DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

“Development of textile-based sensors for inspection of composite materials„

Dr. Reinhold Schneider, S. Frick, A.Lenz, H. Brühl, S. Brenner

German Institutes of Textile and Fiber Research

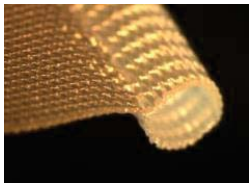
- Europe‘s largest textile research center
- Founded in 1921, foundation under public law
- 3 research centers, 1 production company (ITVP)
- Application oriented research from molecule to product on 25,000 m^2
- Research with industrial pilot facilities, focus on technical textiles and life sciences
- Connected to University of Stuttgart and Reutlingen University by 3 chairs and 2 professorships

German Institutes of Textile and Fiber Research

Key figures 2016

- Employees: approx. 300
- Turnover: approx. 29 Mio. € (11 Mio. € public, 18 Mio. € industry)
- Industry: (without ITVP)
  31% Baden-Württemberg
  35% national
  34% international
  49% small and medium-sized enterprises

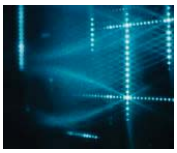
Application oriented research from molecule to product

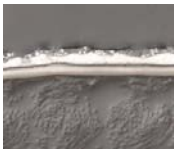


German Institutes of Textile and Fiber Research

Research fields

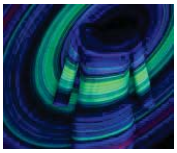
High Performance Fibers and Yarns


Smart Textiles


Functionalized Textiles and Finishing

Medical Technologies

Lightweight Design and Fiber Composites


Textile 4.0

Application fields (2016)

Architecture and Construction	8%
Health and Care	10%
Mobility	15%
Energy and Environment	19%
Production Technologies	38%
Clothing and Home Textiles	10%

High Performance Fibers and Yarns

Today

Ceramic fibers for
high temperature applications

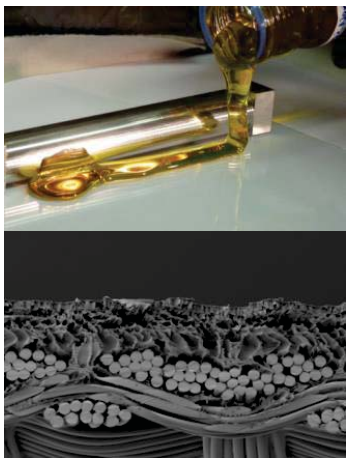
Future

Processing of recycled high-performance fibers

Vision

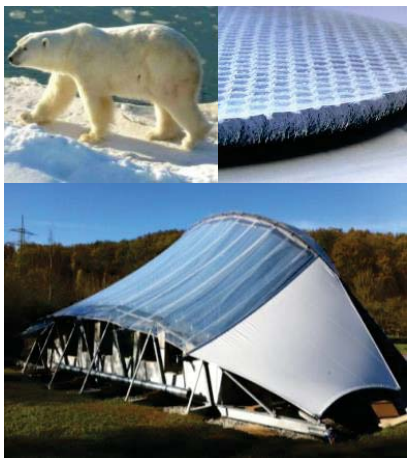
Cost-effective carbon fibers from renewable raw materials

Functionalized Textiles and Finishing



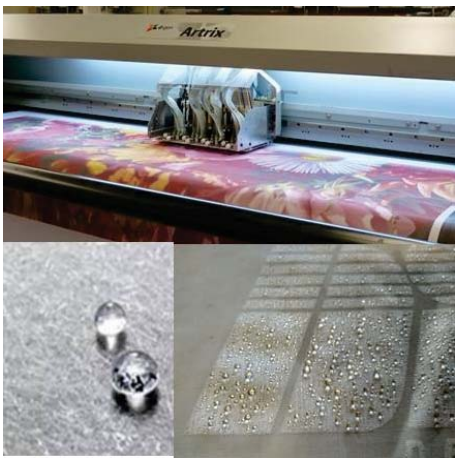
Today

Coatings out of ionic liquids enable new material combinations



Future

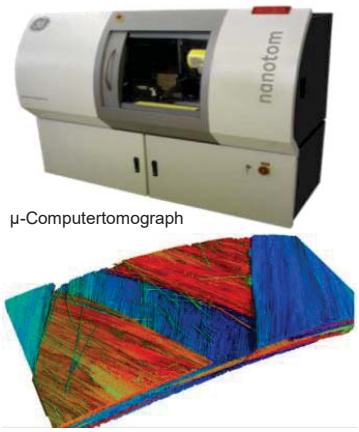
Energy-independent building with flexible solar thermal textile collectors



Vision

Factory of the future
Local functionalization with digital printing technology

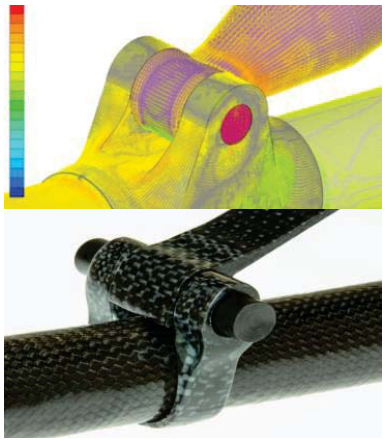
Lightweight Design and Fiber Composites



µ-Computertomograph

Today

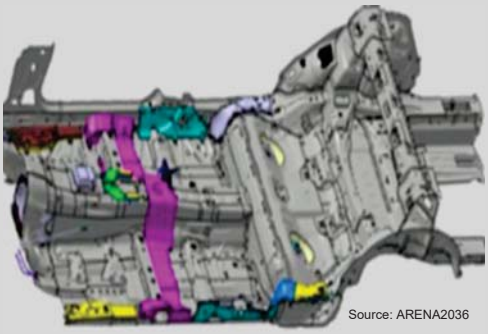
Non-destructive testing of lightweight structures and textile constructions



Future

Complex 3D outline woven figures for composites

Multifunktionales PKW-Bodenmodul

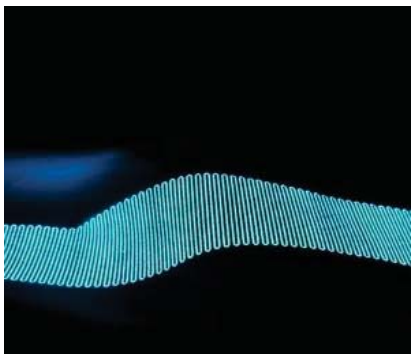


Source: ARENA2036

Vision

Intelligent lightweight design with functional integration

Smart Textiles



Today

Electroluminescent printed structures

Future

Sensor shirt for monitoring vital parameters for the protection of firefighters

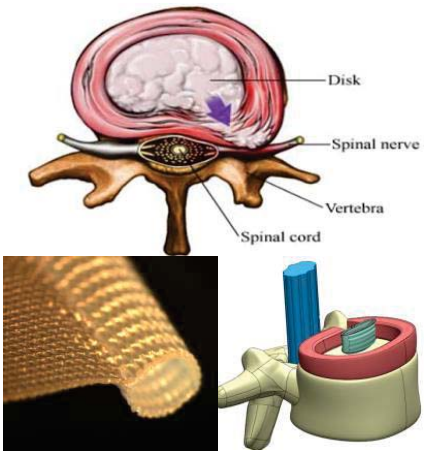
Vision

Energy and weight savings with textile power actors for automation process

Medical Technologies

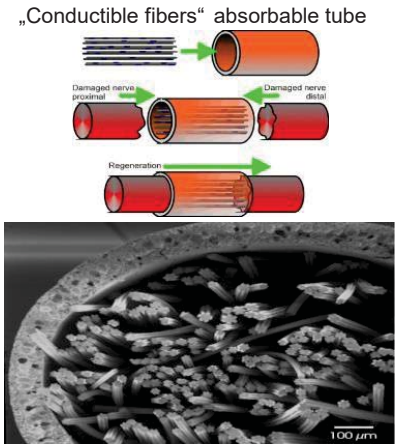
Today

Medical implants



Future

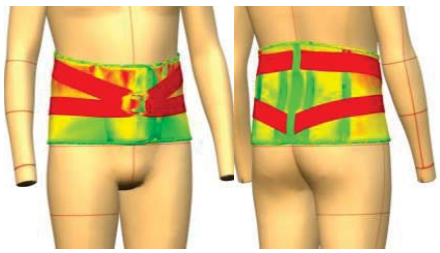
Intervertebral disc closures



Vision

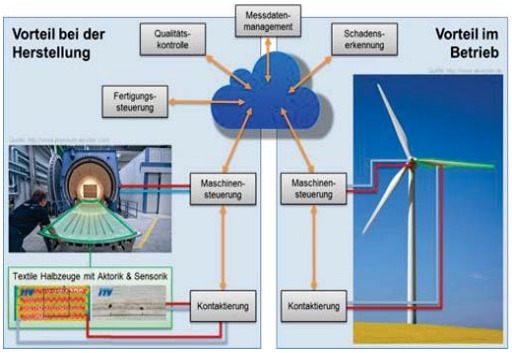
Nerve regeneration

Textile 4.0



Today

Individualized products manufactured by big data optimized processes



Future

Networked process monitoring of fiber composite components with integrated sensors

Vision

Dynamic, adaptive self-organized and learning textile processes, materials and clothes

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

“Development of textile-based sensors for inspection of composite materials„

Dr. Reinhold Schneider, S. Frick, A.Lenz, H. Brühl, S. Brenner

Introduction

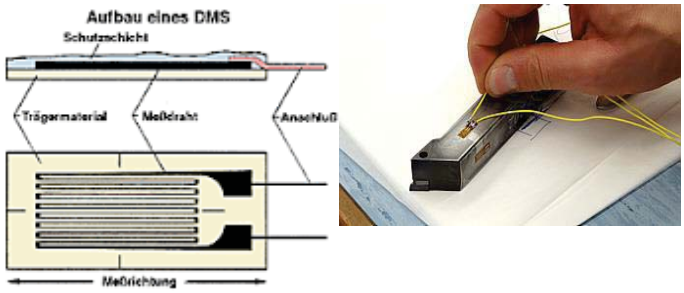
DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

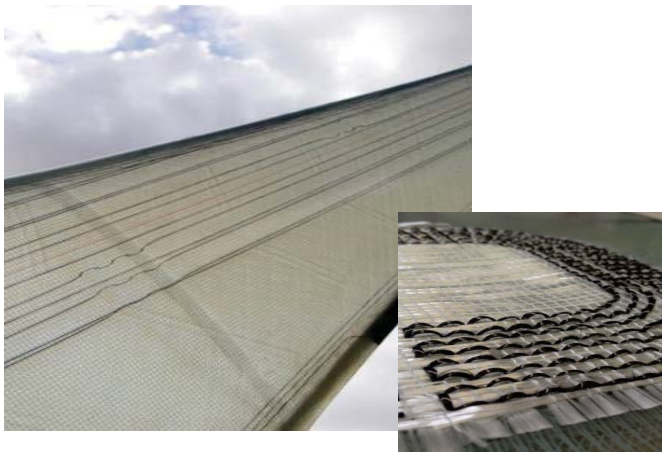
- **Applications for composites in light-weight constructions**

- **Monitoring of mechanical deformation and damage is demanded**

State of the art

- **Established sensors**
  - **Strain gauge (small sensors)**





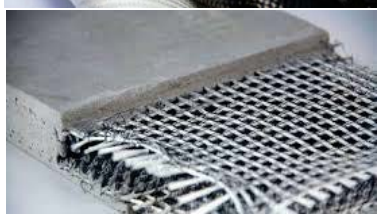
  - **Sensoric Fibres (expensive)**
    - **Fibre optical sensors/Bragg grid**
    - **Piezoelectric sensors (PVDF)**

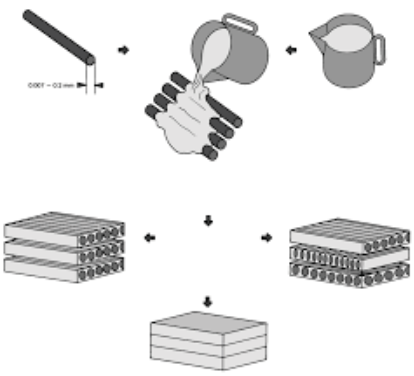
Objectives

- **Development of a large area sensor, individual and arbitrarily dimensioned**
- **Avoidance of predetermined breaking points**

→ Use of textile based sensors

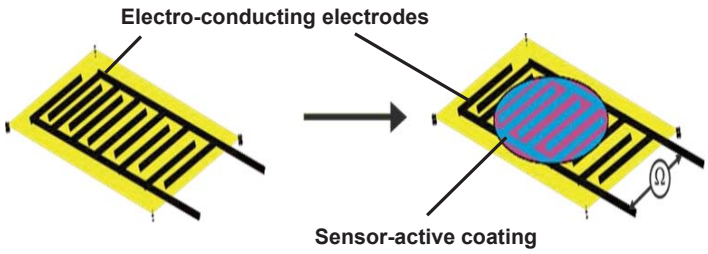
- **Printing/coating of sensing materials on**
  - **Reinforcing textile**
  - **Composite**





Construction of a textile-based sensor

- **Basic requirements**
  - 2 Electrodes
    - **Non insulated Electrodes → Δ R, Δ U**
    - **Insulated Electrodes → Δ C**
  - Sensoric coating materials

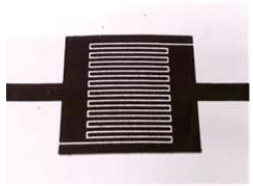


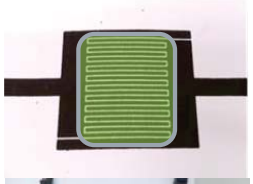
Function	Coating Material
Piezoelectric effect	PVDF, ZnO, AlN, Zr-Titanat, Polyacetylene, Polypyrrole
Thermoelectric	Poly(p-phenylenvinylene), Semiconductors, NTC
Photoelectric	CdS, CdSe,Polyacetylen-ZnS, Cu-Phthalocyanine, Polyaniline, Polythiophen-Complexes
Magnetosensoric	Ni-Co alloys, Ni-Fe-alloys
Gassensors	Semiconducting metal-oxides Ga_2O_3, SnO_2

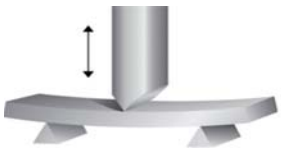
Approach

Printing of sensors on reinforcing textile

- **Printing of electroconductive interdigital structures as electrodes for recording of measuring signal**
- **Printing/Coating of reinforcing textile using sensor active materials (conduct. Polymers, carbon….)**
- **Manufacturing of composites (vacuum infiltration)**
- **Measuring of resistivity or capacitance under mechanical load/bending**



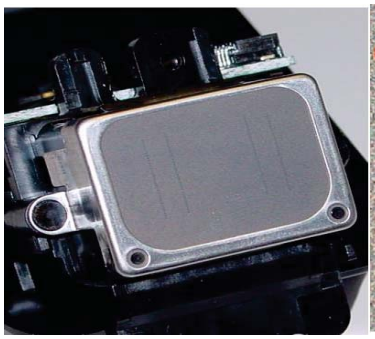


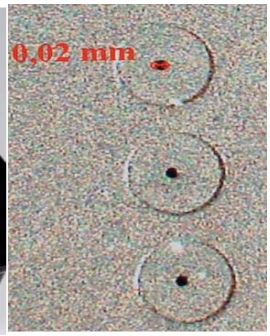


Demanded Ink Specifications

Inkjet (Epson)

-Viscosity	1…5 mPas
-Surface tension	20..50 mN/m
-Particle size	< 1µm
-Add-on/pass	15 g/m²

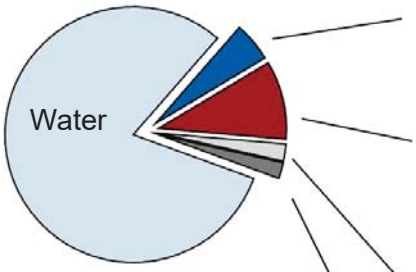




Valvejet (Chromojet)

-Viscosity	50…500 mPas
-Surface tension	30..50 mN/m
-Particle size	< 20 µm
-Add-on/pass	200-1000 g/m²

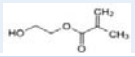
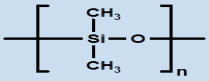
Formulation of functional inkjet inks



- **Binders (< 15%)**
  - Thermal or UV-curable Acrylate (Polyurethane-, PEG-acrylate)
- **Pigment dispersions/functional chemicals(< 10%)**
  - Electr.-conduct. particles (Graphite, Carb.black, silver, electrocond.Polymer (Pedot))
  - Optical brighteners, FC, ...
- **Photoinitiators (< 1 %)**
  - Methylbenzophenone, α-Hydroxyketone
  - Acylphosphinoxide
- **Additives (< 2%)**
  - Surfactants & hygroscopic substances

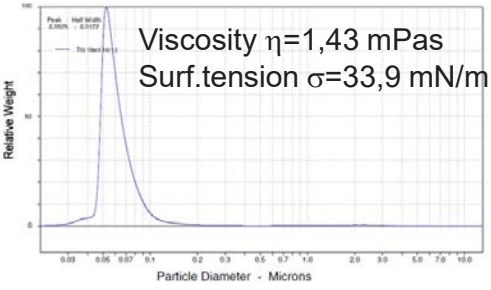
Procedure: 1) Pigment grinding + 2) Additives & Binders→ 3)Filtration down to 0,8 µm

Functional inks – Function versus chemistry

Function	Chemistry
Electrically conductive	Metals (Ag, Cu,…), Carbon, ITO, electrocond. polymers (PEDOT,….)
Electrically insulation	Polymers (Binders, silicones…)
IR-Reflection	Metals (Al, Ag..)
IR-Absorption	Carbon black, ATO,
UV-Activity	Optical brighteners such as stilbenes
Hydrophilicity	Polyacrylates, HEMA 
Hydrophobicity	Al/Zr-Stearate $(C_{17}H_{35}COO)_3Al$ Fluorcarbone $HOOC-CF_2-CF_2-CF_2-CF_2-CF_2-CF_2-CF_3$ Silikone 
Electroluminescence	(doped CdS, ZnS) & $BaTiO_3$

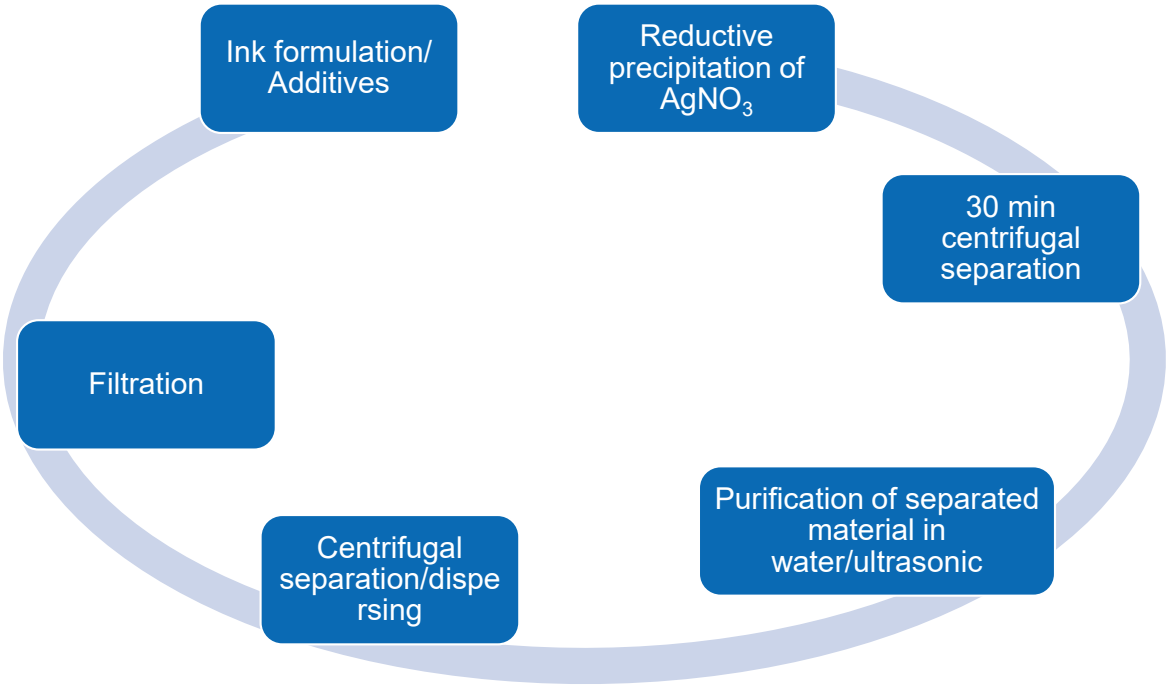
Ink formulation

- **Manufacturing of C-based electroconducting inks**
  - 4h grinding of functional particles (electro-conducting pigments and dispersants in nanomill (picoline)
  - Particle size <800 nm
- **Addition of chemicals**
  - Dilution (< 0,1% IR)
  - Binders (5%)
  - Additives (up to 5%)
- **Filtration**
  - Filtration down to 0,8 µm
  - Particle size < 800nm



Viscosity η=1,43 mPas
Surf.tension σ=33,9 mN/m

Ag-nano particles & ink formulation



Printing Pastes

Printing paste for electrodes
40% Ag-Flakes
9% Binder
4% Thickener
47% Water

Paste	Conductivity (Ω/sq)
Silver paste ITCF	~ 1
Carbon paste ITCF	~ 6000
Silver ink (30%Ag)	~ 1…10 (5 OP)
Carbon ink (5%C)	10.000-50.000 (1 OP)

Sensing coating
4% Carbon black
5% Binder
1% Thickener
1% Dispersing agent

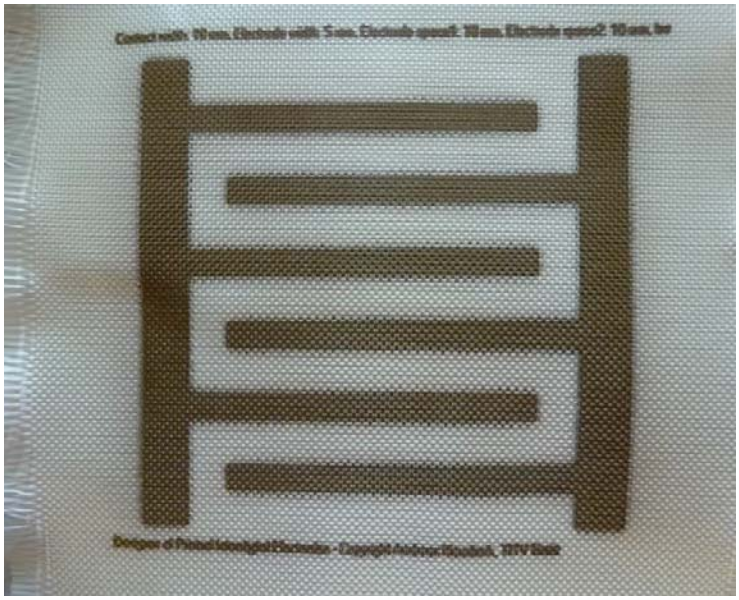
Manufacturing of sensing reinforcing textile

1. Imprinting of electro-conducting interdigital structures/electrodes on reinforcing textile using screen printing or inkjet printing.
2. Coating of electrodes using sensing materials (Carbon..)

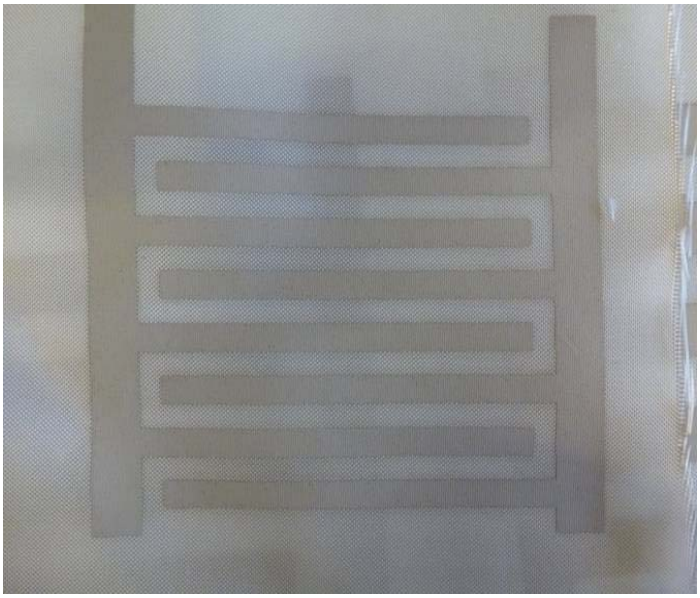
Printing of electrodes on glass fibre fabrics

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

Inkjet printing with Ag-ink on GF (R< 5 Ohm/sq (5OP)

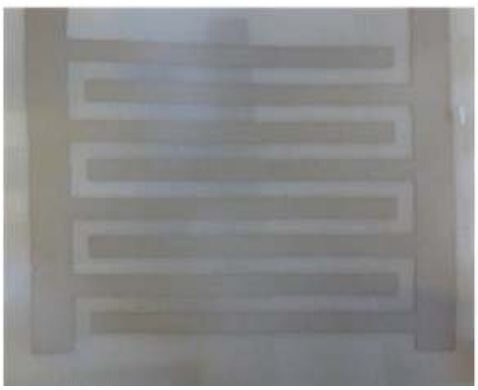


Screen printing with Ag-paste on GF (R< 5 Ohm/sq)

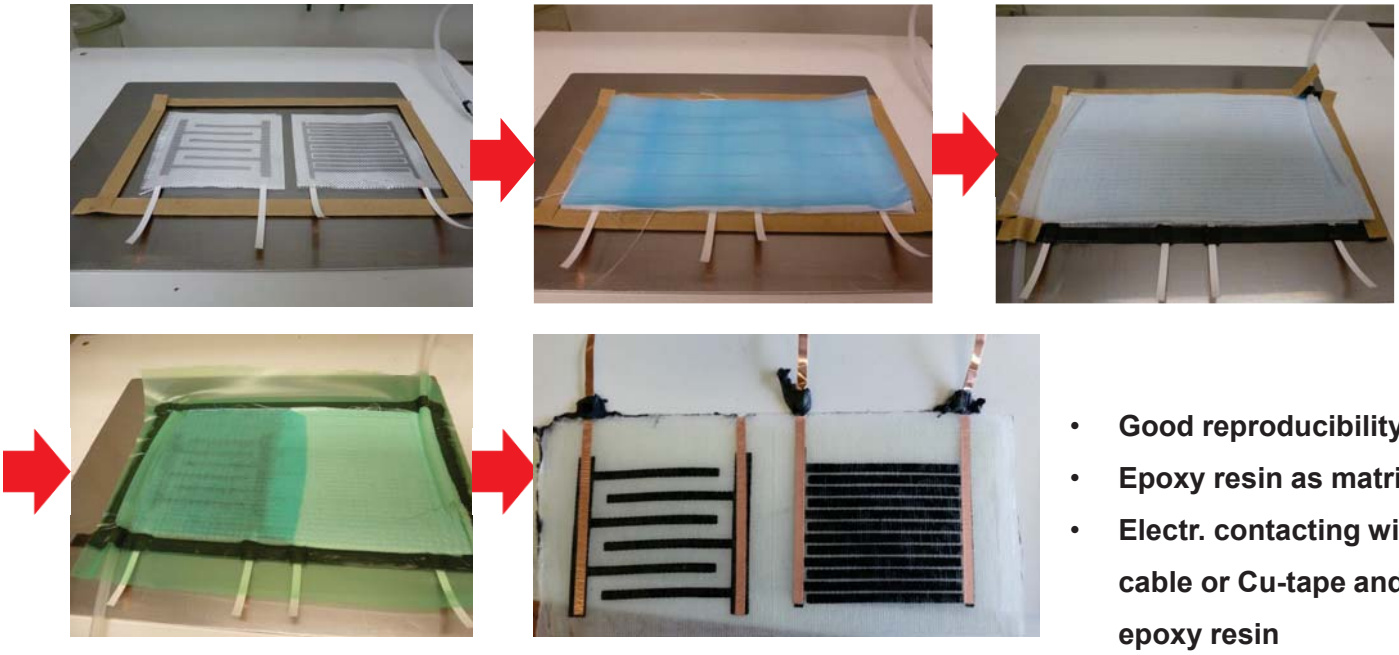


Sensors on Glass fibre fabrics

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

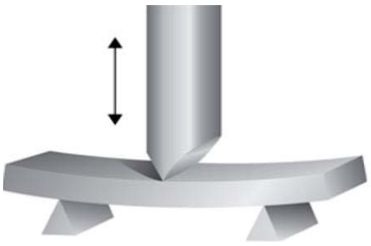


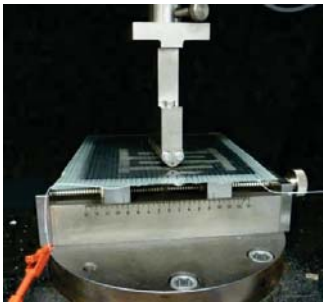
Manufacturing of composites using vacuum infiltration



- Good reproducibility
- Epoxy resin as matrix
- Electr. contacting with cable or Cu-tape and Ag-epoxy resin

Testing of sensing composite

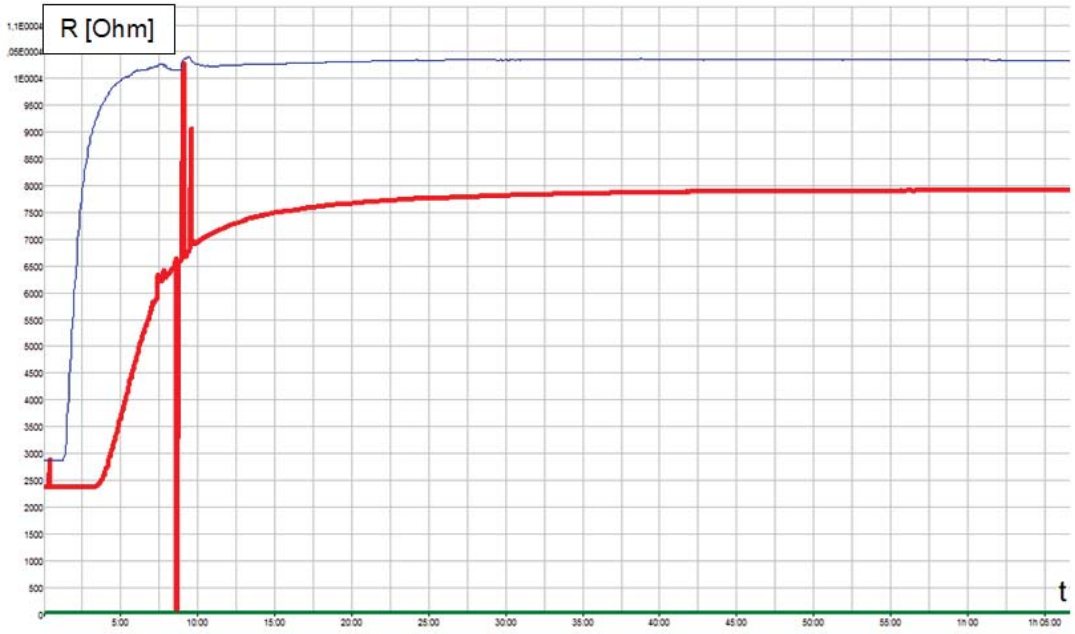




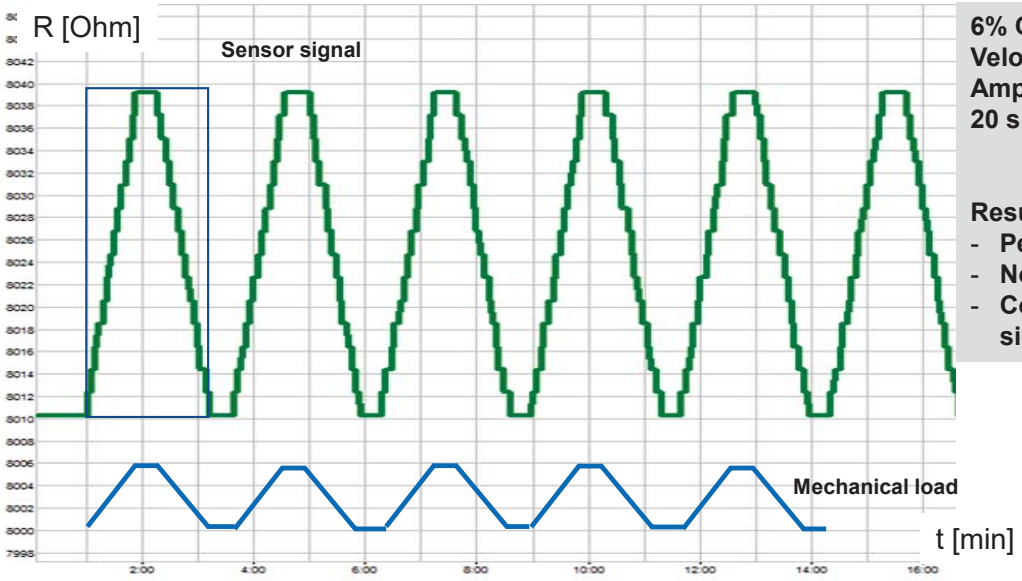
- Bending test (Zwick apparatus)
  →Reproducible loads
  →Variation of bending speed and amplitude

- Measurement of ohmic resistance (current at constant voltage)

Change of ohmic resistance in sensoric coating during infiltration



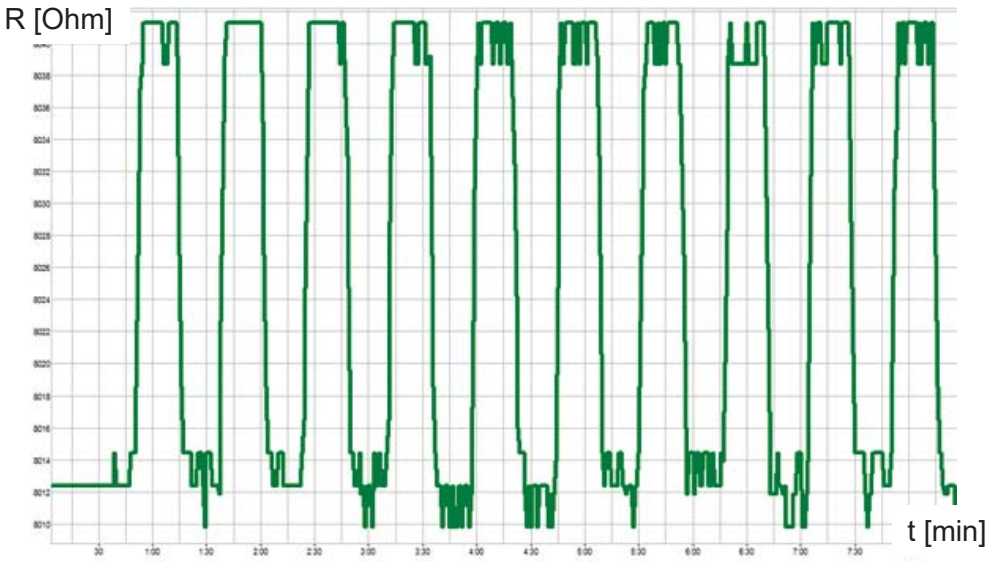
Testing of composites sensing properties



6% C-paste on reinforcing textile
Velocity 5mm/min
Amplitude 5 mm
20 s stop after deformation

Result:
- **Periodic signal**
- **No hysteresis**
- **Correlation between bending and signal**

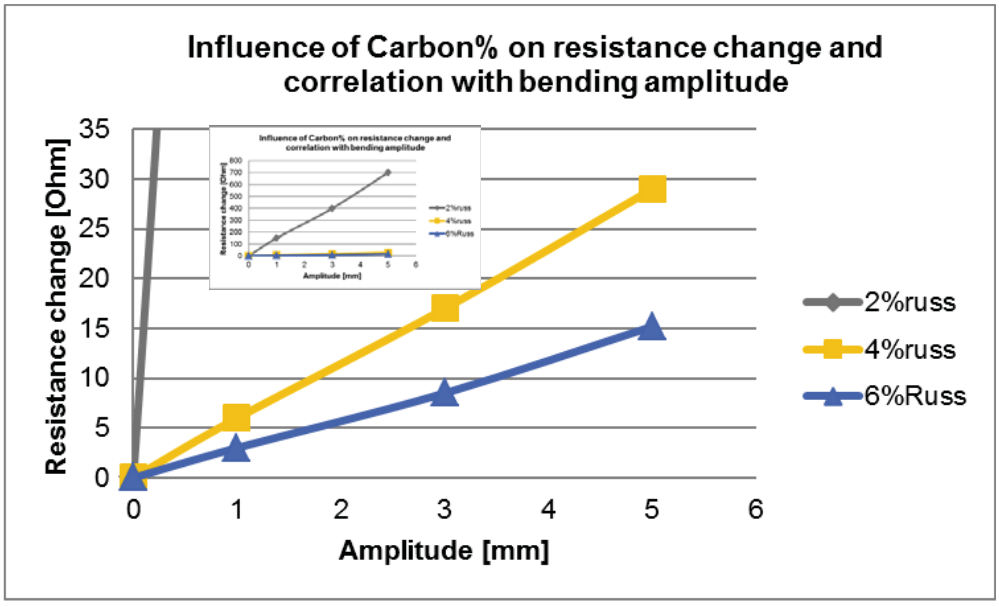
Testing of composites sensing properties



4% C-paste on reinforcing textile
Velocity 100 mm/min
Amplitude 5 mm
20 s stop after deformation

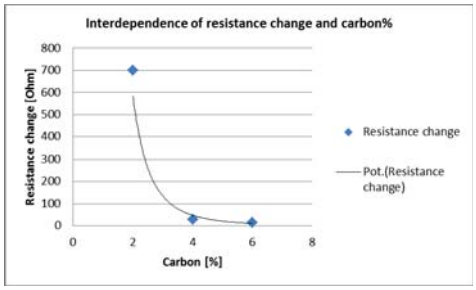
Result:
- **Periodic signal**
- **No hysteresis even at high velocity**
- **Correlation between bending and signal**

Testing of composites sensing properties

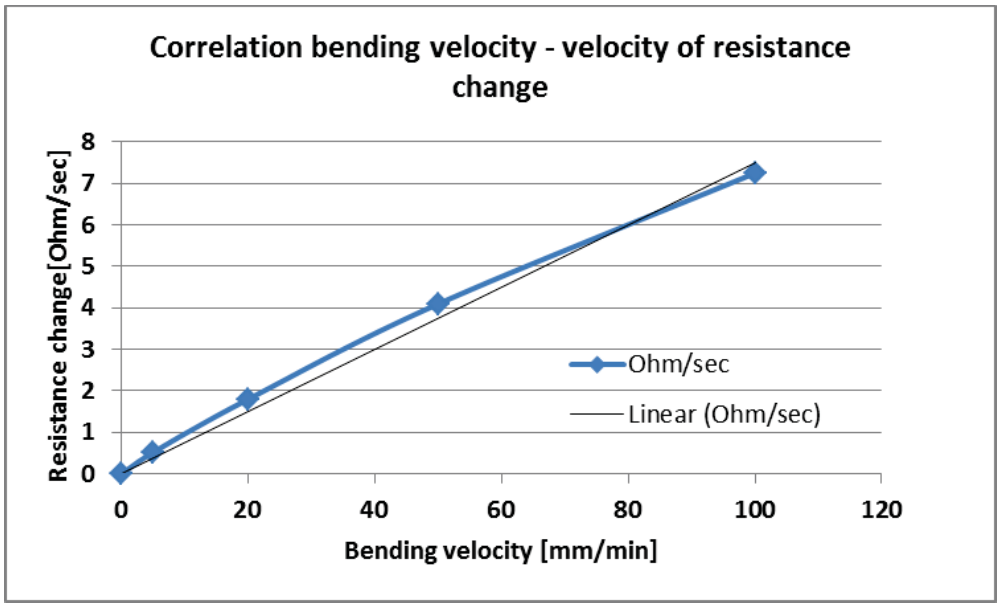


2-6% C-paste on reinforcing textile

Result:
- **Linear correlation of bending amplitude and resistance change**
- **Low carbon% results in high resistance change**



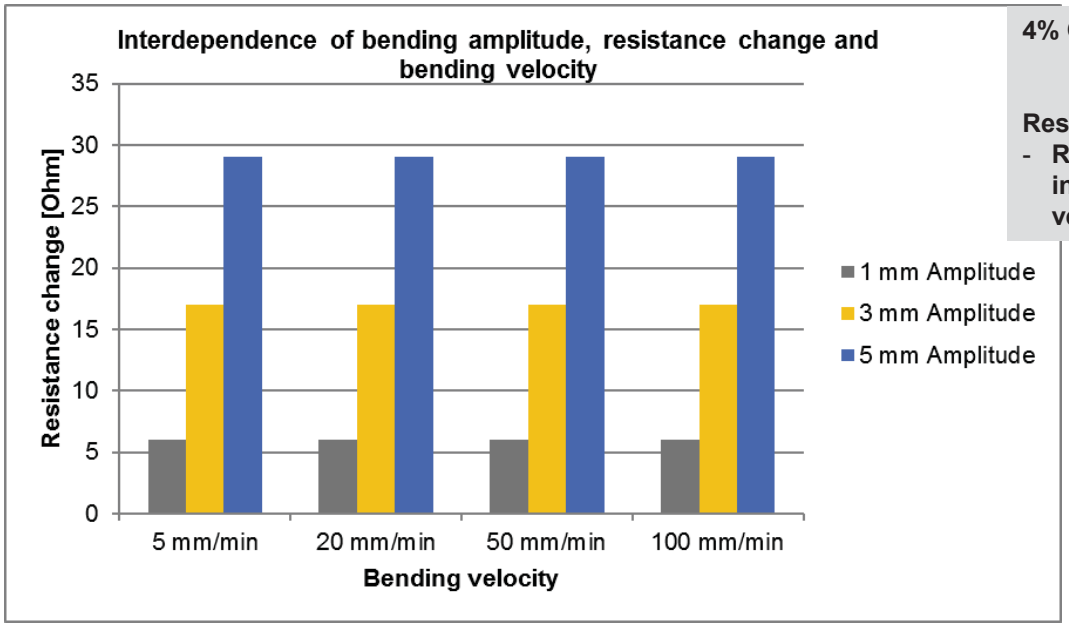
Testing of composites sensing properties



4% C-paste on reinforcing textile

Result:
- **Linear correlation of bending velocity and resistance velocity**

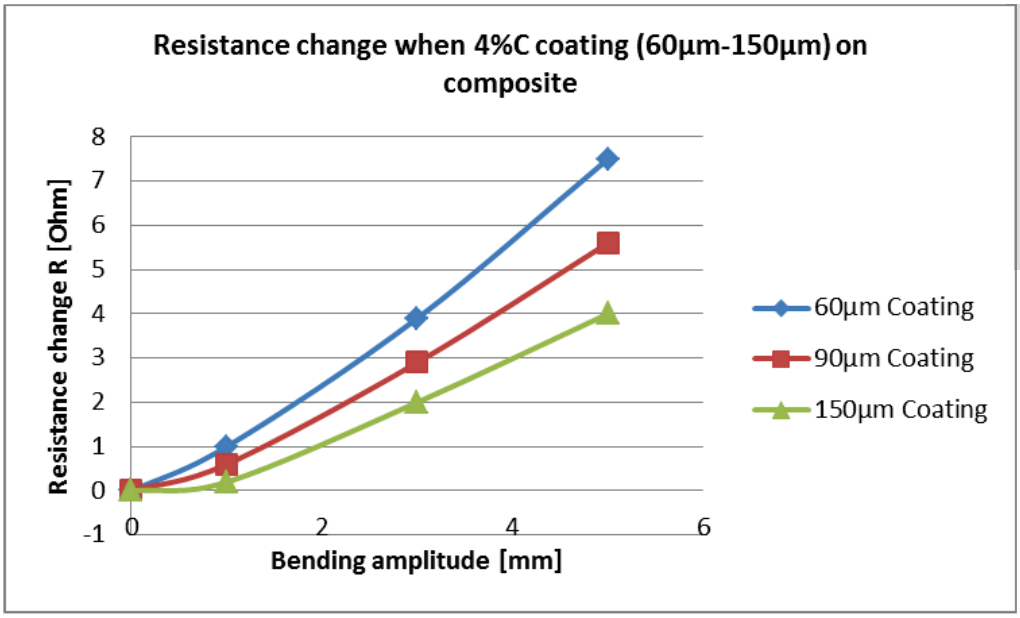
Testing of composites sensing properties



4% C-paste on reinforcing textile

Result:
- **Resistance change is independent from bending velocity**

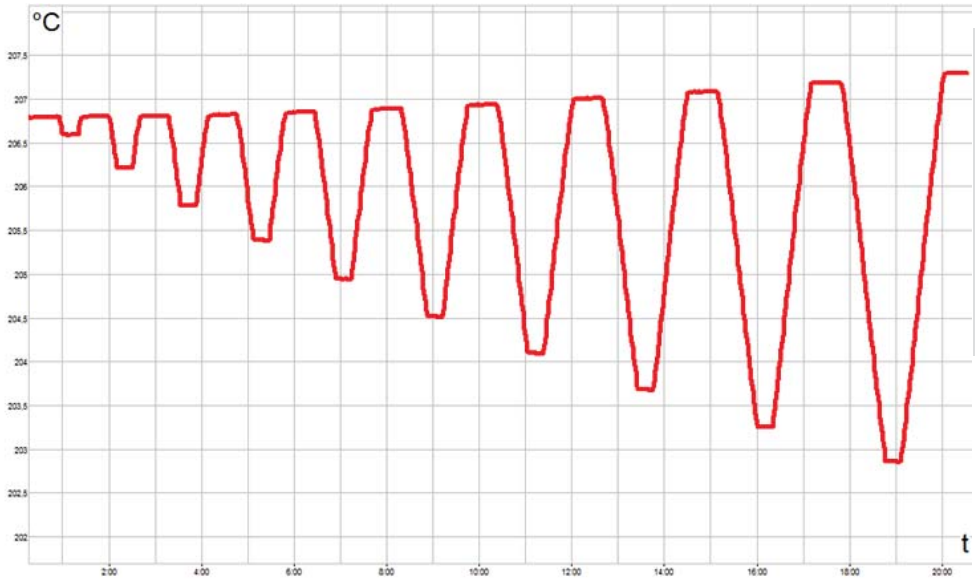
Testing of composites sensing properties (coating)



4%C coating on the composite

Result:
- **Resistance change depends on coating thickness and C%**
- **Largest resistance change at low C% and thin sensing coatings**

Testing of composites sensing properties (coating)



4%C , 150µm coating on the composite; Increasing amplitude Start 1mm, +0.5mm/cycle; 5 mm/min, 20sec stop

Result:
- **Resistance change correlates linear with amplitude**
- **No hysteresis**

Conclusion

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

- **Large area strain gauge sensor on reinforcing textile was developed**
- **Resistance change correlates with bending amplitude**
- **Resistance change depends on C% in printing paste; low C% results in high resistance change**
- **No hysteresis even at high bending velocity**
- **No influence of bending velocity on resistance change**
- **Large area strain gauge sensors were also realized by means of coating on the composite**
- **Resistance change depends on coating thickness and C%; largest resistance change at low C% and thin sensing coatings**