Enabling new applications for pultruded profiles by processing local and tailored fiber-reinforcements for improved strength and safety of bolted joints

Patch-Pultrusion

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International Conference on Composite Materials
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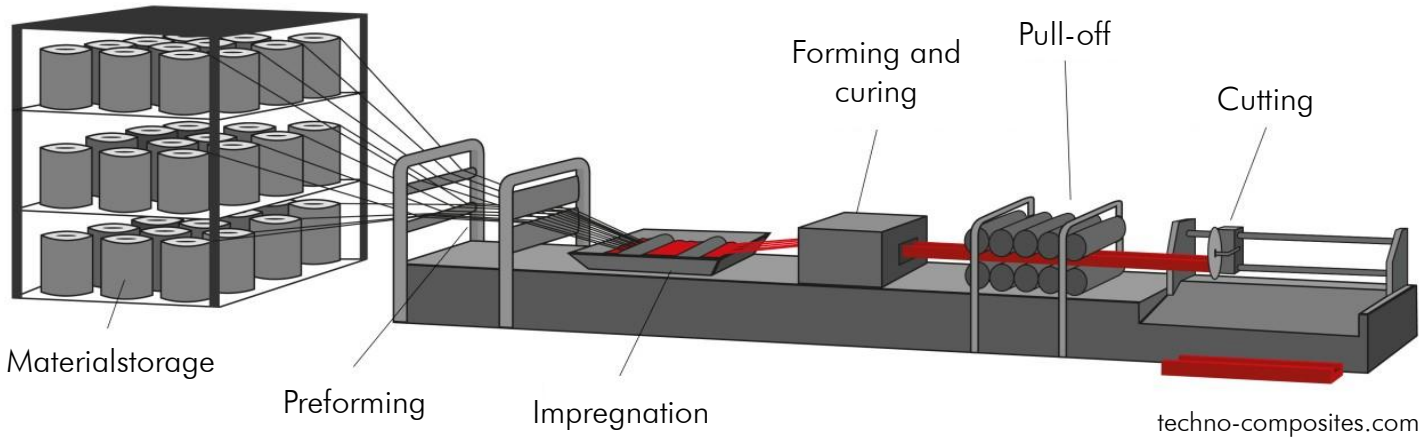
Pultrusion Technology

Process:

- **Continuous process** for manufacturing of FRP
- High degree of **automatization** and **productivity**
- Profiles with constant cross section
- **High fiber volume content and mechanical properties**
- **Low cost** raw materials and plant equipment



techno-composites.com

Materials:

- Fibers: Glass, Carbon, Aramid
- Resins: Polyester, Vinyl ester, Epoxy, Polyurethane, Phenolic

Applications:

- Construction, Wind energy, Chemical processing
- Automotive, Transport


falconsfiber.com

Load introductions in high-performance pultrusion profiles

Problem:

- Pultruded profiles offer excellent **axial strength and stiffness**

→ **High potential** for applications in links, rods or struts

- Mainly **unidirectional oriented fibers**, constant cross-section, invariable lay-up/fiber orientation

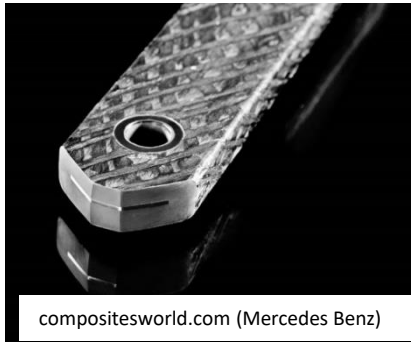
→ **Difficult load introduction** in pultruded profiles

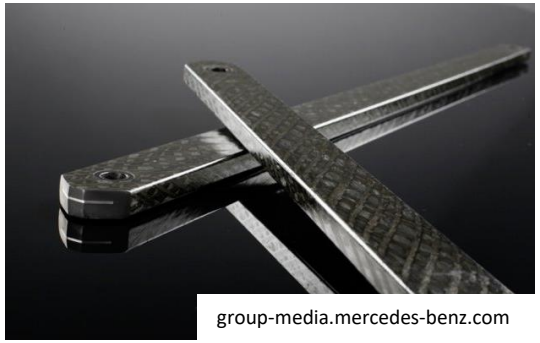
Solution:

- Locally adapted reinforcement textiles

→ Tailored textiles for high-performance load introductions **without decrease in axial stiffness**


ZF Friedrichshafen AG


compositesworld.com (Mercedes Benz)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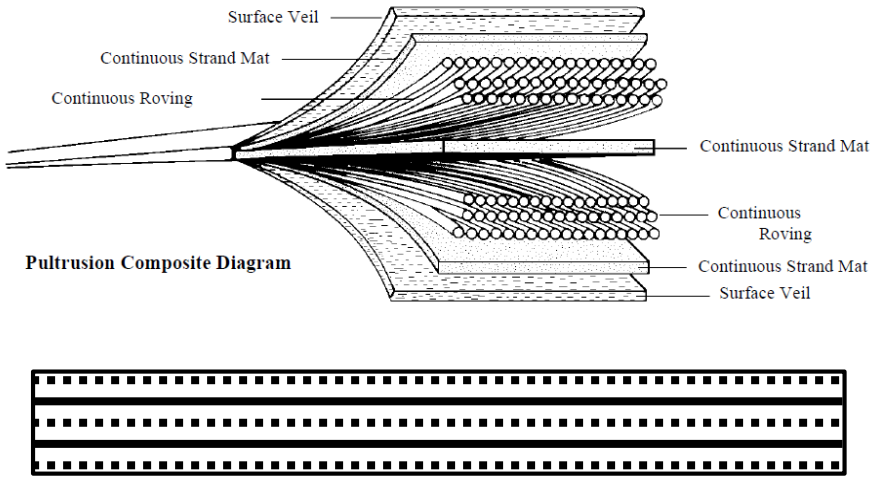
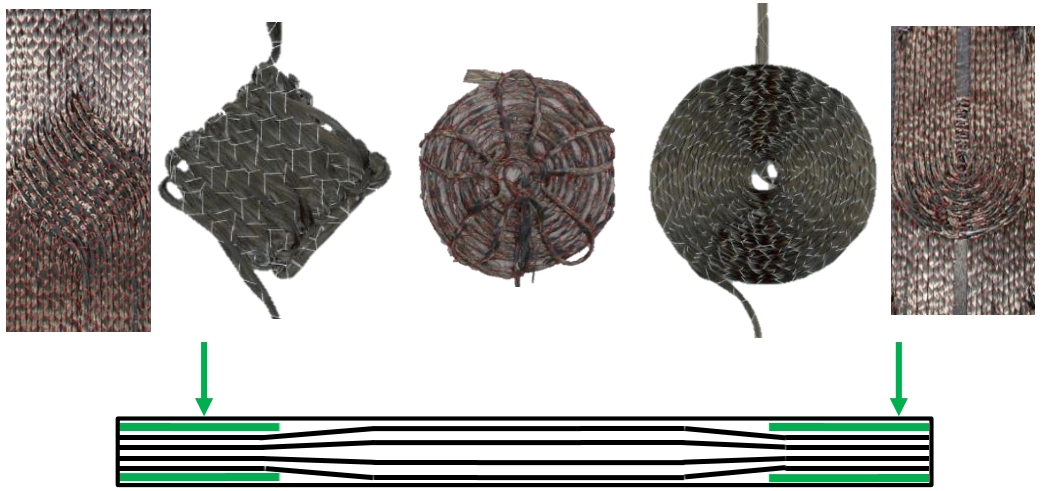
Institut für Textiltechnik (ITA)

Conventional and local reinforced profiles



Conventional pultrusion profile



Locally reinforced profile

Lay-up of conventional pultrusion profiles:

- Predominantly **unidirectional reinforcing fibers**
- Multiaxial reinforcements (mats/NCF/fabrics)
- Profile thickness needs to be increased over total profile length

→ **Oversizing** in most areas of the profiles

Locally reinforced pultrusion profiles:

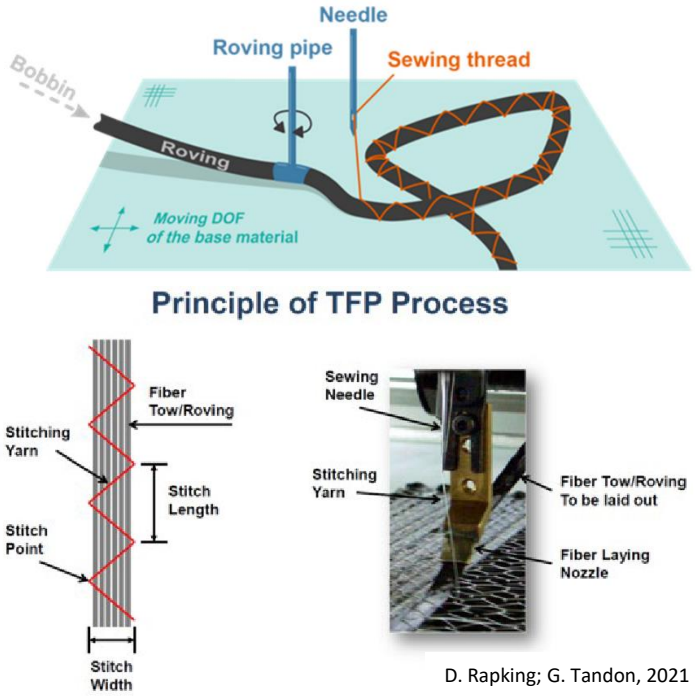
- Locally integrated fiber-reinforcements
- Locally increased fiber volume content

→ **Decrease of profile thickness**

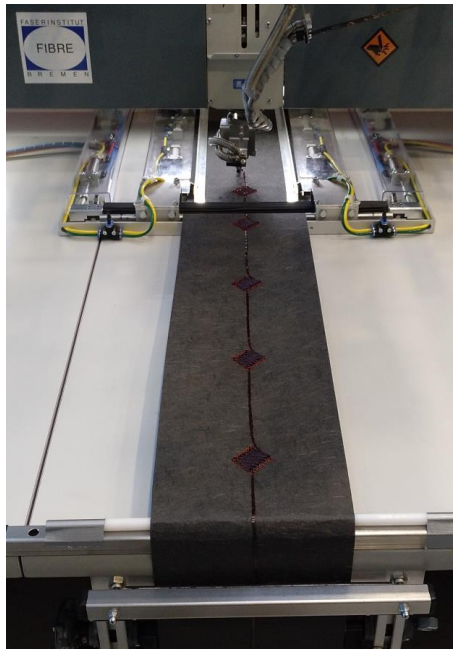
→ **Decrease of material input**

Tailored Fiber Placement (TFP) Process

- Placement of rovings in nearly any two-dimensional paths
- → Excellent technology for load-adapted fiber-preforms
- Parallel-stitching for higher cost-efficiency
- Roll-to-roll variant for fiber-placement on continuous carrier tape



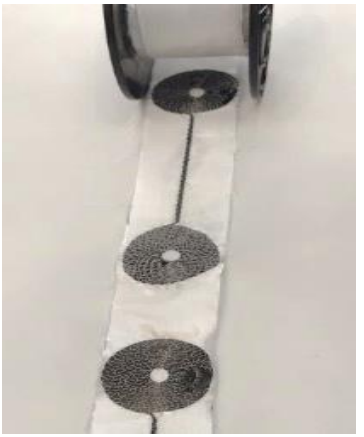
D. Rapking; G. Tandon, 2021



Roll-to-roll TFP process

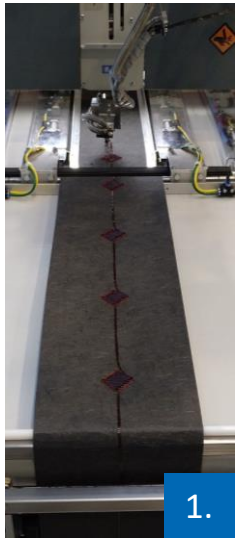
TFP multi-head machine

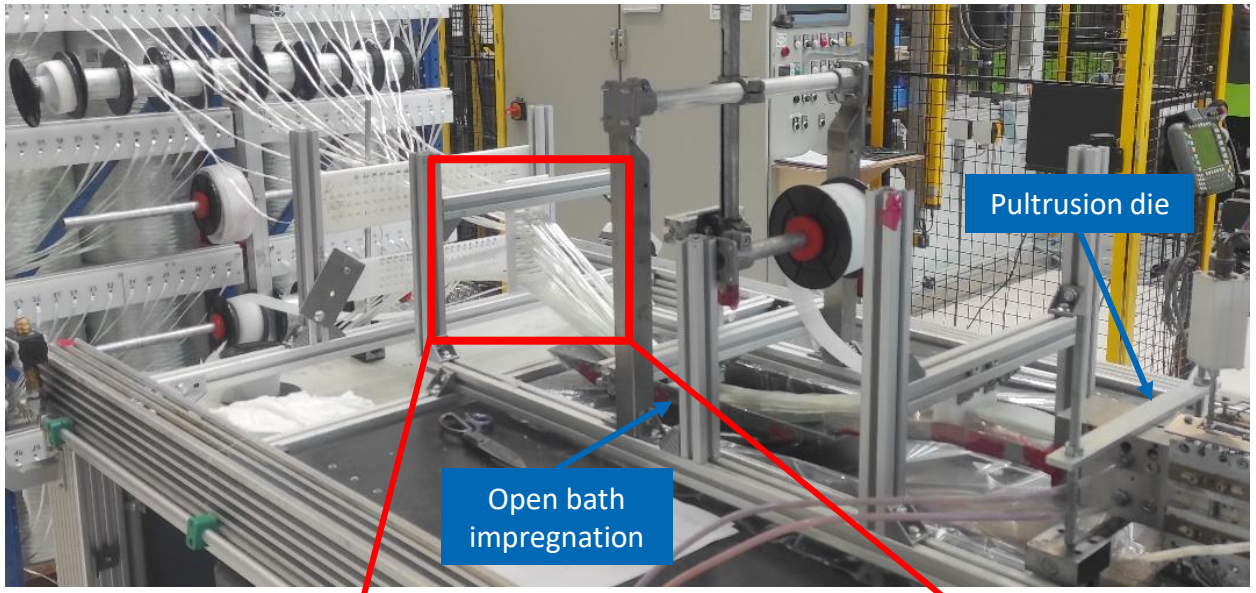
TFP-preform

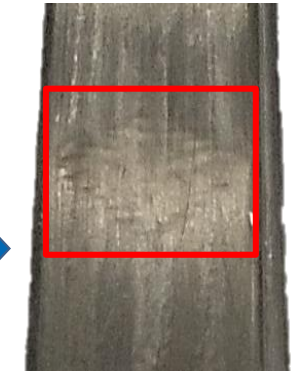


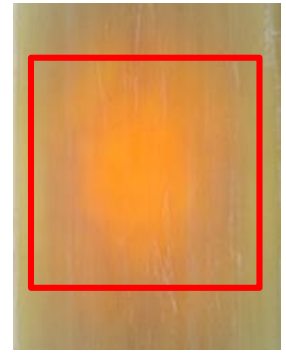
Continuous carrier tape

„Patch-Pultrusion“ Process









1. Production of local reinforcements in TFP process
2. Cutting and roll up of the continuous reinforcing semi-finished product
3. Integration in pultrusion process

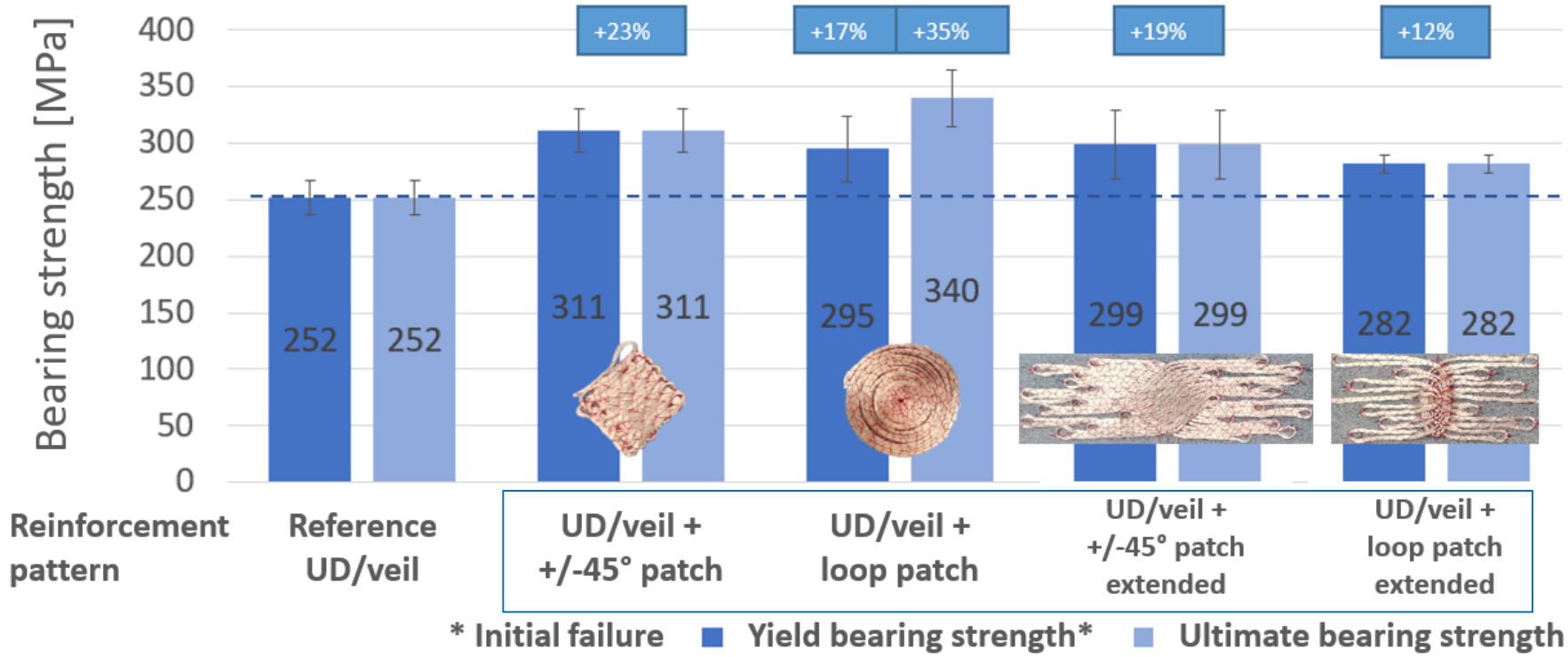
→ Impregnation, forming, curing and cutting

4. Relocation of local reinforced areas

Mechanical properties

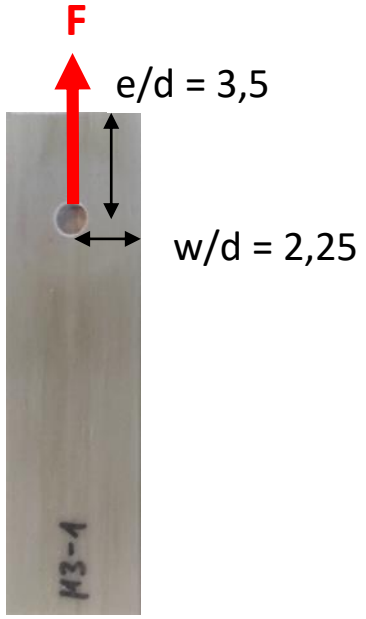
Pin-bearing tensile strength of 45x5 GFRP profiles

Pin-bearing strength tensile test (adapted from DIN EN 6037)



Ca. **+13% local reinforcement** of the total fiber volume content

Sample size:
160 x 45 x 5 mm (D10)



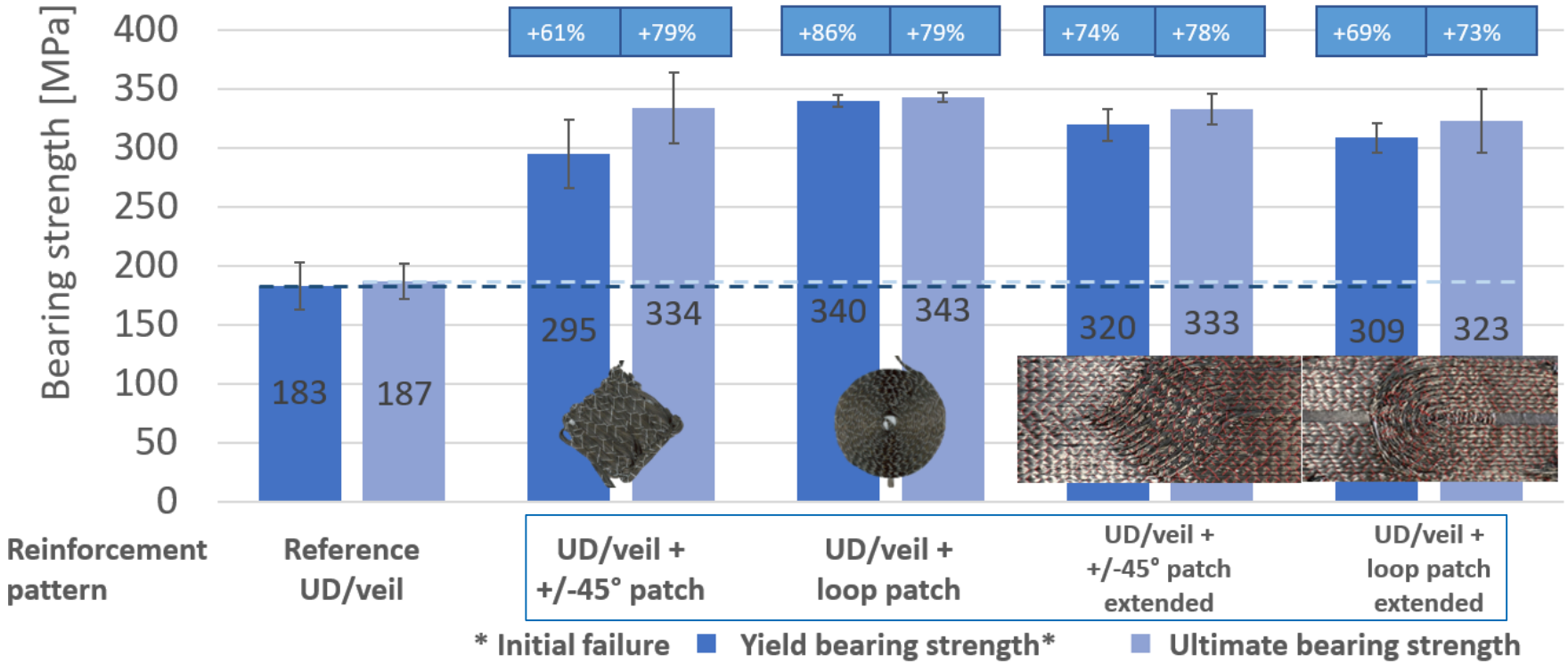
Fibre volume content:
UD-profile: 62%
Local reinforcement area: 70%

Material:
9600 tex/1200 tex ECR glass fiber
EP-Anhydrid resin

Mechanical properties

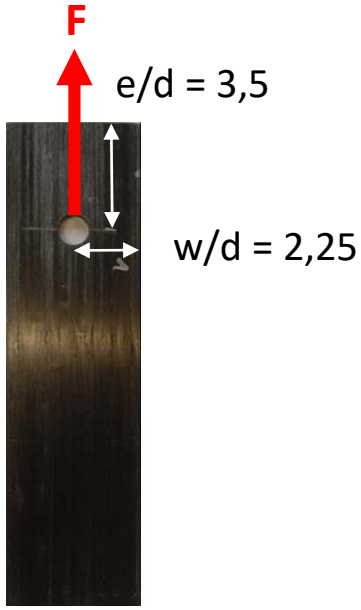
Pin-bearing tensile strength of 45x5 CFRP profiles

Pin-bearing strength tensile test (adapted from DIN EN 6037)



Ca. **+15% local reinforcement** of the total fiber volume content

Sample size:
160 x 45 x 5 mm (D10)



Fibre volume content:
UD-profile: 61%
Local reinforcement area: 70%

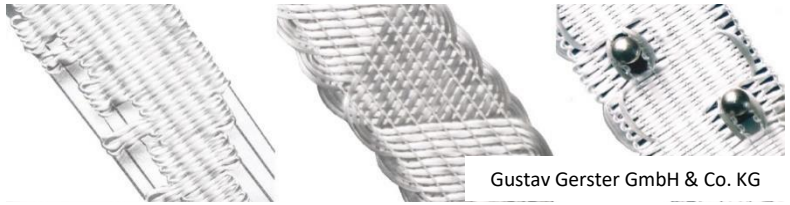
Material:
3700 tex/800 tex carbon fiber
EP-Anhydrid resin

Transfer to more efficient textile manufacturing process

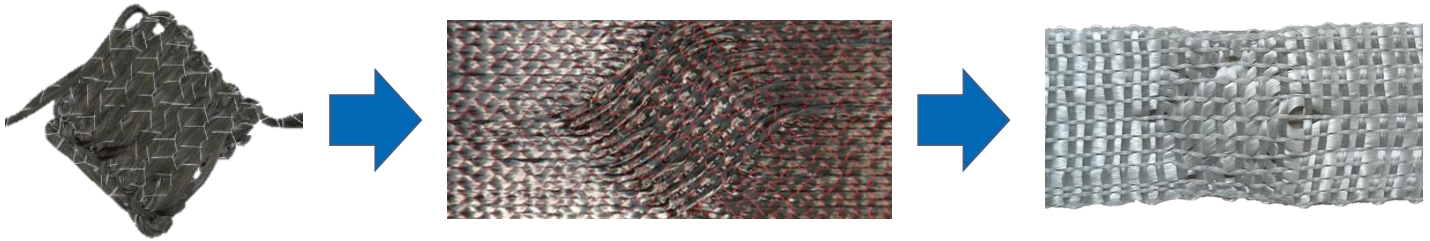
- **Cost reduction** by the use of more efficient textile manufacturing processes
- Crochet gallon technology offers **local adjustability of fiber orientations**
- Crochet gallon machine = Warp knitting with variable weft insertion system

→ Creation of patterns for **local load introductions** possible

Examples of Crochet gallon textiles:



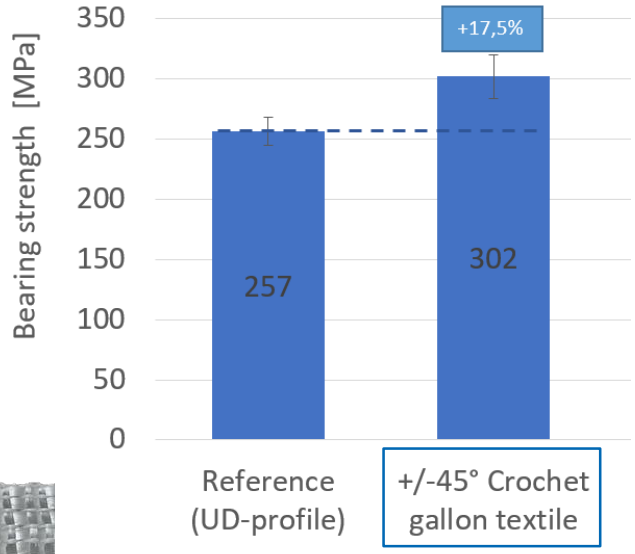
Transfer of TFP preform to Crochet gallon textile:



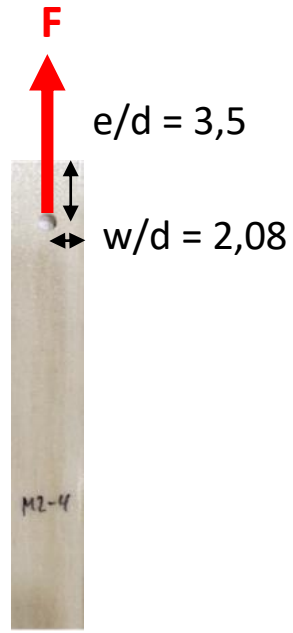
Single TFP preform | Filled TFP preform | Crochet gallon textile

Sample size:
160 x 25 x 4 mm (D6)

Pin-bearing strength tensile test (adapted from DIN EN 6037)



Ca. **+8% local reinforcement** of the total fiber volume content



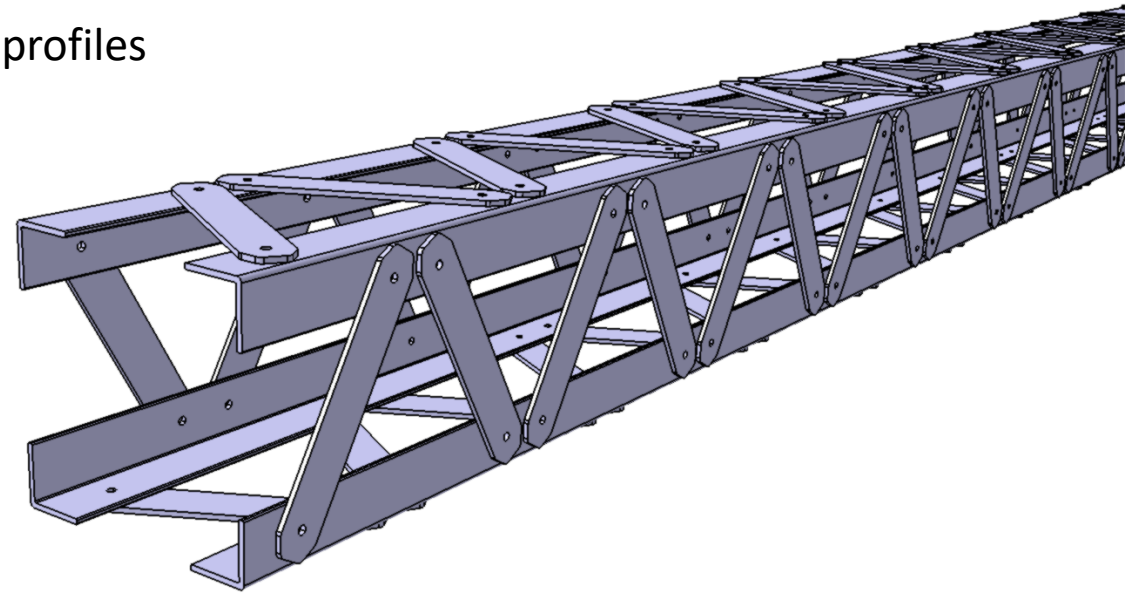
Fibre volume content:
UD-profile: 63%
Reinforced profile: 69%

Material:
9600 tex ECR glass fiber (UD)
EP-Anhydrid resin

Conclusion and Outlook

New opportunities:

- Locally reinforced profiles can efficiently **increase bearing strength**
- **High axial- and bending-stiffness** maintained due to mainly 0° reinforced profile
- **Saving of material** expected for mainly compression/tension loaded parts
- **Cost savings** expected especially for carbon fiber reinforced profiles



Outlook:

- Investigation of possible applications

→ Transfer to serial production

- Investigation of a possible follow-up project

→ Transfer to other process variants

Thanks a lot for your attention!

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Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

Forschungskuratorium textil

Appendix:

- Introduction: Faserinstitut Bremen e.V. (FIBRE Institute)
- Pultrusion activities of the FIBRE Institute
- Additional material characteristics

Faserinstitut Bremen e.V. („FIBRE“)

History:

1969: Foundation from laboratory of Bremen Cotton Exchange

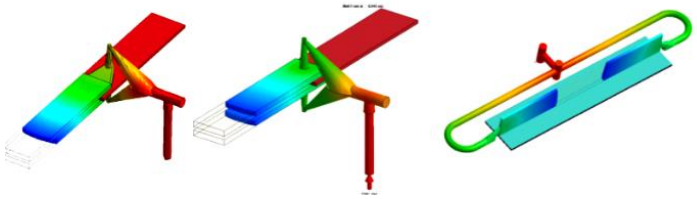
1987: Cooperation with the University of Bremen

- Legally independent, 90% financed by projects and services, 10% by the country of Bremen
- Basic research and applied research activities

FIBRE office at the university

Bremen Cotton Exchange

New FIBRE office (EcoMat)



Pilot plant equipment at EcoMaT

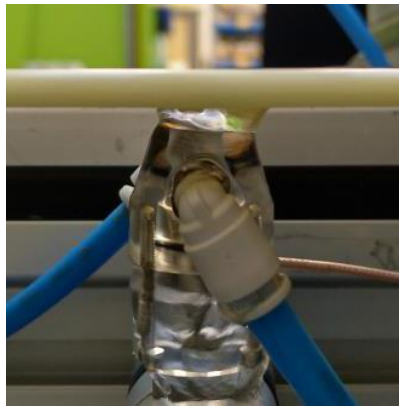
Areas of competence:

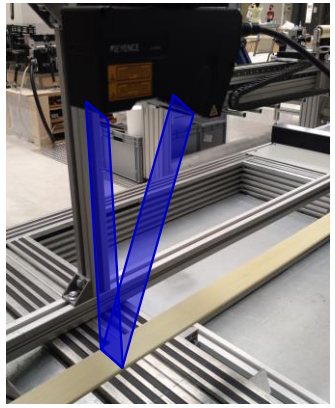
- Fiber and Material development
- Measurement Systems an Monitoring
- Composite Design and Manufacturing Technologies
- Modelling and Simulation

Pultrusion Activities

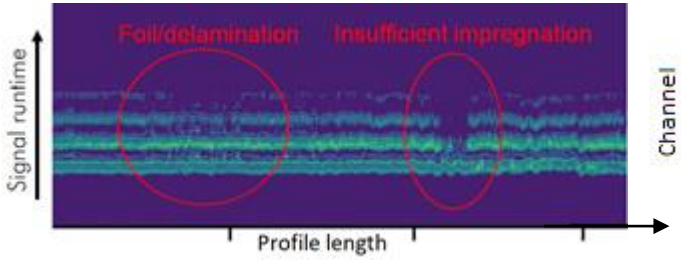
Process Monitoring and Quality Assurance

Inline Microwave Testing

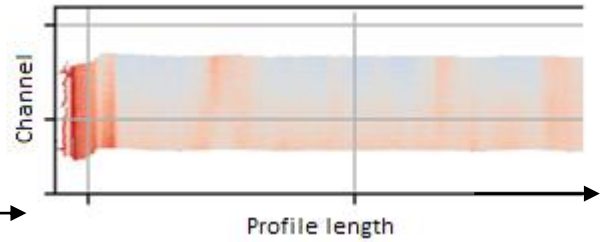

Inline Ultrasonic Testing


Inline Laser-Scanner

Ultrasonic signal



Surface scan (Laser-Scanner)



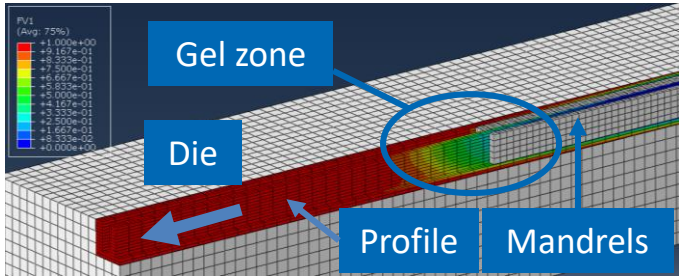
Process Modeling and Simulation

Example:

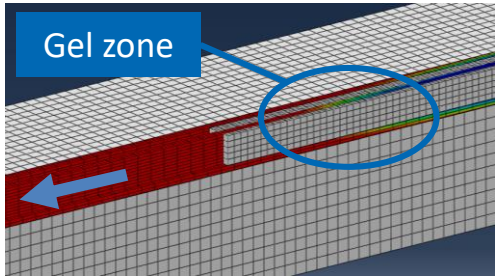
Problem: Incomplete curing of profile after start-up due to transient effects of the process

Approach: Process simulation of heat transfer and curing (using ¼ model in Abaqus)

Before:



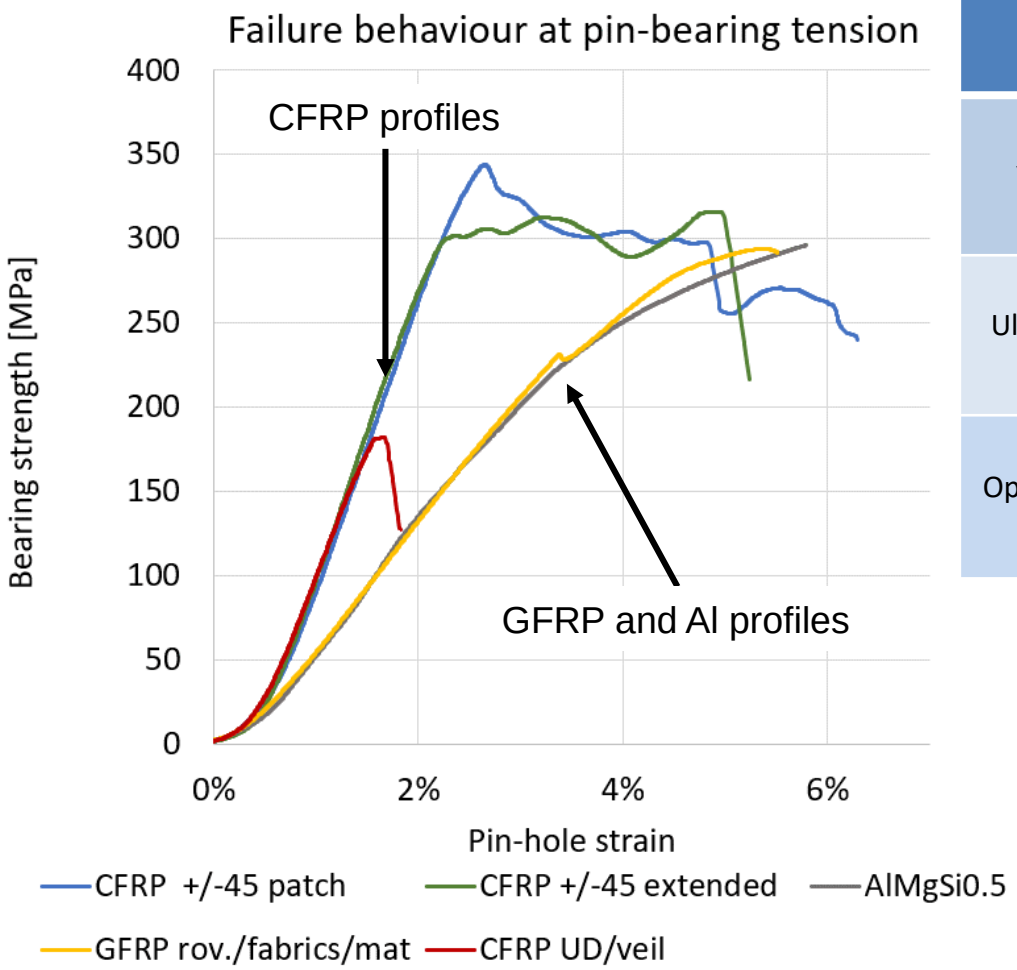
After:



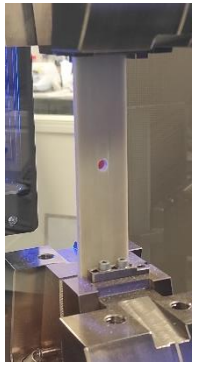
- Moving gel zone after 20 min
- Insufficient curing
- Bad profile quality

- Constant gel zone
- Complete curing
- Better quality

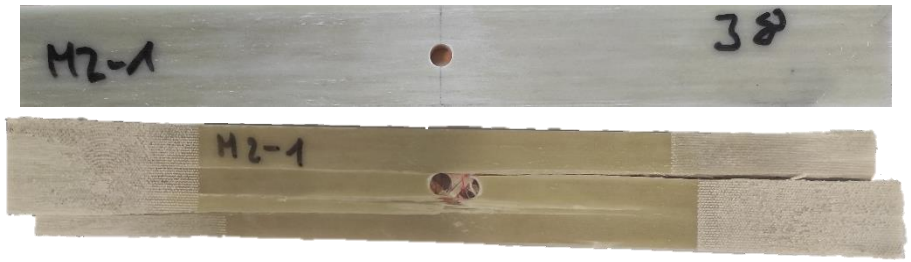
Failure behavior and supplementary tests



Property	Reference	+/- 45°	+/- 45° (extended)	Loop	Loop (extended)
Compression test Yield bearing strength (in MPa)	469	446	426	469	408
Standard deviation	34.8	38.9	44.1	26.3	51
Compression test Ultimate bearing strength (in MPa)	469	452	436	469	411
Standard deviation	34.8	40.5	27.3	26.3	47.4
Tension test Open-Hole tensile strength (in MPa)	597	Not tested	650	Not tested	Not tested
Standard deviation	17.8	-	13.9	-	-

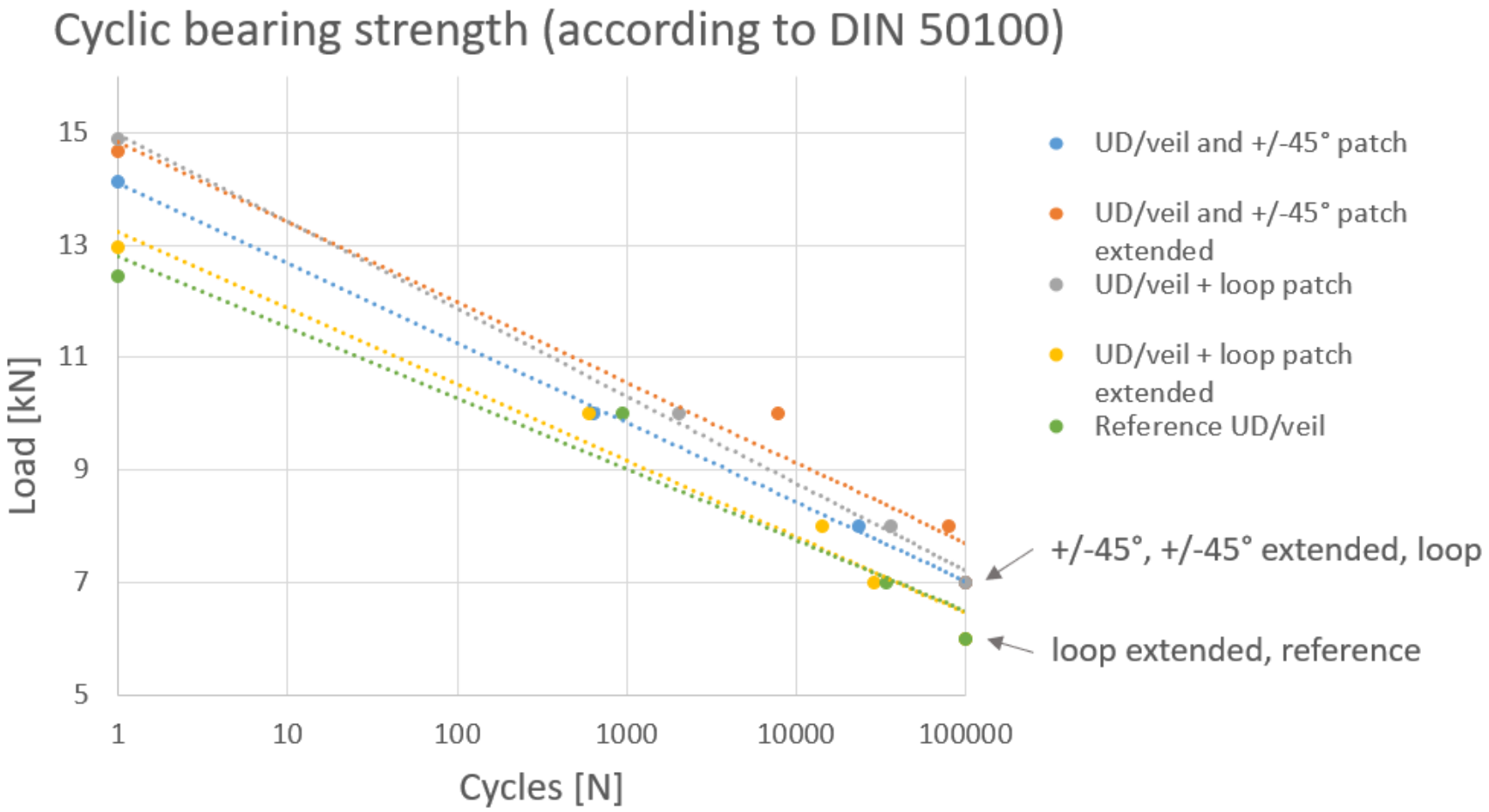


Open-Hole Tensile Test



Open-Hole Test Specimen before (top) and after failure (bottom)

Cyclic testing



Test setup (left) and failed specimen (right)