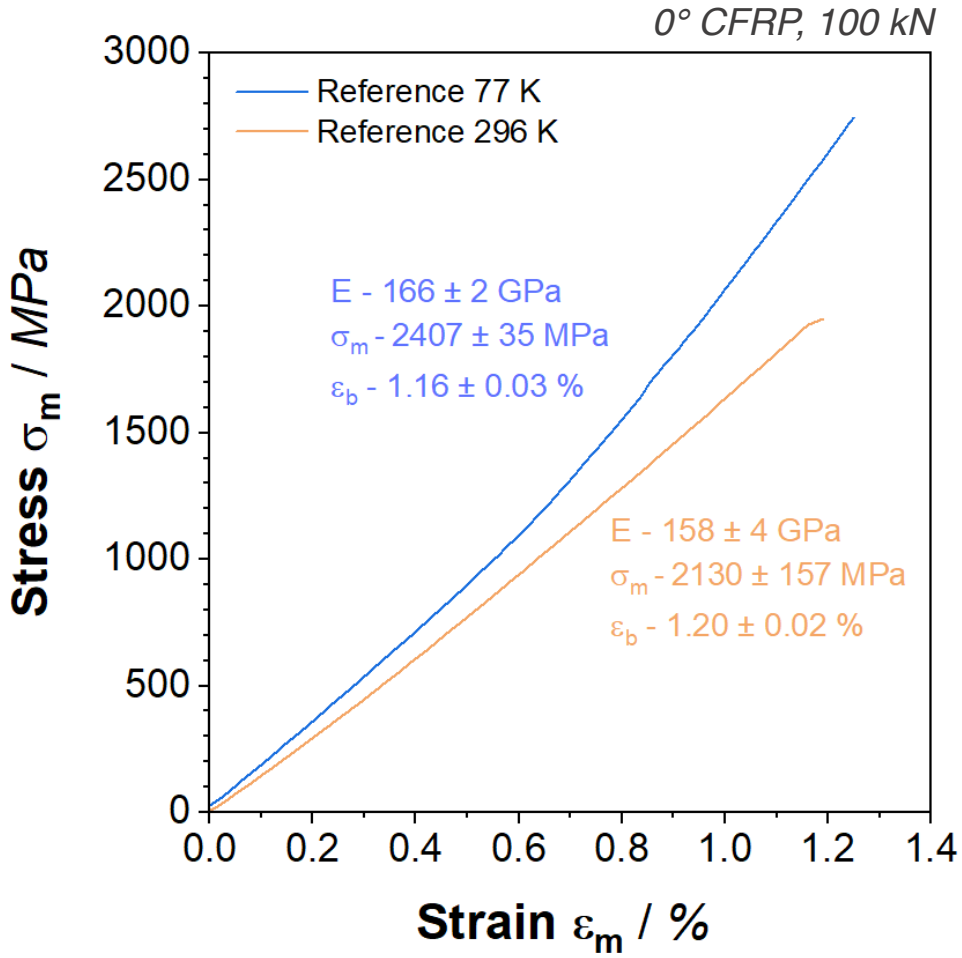


The incorporation of a rigid additive such as graphene, promotes **substantial decrease on the CFRP G_{IC}**, indicating embrittlement and stiffening of the matrix

Tensile properties in cryogenic environments 77 K







Acknowledgements

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