# The Fiber Society
# 2017 Spring Conference

## *Next Generation Fibers for Smart Products*

## May 17–19, 2017

### Conference Chairs


**Dr. Thomas Gries and Dr. Yves-Simon Gloy**

**Institut für Textiltechnik der RWTH Aachen, Germany**


### *Venue*

*RWTH Aachen University*

*SUPER C, Templergraben 57*
*Aachen, Germany*

## *Program*

**Tuesday, May 16**
**Location: Institute für Textiltechnik, RWTH Aachen University, Otto-Blumenthal-Str. 1**

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| 1:00 PM–5:00 PM | Governing Council Meeting: Conference Room Nord/Süd |
| 5:00 PM–8:00 PM | Early Bird Registration, Social, and Guided Tours: Entrance Hall |

# Wednesday, May 17

## Location: Conference Venue at SUPER C, Templergraben 57, Aachen

7:30 Registration and Continental Breakfast: 6th Floor Foyer
8:10 Welcoming Remarks, Business, and Announcements – Room A

*Thomas Gries, Conference Chair*
*Laurence Schacher, Fiber Society President*

8:20–9:00 **Keynote Speaker:** Thomas Gries, RWTH Aachen, *Fibers and Textile Materials 4.0*.

9:00–9:40 **Keynote Speaker:** Tae Jin Kang, Seoul National University, *Adaptive Protective System for Smart Textiles*

9:40 Break

### *Morning Session*

| | **Room A** | **Room B** |
|---|---|---|
| | **Session: Smart Polymers, Fibers, and Textiles** ***Chair, Thomas Gries*** | **Session: Multimaterial Fibers** ***Chair, Fabien Sorin*** |
| 10:00 | *Smart Functions Observed on Polymer Gels* Toshihiro Hirai, Shinshu University | *Multimaterial Fibers: Challenges and Opportunities* Fabien Sorin, EPFL |
| 10:25 | *Thermo-sensitive Nanofibers Based on Biobased Materials* Aleksandra Miletic, University of Novi Sad | *Multimaterial Fibers for Electromechanical Touch Sensing* Alexis Page, EPFL |
| 10:50 | *Stress-memory Filaments as Advanced Material for Smart Compression Management* Harishkuma Narayana, Hong Kong Polytechnic University | *Intermediate-Tg Phosphate and Tellurite Glasses for Multimaterial Fiber Devices* Sylvain Danto, University of Bordeaux |
| 11:15 | *ECG Measurement via AgNW/PU Nanoweb Electrodes and Comparison with Ag/AgCl Electrodes* Eugene Lee, Yonsei University | *Multimaterial Porous Fibers* Benjamin Grena, Massachusetts Institute of Technology |
| 11:40 | *PVDF Nanofibers Membrane Grown with Zinc Oxide (ZnO) Nanorods for Enhanced Wearable Sensing* Jintu Fan, Cornell University | *Microstructure Tailoring of Semiconducting Materials within High-performance Optoelectronic Fibers* Wei Yan, EPFL |
| 12:05 | *CNTs in Fibres: The Influence of Dispersion on Conductivity* Merle Bischoff, Institut für Textiltechnik | *Multimaterial Inorganic Optical Fibres and Sphere Breakup Experiments* Daniel Milanese, Politecnico di Torino-DISAT |

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| 12:30–1:40 | ***Lunch*—6th Floor Foyer** |

### *Afternoon Session*

1:40– 2:10 **Plenary Speaker:** Brit Maike Quandt, Empa, *Soft Polymer Optical Fibers for Healthcare: Tailoring Production and Properties of Photonic Textiles* (Room A)

| | **Room A** | **B Room** |
|---|---|---|
| | **Session: Functional Fibers**<br>***Chair, Thorsten Anders*** | **Polymer Optical Fibers**<br>***Chair, Marcus Beckers*** |
| 2:10 | *Organic-Inorganic Hybrids for Functional Fiber Materials*<br>Meifang Zhu, Donghua University | *Materials for POF Production: Scattering and Transmission in Fiber Optics*<br>Arne Schmidt, Evonik Performance Materials |
| 2:35 | *Sputter Deposition of Silver onto Monofilament Yarns: Influence of Processing Parameters on Yarn Properties*<br>Anne Schwarz-Pfeiffer, Hochschule Niederrhein | *Smart Geosynthetics for Structural Health Monitoring Applications*<br>Aleksander Wosniok, Federal Institute for Materials Research and Testing |
| 3:00 | *Multifunctional Properties of Carbon Nanotube Fibres*<br>Juan Carlos Fernández-Toribio, IMDEA Materials Institute | *Application of Thermography for Process Control in the Production of Polymer Optical Fibers*<br>Robert Evert, Institut für Hochfrequenztechnik |
| 3:25 | *Development of Carbon Fiber-based Electrodes for Microbial Fuel Cells*<br>Sascha Schriever, RWTH Aachen University | *Demultiplexer in PMMA for POF Over WDM*<br>Matthias Haupt, Harz University of Applied Sciences |
| 3:50 | *Usage of Splittable Microfilament Yarns as Carpet Pile*<br>Hatice Kübra Kaynak, Gaziantep University | *POF-based Distributed Brillouin Sensing*<br>Andy Schreier, Federal Institute for Materials Research and Testing |
| 4:15 | *Intensity Relationships of $CH_2$ Bands ($\nu$, $\delta$)in FT-IR Spectra of Syndiotactic Polyacrylonitrile and the Calculation of Dipole Moment*<br>Masatomo Minagawa, NPO Dream-Create-Laboratories *sent for affiliations 9/5* | *Experimental Investigation of the Wavelength-dependent Far Field for Different Mode Groups in Step-Index Polymer Optical Fibers*<br>Emmanuel Nkiwane, Technische Hochschule Nümberg |
| 4:40 | *open* | *Overview of the POF Market*<br>Peter Kröplin, Sojitz Europe plc |
| 5:00–7:00 | **Poster Session and Competition: Super C, 6$^{th}$ Floor** | |
| 8:00–9:00 | **Guided Walking Tours Through Aachen: Meeting Point at Tourist Information Center in Aachen** | |

## Thursday, May 18

7:30 Registration and Continental Breakfast: 6th Floor Foyer

8:00– 8:40 **Keynote Speaker:** Azusa Inoue, Keio University, *Status of GI POF Technology for Upcoming 4K/8K Era* (Room A)

8:40 Break

### *Morning Session*

| | **Room A** | **Room B** | **Room C** |
|---|---|---|---|
| | **Session: Fiber Characterization and Testing**<br>***Chair, David Seveno*** | **Session: Polymer Optical Fibers**<br>***Chair, Christian-Alexander Bunge*** | **Nanofibers**<br>***Chair, Ashwini Agrawal*** |
| 9:00 | *Wettability of Carbon Fiber Tows*<br>David Seveno, KU Leuven | *Fabrication of Microstructured Polymer Optical Fibres for Sensing*<br>Joseba Zubia, University of the Basque Country | *ZnO Nanorods-assisted Carbonization of PAN Nanofibers*<br>Ashwini Agrawal, Indian Institute of Technology |

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|---|---|---|---|
| 9:25 | *Effect of Boric Acid Addition to Bulked Continuous Filaments Polypropylene via Melt Spinning Method Used in Carpet Manufacturing for Flammability*<br>Nazan Avcioğlu Kalebek, Gaziantep University | *Polymer Optical Fibers for Sensing Applications: Ionizing Radiation Monitoring*<br>Pavol Stajanca, Bundesanstalt für Materialsforschung und-prüfung | *Electrospun Nanofiber-assisted Hydrogel Thin Film on Shaped Surfaces*<br>Yakup Aykut, Uludağ University |
| 9:50 | *New Measurement Technology for Evaluation of Transversal Interfiber Friction*<br>Anwar Shanwan (Artan Sinoimeri), Université de Haute-Alsace | *Influence of Scattering Characteristics on the Angle and Time-dependent Backscattered Power in Polymer Optical Fibers*<br>Martin Gehrke, Technische Hochschule Nümberg | *Application of Nanofibers for Dye Removal of Colored Wastewaters*<br>Mohammad Ebrahim Olya, Institute for Color Science and Technology |
| 10:15 | *Multiscale Investigation of Hair Fiber Surface Properties: Links Between Morphological and Tribological Behavior*<br>Judith Wollbrett-Blitz, L'Oréal Research and Innovation | *Influence of the Impulse Rebound on Optical Strain Sensors Based on Step-Index Polymer Optical Fibers*<br>Thomas Becker, Technische Hochschule Nümberg | *Investigation of the Structural Parameters in Electrospun Piezo Nanofibers and Yarns*<br>Maryam Yousefzadeh, Amirkabir University of Technology |
| 10:40 | *Intrinsic Traceability of High-value Textiles Manufacturing Using Natural Fibres*<br>Steve Ranford, AgResearch Limited | *Low OH Tellurite Glasses for Nonlinear Optical Fibers and Supercontinuum Generation Beyond 3µm*<br>Clément Strutynski, University of Bordeaux | *open* |

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| 10:40 | ***Break*** |

| | **Session: Smart Polymers, Fibers, and Textiles**<br>***Chair, Martin Harnisch*** | **Session: Biobased Materials**<br>***Chair, Gunnar Seide*** | **Session Biomedical Applications**<br>***Chair, Buket Demir*** |
|---|---|---|---|
| 11:05 | *Characterization of Heat Storage Properties of Textiles Incorporating Phase Change Materials by Means of Heat Release Tester WATson*<br>Martin Harnisch, Hohenstein Institut für Textilinnovation | *Development of Biobased Self-reinforced Polymer Composites*<br>Thomas Köhler, RWTH Aachen University | *N-halamine Technology for Antimicrobial Wound Dressings*<br>Buket Demir, Auburn University |
| 11:30 | *AgNW-treated PU Nanoweb/ PDMS Composites as Wearable Strain Sensors for Monitoring Joint Flexion*<br>Inhwan Kim, Yonsei University | *Tailored Fiber-reinforced Gelatin Hydrogels for Biocomposite Printing*<br>Christopher Anderson, Philadelphia University | *Development of Novel Coextruded and Wet Spun Fibers for Medical Applications*<br>Klas-Moritz Kossel, RWTH Aachen University |
| 11:55 | *open* | *Cellulose Aerogel Fibres for Thermal Encapsulation of Diesel Hybrid Engines*<br>Jens Mroszczok, RWTH Aachen University | *Interaction of Material and Structural Elasticity in a Small Calibre Vascular Graft*<br>Alexander Löwen, RWTH Aachen University |

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| 12:20 –1:40 | ***Lunch*—6th Floor Foyer** |

## *Afternoon Session*

1:40–2:10 **Plenary Speaker:** Gunnar Seide, Aachen-Maastricht Institute for Biobased Materials (AMIBM), *Biobased Materials: Challenges of Applications and Process Development* (Room A)

| | **Room A** | **Room B** | **Room C** |
|---|---|---|---|
| | **Session: Yarns and Fabrics: Processes, Structures, and Properties**<br>***Chair, Laurence Schacher*** | **Session: Modeling and Simulation of Textiles and Processes**<br>***Chair, David Breen*** | **Session: Composites**<br>***Chair, Wilhelm Steinmann*** |
| 2:10 | *Examining the Effects of Fiber Types and Fabric Tightness on Bursting Strength of Circular Knit Fabrics Produced from Vortex Yarns*<br>Seval Uyanık, Gaziantep University | *An Optimized Yarn Geometric Model for Knitted Material Simulation*<br>David Breen, Drexel University | *Enhanced Damping of Carbon Fiber-reinforced Composites by Novel Liquid-Core Fibers*<br>Rudolf Hufenus, Empa |
| 2:35 | *An Investigation of Performance Properties of Warp Knitted Carpets*<br>Züleya Değirmenci, Gaziantep University | *Modeling Approaches for 3D Woven Composites: Potential and Limitations*<br>Mohamed Saleh, University of Sheffield | *A Novel Automated Method for Manufacturing New Semi-finished Photo Composites*<br>Anwar Shanwan, Université de Haute-Alsace |
| 3:00 | *Emissivity Characterization of Different Stainless Steel Textiles in the Infrared Range*<br>Maria Cristina Larciprete, Sapienza Università di Roma | *Internal Structure of the Bundle Manufactured by Friction Method*<br>Jung Ho Lim, Kyung Hee University | *Metal Composite Yarn Production with Commingling Technique and Properties of Textile Surfaces Obtained from These Yarns*<br>İlkan Özkan, Çukurova University |
| 3:25 | *How Nonwovens Avoid the Shrink?*<br>Amit Rawal, Indian Institute of Technology-Delhi | *Effect of Staple Length on the Sliver Dynamics in Roller Drafting*<br>You Huh, Kyunghee University | *Strategies for Improving Durability of Vegetable Fiber-reinforced, Cement-based Composites*<br>Mònica Ardanuy, Universitat Politècnica de Catalunya |
| 3:50 | *Effects of the Laundering Process on Dimensional Properties of Lacoste Fabrics Made from Modal/Combed Cotton-blended Yarns*<br>Ebru Çoruh, Gaziantep University | *Modeling of the Mechanical Properties of Cotton Fibers*<br>Wafa Mahjoub, Université de Haute-Alsace | *Basalt Fiber as Technical Textile Material*<br>Ertan Özgür, University of Çukurova |
| 4:15 | *Antibacterial Activity of Nonwoven Cleaning Materials Treated with Silver Nanoparticles after Newly Developed Repeated Washing Process*<br>Emel Çinçik, Erciyes University | *open* | *open* |

**6:00–6:30** **Reception: Alter Ballsaal, Kurhausstraße 1, Aachen (5 minute walk or bus station: Aachen, Bushof)**
**6:30** **Banquet**
**Music: German Classics**

# Friday, May 19

7:30 Continental Breakfast: 6th Floor Foyer

8:00–8:40 **Keynote Speaker:** Yves-Simon Gloy, RWTH Aachen, *Digitalization in the Textile Industry* (Room A)

8:40 Break

| | **Room A** | **Room B** | **Room C** |
|---|---|---|---|
| | **Session: Reinforcing Structures**<br>***Chair,* Yves-Simon Gloy** | **Session: Fiber Formation, Structure, and Properties**<br>***Chair, Takeshi Kikutani*** | **Yarns and Fabrics: Processes, Structures, and Properties**<br>***Chair, Janice R. Gerde*** |
| 9:00 | *Characterization of Warp-knitted Reinforcing Fabrics and Cement-based Composites: Influence of Yarn and Stitch Types on Mechanical Performance*<br>Till Quadflieg, RWTH Aachen University | *Crystallization and Melting Behaviors of Polypropylene Blend Fibers Consisting of High and Low Stereo-regularity Components*<br>Takeshi Kikutani, Tokyo Institute of Technology | *Tactile Feeling of Textiles: A Comparative Study Between Textiles Attributes of France, Portugal, and Brazil*<br>Maria José Abreu, Minho University |
| 9:25 | *In-plane Permeability Characterization of Reinforcing Fabrics Based on Radial Flow Experiments: Comparative Studies*<br>Ewald Fauster, Montanuniversität Leoben | *Tungsten Wire Fabrics Used in Tungsten Fibre-reinforced Composites*<br>Philipp Huber, RWTH Aachen University | *Determination of the Heat Dissipation of Sport Bras Using Thermal Manikin and Thermography*<br>André Catarino, Minho University<br>Sent a second set 7/20 |
| 9:50 | *Investigation of the Production of Hollow Carbon Fibres*<br>Robert Brüll, RWTH Aachen University | *Numerical Analysis of Non-steady State Melt-blowing Process Based on a Particle Method*<br>Wataru Takarada, Tokyo Institute of Technology | *A Study to Improve Drying Property of Towel Fabrics*<br>Sait Yilönü, Çukurova University |
| 10:15 | *Analysis of Ceramic Fibre Processing with Braiding Machines for Two- and Three-dimensional Reinforcement Structures*<br>Lisa Papenbreer, RWTH Aachen University | *Strength Improvement of Polypropylene Fine Fibers by Increasing Beta-crystal Content*<br>Kyung-Ju Choi, Clean & Science, Ltd. | *3D Knitting Using Large Circular Knitting Machines*<br>Kristina Simonis, RWTH Aachen University |
| 10:40 | *open* | *Wet-spinning of Silk Fibroin-based Conductive Core-Sheath Fiber*<br>Bin Fei, Hong Kong Polytechnic University | *The Measurement of Textile's Warm-Cool Feeling*<br>Lexi Tu, Donghua University |
| 11:05 | *open* | *open* | *Radiant Heat-protective Performance of Fabrics Used in Firefighters' Clothing: A Scientific Study*<br>Sumit Mandal, Empa |

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| 11:30 | ***Break*** |

| | Open | Session: Fiber Formation, Structure, and Properties *cont'd* | Yarns and Fabrics: Processes, Structures, and Properties *cont'd* |
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| 11:40 | *open* | *The Evolution and Formation Mechanism of Gradient Structure During Melt Spinning of Blend Fiber*<br>Dan Pan, Donghua University | *Airflow Characteristics During Rotor Spun Composite Yarn Spinning Process*<br>Ruihua Yang, Jiangnan University |
| 12:05 | *open* | *Spinnability of Polyacrylonitrile Solution Research Based on Dry-Jet Wet Spinning Dynamics Simulation*<br>Jianning Wang, Donghua University | *Twisting Robustness in the Ring Spinning System with Single Friction-belt False-twister*<br>Rong Yin, Hong Kong Polytechnic University |
| 12:30 | *open* | *Increase of the Adhesion Property of CFRP and CFRTP Materials and Preparation of New FRP Using Modified Fiber*<br>Hitoshi Kanazawa, Fukushima University | *Development and Characterization of a New 3D, Nonwoven, Pleated Shockproof Product Inserted in Clothing for Body Protection*<br>Abdelbaki Djerboua, ENSISA |
| 12:55 | *open* | *Grafting β-cyclodextrin on Cotton Fabric*<br>Malihe Nazi, Standard Research Institute | *open* |

| 1:20 | ***CONFERENCE CLOSES*** |
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**1:25–1:45** **Snack**

**1:45–2:15** **Buses Load from Super C to ITA**

**2:15–3:45** **Tour of Research Facilities at ITA, RWTH Aachen University**

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# Poster Session

**Wednesday, May 17, 5:00 p.m.–7:00 p.m., Super C,** 6th Floor Foyer

| Presenter | Title |
|---|---|
| Run Wen | *Design of Freestyle Machine Embroidery* |
| Alenka Ojstršek | *Flame Retardant Activity of Fabrics Based on Aluminosilicate Coatings* |
| Pınar Duru Baykal | *Determining the Effect of Different Washing Types on Tear Strength of Denim Fabrics* |
| Belkıs Zervent Ünal | *The Effects of Abrasion Process on Water Repellency Performance of Upholstery Fabrics* |
| Yurong Yan | *Micro- and Nanoscale Polyester-based Hybrid Acoustic Insulation Materials* |
| Darinka Fakin | *Preparation of Polyamide 6/Zeolite Composite Filaments* |
| Maryam Yousefzadeh | *Photo-Catalysis Properties of Electrospun Ceramic $TiO_2$ Nanofibers with Different Structures and Morphologies* |
| Benjamin Mohr | *Potential of POF Sensors for Structural Health Monitoring of Fiber Composites* |
| Fumei Wang | *Dual-beard Algorithm for Fiber Length Histogram* |
| Lin Zhou | *A Study of 3D Auxetic Textile Reinforced Composite* |

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| Wing Sum Ng | *Negative Poison's Ratio Behavior and Pore Characteristics of Woven Fabric Made of Auxetic Plied Yarn Under Tension* |
| Guangbiao Xu | *Tensile Property of PTFE Under Different Conditions* |
| Xiaohuan Ji | *Synthesis of Monodisperse and Porous Ag Nanoparticles/Polystyrene Microcomposite Particles by Seeded Suspension Polymerization* |
| Jong Sung Kim | *Investigation on Air Suction Phenomenon for a Rotating Flyer* |
| Tobias Schlüter | *Polymer Blends for Textile and Composite Applications* |
| Eunji Jang | *PU Nanoweb Transmission Lines Coated with Non-oxidized Graphene for Smart Clothing* |
| Emel Ceyhun Sabır | *Textile Energy Storage* |
| Nils Gerstein | *Recyclability of Carbon Fiber-reinforced Concrete Structures* |
| Mario Löhrer | *Interactive Learning Systems for Textile Technology* |
| Gözdem Dittel | *Tailored, Warp-knitted Reinforcing Textiles for Construction Applications* |
| Merle Bischoff | *Development of an "Anti-bug" Bicomponent Fibre* |
| Alan Grice | *Modeling Dynamic Fiber Behavior in a Meltblowing Die Utilizing FSI* |
| Jiaojiao Shang | *Fabrication of Ultrasensitive $CO_2$-responsive Nanofibers via Post-polymerization Modification for the Visual Detection of $CO_2$* |
| Kai Hou | *A Novel Dynamic-Crosslinking-Spinning Technology for Fabrication of Hydrogel Fibers* |
| Musa Akdere | *Cribellate Spiders: A Biomimetic Inspiration for Processing and Handling Nanofibers* |
| Maria José Abreu | *PVC-based Synthetic Leather with Thermal Comfort for Automobile Applications* |
| Inhwan Kim | *Comparative Analysis of Wearable Respiration Sensors Based on PU Nanoweb/PDMS Treated with AgNWs and PPy* |
| Kang Chen | *Insight into the Relationship Between Creep Behavior and Structure of Polyester Industrial Yarns* |
| Sascha Schriever | *Economical and Technical Investigation on the Recycling of Polyacrylonitrile(PAN)-containing Waste* |
| André Catarino | *Shape Memory Alloys Applications on Weft Knitted Fabrics: Toward a Compression Sock for Venous Disease* |
| Malihe Nazi | *Identification of Specific Animal Hair Fibers Using Forensic Science* |
| Maximilian Kemper | *Storefactory—Customizable In-store Textile Production* |
| Itxaso Parola | *Double-doped Polymer Optical Fibers for Fluorescent Fiber Applications* |
| Inga Noll | *A New Shape Factor Method for Profiled Polyester Fibers* |
| Chung Hee Park | *Influence of Alkaline Treatment on Surface Roughness and Wetting Property for Hydrophobized Silk Fabrics* |
| Wan-Gyu Hahm | *Analysis of PET Fiber Deformation in High-speed Melt Spinning by Using 2-way On-line Diameter Measurements* |
| Jan Kallweit | *Nanoparticle Modified Polymer Melts and the Theory of Similarity* |
| Jeanette Ortega | *Prediction of Yarn Properties by Inline Measurement and Numerical Modeling* |
| Georgi Gogoladze | *Stability of Basalt Fibers in the Alkaline Environment* |
| Riada Meyer | *Investigation of the Spinnability of Polymers with a High-speed Rheometer* |
| Milad Asadi | *A Study in Flame Retardancy of Flavonolignans Composition in Polypropylene Filaments* |
| Hitoshi Kanazawa | *Modification of Chemically Stable Polymeric Materials 90: Increase of the Adhesion Property of Chemically Stable Polymeric Materials and Preparation of New FRP Using Modified Fiber* |

# Keynote and Plenary Speakers

# Fibers and Textile Materials 4.0

Thorsten Anders, David Schmelzeisen, Thomas Gries

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This oral presentation summarizes work about fibers and textile materials 4.0 in the ITA group.

The ITA Group is an I4 Institution – interdisciplinary integrated, industry-oriented and international. It covers the whole textile process chain from material, to fiber and yarn, to fabric and finally the textile product. Scientists at ITA develop continuously innovative fibers and textile products for future application. The characteristics of the final product are achieved by textile structure, process parameters, fiber and yarn composition and material composition.

**FOUR DIMENSIONS OF FUNCTIONALITY IN FIBERS**

Our functional fibers are divided in four dimensions: signal transmission fibers, sensor fibers, energy converting fibers and energy storage. We developed a continuous efficient process to spin refraction-index profile fibers based on a physical cooling process. This cost efficient process opens new product applications for polymer optical fibers. Sensor fibers from ITA are multicomponent core shell fibers with an electric conductive core and a piezoelectric shell. Due to mechanical stress on the fiber an electrical signal is transmitted and detected. Energy converting fibers were developed, which transport heat and convert electrical energy into heat. Those fibers are modified nano particles, which change the thermal and electrical properties of the textile. With phase change materials (PCM) integrated into wear layer, supporting material and backing of a carpet. ITA prepared an energy storing textile. The carpet takes up heat when the room is warm and releases the heat when the room cools down.

**4D TEXTILES**

Our hybrid morphing textiles process starts with simulation of the fabric structure, continuous with validation trials, the design of the textile product and in the end the production of the product. Due to our work on this field new textile products will be possible like shape changing textiles for active aerodynamic, self-assembled stents or interactive façades.

# Adaptive Protective System for Smart Textiles

Tae Jin Kang

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Smart textiles have attracted considerable attention due to their potential to bring huge impacts on human life as well as fashion business. Generally, smart textiles are referred as textiles products with additional functionalities, i.e. they have the common properties of textiles, but insure additional functions, providing attractive solutions for a wide range of application areas, such as healthcare, protective clothing, sports, automotive industry, etc.

The aim of adaptive protective textiles is to elucidate protective mechanism of smart textile fibers and composites against various environmental changes and to develop the technologies for the fabrication, hybridization and lamination of intelligent protective textiles. Understanding of drivers, state-of-the-art and tendencies in smart textiles ensures further efficient development strategy of the textile business as well as its interaction with manufacturers and consumers. Despite much promising progress in this newly emerging area, there still exists a continuous effort to develop advanced technologies to solve many technical issues in integration into the flexible textiles.

The author will presents the applications of smart textiles for various end-use functions as well as their principles, and introduces the scientific backgrounds and state-of-art technologies for smart textile development.

# Soft Polymer Optical Fibers for Healthcare: Tailoring Production and Properties of Photonic Textiles

Brit Maike Quandt, Luciano F. Boesel, René M. Rossi

Empa, St. Gallen, Switzerland

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For the development of novel sensors or treatment options in healthcare, photonic textiles can provide valuable options. They have to fulfil various prerequisites for textile production as well as sensor performance. We report our recent developments of polymer optical fibers with exceptional properties and their subsequent integration into textiles for the design of a range of wearable sensors or therapy devices.

Our polymer optical fibers were produced by melt-spinning of thermoplastic polymers. The different types of polymer optical fibers show high flexibility to allow for textile integration while continuously transferring the signal. Among other properties, the fibers' mechanical and optical properties were investigated.

We have such realized several different types of photonic textiles, with different applications behind them.

**HEART RATE SENSOR[1]**

We present a flexible, photonic textile based-sensor for the continuous monitoring of the heartbeat and blood flow with a lower static coefficient of friction (COF) than conventionally-used bedsheets.

The used bi-component polymer optical fibers (POFs) were melt-spun continuously embroidered to form sensing structures. The resulting sensor withstands disinfection. Measurement accuracy can be compared to commercial devices.

**PRESSURE SENSOR[2]**

Pressure sensors have been realized: Mono-component POFs were produced continuously by melt-extrusion. Advantageously for pressure sensing, the un-clad fibers are more susceptible to macro-bending. We showed linear responses of change in light intensity to load on the fiber as well as a correlation between production parameters and mechanical properties.

**LUMINOUS TEXTILES[3]**

Side-emission from yarn-like optical fibers can be used to create a homogeneous luminous textile. Weaving patterns and hence the bend radii within the textiles are examined for the best result. The optical fibers have to show homogeneous side out-coupling along the fiber.

These advances in the development of polymer optical fibers allow producing novel, textile sensors. We will also give an outlook on further developments.

**REFERENCES**

[1] B.M. Quandt, F. Braun, D. Ferrario, R.M. Rossi, A. Scheel-Sailer, M. Wolf, G.-L. Bona, R. Hufenus, L.J. Scherer, L.F. Boesel. *Journal of The Royal Society Interface*, 2017: 14.

[2] B.M. Quandt, R. Hufenus, B. Weisse, F. Braun, M. Wolf, A. Scheel-Sailer, G.-L. Bona, R.M. Rossi, L.F. Boesel. *Eur. Polym. J.*, 88, 2017: 44.

[3] B.M. Quandt, M.S. Pfister, J.F. Lübben, F. Spano, R.M. Rossi, G.-L. Bona, L.F. Boesel. *Biomedical Optics Express*, 8, 2017: 4316.

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# Status of GI POF Technology for Upcoming 4K/8K Era

Yasuhiro Koike, Azusa Inoue

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Recently, ultra-high definition (UHD) displays have been rapidly developed for video formats with 4K (3840×2160) and 8K (7680×4320) resolutions. In Japan, 4K/8K broadcastings through satellites are scheduled to start, following a road map announced by the Ministry of Internal Affairs and Communications. This has accelerated research and development of 4K/8K distribution technologies toward the 2020 Tokyo Olympics and Paralympics. Current UHD displays require uncompressed video transmission with a bit rate over 100 Gb/s, suggesting that extremely high bit-rates are required even at home in the upcoming 4K/8K era. However, 8K video transmission through a conventional metal interface cable results in significant power consumption because their increased losses with an increase in frequency. Moreover, the metal interfaces are not suitable for the consumer applications because they require so many thick cables and electromagnetic interference prevention. Therefore, consumer-friendly pluggable optical interface has been highly demanded.

A graded-index plastic optical fiber (GI POF) has been a promising transmission medium for home and building networks because of its flexibility, high bandwidth, and low installation cost. Transmission speeds with a GI POF have been increased up to ~ 40 Gb/s for a length of 100 m with the development of the low-dispersion polymer whose material dispersion is lower than a silica GI multimode fiber (MMF). Recently, we could significantly decrease bit error rate (BER) by using novel low-noise GI POF in an extremely short MMF link without an optical isolator because of intrinsic noise reduction effects which are closely related to microscopic heterogeneities of the GI POF core material, as shown in Fig. 1. These allow for a high-speed optical module without an optical isolator and angled fiber end-faces, which increase loss, production cost, and module size. Moreover, we developed consumer-friendly pluggable interconnects for GI POFs based on ballpoint-pen technologies enabling easy connection, low-cost production, and fiber end face protection of GI POFs. Here, these newly-developed GI POF properties of high-speed, low-noise, and easy connection for the upcoming 4K/8K era will be reviewed.

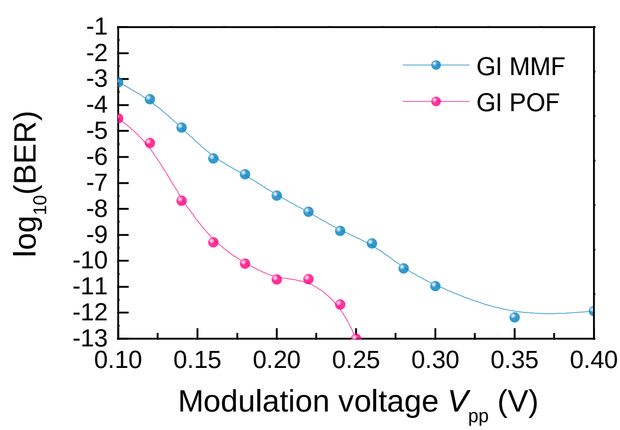


Fig. 1. BERs for the developed low-noise GI POF and the conventional silica GI MMF as a function of modulation voltage.

# Biobased Materials—Challenges of Applications and Process Development

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Biopolymers? Do they play a role in the fibre industry? Many people may answer: No! Biopolymers are too expensive and often have too low technical performance. That's in a way true, only 0.3 % of the world wide polymer market consists of biopolymers.

The most important role is played by regenerated cellulose fibres. In 2014 5.97 Mio. tons of cellulosic fibres have been produced. This is round about 10 % of the production of synthetic fibres with 60.05 Mio. tons. [cirfs] The global production capacity of bio-based materials, obviously without fibres, is 1.7 Mio. tons [european bioplastics] biopolymers in 2014. The numbers show: The world production of cellulosic fibres is more than three times higher than the world production of all other biopolymers together.

However, the development of bio-based materials for melt spinning is running at many places in the world. And there is a growing demand of the industry. The following buzz words are part of the discussion: "Microplastics and marine litter", "Carbon footprint", "Land use for bioplastics", "Bio-polymer", "Bio-based", "Bio-degradable", "Bio-compatible", "Drop-in polymers."

What are now the challenges of fostering bio-based materials?

- Identification of technical applications where bio-based material is the superior solution.
- Reduction of price to a reasonable level (economies of scale, cost of feedstock material).
- Adaption or invention of suitable process technologies.
- Development of additives to enhance biopolymers.
- Development of models to predict processability and product properties from material data or on the long run from molecular structure to allow target oriented development of materials.
- Development of scenarios for market entry.

To solve such challenges Maastricht University and RWTH Aachen University have established a European cross-border research institute focusing on the development of advanced biobased materials. The Aachen-Maastricht Institute for Biobased Materials (AMIBM) is located on the Chemelot Campus in the Netherlands Province of Limburg. The AMIBM vision is to provide the missing links between fundamental, applied and translational research in the field of biobased materials, by changing the relationship between the production of biobased materials and the value chain.

The presentation shows the research portfolio of the chair polymer engineering concerning biobased fibre materials.

We will see a lot of innovation in the field of biobased fibre materials. There will be no sustainable future which is built on limited resources.

Biobased polymers—It's only a matter of time.

# Digitalization in the Textile Industry

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What is *digitalization* for the textile industry? From an engineering point of view, you can distinguish four aspects:

1. Digital Processes (Inkjet, Jacquard, 4D etc.)
2. Digital Production (Industrie 4.0)
3. Digital Product Design
4. Digital Products (Smart Textiles)

The presentation will give successful examples of these aspects. Furthermore the German project Industrie 4.0 will be presented. In Industrie 4.0 use of Cyber-Physical Systems, which are using realtime- and internet-capable, intelligent sensors and actuators, is important. Applications of Cyber-Physical Systems in the textile production are shown, such as OnLoom Imaging or new forms of Human-Machine-Interaction with looms. An important role in Industrie 4.0 lies also in the machine to machine communication. As example, communication between a winding and weaving machine using RFID technology integrated into spools is presented. Furthermore successful examples like the Speedfactory and Strorefactory with adidas AG, Herzogenaurach, Germany are shown and also application of industrie 4.0 in the production of composites

The use of smart textiles like woven RFID antenna and chairs using pressure sensors will also lead to new business models. In most cases overcall aim of the digitalization in textile industry is to raise the efficiency of the processes.  The presentation ends with the demonstration of the DCC - a joint learning factory with company McKinsey Inc., New York, USA in order to transfer knowledge on digitalisation into companies.

# Smart Polymers, Fibers, and Textiles

# Smart Functions Observed on Polymer Gels

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Conventional polymer materials are fluctuating in various ways. These “soft” states provide various phenomena through coupling with various forces. The complicated transient state can be the origin of the so-called “smart” start functions.

In this presentation, several phenomena which can be categorized as “smart” functions of some conventional polymers. The polymer materials are soft gel like materials. The phenomena are uphill transport, shape memory, actuators, sensors, and electroactive functions.

Simple complex membrane can sense the environment and facilitates the transport of a solute against its gradient. On a shape memory, some polymer gel in which asymmetrically imprinted chemical history can induce symmetric shape recovery. On the degradation process of a complex, complex does not simply degradate, but can induce dynamic structure formation, such as an oscillation. On the electro-active function of a polymer gel, an application of the electric field induced various functions such as electro-mechanical, mechano-electrical, electro-optic functions.

The phenomena are observed on conventional polymers, elucidating that they generally have potential as smart materials. General definition will be discussed on the smartness of the materials.

# Thermo-sensitive Nanofibers Based on Biobased Materials

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According to definition, sensors are devices that respond (react) to some environmental changes, like pH value, humidity, presence of some ions, light, temperature and more various types of phenomena. Scientists are always looking for higher sensitivity and more precise results of experiments. Building materials from nano to macro dimensions gives better sensitivity of materials which is enabled with the development of nanotechnology. There are few nanoforms developed and the newest which are under huge interest are nanofibers. With their remarkable properties caused by high diameter to surface ratio, they are ideal candidates for applications such are sensors, as well as in pharmacy, biomedicine, food industry etc. Even there are few possible techniques for nanofibers production, electrospinning is most promising one because it is quite simple and offers many possibilities of functionalization and morphology of non-wovens. In this work, gelatin and gelatin/polyamide nanofibers were loaded with thermo-sensitive agent making nanofiber-based heat sensor, with indication of color change with increasing of temperature. The amount of thermo-sensitive agent is in direct connection with intensity of color and sensitivity of sensor. Uniform nanofiber morphology was proven with SEM and thermal properties were determined using DSC.

**ACKNOWLEDGMENT**
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# Stress-memory Filaments as Advanced Material for Smart Compression Management

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Shape memory polymers are being considered as an important class of smart stimulus responsive material over past few decades. Shape memory polymers are not only limited to memorize the shape and it allows to program other physical parameters such as stress, temperature, and chrome. They have been widely used in broad applications in different forms such as fibre, foam, and film. At present, other than shape memory property, no other unique behavior has been discovered in memory polymers especially at filament/fibre level to unveil their great hidden potentiality. A thermal sensitive semi-crystalline segmented polyurethane was synthesized and prepared film and filaments to investigate stress-memory behavior with a comprehensive experimental design. An unprecedented effort has been made to uncover the unique stress-memory behavior specifically at fibre level. Thermo-mechanical tensile stress-memory programming was carried out at different constraint strain levels (20%, 40%, 60%) to evaluate the memory stress as a function of temperature. Thermal, mechanical, and structural studies have unveiled the underpinning reason for achieving higher memory stress in melt spun filaments compared to film. Memory filaments were also integrated into compression stockings to realize the stress-memory behavior. Understanding the fundamental memory behavior at filament level would definitely help a material/textile scientist to control the stress in smart structures and to implement into broad horizon of materials for numerous applications needing stimulus responsive force.

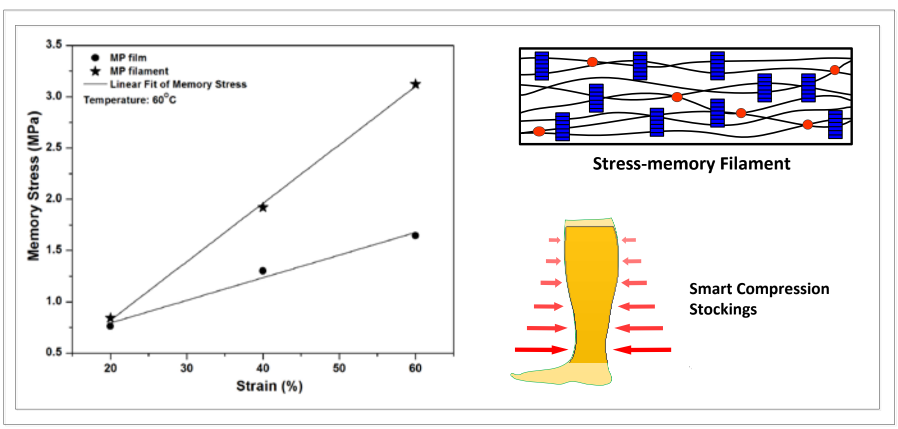


Figure 1: Evolution of memory stress with strain and temperature in smart filaments for advanced compression.

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# ECG Measurement via AgNW/PU Nanoweb Electrodes and Comparison with Ag/AgCl Electrodes

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The polyurethane nanowebs were imparted electrical conductivity, with the use of silver nanowire (AgNW). Recently, the AgNW/PU nanowebs turned out to have good mechanical property and verified the potential usage of silver nanowire treated PU nanowebs for textile sensors related to biomonitoring. Thus, in this study, experimental tests were conducted using AgNW/PU nanowebs as electrocardiogram (ECG) electrodes. And also, bio-signals of the textile electrodes and those of Ag/AgCl electrodes were compared to investigate performance of the textile electrodes. To prepare samples, commercially available PU nanowebs (Diameter : 500nm~1μm, Weight : 13g/m$^2$) were used. 1wt% of silver nanowire (Length : 20~25μm, Diameter : 30~35nm) was dispersed in ethanol. The samples were made at the same size of commercially used Ag/AgCl electrodes, which is 3cm × 3cm. To examine the ECG signals measured by textile electrodes, ten participants who were healthy and non-smoking adults in their twenties were collected. The ECG signals of participants were measured at rest state and stress state in anechoic chamber using Lead I method. Heart rate (HR) and heart rate variability (HRV) of ECG signals were acquired by using MP150 (Biopac system Inc., U.S.A.), and the Acqknowledge (ver. 4.2, Biopac system Inc., U.S.A.) was used to analyze the acquired data. And then, t-test was conducted to statistically compare signals of Ag/AgCl electrodes and signals of AgNW/PU nanoweb electrodes by using R statistical language and Rstudio. ECG signal morphology was also examined. After comparing morphology waveforms, no difference was noticed in P-waves, T-waves, and QRS waves between two different electrodes, which meant that the textile electrodes measured ECG signals properly. Also, R-peaks extracted from the signals of textile electrodes and R-R intervals were properly measured as well. In addition to the visual similarity, there was no statistically significant difference found between signals of Ag/AgCl electrodes and signals of AgNW/PU textile electrodes. These results implied that the signals between these different type electrodes had a similarity tendency. Therefore, this study demonstrated that the textile sensors made by the AgNW/PU nanowebs could be adequately used in electrocardiogram measurement.

**ACKNOWLEDGMENT**
This research was supported by the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. NRF-2016R1A2B4014668) and the Brain Korea 21 Plus Project of Dept. of Clothing and Textiles, Yonsei University in 2017.

# PVDF Nanofibrous Membrane Grown with Zinc Oxide (ZnO) Nanorods for Enhanced Wearable Sensing

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Piezoelectric ceramic and polymer composites have been shown to have remarkable piezoelectric constant. However, such composites lacks flexibility and breathability and sometimes have health issues for application in wearable fashion. The said limitations can be alleviated by electrospinning piezoelectric polymers containing non-toxic piezoelectric ceramics into porous membranes. PVDF is one of the most frequently used piezoelectric polymers due to its high piezoelectric coefficient values, and unlike many piezoelectric ceramics containing heavy metal, ZnO is a non-toxic material which has been widely used in many fields of applications including cosmetics. Here we report on a novel breathable piezoelectric membrane which has zinc oxide (ZnO) nanorods grown on the surface of electrospun polyvinylidene fluoride (PVDF) nanofibers using hydrothermal method. Fabrication process is simple and economical due to no additional poling process needed for PVDF membranes after electrospinning in high electric field, and ZnO growth temperature being lower than water boiling temperature in aqueous solution. Significant improvements in piezoelectric response of PVDF membrane was achieved without compromising breathability, conformability, or health risk of the material.

# CNTs in Fibres: The Influence of Dispersion on Conductivity

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Nanocomposites have become more and more important as the implementation of nanoparticles in polymer allows additional functions in common industrial parts. Especially in the fabrication of filaments or fibres nanomodification is important, as only very small fillers can be added to the very fine fibres (common fibre diameter is 20 µm, fine filaments are 1 µm).

Discharging fibres, conductive fibres and many other functional fibres raise in their importance nowadays, as the need for highly functional but flexible surfaces, such as textiles rises. Especially the dispersion quality is essential for the final enhancement of the filament propertied. Homogeniously distributed particles serve function throughout the full fibre giving equal mechanical and functional properties over the length of the fibre and of the manufactured textile.

In this presentation the dispersion of carbon nanoparticles in polymer melt is enhanced by a newly developed sonication unit of ITA and BANDELIN electronic GmbH & Co. KG. The first development steps of the unit fabrication as well as the first experimental results of the modification of the dispersion will be shown in the presentation. Special focus will be laid on the sealing of the new sonication unit as well as the positioning and equipment size when being implemented in an existing melt spinning unit. Furthermore, the influence on the thereby manufactured nano-modified filaments will be shown.

The presentation will show the status of the project as well as the next steps, to show other participants the potential of the newly developed unit.

# Characterization of Heat Storage Properties of Textiles Incorporating Phase Change Materials by Means of Heat Release Tester WATson

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## INTRODUCTION

In the 1980ies, NASA developed clothing with incorporated phase change materials (PCM) for use in space. Nowadays, such textiles are used in huge variety of clothing systems here on earth, too. Manufacturers promise fast absorbance and release of heat respectively, resulting in high thermal comfort. On the other hand, there is no excepted standard to test thermal properties of textiles incorporating phase change materials. European standardization process for testing of fabrics is still ongoing.

## MATERIALS & METHODS

Several manufactured textiles incorporating PCM as well as textiles, which were especially finished in the laboratory (table I), were tested for their heat storage capacity. The heat release tester WATson was used to investigate different measurement designs to show PCM-effects best.

Table I: Description of laboratory coated non-wovens

| sample no. | thickness [µm] | sample weight [g] |
|---|---|---|
| 1 | 0.258 | 5.10 |
| 2 | 0.556 | 14.51 |
| 3 | 0.606 | 14.99 |
| 4 | 1.023 | 36.03 |

## RESULTS & DISCUSSION

Final test design is able to show differences in heat storage between PCM and control sample as well as between different PCM samples. Furthermore, results show that the amount of stored heat is related to the amount of incorporated PCM and the effect is just a temporary one. In addition, presentation will imply disadvantages and benefits of all measurement designs investigated.

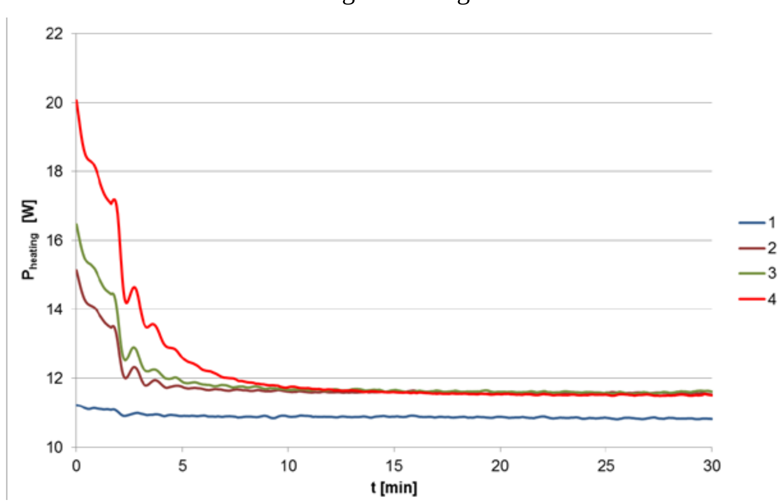


Figure 1: Exemplary course of time of heat release ($P_{heating}$) after putting on acclimatized sample ($T_{sample}$=10°C) on heat release tester ($T_{skin}$=32°C)

## ACKNOWLEDGMENT

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# AgNW-treated PU Nanoweb/PDMS Composites as Wearable Strain Sensors for Monitoring Joint Flexion

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The purpose of this paper is to (1) fabricate polyurethane (PU) nanoweb composites treated with silver nanowires (AgNWs) and polydimethylsiloxane (PDMS), (2) investigate electrical resistance changes according to elongation in order to explore their practical usages as strain sensors, (3) application to an arm joint of a dummy and human subjects. The PU nanoweb was purchased from Pardam, s.r.o. (Ltd). Dispersed AgNWs in ethanol were purchased from KLK Co. and the ratio of AgNWs and ethanol was varied (0.5 wt%, 0.75 wt%, and 1 wt% of AgNWs). The PU nanowebs were coated with the AgNW solution. The coated nanowebs were cut into size of 2 x 10 cm and snap buttons were attached. PDMS precursor part-A and PDMS precursor part-B were mixed at a ratio of 10:1. Doctor blade (Sheen, SH1117/200) was utilized to coat the liquid phase PDMS onto the planner aluminum plate with thickness of 0.5 mm. The specimens were placed onto the applied PDMS. PDMS were polymerized and dried at 50℃ for 2 hours at a thermo-regulating chamber. Initial electrical resistance and its change according to elongation was measured by a RCL meter (FLUKE PM6304) via wear trials with the dummy. The data showed increasing trend with decrease in content of AgNWs and elongation. The degree of the dummy's joint angles ranged from 0º to 135º and the interval was 15º, respectively measured by RCL meter. The electrical resistance showed increasing trend and it decreased back at the range of 60~75º. The arm joints of the dummy and the human subjects moved at speeds of 0.125 ~ 0.5 Hz while real-time data was obtained through MP150 (Biopac system Inc., U.S.A.) and the Acqknowledge (ver. 4.2, Biopac system Inc., U.S.A.) connected to analog circuit with amplifiers. Specimens with 1 wt% of AgNWs showed the best performance as wearable strain sensors with more accurate signals and stability even under higher frequency, while the specimen with 0.5 wt% of AgNWs showed poor performance even at low frequency.

**ACKNOWLEDGMENT**
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# Multimaterial Fibers

# Multimaterial Fibers: Challenges and Opportunities

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Advanced fibers and textiles are experiencing an unprecedented development owing for a large part to recent scientific and technological breakthroughs in fiber processing. The thermal drawing process in particular, the same method used in the optical fiber industry, now allows for the fabrication of multi-material fibers with a large range of feature sizes, architectures and functionalities. Thin and long polymer fibers can now integrate waveguides structures but also metallic electrode arrays contacting piezoelectric or semiconducting domains, micro-channels, or textured surfaces. This imparts fibers with novel and unforeseen electronic and optoelectronic functionalities, with intriguing opportunities in fiber probes, bioengineering, energy harvesting and storage, sensing, and advanced textiles. In this presentation, I will present the field of multi-material fibers with an emphasis on the materials and processing challenges, as well as the opportunities for advanced fibers and textiles. I will in particular present the materials selection, fabrication approach, and how one can tailor the interplay between viscosity and surface tension to realize a variety of complex cross-sectional architectures and surface textures. We will then discuss a series of recent results to highlight these opportunities, including the texturing at the nanoscale of polymer fibers and micro-channels, electronic fibers for touch sensing, and highly efficient photo-detecting and temperature sensing fibers based on fiber-integrated nanowries.

# Multimaterial Fibers for Electromechanical Touch Sensing

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The highly scalable thermal drawing process originally used to fabricate optical fibers has recently been shown to be compatible with a broader range of materials that can be combined in complex cross-sectional architectures. This approach can now enable the integration of conducting, insulating and semiconducting components in multi-material fibers to realize functional fiber devices not only for optical transport but also for optoelectronic, sensing or biomedical applications. So far however, multi-material fibers have been designed to work while keeping a fixed shape in the cross-sectional plane. On the other hand, MicroElectroMechanical systems (MEMS) frequently employ moving parts such as cantilevers for sensing or actuation. In this contribution, we demonstrate that the design of fiber devices can be inspired by the MEMS technology and comprise freely moving domains to deliver a given functionality. We show in particular the fabrication of a MicroElectroMechanical fiber (MEMF) that acts as a touch sensing device based on a free standing conductive polymer sheet that can locally bend upon an applied pressure. This mechanical actuation can bring the bending sheet in contact with a second conducting polymer domain, creating an electrical signal that allows the fiber device to precisely detect and locate a pressure point along its length. We also show that the information on presence and position of a pressure applied can be decoupled using an appropriate electrical circuit. Another type of touch sensing fiber that we created by thermal drawing relies on a capacitive effect, and both types can be integrated into fabrics. It appears that touch and pressure sensing systems that can cover large areas or even curved surfaces are becoming increasingly important in a variety of applications, ranging from healthcare monitoring to robotics and prosthetics. The functionalization of such systems is however usually achieved at the expense of spatial resolution, or at the cost of complicated fabrication schemes. Our novel approach to fabricate touch sensing fibers allows for the programming of a device that can act as a flexible electronic interface integrated within smart textiles, wearable electronics or medical fabrics in a variety of configurations and represent significant opportunities for applications.

# Intermediate-$T_g$ Phosphate and Tellurite Glasses for Multimaterial Fiber Devices

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Research on multimaterial multifunctional fibers flourished in the recent years, proposing an ever growing set of materials suitable for co-drawing as well as of fiber functionalities. So far however advances relied mostly (i) on high-$T_g$ silica-based materials ($T_g$ > 1000 °C) due to the technological interest of silica, and (ii) on low-$T_g$ chalcogenide glasses ($T_g$ < 250 °C) that were deployed for integration in multimaterial glass/polymer/metal fibers. Here we explore the feasibility of fabricating multimaterial fibers using glasses with intermediate glass transition temperatures. The presentation focuses on phosphate glasses ($T_g$ ~350-450°C) and on tellurite glasses ($T_g$ ~250-300°C). Firstly, we explore phosphate-based hybrid fibers (fibers with the active function being embedded within the glass matrix). We report on the drawing of photosensitive, photo-writable Ag-containing glass ribbon fibers. We demonstrate that luminescence properties of the native glass are preserved after shaping. Furthermore, we establish that the unique fiber's flat geometry allows for the direct, accurate Laser writing of complex luminescent silver clusters patterns and functionalities within the glass matrix.

Alternatively, we explore tellurite-based composite fibers (fibers made from a stack of materials with disparate electrical/optical/thermal properties). Here, bringing together the merits of these materials with fiber optic technology, we report on the first tellurite-based core-clad dual-electrodes composite fiber made by direct, homothetic preform-to-fiber thermal co-drawing. The rheological and optical properties of the selected glasses allow both to regulate the metallic melting flow and to manage the refractive index core/clad waveguide profile. We demonstrate the electrical continuity of the electrodes over meters of fiber. We believe the drawing of architectures merging electrical and optical features in a unique elongated wave-guiding structure will enable to develop new in-fiber functionalities based on hybrid electric/optic nonlinear effects.

Great challenges lie ahead when it comes to mastering the implementation of intermediate-$T_g$ oxide glasses within multimaterial fibers, but great opportunities lie ahead too, as it would give access to a whole new range of materials properties, and hence of functionalities, in linear/nonlinear optics, photonics, electro-optics or sensing.

# Multimaterial Porous Fibers

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Preform-to-fiber thermal drawing is a versatile process that allows the fabrication of polymer- or glass-based fibers with complex, multimaterial, internal structures that grant them functions ranging from optical transmission to chemical detection. However, while a wide range of materials such as metals, semiconductors or composite and ferroelectric polymers have been successfully drawn in various phases, the fabrication of fibers with internal porous domains has remained elusive thus far. Because the thermal drawing technique intrinsically relies on the flow of the fiber materials in a low-viscosity state, direct incorporation of porous materials in the preform is inadequate, as pores tend to elongate and collapse during the process.

Here we report on the fabrication and characterization of thermally-drawn multimaterial fibers encompassing internal porous domains alongside non-porous insulating and conductive materials, in highly controlled device geometries. Our approach utilizes phase separation of a polymer solution during the preform-to-fiber drawing process, generating porosity in the fiber during the drawing process itself. Engineering the preform structure leads to control over the geometry and materials architecture of the final porous fibers. Further control over the fibers cooling rate enables pore size tunability, through regulation of the phase separation kinetics. We finally demonstrate electrical activity of multimaterial porous fibers by performing ionic conductivity measurements of electrolyte-loaded pores. Such domains could be highly desirable for applications ranging from flexible fiber batteries to chemical delivery using fibers.

# Microstructure Tailoring of Semiconducting Materials within High-performance Optoelectronic Fibers

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The integration of electronic and semiconducting architectures within thermally drawn thin and flexible fibers is bringing novel opportunities for smart sensors, biological probes, energy harvesting and advanced textile. So far however, the optical, electronic and optoelectronic performances of multi-material fibers have been limited due to the poor control over the microstructure of the chalcogenide semiconductors. Here we report on newly developed crystallization schemes to tailor the microstructure of semiconductors in multi-material fibers. We first show that laser-based heat treatment leads to an improved polycrystalline microstructure with larger grain size and better crystallographic orientation. To realize single crystal based structures and further improve device performance, we then turn to a simple and robust Selenium nanowire growth sonochemical approach applied to amorphous semiconductor domains. The anisotropic surface energy of crystal planes in the solvent allows us to control the phase and orientation of monocrystalline nanowires that grow along the desired axis, directly in intimate contact with built-in electrodes. The resulting nanowire-based devices exhibit an unprecedented combination of excellent optical and optoelectronic properties in terms of light absorption, responsivity, sensitivity and response speed that compare favorably with reported other nanoscale planar devices. We then demonstrate in particular a fiber-integrated architecture with two nanowire-based devices positioned around a step-index optical fiber, enabling fluorescence imaging using a single multi-functional fiber. This work sheds light on how the in-depth understanding of the interplay between the materials microstructure and device performance can open new opportunities for increasingly sophisticated functionalities in fiber devices.

# Multimaterial Inorganic Optical Fibres and Sphere Breakup Experiments

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**INTRODUCTION**

Optical fibers have been used for several years in numerous application fields, ranging from telecom to sensing and materials processing, and acting respectively as waveguides, transducers or laser sources. In most cases however, the materials constituting the core and cladding components were derived from the same material, differing slightly in composition.

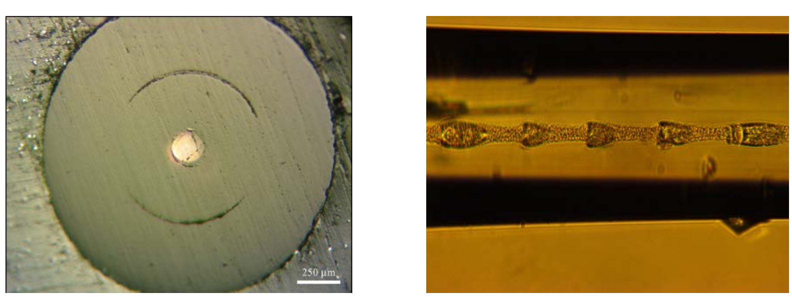
We report on the fabrication of multimaterial fibres combining two or more different glass families with the aim of obtaining structured micro and nano sized spheres by capillary instability. The selected glasses were silica for the cladding and rare earth doped multicomponent phosphate for the core. These two materials are characterized by significant differences in terms of characteristic temperatures and viscosity curves which is one of the key element of capillary instability leading to the formation of micro-spheres.

**PHOSPHATE GLASS AND HYBRID FIBRE FABRICATION**

A phosphate glass composition was selected for the fabrication of the phosphate /silica hybrid optical fibre. This glass composition was doped with $Yb^{3+}$ and $Er^{3+}$ ions, fabricated by melt quenching and characterized in situ by thermal analysis and optical spectroscopy. Glass structured preform rods were manufactured by melt quenching techniques. Optical quality polishing of the components was carried out to minimize scattering losses and provide seamless interfaces among the subunits of the preforms. The phosphate core was stretched then inserted into two silica tubes. Drawing of phosphate/silica multimaterial optical fibres followed.

**FIBER CHARACTERIZATION AND SPHERE BREAKUP**

Raman spectroscopy on the phosphate/silica optical fibres could demonstrate the multimaterial nature of the prepared optical fibres and no inter diffusion of core and cladding components could be observed within the resolution of the used equipment. Sphere break-up experiments were carried out, leading to the formation of spheres inside the tapered multimaterial optical fibre. Fig. 1(a) reports the optical microscope picture of the hybrid fibre, while a peculiar result of the experiments of capillary instability is reported in Fig. 1(b).




(a) (b)

Fig. 1 – (a) Micrograph of the hybrid optical fibre; (b) image of a type of capillary instability result.

**ACKNOWLEDGMENT**

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# Functional Fibers

# Organic-Inorganic Hybrids for Functional Fiber Materials

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Organic-inorganic hybrid is effective on functional materials design by multi-scale compositing of organic and inorganic materials in nano or mesoscopic level. On one hand, such hybrid materials possess properties belonging to each component, respectively. On the other hand, hybrid materials always reflect unique collaboration features such as enhanced mechanical performance and multi-functions. With the continuous development of fiber materials, it is urgent to provide new technology to functionalize general fiber products as well as improve their added value. Therefore, the organic-inorganic hybrid has been considered as an innovative method for functional fiber manufacture, and broaden the applications of general fibers.

We have done lots of basic scientific and technical research on construction of general fibers-based organic-inorganic hybrid fibers, including the design and in-situ polymerization of functional polymers, dynamic control of spinning processing and interface properties of functional fiber as well as their mechanism. As a result, a series of hybrid fibers with different functional properties have already been manufactured, such as fire-retardant recycled polyester (PET) and polylactic acid (PLA) fibers, antibacterial PET, polypropylene (PP) and polyamide (PA6) fiber, stainable PP fiber, anti-UV polyphenylene sulfide (PPS) fiber, thermoregulating PA6 fiber and wave absorbing polyvinyl alcohol (PVA) fibes et al. These functional fibers have also achieved broad applications in fields of daily life, intelligent devices, security protection, biomedicine and so on.

In conclusion, based on organic-inorganic hybrid technology, fiber material tends to heterogeneous and multifunctional, that promote the value-adding of existing general fibers. Moreover, we will improve the level of technical innovation of functional fibers with high quality and enhance the international competitiveness endlessly.

# Sputter Deposition of Silver onto Monofilament Yarns: Influence of Processing Parameters on Yarn Properties


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**INTRODUCTION**

One important part in the development of smart textiles are the required connections between the different components in order to transfer energy and data. Using textile materials as connectors has certain advantages compared to traditional cables, as they keep up the textile character of the product. There are numerous technologies to realize electrical conductivity on different levels: in the fiber, the yarn, or the textile. One promising technology to make yarns electrical conductive is the sputter deposition of metals.

**METHOD**

Sputter deposition is a physical process of energetic ions bombarding a target and by this vaporizing atoms from this solid. The sputtered particles deposit on a substrate to build a thin film. This technology allows very thin films to form, in the nanoscale, on generally any kind of substrate.

The target used in this case is silver, as it is known for its excellent conductive properties and additionally offers an antimicrobial efficacy, which can be important for applications close to the body. The substrates that are coated are polyamide 6 (PA 6), polyester (PET) and polyvinylidene fluoride (PVDF) monofilaments with varying diameters of 0.25, 0.5 and 1 mm.

Regarding their influence on the electrical resistance of the coated yarns the processing parameters speed, generator power and gas supply are considered. Also the impact of the different polymers and thicknesses of the monofilaments is analyzed.

**RESULTS AND DISCUSSION**

The parameter speed has the clearest impact on the electrical resistance of the coated yarns. The resistance decreases with a decreasing speed, because more silver particles can deposit on the substrate. The lowest resistances are always achieved at a speed of 25%.

Table I: Settings with the lowest resulting resistances for each material.

| Material | Generator [W] | Gas [%] | Resistance [Ω m] |
|---|---|---|---|
| PA 6 | 55 | 45 | 357.33 |
| PET | 50 | 45 | 382.00 |
| PVDF | 50 | 50 | 404.00 |

Table I shows the lowest achieved resistances for each material and the related parameters. In general, a higher generator power (50 W or 55 W) is advantageous and the gas supply should not be lower than 40 %.

A direct influence of the chosen polymer material cannot be stated. But of course, the diameter of the filament plays an important role, so that the electrical resistance decreases with an increasing diameter. Therefore, the yarns with the lowest resistances have a diameter of 1 mm.

# Multifunctional Properties of Carbon Nanotube Fibres

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It is well known that carbon nanotubes (CNTs) possess outstanding physical properties. However, current synthesis methods have been able to provide nanotube lengths of up to several millimetres. This is why the fabrication of CNT-based materials have been necessary in order to utilize the excellent properties of individual nanotubes at a macroscopic level. In this sense, the assembly of CNTs parallel to each other along a macroscopic fibre maximize the transference of their remarkable axial properties.

Carbon nanotubes in many ways resemble a rigid conjugated polymer. Both nanotubes and polymers are macromolecules consisting of long chains of repeating molecular units, and have large values of aspect ratio (length/diameter). This is why classical theory of polymer fibres has been successfully used to describe the mechanical properties of CNT fibres.

In a same way, sensing capabilities exhibited by CNTs are also shown in CNT fibres. Thus, electrical conductivity of CNT yarns is extremely sensitive to the exposure of certain chemicals. Based on this electrochemical doping effect, a new analytical model has been developed. According to it, CNT fibres were successfully used in a vacuum infusion process as polymer flow sensors by simply measuring their electrical resistance.

# Development of Carbon Fiber-based Electrodes for Microbial Fuel Cells

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Microbial fuel cells (MFCs) have great potential to reduce the high energy costs of waste water treatment. For this purpose, electrical energy is produced by exo-electrogenic microorganisms during wastewater treatment. In order to transfer this technology from research into industrial applications, a significant increase in the efficiency of the electrodes is required. Conductive textiles based on carbon fibers offer the opportunity to achieve these improvements by their large surface area, good electrical conductivity, high resistance to chemicals and waste water and known processing processes. To date, the knowledge about the development and properties (e.g. surface and chemical properties) of the fibers and textiles required for this purpose is missing to achieve maximum performance.

In order to investigate the influence factors, woven test specimens are designed and characterized. Furthermore, mechanical tests are carried out to investigate the influence of the weaving parameters on the stability and long-term stability of the textile electrodes. Therefore relevant properties of various carbon fibers, e.g. on a pitch or PAN basis, will be compared. For the fabricated fabrics various desizing methods and surface treatments are then investigated in order to improve the formation of the biofilm and thereby improve the performance of the MFCs. Different influence factors regarding performance of carbon fiber electrodes are shown in figure 1. The effects of different parameters and methods on the colonization of bacteria are determined by REM images. The electrodes thus obtained are tested in the laboratory reactor of the iAMB with both synthetic waste water and known test microorganisms as well as with real waste water and a wastewater microbial community. In addition to the consideration of the economics of the complete process chain, the transfer to other fields of application is also considered.

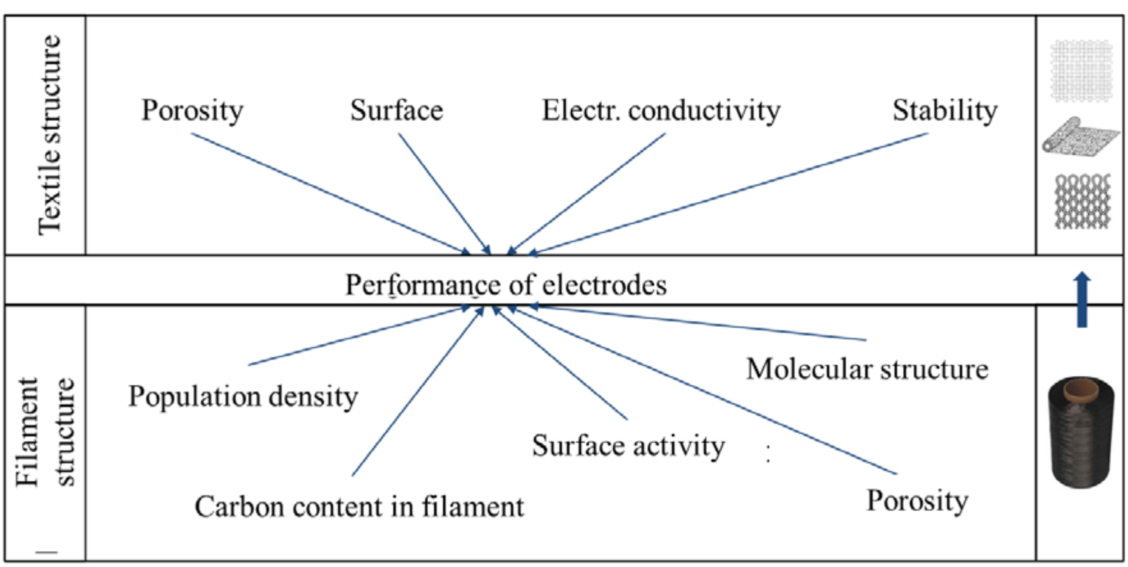


Figure 1: Influence factors regarding performance of carbon fiber electrodes

**ACKNOWLEDGMENT**

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# Usage of Splittable Microfilament Yarns as Carpet Pile

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## INTRODUCTION

Fibers finer than 1 dtex or 1 denier are called as microfibers. Microfibers are classified into two types, continuous filament type and staple type. Continuous microfilaments can be produced by bicomponent spinning. Among bicomponent microfilament production methods, splittable microfilament is an important type. In split spinning, the starting fibre consists of segments of two different polymers, which these two polymers have poor adhesion to each other. The fibres are designed to split into the segments by different treatments to produce the ultimate microfiber. Segmented pie fiber type is a well-known type of '***splittable microfibres***'. In the scope of this study, differently from the previous studies and in addition to many end uses, cut pile and loop pile carpet samples are produced by using the splittable microfilament yarns as carpet pile. By this way it is aimed to obtain a soft and luxurious hand for carpets and to produce high quality carpets although low number of piles per unit area. For this aim, the performance properties of the samples are investigated before and after splitting process in order to determine the use life performance of the carpets with splittable microfilament pile yarns.

## MATERIAL and METHODS

In this study, it is aimed to investigate the performance of splittable microfilament yarns on machine woven face to face wilton-type carpets. In this context, Teijin brand 50-50% polyester-naylon 84 dTex/20f splittable yarn (segmented pie/16 segments) is used (Figure 1). The carpet samples are woven with two different pile types as loop pile and cut pile. Structural properties of samples are given in Table I.

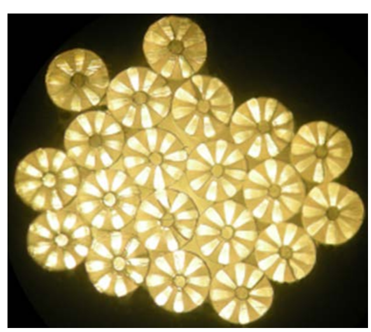

Figure 1. Cross sectional view of Teijin brand splittable microfilament yarn (50-50% Polyester-Nylon)

Table I. Structural properties of samples

| **Parameter** | **Value** | **Parameter** | **Value** |
|---|---|---|---|
| **Weave structure** | 1/2 V | **Pile density** | 640.000 points/m² (cut pile)<br>320.000 loops/m² (loop pile) |
| **Pile height** | 12 mm (cut pile)<br>6 mm (loop pile) | **Pile length** | 30 mm (cut pile)<br>20 mm (loop pile) |
| **Weft yarn** | Ne 6/4, 100% cotton | **Weft weight** | 703 g/m² (cut pile)<br>668 g/m² (loop pile) |
| **Stuffer warp yarn** | Ne 12/4, 100% cotton | **Warp weight** | 571 g/m² (cut pile)<br>510 g/m² (loop pile) |
| **Chain warp yarn** | 780 denye, %100 polyester | **Pile weight** | 2246 g/m² (cut pile)<br>1332 g/m² (loop pile) |

At present, there are many ways to split bicomponent filaments into microfilaments. In this study, alkali deweighting method is used. The conditions of the alkali deweighting method are proposed by Teijin (producer of the splittable yarn) as a receipt. Sample carpets are treated with NaOH, at 35 g/l concentration and 1:30 liquor ratio. Treatment temperature is 85°C and duration is 30 minutes. After alkali treatment, samples are washed with tap water and neutralized with PH 4-5 acetic acid solution. Then the excessive water on the samples are squeezed by a rotating tumbler and dried by a steam drying chamber with 0.35 m/min speed. Cross sectional SEM (Scanning Electron Microscopy) view of the pile yarn before and after splitting process is seen in Figure 2. Warp, weft and pile weight of the samples after alkali treatment are given in Table II.

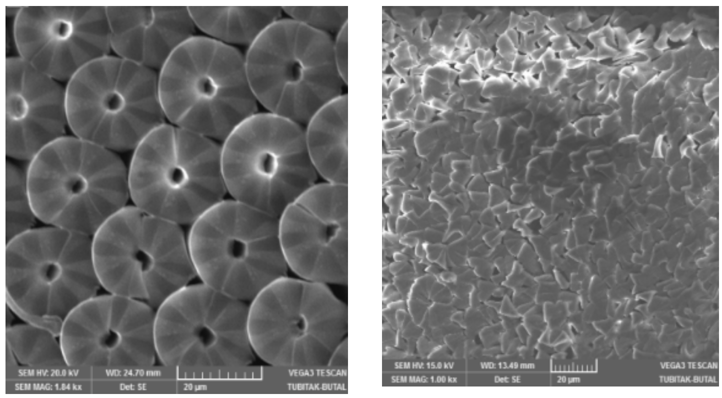

Figure 2. Cross sectional SEM (Scanning Electron Microscopy) view of splittable microfilament yarn (left-before splitting / right after splitting) <u>Before splitting process: </u>84 dtex 20 filament ⇒ 4.2dtex, <u>After splitting process: </u>84 dtex 320 filament⇒ 0.26dtex

Table II. Warp, weft and pile weight of the samples after alkali treatment

| | **Samples** | | | |
|---|---|---|---|---|
| | **Loop pile** | | **Cut pile** | |
| | **Before splitting** | **After splitting** | **Before splitting** | **After splitting** |
| **Weft weight, g/m²** | 668 | 670 | 703 | 726 |
| **Warp weight, g/m²** | 510 | 495 | 541 | 595 |
| **Pile weight, g/m²** | 1332 | 1245 | 2246 | 2316 |

The carpet samples are woven with two different pile types as loop pile and cut pile. Pile withdrawal force and thickness loss after dynamic loading test were determined after the tests. Pile withdrawal force test was done according to TS 5145. Dynamic loading test was done according to TS 3375 ISO 2094.

**RESULTS AND DISCUSSION**

Pile withdrawal force results are given in Table III and thickness loss values of the samples after dynamic loading test are given in Figure 3.

Table III. Pile withdrawal force

| **Pile withdrawal force, gf** | | |
|---|---|---|
| **Loop pile** | **Before splitting** | 3507 |
| | **After splitting** | 4050 |
| **Cut pile** | **Before splitting** | 1638 |
| | **After splitting** | 2034 |

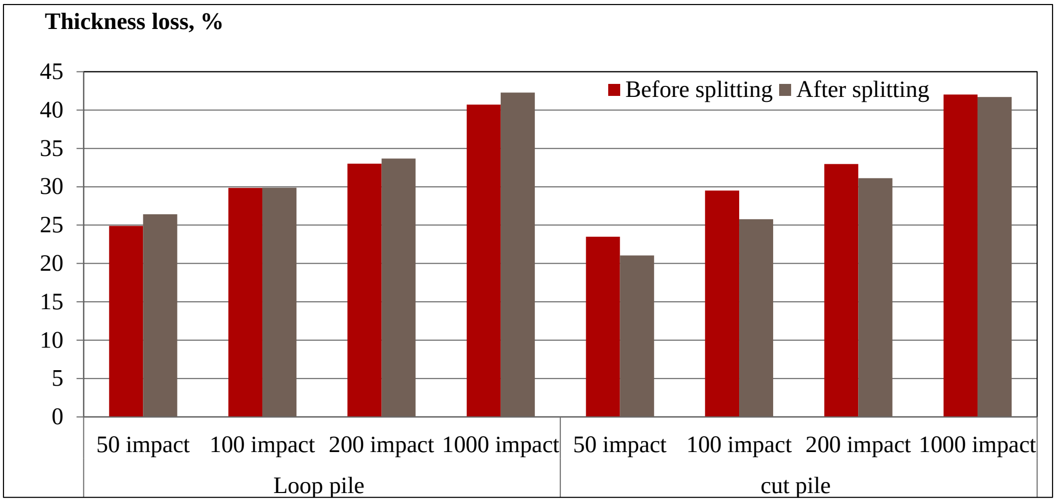


Figure 3. Thickness loss values after dynamic loading test

## CONCLUSION

After splitting process soft touch and luxurious hand is obtained for both loop pile and cut pile samples. It is seen from the appearance and touch of the samples, higher quality carpets can be produced although low number of points per unit area. Pile withdrawal force is increased after splitting process for both cut pile and loop pile samples. So the quality of the carpet samples is increased. According to dynamic loading test the quality of the loop pile sample is deteriorated whereas, the quality of the cut pile sample is improved. Consequently, it is convenient to produce cut pile samples with splittable microfilament pile yarns.

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## ACKNOWLEDGMENT

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# Intensity Relationships of $CH_2$ Bands (ν, δ) in FT-IR Spectra of Syndiotactic Polyacrylonitrile and the Calculation of Dipole Moment

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**ABSTRACT:** The stereoregular syndiotactic rich polyacrylonitrile (PAN) was successfully prepared by solid state polymerization. In FT-IR spectra, no IR characteristic bands existed, however. Configurational difference appeared in the intensity of methylene ($CH_2$) bands. The intensity was in the following order: in the stretching mode ( ν ), isotactic > atactic > syndiotactic, whereas in the deformational mode ( δ ), the results were visa versa, syndiotactic > atactic > isotactic. Dipole moment (DM) of each PAN was calculated by using 3 different stereochemical models (4 monomer sequences). The calculated data agreed completely with the above IR results (the order of the intensity relationships), which suggest the assumption employed is correct and valid.

**INTRODUCTION:** Infrared (IR) spectroscopy is a powerful analytical tool for the investigation of molecular structure and physical properties of polymers. Dipole moment (DM) is related to IR absorption spectra, whereas polarizability (induced dipole) does to Raman scattering spectra. There is very little evidence indicating how the DM is related to the IR data. Quite recently, syndiotactic rich PAN's were prepared by solid state polymerization by using Zeolites [1]. This is the first case, where syndiotactic rich PAN was synthesized actually, and its configuration was confirmed by $^{13}C$ NMR spectra. In the IR spectra, there was no characteristic band in syndiotactic PAN. This makes a clear contrast with the results of isotactic PAN [2]. However, detailed analysis showed that configurational difference appeared in the intensity of $CH_2$ bands.

**RESULTS AND DISCUSSION:** In IR spectra of PAN, 3 peaks were clearly seen at 2940 and 1460cm$^{-1}$, and 2240cm$^{-1}$. The former two were $CH_2$ bands, while the 3$^{rd}$ was CN one. The difference appeared in the intensity of the $CH_2$ band. DM of 3stereoregular sequence of PAN across cross sectional view was calculated by using tetrad-models (4 monomer units) (Figure 1). Total DM was separated into parallel ( ν ) and vertical components ( δ ). Figure 2 shows the results.

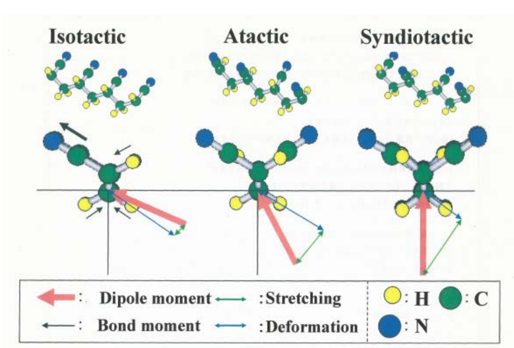


Fig. 1. Calculation of the DM based on 3 PAN's chain

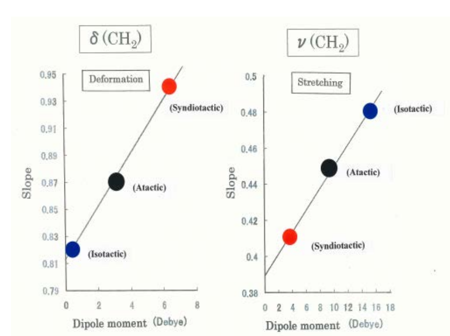


Fig. 2. The results of the calculated DM

**CONCLUSION:** The intensity difference of methylene $CH_2$ bands ( ν , δ ) in PAN was revealed by the detailed quantitative FT-IR analysis. DM of 3 stereoregular PAN's chains was calculated by using tetrad-models. Agreement between the calculation and IR experimental results was quite good. It was verified that the order of the intensity of the $CH_2$ bands in FT-IR spectra is determined by the DM of stereochemical structure of PAN.

# Polymer Optical Fibers

# Materials for POF Production: Scattering and Transmission in Fiber Optics

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First, optical polymers are introduced in general. The properties of optical polymers made from Polycarbonate, Polymethylmethacrylate, etc. are presented.

After that, options and methods to produce light scattering properties with optical polymers are discussed. This involves a general introduction in light scattering and the discovery and scientific description of light scattering by Lord Rayleigh and Gustav Mie. Also discussed are the difference between bulk and surface scattering, methods to produce light scattering with polymers and limitations and restrictions of light scattering polymers.

Then, different applications with light scattering properties are presented in different categories. As an application using surface scattering technology, PLEXIGLAS® light guide film offers high light transmission and accurate light scattering by using microstructures. A back light unit is given as an example of printed light scattering structures. As applications using bulk scattering technology, the PLEXIGLAS® DF-product range is given as an example for organic based light scattering spheres with high scattering properties and diffuse light outcoupling. The PLEXIGLAS® LD-product range is given as an example for minimal light scattering for edge light applications.

A huge variation of plastics in combination with scattering spheres or pigments are available. The correct material choice for an application is complicated. The processing of plastics has an influence on the light-scattering properties. Light scattering plastics are offering options for high efficient lighting applications.

# Smart Geosynthetics for Structural Health Monitoring Applications

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Responding to a growing need for intelligent monitoring of critical geotechnical and civil infrastructures, new multifunctional geotextiles and geogrids with integrated optical fibers were developed and investigated within several research projects. Such smart two-dimensional geosynthetics intercorporating optical fibers as distributed sensors provide solutions both for soil reinforcement, erosion control, drainage or environmental protection and for cost-effective monitoring of critical mechanical deformations and temperature distribution in geotechnical and masonry structures at the same time. The integrated fiber optic sensors provide online information about the condition of the monitored structure and about the occurrence and localization of any damage or degradation for the purpose of preventing a total collapse. The optical fibers have a serious advantage over other kinds of sensors due to their fibrous nature, so they can be ideally processed like standard textile yarns.

The monitoring of extended geotechnical structures like dikes, dams, railways, embankments or slopes requires sensor technologies with measurement lengths of at least some hundred meters which can be realized by the use of silica fibers. However, the integration of silica fibers into geosynthetics during the manufacturing process experienced problems of sensor brittleness, low strain range not exceeding 2 % and bending-related attenuation increase optimized to the value of 1.5 dB/km. Unlike silica fibers, the integration of polymer optical fibers (POFs) into various geosynthetics was easily achieved free of bending losses enabling distributed high strain measurements up to 40 % using PMMA POFs. The first industrial product GEDISE based on a geogrid with integrated PMMA POFs is on the market.

Due to the five times lower attenuation of low-loss perfluorinated graded-index POFs (PFGI-POFs), compared to PMMA POFs, the measurement range can be extended to 500 m. The low-loss PFGI-POFs offer the possibility of implementation of Brillouin optical fiber frequency domain analysis (BOFDA) which will significantly improve the measurement accuracy and spatial resolution in comparison with existing POF-based distributed measurement methods like POF OTDR. The development of a distributed Brillouin system based on PFGI-POFs is in progress.

# Application of Thermography for Process Control in the Production of Polymer Optical Fibers

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A thermographic camera is used to control the fabrication process of polymer optical fibers. The camera is used as temperature control sensor for the furnace. It is further used to record the spatial temperature distribution and the position of the preform in the furnace and it allows to identify drawing problems.

The production of short polymer optical fibers from small material batches is valuable for material research. It allows to examine and compare many different materials and material mixtures. For this purpose we use a two-step fiber drawing process, where a bulk polymerized preform is heated and drawn to a fiber. An important parameter is the temperature program for the individual preforms. Measurements using contactless methods are preferred, because they allow for online measurements and do not affect the drawing process. Such a method is the utilization of a pyrometer, which allows the measurement of a wide range of temperatures but requires a precise adjustment of the measurement spot to the center of the preform.

To circumvent this limitation we use an Optris Pi 400 infrared camera with 288 x 382 pixels and a telephoto lens, which gives a resolution of 100 µm per pixel in the heating zone. The temperature measurement range is 0 - 250 °C, which fits the decomposition temperature of the polymer. The device is installed outside the optical heating furnace, which is equipped with six 500 W halogen lamps in mirror shaped grooves. Since the camera operates in the spectral range between 7.5 and 13 µm, a hole on the side of the otherwise closed furnace is covered with a 2 mm KBr crystal window.

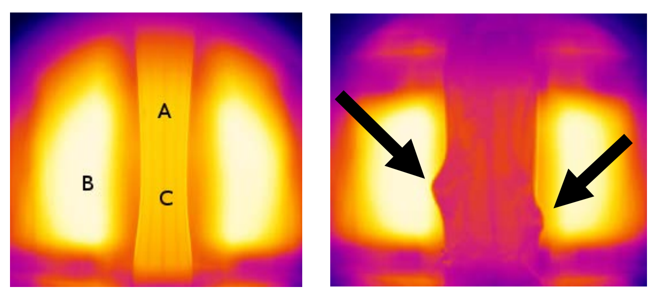


Figure 1: Image of the preform through the crystal window, while drawing with 3 measurement spots (left), foaming problem (right).

In Figure 1 the left side shows an example of a measurement of the temperature using this method. The width of the preform is 8 mm and the formation of a neckdown region is visible in the center. The main process temperature is taken at spot A, whereas points B and C give a further reference for the background temperature of the furnace and the temperature in the neckdown region. These values are fed back to the control loop and the heating power is set accordingly.

As an example for the online identification of problems, the material of the preform in Figure 1 on the right side is foaming during the heating process. This is a typical result of an inadequate preform fabrication and drawing that preform is impossible.

**ACKNOWLEDGMENT**
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# Demultiplexer in PMMA for POF Over WDM

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Data communication over Polymer Optical Fibers (POF) is limited to only one channel for data transmission. Therefore the bandwidth is strongly restricted. By using more than one channel, it is possible to break through the limit. This technique is called Wavelength Division Multiplexing (WDM). It uses different wavelengths in the visible spectrum to transmit data parallel over one fiber. Two components are essential for this technology: A multiplexer (MUX) and a demultiplexer (DEMUX). The multiplexer collects the light of the different sources to one fiber and the demultiplexer separates the light at the end of the fiber into the different fiber output ports.
To separate the channels at the output ports, one interesting option for high multimode transmission systems is to use an optical grating. Here, the optical grating is placed on an aspheric mirror, which focuses the monochromatic parts of light into the outgoing fibers. In order to keep the advantage of cost-effective POFs it is necessary to mass-produce the MUX and DEMUX component at reasonable prices. For polymers, injection molding is the only technology, which offers high potential to achieves this goal. Before starting the production of the mold insert, a demonstrator of the DEMUX is fabricated by directly machining it in the PMMA material by means of diamond turning technique. Thus, the same diamond-turning technology is used for the manufacture of the mold insert. This step is done due to validate the simulation results with the produced component.

Several measurements are required to validate the demonstrator for example to locate the exact position of the focus points of the separated wavelength. The paper discusses the results of the different development steps, the measurements done with the first demonstrator and the challenges related to the injection molding process.

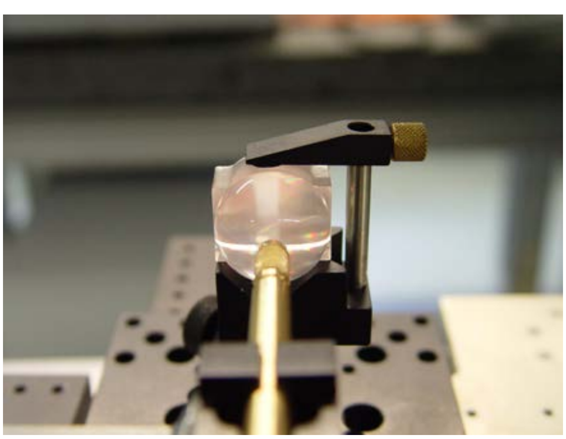

Fig. 1: Integrated demultiplexer prototype

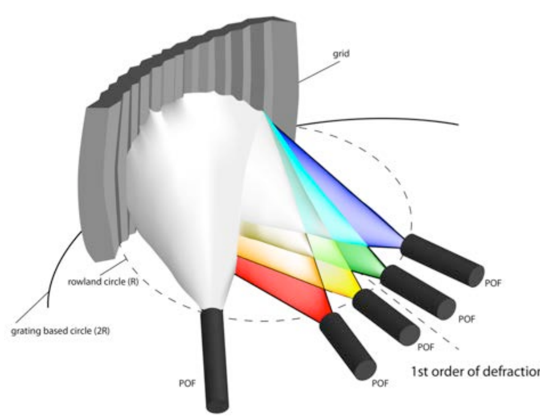


Fig. 2: Rowland set-up of demultiplexer

# POF-based Distributed Brillouin Sensing

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**ABSTRACT**
Owing to intense research in the field of fiber optic sensing, distributed sensors based on stimulated Brillouin scattering (SBS) are commercially available today. In typical SBS sensing systems, a single-mode silica fiber (SMF) is used for simultaneous temperature and strain monitoring over long distances in the order of tens of kilometers. The unaffectedness of the measurement method towards sensor fiber bending and positioning as well as spatial resolutions in sub-meter range also paved the way for modern distributed in-situ SBS monitoring in civil and geotechnical applications.

Limiting factors of SBS sensing systems are the optical and mechanical properties of the sensor fiber itself. SMFs reach, due to their low attenuation at 1550 nm, several tens of kilometers of sensing length, but are limited to strain loads up to 2 %. Additionally, mismatches in stiffness as well as in thermal expansion coefficients between the sensor fiber and the monitored object material cause challenges with regard to the interpretation of the measurement data.

Most promising candidate to overcome the pointed problems is the usage of perfluorinated graded-index polymer optical fibers (PFGI-POFs). Their most striking characteristics are a maximum strain loads without fiber breakage up to 100 % and a fully elastic strain limit of 2 %. Furthermore, the thermal expansion coefficient and the stiffness of the PFGI-POFs is similar to polymer-based materials which provides new fields of applications.

In general, SBS sensing in PFGI-POFs is suitable for all structural health monitoring applications with potential high strain, especially crack detection in composite and polymer-based materials provide new perspectives. Thanks to listed advantages, PFGI-POF integration offers distributed in-situ SBS strain and temperature monitoring systems not only in automotive and aerospace industries, but opens new opportunities for lightweight constructions. Furthermore, an integration into textiles is conceivable by using the PFGI-POF as a normal yarn without any additional bending-related attenuation, due to minimum bending radius of below 2 mm. Following this idea, distributed in-situ SBS strain sensing based on integrated PFGI-POFs are feasible into ropes and lashing straps in industrial heavy duty applications.

# Experimental Investigation of the Wavelength-dependent Far Field for Different Mode Groups in Step-Index Polymer Optical Fibers

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From our previous experimental investigations at the Polymer Optical Fiber Application Centre (POF-AC), we have shown that the far field distribution in step-index polymer optical fibers (SI-POF) is wavelength dependent. This phenomenon seems to be an inherent characteristic of polymer optical fibers in general since it was observed for fibers from different manufacturers. There are different processes that affect the shape of the far field. Absorption in the core material which contributes to mode dependent attenuation and scattering with in the core and at the core cladding interface which contributes to both mode dependent attenuation and mode mixing. If these processes are wavelength dependent then the far field will also be wavelength dependent.

It is crucial to investigate the interplay of these effects and to determine which effect contributes significantly to the difference in far fields at different wavelengths and from where within the fiber it comes from. With the introduction of fast GaN-LEDs with-in the green and blue spectral region, a deeper understanding of the spectral characteristics of the medium would aid in explaining wavelength dependent system performance. To fully understand this phenomenon, we carried out experiments to observe the development of the far field at different wavelengths and fiber lengths for different launch mode groups. In addition to the far field, the near field and optical power were measured for each launch angle (mode group). Two laser diodes (405 nm and 650 nm), two fibers types with different diameters (1 mm and 0.5 mm) and for each fiber type, samples having lengths of 1 m, 5 m, 10 m, 20 m, 50 m and 100 m were used.

From the results it was evident that identical mode groups launched at the fiber input generated distinct far field distributions at different wavelengths. For short fibers and a wavelength of 405 nm, it was observed that even though higher order modes were coupled into the fiber there was significant optical power being coupled into lower order modes after 1m. For longer fiber lengths and a wavelength of 405 nm, the intensity in the lower order modes was higher relative to that in higher order modes. The mode mixing and mode dependent attenuation seemed to be more pronounced at shorter wavelengths. To gain more insight into these findings a fiber simulation model which incorporates both core and core-cladding interface scattering will be developed. Such a model will aid in the prediction of the far field at different wavelengths and also power distribution to different mode groups at different wavelengths which have a potential of affecting the system bandwidth and consequently data transmission capacity of a POF based system.

# Overview of the POF Market

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Since polymer optical fibres (POF) were developed, the POF market developed significantly. Today the worldwide market is very diverse and still has unused development potential. This article offers a detailed overview of the current POF market and its development. It shows market distributions, describes current products and introduces major manufacturers of POF products and their portfolio.

First a general overview of the worldwide POF market is given. It shows the annual growth rates of the overall market and divided by the field of application. The presented market volumes and unit prizes are based on expert interviews with Peter Kröplin, product manager of Sojitz Europe plc. Following is an overview of the various design types of available polymer optical fibres, their structure and use.

After the general inspection, the current market is divided by various aspects. The market overview by field of application shows the market distribution divided by the fields home, automotive, industrial, architecture, office, medical and military in detail. The fields of application are analyzed relating to their POF demand, the quality of the products and the price ranges. Also, the markets are compared by their geographical position. In the next section, the market is looked at from the perspective of function of the POF products, which are illumination, data transmission and sensing. The market distribution is closer analyzed by those functions and the connection between functions and fields of application is shown. Finally, the market is divided by the fibre type, such as step index POF (SI-POF), gradient index POF (GI-POF) and multi core POF (MC-POF). The price ranges, functions and fields of application of the different fibre types are presented.

The last section shows an overview of the current major manufacturers worldwide. The major manufacturers are mainly based in Japan, China, France and the United States of America. The portfolio and POF products of each presented manufacturer is shown in detail.

# Fabrication of Microstructured Polymer Optical Fibres for Sensing

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The advent of photonic crystal fibres made of polymer (mPOF) has made it possible single-mode guidance in the visible part of the spectrum, which adds great value to the ruggedness and low cost of POFs for the development of high resolution sensor applications. In contrast to conventional POFs, single-mode (SM) mPOFs exhibit polarization properties (birefringence) that make them interesting for the design and construction of polarimetric fibre optic systems. Besides long-period gratings (LPGs) written on mPOFs have been proposed for detecting and measuring the strain rate and magnitude of engineering structures.

In this paper we will report on our efforts on both topics, fabrication of both mPOFs and mPOF-sensors. More specifically, we will summarize the process of mPOF fabrication and the results on strain measurements with long period gratings inscribed on mPOFs as well as some measurements based on the light polarization state for detecting bending and twisting.

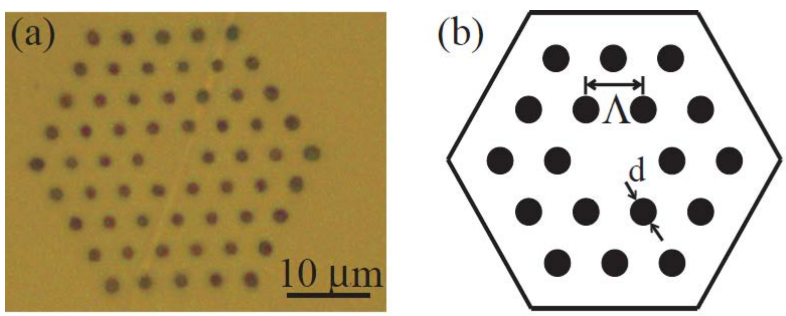


Figure 1.-(a) Micrograph of the SM mPOF used in the experiments. (b) Schematic of the structure with dimensions marked in.

**ACKNOWLEDGMENT**
This work has been funded in part by the Fondo Europeo de Desarrollo Regional (FEDER); by the Ministerio de Economía y Competitividad under project TEC2015-638263-C03-1-R and by the Gobierno Vasco/Eusko Jaurlaritza under projects IT933-16 and ELKARTEK (KK-2016/0030 and KK-2016/0059.

# Polymer Optical Fibers for Sensing Applications: Ionizing Radiation Monitoring

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In the last decades, considerable attention has been paid to the development of polymer optical fibers (POFs) that may in certain cases represent more suitable or cost-effective alternative to their glass-based counterparts. Due to some of their unique properties, POFs have found applications in the area of data transmission, lighting as well as optical sensing. Compared to the glass-based fiber sensors, POFs are more robust and flexible, yielding sensors suitable also for larger-strain applications. They have better biocompatibility and are generally more acceptable for medical applications. In addition, POFs can provide higher inherent sensitivity to some of the more alternative measurands such as humidity or ionizing radiation.

Over the last three years, BAM's Division 8.6 has been participating in the European FP7 project "TRIPOD" devoted to the development of POF technology for sensing applications. Among other applications, special attention was paid to the utilization of optical fiber sensors in radiation environments. In the recent years, ionizing radiation has found numerous applications also outside the nuclear industry, e.g. in material processing, sterilization or medical applications. With increasing importance of radiation processes, demand for suitable monitoring techniques is rising as well. Among available dosimetry solutions, optical fiber based dosimeters offer numerous advantages such as electromagnetic immunity, small dimensions and possibility of remote and real-time monitoring. A concept of attenuation-based radiation sensing with perfluorinated POFs will be presented as a potential candidate for low-cost easy-to-use on-line radiation monitoring system.

**ACKNOWLEDGMENT**
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# Influence of Scattering Characteristics on the Angle and Time-dependent Backscattered Power in Polymer Optical Fibers

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This paper presents an analysis of the influence of various different launching conditions and angular scattering distributions on the backscattered angular and temporal power flow distributions of large core step-index (SI) polymer optical fibers (POF).

During propagation along the fiber light pulses, which could be used in backscatter sensing applications such as optical time-domain reflectometry (OTDR) or optical frequency-domain reflectometry (OFDR), are subjected to interaction processes with the fiber core, cladding, and the core-cladding interface. A multitude of consequences such as modal and chromatic dispersion, absorption and scattering can be observed. In forward propagation or transmission direction the resulting effects of impulse broadening, mode mixing, and angle dependent attenuation have previously been analyzed and described in literature.

The provided investigation in this paper will instead focus on backward scattered light pulses, which could be observed from the beginning of the fiber as would be the case for reflectometry based sensing measurements. In order to acquire the necessary simulation data we use a modified and improved version of our previously published backscattering simulation model, which is based on the power flow equation by Gloge.

As part of this paper we investigate the influence of the specific angular shape resulting from scattering as the input condition of the backward propagating signal as well as the consequences of the original launching condition. We specifically expand the investigation to show the influence a more directional scattering function shows on the simulation results for three different SI-POF. In this case we use the Henyey-Greenstein phase function, which uses an abstract parameter to set the rate of directionality of the scattering distribution as a first test to approximate the true scattering characteristics of the fibers. The following graph shows two examples of the simulated backscatter power flow response over time delay and far field angle using a uniform mode distribution (UMD) as the excitation condition with two different scattering distributions for a standard Mitsubishi Eska GH fiber. An isotropic scattering distribution is shown in the left figure, while a more directional Henyey-Greenstein distribution is shown in the right figure (fiber end reflex not shown). It can be observed that the power of higher order modes shows a significantly reduced impact on the recorded backscattered power distribution for the more directional scattering distribution after shorter travelling time.

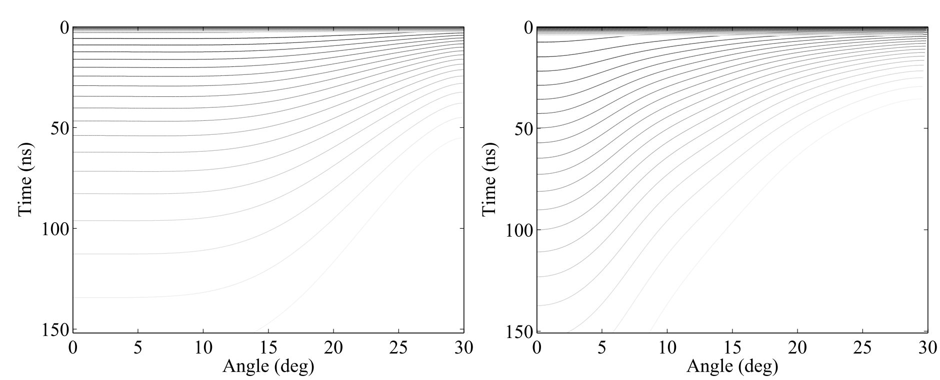


Figure 1. Relative power over far field angle and time for Mitsubishi Eska GH fiber with UMD launching condition and with isotropic scattering distribution (left) and a more directional scattering distribution (right).

# Influence of the Impulse Rebound on Optical Strain Sensors Based on Step-Index Polymer Optical Fibers

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When light propagates along a fiber, a part of it is reflected at the fiber's end surfaces. We investigate the impact of these reflections on an optical strain sensor, which is based on the phase measurement of a modulated signal. For this purpose we model the optical transmission lines as transfer functions in the frequency domain and evaluate the impact on the phase responses. Finally we calculate the resulting measurement error and discuss possibilities how this error could be reduced. While this paper focuses on the consequences on an optical strain sensor, it has to be mentioned that the observed effect is not exclusive to this application. Since both amplitude and phase response are concerned, almost any POF based system in the field is affected, whether it comes to data transmission or analog sensing applications.

The functional principle of the sensor is as follows. A light source, which is modulated with the frequency $f_{mod}$, is connected to a Y-coupler. Each output of the Y-coupler leads to a step-index polymer optical fiber (SI-POF), the reference fiber and the sensing fiber, respectively. Both fibers are connected to receivers which pass the modulated signals to a phase comparator. The phase comparator produces a voltage which is proportional to the phase difference between the two signals. If the sensing fiber gets elongated by $\Delta L$, the transit time needed to pass the sensing fiber will increase which leads to a change in the phase difference and in the output voltage $U$ of the phase comparator.

In an ideal fiber, the phase difference would have a linear dependency on the elongation. Therefore $U$ would be proportional to the elongation. This linear dependency is important for the accuracy of the sensor. However as shown before, various fiber effects, e.g., modal dispersion, scattering and attenuation as well as the launching condition of the light source, spoil the linearity. The desired linearity results in the requirement for a linear phase response or a constant group delay of the transmission function which represents the fiber in the frequency domain. We have measured the frequency responses for 9.9 m[1] SI-POF for three different light sources (650 nm laser diode (LD), 650 nm LED and 405 nm LD). All phase responses are affected by similar frequency ripples. Hence, the linear relation between the elongation of the fiber and the corresponding phase difference is spoiled since both, the reference fiber and the sensing fiber are affected by the frequency ripples. As a consequence, the accuracy of the sensor is reduced. It should be mentioned that the frequency ripples affect the amplitude responses as well.

With a system theoretical approach, we show that the frequency ripples are caused by reflections and determine their amplitude and period. Eventually, we discuss the resulting measurement error that can be expected for a specific setup and how this error could be reduced.

[1]All measurements were normalized to a reference measurement with 10 cm of SI-POF to remove the influence of the light source and the receiver.

# Low OH Tellurite Glasses for Nonlinear Optical Fibers and Supercontinuum Generation Beyond 3 µm

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In recent years, there has been a growing interest in the development of robust mid-infrared (MIR) supercontinuum (SC) sources covering spectral ranges otherwise unreachable with silica-based systems (wavelength above 2.5 µm). For this purpose, important efforts were carried out on the development of alternative MIR materials. Tellurite glasses offer a good compromise for SC generation in this spectral range. They exhibit a moderate transparency window (from 0.5 to 6 µm) comparable to fluoride glasses, but with higher non-linear index suitable for more compact configurations. Moreover, compared with chalcogenide glasses, they show higher damage threshold as well as shorter zero dispersion wavelength (around 2 µm) allowing for the potential development of sources featuring important common user needs for SC applications (single-mode behavior, inexpensive and compact laser pump with moderate power and turn-key system with no user alignment or maintenance required).

In the present work, we report on the fabrication of low OH, highly non-linear tellurite fibers. $TeO_2$-based materials suffer from strong water-related absorptions (especially at 2.9, 3.3 and 4.4 µm) extremely detrimental for spectral broadening in the MIR. In order to ensure full SC coverage over our glasses transmission window, we explored several purification processes such as raw materials dehydration treatments, halogenide compounds addition or precursors fluorination. We demonstrate the fabrication of extremely low OH content tellurite glasses. Attenuation measurements performed on several meter-long single-index fiber samples revealed the nearly complete elimination of water-related absorptions between 3 and 4 µm. Next, the purified $TeO_2$-based materials can be used for the development of highly non-linear optical fibers suitable for SC generation such as microstructured fibers and tapers, as well as step-index fiber profiles. Fine control of the waveguide dispersion and low water-related absorptions allow for different SC generation in the important 3-5 µm spectral range.

# Fiber Characterization and Testing

# Wettability of Carbon Fiber Tows

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Physical adhesion between Carbon Fibers (CFs) and polymer matrices as well as the formation of voids at the interface between these two materials are mostly controlled by the wetting properties of the fibers. Due to the hierarchical structure of CF reinforcements, it is essential to study their wetting behavior at different scales: from the single fiber (microscale) to the fabric (macroscale) via the tow scale (mesoscale). Probing the wettability of CF tows, is however highly challenging, because it couples the effects of surface chemistry and geometry of the fiber assembly characterized by spontaneous capillary wicking and elasto-capillarity induced aggregation.

At the fiber scale (microscale), using a force method (K100SF Krüss tensiometer) and water as a probe liquid, static advancing contact angles were obtained. The contact angle on unsized CFs is 77.3 ± 4.6°, which indicates that these fibers are more hydrophobic than the sized FT300-3000-40A CFs (T300) from Toray (65.8 ± 2.9°). The receding contact angle showed the same trend with a value of 37.6 ± 6.0° for the unsized CFs and values between 20° and 0° for the T300 CFs.

At the mesoscale (Figure 1), an elasto-capillary aggregation effect has been observed during infiltration of the tows. Therefore, a method combining force and optical analysis was developed to better characterize at the same time the porosity of the wetted tow and the external contact angles. This innovative method provided consistent results for both approaches. For wetted T300 CF tow, the external contact angles are 43.1± 4.6° (force method) and 48.8 ± 3.2° (optical method); and for the unsized CF tow, the external contact angles are 63 ± 1.4° (force method) and 65.8 ± 4.4°(optical method). Moreover, contact angles at meso- and microscales have been successfully linked by using the modified Cassie–Baxter model. The wettability of CF tows can thus be predicted from the contact angle obtained at the microscale. In conclusion, the effect of surface sizing on fiber wettability at the mesoscale was assessed, which will enable better prediction and optimization of adhesion between a given polymer matrix and CFs at the tow level.

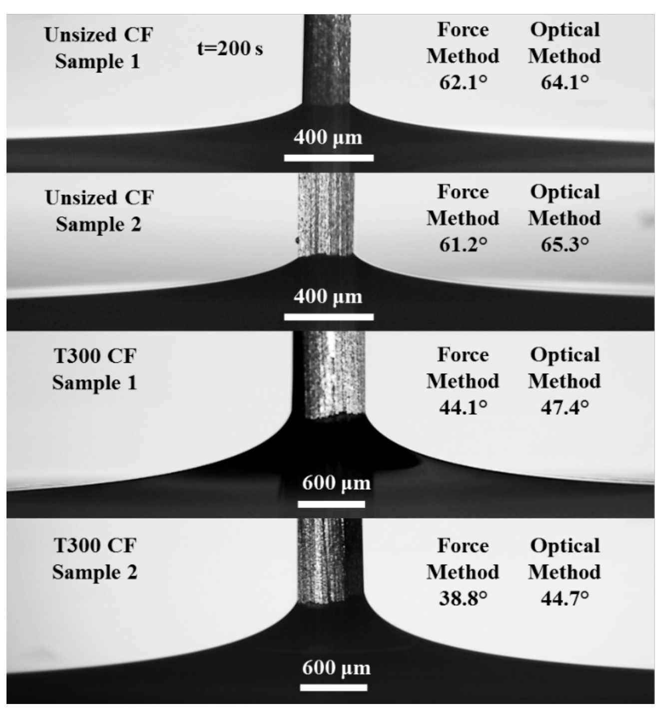


Figure 1: Water menisci formed around CF tows

# Effect of Boric Acid Addition to Bulked Continuous Filaments (BCF) Polypropylene (PP) via Melt Spinning Method Used in Carpet Manufacturing for Flammability

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PP is the major man-made fibers. PP is the first synthetic stereo regular polymer to achieve industrial importance. BCF is becoming widely used in machine-woven carpet manufacturing as a pile yarns, apparel, upholstery, floor coverings, hygiene medical, geotextiles, car industry, automotive textiles, various home textiles, wall-covering, and so on (Figure 1). This is expected that this trend will continue in the near future.

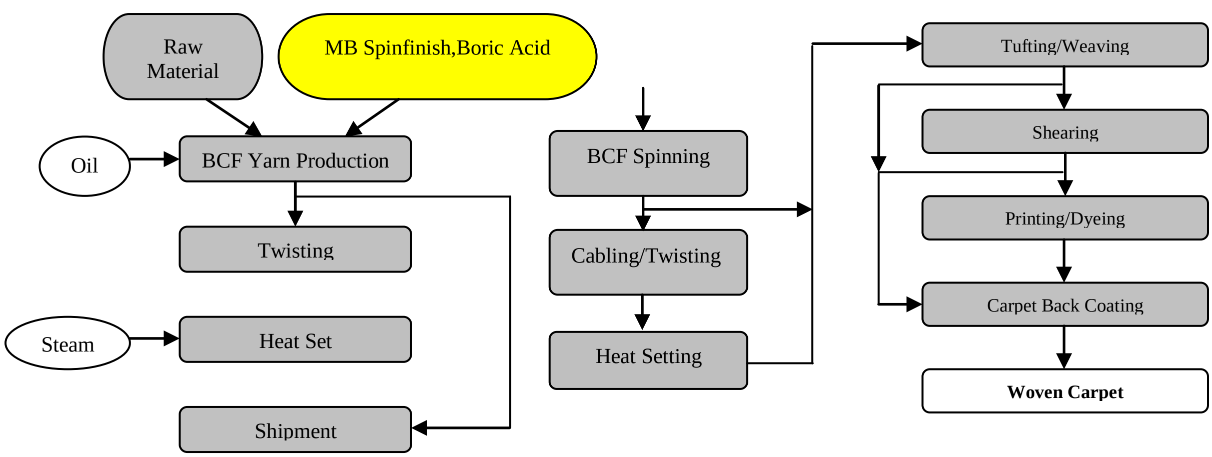


Figure 1. BCF Carpet Production Process

PP is easily flammable and burns in air with a very hot and clean flame without giving any char residue. Its inherent flammability restricts its usage in many fields. For this reason, it is necessary to make PP flame retardant wherever required. Different methods can be used to obtain flame retardant. Additive is widely used for PP. This can be achieved by boron which is abundant in nature, but so far unused mineral especially when there are millions of tons of reserves in Turkey. Boric acid is added to BCF PP yarns during the spin finish operations at the same time of master batch.

The vertical test method is used to measure flammability resistance of samples according to ASTM D6413-08 standard under controlled laboratory conditions. The experimental results have been statistically evaluated by using the Design Expert Analysis of Variance (ANOVA) software with F values of the significance level of $\alpha$ = 0,05.

The research on the flammability behavior of samples can be summarized as follows:

- It can be inferred that boric acid shows better flame retarding effect rather than BCF PP yarns produced by conventional methods without flame retardant.
- In the last few years, green or eco-friendly chemicals have been used because of increased human safety and the search for alternative environmentally materials. Efficient use of borax mines can contribute to the solution of waste accumulation problems of environment and flammability behavior by the aid of applying with adequate quantity.

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# New Measurement Technology for Evaluation of Transversal Interfiber Friction

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**ABSTRACT**

Friction phenomenon occurring inside fibrous structures during their displacements or deformations has a crucial influence on their behavior. In scientific literature, many studies focus on frication evaluation at different scales: macroscopic (reinforcement scale), mesoscopic (yarn scale) and microscopic (fiber scale). For this last one, the different types of friction could be also classified according to three directions, as shown in Figure 1: longitudinal-to-longitudinal (*l-l*), longitudinal-to-transversal (*l-t*) and transversal-to-transversal friction (*t-t*). There are several researches which interest in the two first cases, but there are no studies, up to now, that treated the transversal-to-transversal friction. Thus, this paper presents a new measurement experimental method for (*t-t*) friction evaluation, as well as the associated mathematic model which has been developed.

According to this model, two filaments are first placed as shown in Figure 1(e). Then, their ends are twisted. After few rotations of the two filaments, sliding occurs in the contact zone. According to the mathematical model, the (*t-t*) friction can be evaluated by means of tow parameters: the first-one is the twisting angle recorded just before sliding takes place ($\theta$) and the other one is the tensile force, recorded at the same moment ($F$), which is induced along the filaments. So, to validate this this primary idea, it was important to design and execute an automated machine, capable to achieve the task of measuring and recording of these two parameters ($\theta$ and $F$). By means of this new experimental device, it was possible to fix two filaments in the configuration shown in Figure 1(e), to draw the curve $\mu = f(\theta, F)$ and then to compare it with the theoretical curve drawn by means of mathematical model. Experimental results seemed to be coherent.

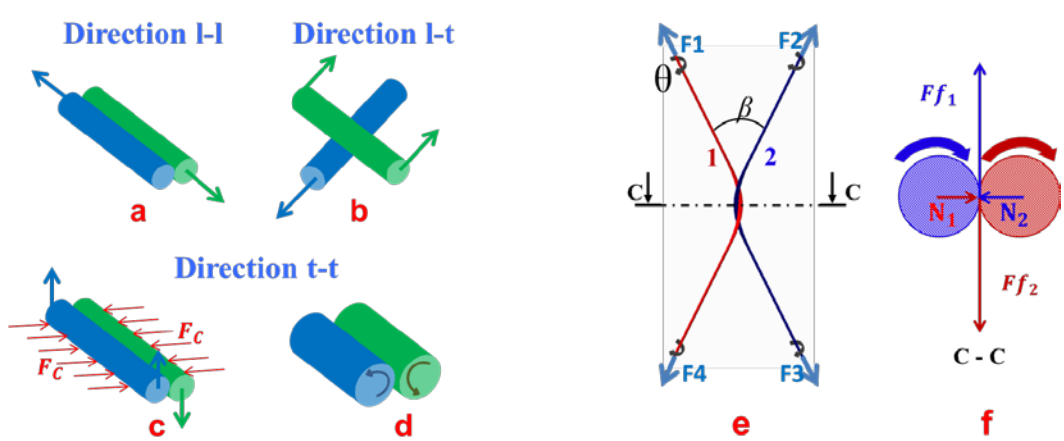


Figure 1 : Different friction types and special transversal friction configuration

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# Multiscale Investigation of Hair Fiber Surface Properties: Links Between Morphological and Tribological Behavior

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Hair that emerges from the human scalp is a highly organized fiber. It is a unique composite material, with a rather well-characterized microstructure. It is well known that the hair surface and structure of both cuticle and cortex can be altered by chemical treatments and daily-life routines (combing, brushing, UV exposure….). Many of the sensorial aspects concerning hair relate to friction. The condition of the hair surface is crucial in terms of cosmetic product applications and sensorial appraisal. Coating or damaging the surface can lead to very different surface states and hence to non-negligible differences in surface properties.

These changes clearly impact the sensory feeling. Predictive evaluation by a fast characterization of different coating can be very useful, but it is previously required to understand the relation between different scales (from microscopic to nanoscopic) and between morphology and tribology. In the present study, we aimed at understanding the link between the surface properties and tribological behaviour in terms of topography. Multi-scale tribological, mechanical and topographic investigations methods were used, to deal with issues such as biologically induced heterogeneities and fiber morphology. Coupling very different technics helps at addressing the following questions:  Is the roughness linked to the friction parameters? What is the contribution of nanoscale roughness to large scale tribological measurements? How does the surface (bio)chemical composition impact surface adhesion? Can we predict the mechanical behavior by a surface scanning? To present this multi-scale analysis approach, as shown on Figure 1, a native non coated hair is used as a reference.

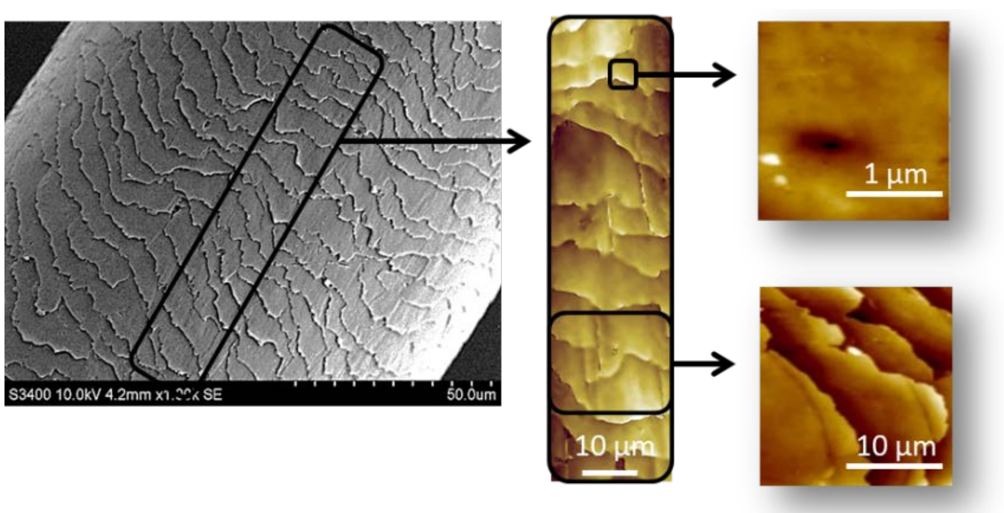


Figure 1: Multi-scale surface topographical analysis of natural hair.

Several techniques, such as friction measurements and mechanical surface properties were used to investigate tribological properties of hair/hair interactions. Novel techniques derived from hair wettability measurements were also used to bring new mechanical insights into fiber/fiber interactions by measuring hair/hair adhesion forces.

**ACKNOWLEDGMENT**

We would like to thank all the contributors for this work: Colette Cazeneuve, Amélie Krief, Sophie Vicic and Andrew Greaves for their help and very constructive discussions.

# Intrinsic Traceability of High-value Textiles Manufactured Using Natural Fibres

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In the wool textile sector new isotope measurement technology is being tested on both interior and apparel textiles to manage supply chain risks leading to opportunities for secure business to business partnerships. The technology, which utilizes stable isotope determination, can facilitate better brand protection and mitigate against negative practices, such as fibre substitution and falsifying labels. Wool fibre is often blended with fibre produced in other countries, however regulations apply to the use of licensed brands that contain particular portions of raw materials. These portions can be fraudulently adjusted to improve revenue, however product quality and performance can be seriously compromised reducing brand value.

**FIBRE TRACEABILITY**

A method using stable isotopes has been developed which is designed to integrate with internationally accepted wool specification systems used for marketing and trading fibre with potential application for other high quality protein fibres and their blends, such as Alpaca, Mohair and Vicuna.

**INTRINSIC MARKERS**

The isotope Delta Values (δ) are expressed in parts per thousand deviations (‰) (often referred to as 'per mil') relative to an international standard for background stable isotope levels. where the standards used for measurement comparisons are described as follows:

- $\delta^{2}H_{VSMOW}$, hydrogen isotope compared to the Vienna Standard Mean Oceanic Water (VSMOW),
- $\delta^{18}O_{VSMOW}$, oxygen isotope compared to VSMOW,
- $\delta^{15}N_{AIR}$, nitrogen isotope compared to the Ambient Inhalable Reservoir (AIR) standard,
- $\delta^{13}C_{VPDB}$, carbon isotope compared to the Vienna Pee Dee Belemnite (VPDB) standard, and
- $\delta^{34}S_{CDT}$, sulphur isotope compared to the Canyon Diablo Troilite (CDT) standard.

**BENEFITS**

Benefits arise from improvements in three main directions including risk management, product differentiation and productivity. Results discussed in this paper demonstrate the ability to discriminate between wool products from different locations using isotope markers as an effective method to verify credence claims associated with end products. These claims include the fact that wool fibre is produced sustainably in a number of countries subscribing to International Wool Textile Organization (IWTO) trading practices. These practices include an agreed platform of reputable technical and commercially focused standards covering natural resources, work place practices, animal welfare practices and performance measures for fibre, fabric and flooring textiles.

# Nanofibers

# ZnO Nanorods-assisted Carbonization of PAN Nanofibers

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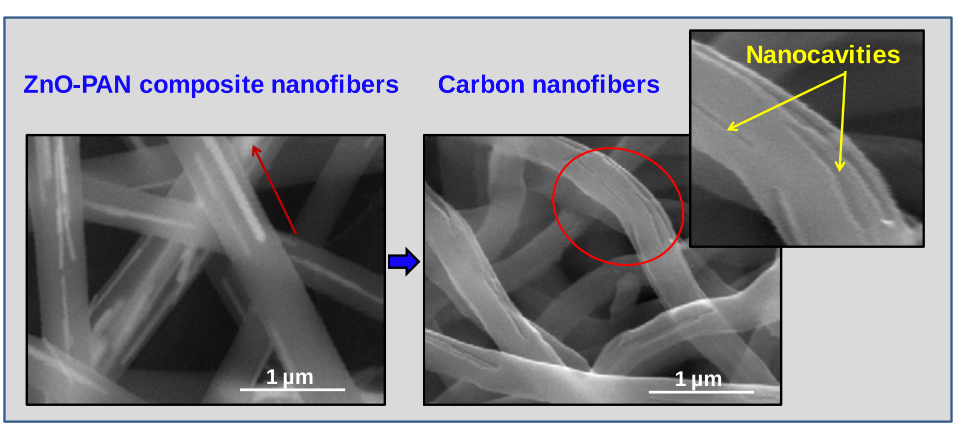
Carbon nanofibers (CNFs) because of their high mechanical strength, stiffness, modulii, high corrosion resistance, excellent thermal and electrical conductivity offer applications in various areas. Though precursor PAN nanofibers can be readily produced using electrospinning process, their conversion to CNFs is challenging. Due to their random nature, it is usually difficult to apply necessary tension or stretch during the conversion process, which is crucial for production of mechanically strong CNF. Also, the carbonization requires a slow two-step process of heat treatment- first step is a stabilization process and the second step is a carbonization process.

In this study, the effect of incorporation of rigid zinc oxide (ZnO) nanostructures on carbonization behavior of electrospun special acrylic fiber grade poly(acrylonitrile) (PAN-SAF) nanofibers was investigated. ZnO nanorods with high aspect ratio were incorporated in PAN-*N*,*N*-dimethylforamide system and the composite nanofibers reinforced with aligned ZnO rods upto 50 wt% were successfully electrospun (Figure 1(a)). The incorporation of ZnO nanorods was found to significantly improve the mechanical properties of the nanowebs. The tensile strength and modulus of the nanowebs with 50 wt% ZnO nanorods increased to 200% and 450%, respectively, compared to the nanowebs without ZnO. The composite nanofibers showed significantly lower extensibility and higher glass transition temperature indicating that the movement of polymer chains was highly restricted by the incorporation of ZnO rods. On carbonized, all the samples with ZnO nanorods were found to have significantly lower $I_D/I_G$ ratios. The $I_D/I_G$ ratio was found to decrease with increasing content of ZnO in the precursor fibers. The values decreased from 4.69 in control sample to 3.40 in samples with 10 wt% ZnO and to 2.33 in samples with 50 wt% ZnO. The rigid ZnO nanostructures present in the fibers played a crucial role by immobilizing the polymeric chains and keeping them oriented during the initial heating process with proper distribution of heat along the fiber.

At the end of the process, the ZnO nanorods were found to completely separate from the carbonized fibers yielding pure carbon nanofibers with high graphitic content and surface area (Figure 1(b)). The approach could be used to eliminate the slow, energy intensive stabilization step and achieve fast conversion of randomly laid carbon nanofiber webs in a single step to carbon nanofibers without the application of external tension or internal templates usually employed to achieve high graphitic content in such systems.




(a) (b)

Figure 1. SEM of (a) ZnO-PAN composite fibers and (b) the generated carbon fibers with nanocavities.

# Electrospun Nanofiber-assisted Hydrogel Thin Film on Shaped surfaces

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## INTRODUCTION

Hydrogels are promising materials composed of hydrophilic networked polymeric structures that absorb high amount of water [1]. Flexibility and tissue of hydrogels are very similar to natural tissue. Hydrogels have been produced and used for variety of purposes including as electrocardiography medical electrodes, encapsulation and immobilization of different materials such as enzymes and nanoparticles [2-3]. Producing hydrogel thin film is challenge because network structure can't allow dissolve or melt to coat shaped substrates easily. Electrospinning is a promising technology that allows nanofibers coating of shaped materials with desired thickness [4]. Hydrogel precursor polymers can be electrospun on a shaped structure. Then, exposing the crosslinking agent to nanofibers causes the formation of hydrogel structures without damaging the shaped structure. In this regards, PVA nanofibers were electrospun on cylindrical pencil graphite surfaces and hydrogel structure forms by treatment with chemical and physical crosslinking agent such as borax, sodium hydroxide and glutaraldehyde. Thikness of the hydrogels were controlled by amount of nanofibers electrospun on the substrate.

## MATERIALS AND METHODS

10 wt% of PVA was dissolved in water in an ambient condition by magnetic stirring. Pencil graphite was located in front of electrospinning needle with a distance of 10 cm. 7 kV voltage was applied to the needle and 1ml/hr was set for solution feeding in the needle. As-spun PVA NFs on pencil graphite were dipped in previously prepared borax/water solution. Finally, thin film hydrogel structures were obtained by the trasformation of PVA nanofibers to crosslinked network structure.

## RESULTS AND DISCUSSIONS

As-prepared PVA/water solution electrospun on cylindrical pencil graphite electrode. As-seen from Figure 1A and 1B, as-spun nanofibers were well coated on cylindrical pencil graphite surface. Nanofibers were randomly distributed to form 3D network structure on the surface. Thin film hdrogel morphology is very obvious on pencil graphite when as-spun nanofibers on pencil graphite were soaked in borax/water solution (Figure 1C and 1D). Some nanofibers din't dissolved and hence form hydrogel nanofibers as a composite structure demonstrated inset Figure 1D. Similar approach were applied by using sodium hydroxide and glutaraldehyde crosslinker.

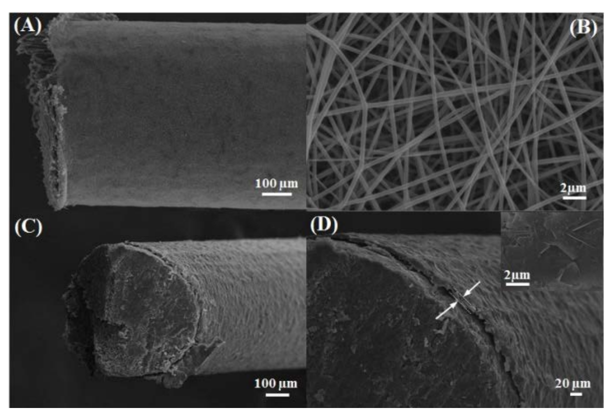


Figure 1. SEM images of (A, B) as-spun PVA NFs and (C, D) thin film hydrogel on pencil graphite.

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## ACKNOWLEDGMENT

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# Application of Nanofibers for Dye Removal of Colored Wastewaters

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In the recent years, the different types of the dyes are usually used in the industries such as Textile, Cosmetics and Food that produce a large volume of the colored wastewaters. These dyes have a hazardous effects for environment, due to their non-biodegradable organic compounds. Different physical and chemical methods are used for these colored wastewater treatment. Recently, there has been great interest for application of nanofibers in the adsorption and photocatalytic treatment processes with a high efficiency.

There are various methods of producing nanofibers, from high-volume production methods such as melt fibrillation, island-in-sea, and gas jet techniques, to highly precise methods like nanolithography and self-assembly, electrospinning and etc. Nanofibers can be effectively produced by electrospinning for the generation of polymer nanoscale fibers, which is a simple and low cost technique. The Nano materials generated using this technic have a large surface area and are highly porous making it very useful in many applications in diverse fields such as energy storage, healthcare, biotechnology, environmental engineering and etc.

In addition, electrospinning allows the production of nanofibers from several materials same as organics and inorganics, natural polymers, polymer blends, nanoparticle- or drug-impregnated polymers. This is highly beneficial for energy devices, where inorganic materials especially metal oxides can be synthesized and electrospun, improving conducting and ceramic properties. For examples, solar cells fabricated with aligned nanofibers metal oxide electrodes provide higher solar–electric energy conversion efficiency, whereas fuel cells made with nanofibers electrodes enable uniform dispersion of catalysts, and thus increase electro catalytic activity to obtain higher chemical–electric energy conversion efficiency.

Also the nanofibers can be used in filtration membranes for environmental remediation, minimize the pressure drop and provide better efficiency than conventional fiber mats. The large surface area-to-volume ratio of nanofiber membranes allows greater surface adsorption of contaminants from air and water, and increases the life-time of the filtration media. Using of electrospun Nano fibrous which have semiconductor properties, is a suitable alternative with nanophotocatalyst particles in photoreactor to reach the optimum efficiency to degradation of colored wastewater in textile industries, and it be considered interactive solution for the environmental issues. In the present research, efficiency of the different nanofibers has been compared to find an optimum condition of the treatment process.

# Investigation of the Structural Parameters in Electrospun Piezo Nanofibers and Yarns

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**ABSTRACT**

Polyvinylidene fluoride (PVDF) is a piezoelectric polymer material which commonly used as film structures for fabrication of different kind of piezo sensors and energy harvesting applications. This polymer is biocompatible, flexible and has lightweight. PVDF is a semi-crystalline material including the nonpolar α phase, polar β phase, γ and δ phase. The piezoelectricity originates from the spontaneous polarization of the C-F dipole on PVDF chain forming the β phase. Electrospinning process is an enabling technique which could enhance the β phase formation during fiber fabrication. Nanofiber-based piezoelectric pressure /bending sensors could be flexible sensing devices applicable in various application such as e-textile, medical devices and implants, and etc. by converting mechanical energy to electrical and vice versa. It could generate the electrical energy by temperature changing, too. In this work we investigate the piezoelectric properties of PVDF electrospun nanofibers in different structures. The geometric parameters in the pressure sensors were evaluated, which include the fineness of nanofibers, the orientation and thickness of nanofiber layers and also yarn structures. The yarn was fabricated by a new method which could be applied additional drawing on nanofibers and also applying the twist.

The pizo-electrical response of nanofiber sensors have shown at least 100% enhancement comparing to pure PVDF films. The XRD and FTIR results indicated that decreasing the nanofibers diameter from ~740 to 240 nm could enhance the β phase formation in resultant nanofibers, as it was obtained ~63% enhancement in piezo test. It was found that the alignment of nanofiber could improve the piezo response to about 30% which could to be enhanced better in nanofibrous yarn by changing the draw ratio and twist level.

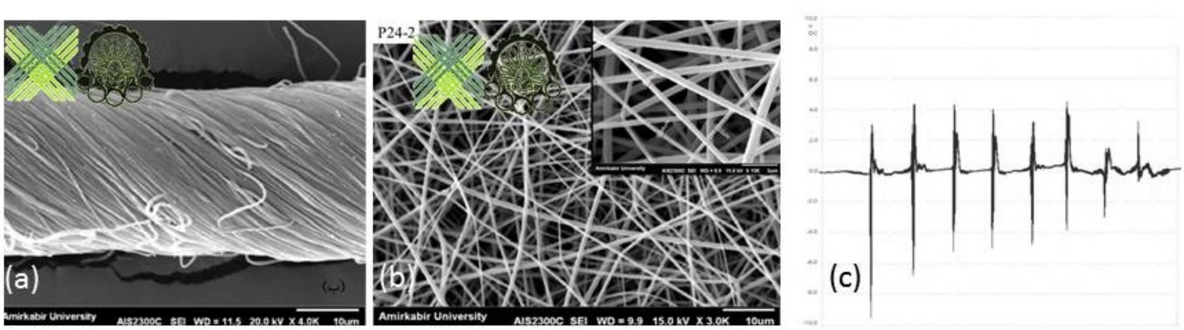


Figure 1: (a) Nanofiber yarn, (b) Nanofiber layer, (c) The output voltage results in the study of nanofiber fineness effects in piezo pressure test.

# Biobased Materials

# Development of Biobased Self-reinforced Polymer Composites

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**INTRODUCTION**

SRPCs combine high stiffness, high impact and high durability without impairing recyclability. In SRPCs the same polymer is used for the reinforcing and matrix phases. The polymers commercially used for self-reinforced polymer composites (SRPCs) today are derived from fossil resources. However, due to a limitation of resources, interest is growing regarding the use of bio-based alternatives. This demand has led to a significant growth of bio-plastics in terms of technological developments. Due to their low mechanical performance and durability, their use is still limited.

**EXPERIMENTAL**

SRPCs can be manufactured by commingling two yarns with different melting temperatures. The use of commingled yarns allows the combination of a large variety of fibres and therefore a wide range of material properties. The commingled yarns are processed into a textile and consolidated afterwards. Only the low melting temperature polymer is molten during the consolidation process. The fibres with the high melting temperature remain intact and act as the reinforcing phase of the composite. The focus of this work is on the production of such composites. The paper will include the process chain from melt spinning to heat pressing of textiles made of bio-based PLA commingled yarns.

**CONCLUSION**

SRPCs can be made by commingling two melt spun yarns with different melting temperatures. The research shows the potential of PLA based SRPCs using the described process chain. SRPCs made from PLA grades enable unique features for lightweight structures like recyclability and biocompatibility. The optimization of the processing parameters will increase the SRPC properties. Also the modification with nanofillers may increase mechanical properties.

**ACKNOWLEDGMENT**

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# Tailored Fiber-reinforced Gelatin Hydrogels for Biocomposite Printing

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Advances in biology and stem cell engineering have placed increasing importance on investigating the technique and application of bioprinting for the generation of novel and highly customized geometries desired in biomedical scaffolds. However, the majority of current bioprinting techniques do not account for mechanical anisotropy within the printing media. In this study, the mechanical properties of a novel extruded fiber reinforced gelatin based hydrogel scaffold were investigated for applications in biocomposite printing. The effect of various environmental parameters on mechanical properties of the biocomposite material were investigated. The primary objective of this study was to establish a repeatable and standardized procedure that could be used for future mechanically tailored biocomposite printing. The secondary goal of this study was to investigate the impact of relevant properties on the mechanical behavior of extruded biocomposite constructs with the aim of more accurately matching native tissue and its complex microstructure. The tertiary goal of this study was the development of an automated machine to utilize tailored fiber orientation to customize mechanical anisotropy. An initial example of tailored fiber reinforced gelatin based hydrogel biocomposite in implementation is presented.

# Cellulose Aerogel Fibres for Thermal Encapsulation of Diesel Hybrid Engines

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**ABSTRACT**

Hybrid engines and efficient mobility are important issues of modern time, with global warming demanding a decrease in $CO_2$ emissions. Current technologies such as Start/Stop automation have proven to be effective to some degree. By insulating hybrid engines, a constant, ideal operating temperature can be attained more easily and emissions can be reduced further. In the case of weight-related limitations, conventional materials cannot be used as a sufficient heat-insulating medium. They are either too heavy, require too much space or have too high thermal conductivities. Aerogel fibres made up of cellulose could revolutionize the efficiency of hybrid motors. Cellulose is one of the most abundant natural materials in the world. It is completely organic and biodegradable, and could be used in the mobility sector as well as for medical implementation. Aerogels are pore systems of solid material consisting of up to 99.9 % air. They can be synthesized out of various polymers using, most commonly, the sol-gel process. Due to their nature these cannot be applied in some fields. By producing aerogels in form of a fibre in a wet spinning process, additional flexibility and strength are added to the material and the range of applications increases drastically. Research was done at the Institut für Textiltechnik (ITA) of the RWTH Aachen University in the production of cellulose aerogel fibres. It is shown that a single fibre production process is not optimal to produce aerogel nonwoven structures. Therefore a solution spinning process producing a nonwoven within the spinning process itself was investigated. An up-scaled laboratory process is developed to process bigger amouts of spinning dope and to prove the possibility to produce bigger amounts of aerogel textiles.

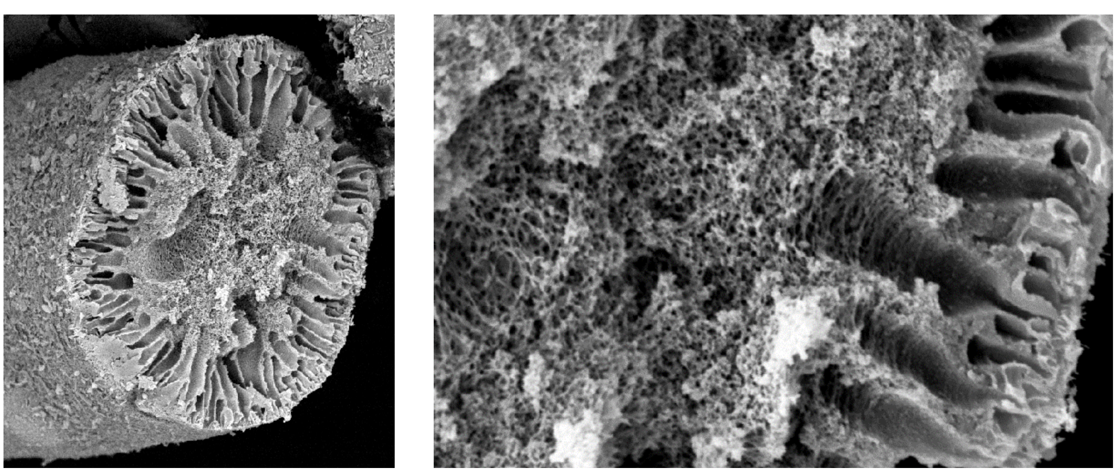

Fig. 1. Cellulose Aerogel Fibre with nano-porous pore system

**ACKNOWLEDGMENT**

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# Biomedical Applications

# N-halamine Technology for Antimicrobial Wound Dressings

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This research focused on developing new antimicrobial wound dressing materials utilizing novel N-halamine chemistry that are less expensive, superior to those technologies on the market today in efficacy against pathogens causing wound infections, and biodegradable in the environment. This work has demonstrated the successful application of the N-halamine technology onto wound dressings rendered antimicrobial by a facile and inexpensive coating process. Currently available wound dressings consist of antibacterial agents such as silver and biguanides that are believed to cause environmental and toxicity problems. High levels of exposure to these agents raise health concerns. To our knowledge, there is no available commercial product that uses novel N-halamine chemistry for wound dressing applications. In this regard, different types of N-halamine compounds, which possess different functional groups and chemistry, were synthesized. Standard non-antimicrobial wound dressings were impregnated with the synthesized N-halamine compounds which contained oxidative chlorine, the source of antimicrobial activity. Antimicrobial efficacies of these wound dressings employed with N-halamine compounds were evaluated against *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Contact time-kill experiments exhibited that the *N*-halamine coated wound dressings inactivated 7 logs of *S. aureus* and *P. aeruginosa* within 30 to 60 minutes of contact time. Moreover, N-halamine activated wound dressings showed superior antimicrobial efficacy when compared to commercially available silver wound dressings. Zone of inhibition tests were also performed to determine if there were any leaching of the antimicrobials from the wound dressing materials. It was observed that there was no significant leaching of the oxidative chlorine from the materials. Shelf life stability tests showed that the dressings were stable to loss of oxidative chlorine when they were stored in a dark environment. They also remained stable under florescent lighting for up to 2 months of storage. They could be stored in opaque packaging to improve their shelf life stabilities. In vitro skin irritation test was performed using three-dimensional human reconstructed tissue model (EpiDerm™). No skin irritation was observed. The results indicated that N-halamine wound dressings potentially can be employed to prevent infections, while at the same time improving the healing process by eliminating undesired bacterial growth.

**KEYWORDS**
N-halamines, antimicrobials, wound dressings

# Development of Novel Coextruded and Wet Spun Fibers for Medical Applications

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**ABSTRACT**

The coextrusion of two or more polymer components into a single filament through melt spinning is state of the art. Multiple fiber geometries such as core-shell or side-by-side are possible. Especially for medical applications, the major disadvantage of this technology is the limitation to the usage of thermally stable polymers and substances. For the combination of thermally instable polymers (e.g. biopolymers, polylactides) and substances (e.g. drugs, growth factors) in a single fiber the wet spinning process is eligible. Due to the development of a novel coextrusion wet spinning line it is now possible to combine different polymers with thermo-sensitive substances like proteins or drugs in one coextruded fiber. This will enable the access to a new field of fibers and has in particular a high relevance for the medical sector. Currently, textiles made out of biodegradable polymers are used in several medical applications such as sutures, wound dressings and implants. Nevertheless, the degradation of most commonly used biomaterials results in a sudden release of acidic degradation products. The acid may lead to massive inflammatory reactions and dramatic clinical complications. Therefore, fibers with a pH-neutral degradation are required. Our work in this field focusses on the coextrusion of fibers which show pH-buffering properties using thermosensitive buffer systems. Accordingly, the acid released during the degradation will be neutralized before becoming clinically relevant.

# Interaction of Material and Structural Elasticity In a Small Calibre Vascular Graft


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**ABSTRACT**

Cardiovascular diseases remain one of the most common causes of death in developed countries, such as Germany. In terms of diseases vessel segments of the arterial system, various commercially synthetic vascular grafts are available for treatment. Despite continuous progress in research, small calibre vascular prostheses (diameter < 6 mm) used in clinical routine show low long term patency rates. One of the causes often mentioned in literature is the compliance mismatch between the vascular graft and the native vessel.

At the Institut für Textiltechnik of RWTH Aachen University a textile vascular graft (ElaGraft) is developed. Hereby, a novel approach combining both material and structural elasticity in order to mimic the stress-strain behaviour of native vessels is used. Elastic and non-elastic yarns are combined within the fabric by use of warp knitting technology. The aim of the development is a small-calibre vascular graft (d ≤ 6 mm) with significantly enhanced compliance properties compared to today's clinical standard.


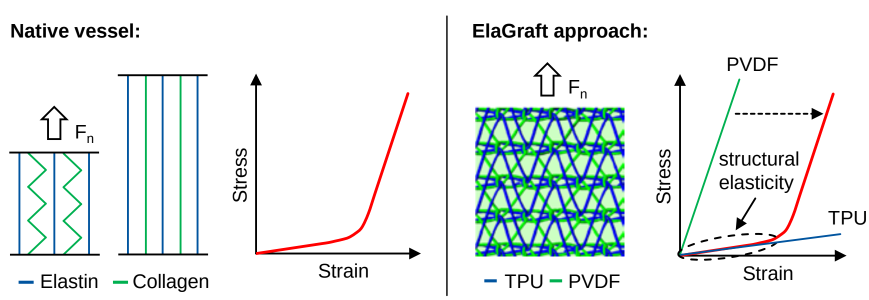


Figure 1: Simplified representation of the mechanical structure of native vessels (left) and transfer of these physiological characteristics into a vascular graft combining material (TPU) and structural (warp knit) elasticity (right)

In a first step, melt spun thermoplastic polyurethane (TPU) multi-filament fibres are developed. Due to its elastic properties combined with high hydrolytic and oxidative stability, a medical grade polycarbonate urethane (PCU) is chosen for this purpose. The elastic TPU fibres are combined with non-elastic PVDF fibres in a warp knitted tubular fabric by use of a counter-lapping 1x1 lap - 2x1 lap. The desired mechanical properties of the textile vascular graft are achieved by systematic variation and interaction of the melt spinning parameters and warp knitting parameters. The validation of the tubular warp knitted fabrics is performed by measuring the compliance properties under physiological conditions. The data obtained is compared to the compliance of native vessels and commercially available vascular grafts.

In this presentation the development of a small-calibre vascular graft from the yarn to the final tubular fabric will be described. In the first part the focus will be on the melt spinning parameters and the resulting yarn properties. In the second part the focus will be on the interaction of the TPU yarn properties and the warp knitting parameters with regards to the compliance and stress-strain behaviour of the final fabric.

# Yarns and Fabrics: Processes, Structures, and Properties

# Examining the Effects of Fiber Types and Fabric Tightness on Bursting Strength of Circular Knit Fabrics Produced from Vortex Yarns

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## INTRODUCTION

Murata Vortex spinning (MVS) is one of the unconventional systems for yarn manufacturing. The vortex yarn spinning process is suitable to the spinning of 100% cotton fibers, synthetic fibers and cotton/synthetic fiber blends from 1″ length. The products as Ne 15-60 are used in home textiles, clothing and still most circular knitting. The previous works focused on determining yarn formation, yarn structure, and the effect of process parameters on vortex yarn properties. In the other studies, the produced vortex yarns and fabrics were compared with ring and rotor spinning systems by using man-made fibers, combed cotton fibers and their blends.

## MATERIAL AND METHODS

The aim of this study is to investigate the effects of fiber types and fabric tightness on bursting strength of circular knit fabrics produced from vortex spun yarns. For this purpose, 17 yarns were produced at different blend ratios in Murata Vortex Spinner. These yarns were knitted in circular knitting machine, and were dyed. The bursting strength tests were applied for these fabrics in accordance with TS EN ISO 13938-2 standard. Hence, the properties of the yarns and knit fabrics were determined according to relevant standards. In the following tables, fiber properties, production parameters, yarn properties, and fabric properties, respectively.

Table I. Fiber properties

| | Fiber symbols | Fineness, dtex | Length, mm | Tenacity, cN/tex | Elongation, % |
|---|---|---|---|---|---|
| **Cotton** | CO | 1.8 | 29.25 | 30.13 | 6 |
| **Viscose** | CV | 1.3 | 38 | 23.84 | 19 |
| **Modal** | CMD | 1.3 | 39 | 35 | 13 |
| ***Flexsil-D2™** | FD2 | 1.3 | 38 | 62 | 18 |
| **Polyester** | PES | 1.3 | 38 | 57.4 | 23 |
| **Nylon 6.6** | PA | 1.7 | 40 | 55 | 46 |

*Polyester fiber containing silver ions

Table II. Vortex yarn and fabric production parameters

| **Yarn spinning** | |
|---|---|
| Machine type | Vortex 861 |
| Delivery speed | 350 m/min |
| Air pressure | 5.5 bar |
| Spindle diameter | 1.1 mm |
| FR-SP distance* (high cotton ratio) | 19 mm |
| FR-SP distance* (low cotton ratio) | 20 mm |
| Yarn count | 30 Ne |
| **Fabric production** | |
| Machine type | Mayer-Relanit |
| Diameter | 30 inch |
| Gauge | 28 |
| Stitch lengths | 2.7 mm and 3.0 mm |
| Dying process | According to fiber type |

*The distance between front roller and spindle

Table III. Yarn properties

| % | Fiber types | Diameter mm | Shape | Density g/cm | Unevenness CV% | Thin -50% | Thick +50% | Neps +200% | Hairiness H | *Tenacity cN/tex* | *Elongation %* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100% | **CO** | 0.236 | 0.73 | 0.42 | 17.41 | 200.5 | 192 | 576 | 4.3 | ***10.39*** | ***4.98*** |
| | **CV** | 0.221 | 0.78 | 0.51 | 12.65 | 4.5 | 20 | 17 | 4.04 | ***13.41*** | ***7.99*** |
| | **CMD** | 0.207 | 0.78 | 0.58 | 12.11 | 0.5 | 4 | 15.5 | 3.55 | ***19.25*** | ***8.18*** |
| 95-5% | **CO-FD2** | 0.226 | 0.73 | 0.43 | 18.08 | 264.5 | 244.5 | 485.5 | 4.09 | ***9.94*** | ***4.81*** |
| | **CV-FD2** | 0.209 | 0.79 | 0.58 | 12.20 | 1 | 5 | 6.5 | 3.45 | ***14.66*** | ***8.63*** |
| | **CMD-FD2** | 0.212 | 0.80 | 0.58 | 11.21 | 0.5 | 0 | 3.5 | 3.72 | ***18.35*** | ***7.13*** |
| 90-100% | **CO-FD2** | 0.230 | 0.72 | 0.43 | 17.90 | 270.5 | 229 | 499 | 4.2 | ***10.89*** | ***4.80*** |
| | **CV-FD2** | 0.206 | 0.81 | 0.60 | 11.99 | 1 | 1 | 5 | 3.32 | ***15.15*** | ***9.27*** |
| | **CMD-FD2** | 0.211 | 0.79 | 0.58 | 11.46 | 0 | 0.5 | 3.5 | 3.52 | ***18.47*** | ***6.91*** |
| 50-45-5% | **CO-CV-FD2** | 0.217 | 0.79 | 0.54 | 14.57 | 17.5 | 33 | 115.5 | 3.34 | ***10.85*** | ***5.04*** |
| | **CO-CMD-FD2** | 0.219 | 0.78 | 0.53 | 14.18 | 10.6 | 23.1 | 105.6 | 3.43 | ***13.14*** | ***5.46*** |
| | **CO-PES-FD2** | 0.219 | 0.78 | 0.51 | 15.40 | 56 | 81 | 194.5 | 3.46 | ***16.14*** | ***7.22*** |
| | **CO-PA-FD2** | 0.230 | 0.76 | 0.46 | 16.71 | 123 | 109.5 | 102 | 3.56 | ***15.78*** | ***12.59*** |
| 60-30-10% | **CO-CV-FD2** | 0.218 | 0.78 | 0.52 | 15.39 | 38 | 75 | 179.5 | 3.43 | ***10.83*** | ***5.29*** |
| | **CO-CMD-FD2** | 0.219 | 0.78 | 0.52 | 15.75 | 45.5 | 71 | 201 | 3.42 | ***12.84*** | ***5.71*** |
| | **CO-PES-FD2** | 0.224 | 0.77 | 0.48 | 15.38 | 52.5 | 74.5 | 166 | 3.63 | ***14.42*** | ***6.82*** |
| | **CO-PA-FD2** | 0.223 | 0.78 | 0.49 | 16.49 | 105 | 115 | 164 | 3.36 | ***12.92*** | ***9.61*** |

Table IV. Fabric properties

| Fabric types | | Courses/cm, cpc | | Wales/cm, wpc | | Stitch density/cm$^2$ | | Weight, gr/m$^2$ | | Thickness, mm | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2.7** | **3.0** | **2.7** | **3.0** | **2.7** | **3.0** | **2.7** | **3.0** | **2.7** | **3.0** |
| **100%** | **CO** | 18.83 | 15.50 | 14.08 | 14.00 | 265.1 | 217.0 | 129.8 | 114.2 | 0.477 | 0.460 |
| | **CV** | 20.50 | 15.92 | 14.08 | 14.00 | 288.6 | 222.9 | 148.3 | 128.2 | 0.410 | 0.410 |
| | **CMD** | 19.25 | 15.92 | 14.42 | 13.42 | 277.6 | 213.7 | 139.8 | 119.5 | 0.403 | 0.377 |
| **95-5%** | **CO/FD2** | 20.00 | 16.5 | 14.67 | 13.83 | 293.4 | 228.2 | 132.3 | 117.3 | 0.470 | 0.477 |
| | **CV/FD2** | 21.75 | 17.92 | 14.42 | 13.75 | 313.6 | 246.4 | 164.7 | 141.7 | 0.427 | 0.417 |
| | **CMD/FD2** | 20.58 | 17.00 | 14.67 | 13.83 | 301.9 | 235.1 | 162.3 | 136.3 | 0.420 | 0.403 |
| **90-10%** | **CO/FD2** | 20.67 | 17.00 | 14.33 | 14.00 | 296.2 | 238.0 | 137.6 | 124.2 | 0.487 | 0.483 |
| | **CV/FD2** | 22.75 | 17.50 | 14.17 | 14.67 | 322.4 | 256.7 | 169.2 | 147.3 | 0.433 | 0.417 |
| | **CMD/FD2** | 21.67 | 16.75 | 14.00 | 13.92 | 303.4 | 233.2 | 160.7 | 139.5 | 0.427 | 0.410 |
| **50-45-5%** | **CO/CV/FD2** | 23.33 | 19.08 | 14.00 | 13.58 | 326.6 | 259.1 | 175.2 | 156.5 | 0.510 | 0.503 |
| | **CO/CMD/FD2** | 21.50 | 17.50 | 14.17 | 13.75 | 304.7 | 240.6 | 163.3 | 144.5 | 0.483 | 0.477 |
| | **CO/PES/FD2** | 22.00 | 17.92 | 14.33 | 13.83 | 315.3 | 247.8 | 163.3 | 143.2 | 0.503 | 0.490 |
| | **CO/PA/FD2** | 22.00 | 18.17 | 14.83 | 14.00 | 326.3 | 254.4 | 174.0 | 146.5 | 0.513 | 0.503 |
| **60-30-10%** | **CO/CV/FD2** | 22.58 | 18.50 | 14.17 | 13.83 | 320.0 | 255.9 | 169.2 | 149.2 | 0.500 | 0.503 |
| | **CO/CMD/FD2** | 21.75 | 17.83 | 14.50 | 14.00 | 315.4 | 249.6 | 161.7 | 143.5 | 0.487 | 0.493 |
| | **CO/PES/FD2** | 22.00 | 18.00 | 15.00 | 14.42 | 330.0 | 259.6 | 169.2 | 146.8 | 0.503 | 0.497 |
| | **CO/PA/FD2** | 22.33 | 18.00 | 14.08 | 14.00 | 314.4 | 252.0 | 161.3 | 142.5 | 0.503 | 0.503 |

## RESULTS AND DISCUSSION

The bursting strength values of vortex fabrics were given in Figure 1. For two blend fabrics, between the fabrics having cellulosic fibers, the fabrics containing modal fibers have higher bursting strength. Viscose fabrics have lower strength than cotton fabrics as the fabrics containing viscose have higher strength than the fabrics containing cotton at 95-5% and 90-10% blend ratios. The reason of this is that viscose fabrics have lower thickness by expansion than cotton fabrics.

For three blend fabrics, the fabrics containing polyester and nylon fibers have the highest bursting strength values than those of the other fabrics at all different fiber blend ratios and two different fabric tightness. The bursting strength values are very close in the fabrics contaning viscose and modal, and these values are much lower in comparison to the fabrics having polyester and nylon. On the other hand, in the fabrics containing modal, the bursting strength values are lower than expected when compared to the fabrics having viscose since the physical properties of these fabrics  are worse. As for the fabrics having polyester and nylon, the difference in strength can be explain that their elongation values are different. In other words, the fabrics having nylon have higher bursting strength values than the fabrics with polyester owing to the breaking elongation values in nylon fiber and nylon yarn are higher. The correlation coefficient also support this result.

The bursting strength results are correspond to yarn strength values, and so fiber tenacity. In other words, increasing of the yarn and fiber strength increases fabric strength. A clear difference is not observed by changing of Flexsil fiber ratio for the bursting strength values of vortex fabrics. On the other hand, the fabrics having 2.7 mm stitch length have higher bursting strength values than the fabrics having 3.0 mm stitch length.

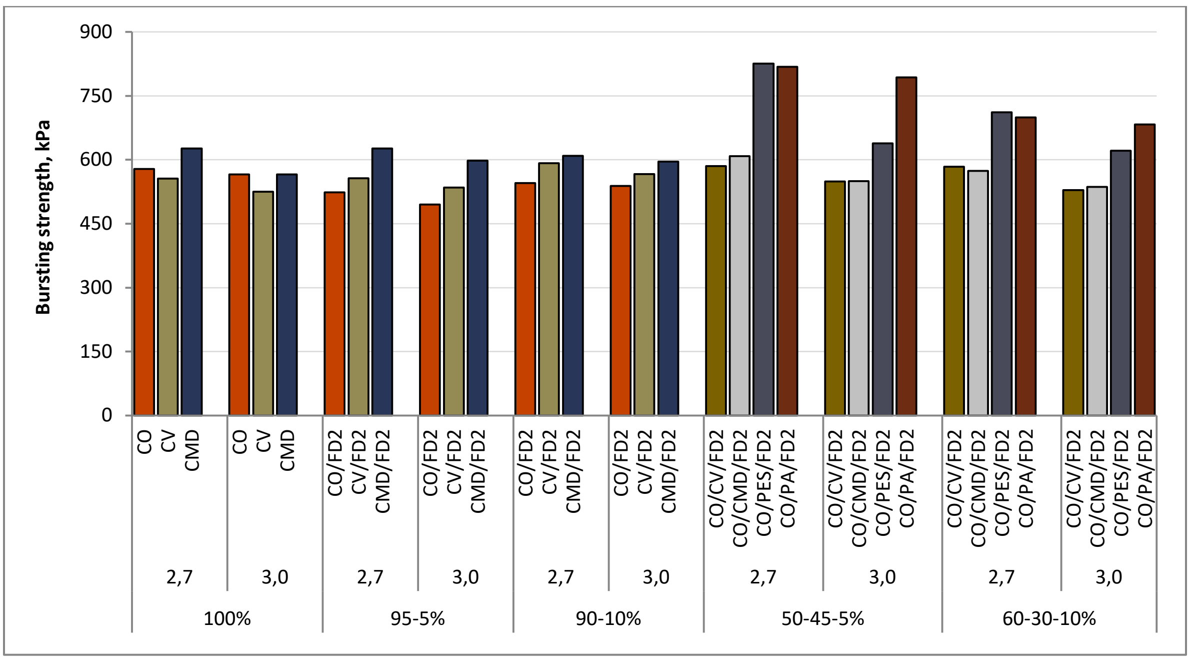


Figure 1. Bursting strength values of vortex fabrics

**CONCLUSION**

- The most effective factor on bursting strength of vortex knit fabrics is fiber type.
- The bursting strength values increase in parallel with yarn and fiber strength values.
- Increasing of the stitch length or decreasing of fabric tightness reduces the bursting strength.
- When the stitch length increased, the effect of yarn elongation is higher than that of yarn tenacity since the stitch find more space to elongate in loose fabrics.  Between the fabrics having cellulosic fibers, modal is the most positive fiber in terms of bursting strength.
- Although cotton fiber has higher tenacity than viscose fiber,  the bursting strength values are lower in the fabrics containing high cotton since the yarns with  high cotton have lower tenacity.
- The fabrics having higher cpc, wpc, stitch density, weight and thickness or in other words the fabrics having more tightness increase the bursting strength.
- Flexsil fiber has not clear effect on bursting strength because it is used in very low ratios.


**ACKNOWLEDGMENT**

We wish to express our appreciation to the employees of SELÇUK IPLIK-ORGU-BOYA IŞLETMELERI, Gaziantep, Turkey, for yarns and fabrics producing, and SANKO IPLIK-BOYA IŞLETMELERI for testing the yarn and fabric samples. We would also like to express gratitude to Çukurova University Scientific Research Project Unit (BAP) for funding (Project Number: FDK-2015-4508).

# An Investigation of Performance Properties of Warp Knitted Carpets

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**INTRODUCTION**

Carpet is a type of floor covering whose appearance is the quite important parameter for preference. Appearance of the carpet is affected abrasive wear, extension, friction, walking, loading, cleaning etc. By these effects, the piles flatten and the surface smoothness, color and attractiveness changes and so using life of the carpet is ended while the durability continues [1]. Therefore, it means that the lifetime of the carpet depends on the appearance retention more than the durability. One of the most important quality factors in carpets is thickness loss (deformation in compress) by static and dynamic loads. By this loss, not only does the carpet appearance on the face lose its original form, but the carpet's resilience capability is also lost [2].Generally, warp knitted carpets are the type of spacer fabrics. Spacer fabrics are produced by double needle bar raschel warp knitting machine. In double needle of machine, fabrics can be produced as double face fabric or single face fabric by changing the movements of two guide bars.

**MATERIALS AND METHODS**

This article investigates the performance of warp knitted spacer carpets. Study was carried out on two different types of warp knitted carpets. The carpet samples were manufactured with raschel type, double bar warp knitting machine. They are differing in pile material (acrylic and polyester), pile density, pile count, pile length and the unit weight. Divided single-face piled gray fabrics were colored by printing machines and then the fabrics were brought to fixation to make their color stable. In the washing unit, extra dyes and chemicals were removed from the fabrics and by cationic softeners the fabrics were softened. Then the fabrics passed to the dryer. After drying the distance between piles were opened by brushers. The name of this process was pre-raising. The faces of the carpets were raised and the lengths of the piles were equalized by scissors. Finally the fabrics were brought to the latex unit. Due to the fact that, warp knitted carpets are generally used as bath carpets, these carpets have to be laminated by latex treatment. Latex application ensures both reinforcement and resistance to slip. In accordance with the using aim, these carpets are exposure to intense mobility. Therefore these carpets have to protect their views and the pile resilience after overriding, hoovering and laundering. Obtained finished carpet samples were conditioned in laboratory conditions (20°C and 65 % Rh) for 24 h [31] and then the performance of the carpets were tested by hexapod tester, dynamic loading tester, abrasion resistance tester and dimensional stability with home type laundering machine according to the international standards [32-35].After all the tests, the results were commented according to their view and thickness loses.

**RESULTS AND DISCUSSIONS**

Following are the significant results of this study:

•In accordance with hexapod test results acrylic warp knitted carpets are more resistant to traffic than polyester warp knitted carpets.

•According to the dynamic loading test acrylic warp knitted carpets can withstand to loading more than polyester warp knitted carpets.

•Polyester warp knitted carpets are more durable than acrylic warp knitted carpets against abrasion test.

•Both acrylic and polyester warp knitted carpets can be laundered with machine with no dimensional and view changes.

•On the durability of warp knitted carpets the pile raw material, pile length and tightness are important parameters according to the test results.

**CONCLUSION**

Briefly, warp knitted carpets can be used at homes by a long time without any deformation. Especially, these carpets are useful at bathroom which is generally wet and has less traffic than other rooms of home. Due to the less cost and less process and good performance of these carpets, they will be popular with near future.

# Emissivity Characterization of Different Stainless Steel Textiles in the Infrared Range

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We investigated, both experimentally and theoretically, the infrared emissivity of a set of stainless steel textiles, prepared using different type of fabrics. Infrared emission of the textiles was characterized in the mid-infrared range by observing their temperature evolution under heating regime with a focal plane array (FPA) infrared camera. Standard test method for measuring and compensating emissivity using infrared imaging radiometers as well as a reference surface of known higher emissivity was applied to the set of metallic textiles. The obtained experimental results allowed to retrieve the infrared emissivity at different applied temperatures. The measured data were interpreted by means of Plank's theory of black-body radiation. Finally, the investigated textiles composed of stainless steel yarns differ by the type of fabrics, while all appear to be suitable for thermal shielding applications.

# How Nonwovens Avoid the Shrink?

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**INTRODUCTION**

Conventional materials having positive Poisson's ratio tend to be thinner in lateral directions due to the applied longitudinal (tensile) strain. Although, there are certain materials that can expand in at least one lateral direction on stretching. These materials are known to be auxetic materials. Designing non-periodic auxetic materials in the form of nonwoven materials is a challenge, which is due to the lack of understanding of governing micro-mechanisms exhibited by such materials.

**OBJECTIVES**

The main objective of the research work was to systematically investigate the out-of-plane auxetic behavior of needlepunched nonwoven materials (NNMs) through theoretical modeling and extensive experiments.

**MATERIALS AND METHODS**

In this research work, a set of sixteen NNMs was prepared from polyester fibers (length: 60 mm, linear density: 3.3 dtex) by varying key process parameters including punch density, depth of needle penetration and direction of needling. On-line Poisson's ratio measurements were determined both in the machine and cross-machine directions using tensile testing equipment by capturing the images in the width-wise and thru-thickness directions under defined levels of strains (5%, 10%, 15%, 20%) using two orthogonally placed digital cameras.

**RESULTS AND DISCUSSION**

Under uniaxial tensile loading, the anisotropy coupled with local fiber densification in NNMs have yielded large negative Poisson's ratio (up to -5.7) specifically in the preferential direction, as shown in Figure 1.

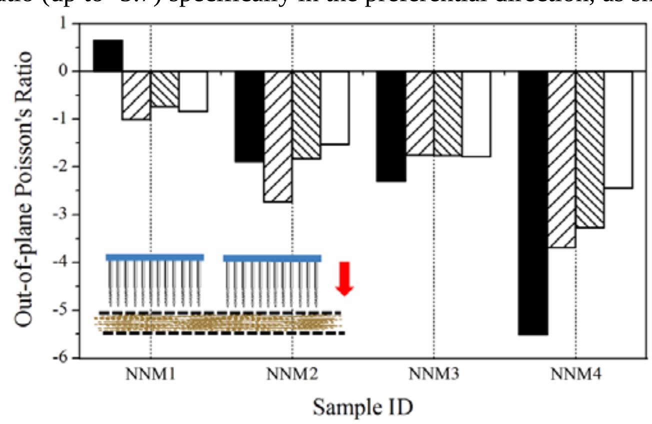


Figure 1. Out-of-plane Poisson's ratio for NNMs in preferential direction

**CONCLUSIONS**

A design strategy to create NNMs with out-of-plane auxetic behavior has been proposed through theoretical modeling and extensive set of experiments. In general, a reasonable agreement has been observed between the theoretical and experimental results of in-plane and out-of-plane Poisson's ratio of NNMs.

**ACKNOWLEDGMENT**

One of the authors (AR) gratefully acknowledges the support of research fellowship for experienced researchers from Alexander von Humboldt Foundation at the Fraunhofer Institute for Industrial Mathematics (ITWM), Kaiserslautern, Germany and Institut für Textil- und Verfahrenstechnik, Denkendorf, Germany.

# Effects of the Laundering Process on Dimensional Properties Lacoste Fabrics Made from Modal/Combed Cotton-blended Yarns

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**INTRODUCTION**

Due to the influence of fashion, the production of knitted goods has been expanded with new fabric designs created with different fiber blends and knit structures. Dimensional change of fabrics, especially due to repeated laundering, is a critical attribute and hence, its accurate quantification is a major concern for all sectors of the textile industry. It was examined the effects of domestic laundering on lacoste knitted fabrics which are made of modal/combed cotton blend yarn over a large number of wash cycles and to identify and damaging aspects of the laundering process.

**MATERIALS AND METHODS**

Modal fiber is one of the regenerated cellulose fibers. It is obtained by process giving a high tenacity and a high wet modulus. Modal fiber's gentle, comfortable handle, lustrous and high wet and dry tensile strength fastness values formed in yarn features with cotton fiber's known characteristics. In this study, 50/50 modal/combed cotton blended yarns were used. Modal fiber fineness 1,2 dtex, fiber length 38 mm. Combed cotton fiber properties as follows; fiber length is 29 mm and fibre fineness of 4.5 μg/inch.

**RESULTS AND DISCUSSION**

In this study is to investigate lacoste knitted fabrics made from modal/combed cotton blended over a large number of wash cycles, and to identify and damaging aspects of the laundering. Also, how similarly constructed modal/combed cotton blends knitwear fabrics were subjected to up to ten laundering cycles in a variety of washing and drying conditions were described.

Modal/Combed cotton blended fabrics were performed ten times repeatedly washing and drying cycle. The changes of the widthwise direction of the lacoste fabrics were measured between 5-15%, on lengthwise direction it was measured between 10-20%.

**CONCLUSION**

This work was to investigate the effect of the principal washing and drying variables on the dimensional stability of knitted fabrics. Experimental study were evaluated, it was observed that dimensional stability, bursting strength and air permeability properties of fabrics change statistically significantly by the change in yarn count and fabric density. Thickness values of the samples were very close to each other and it was found that the differences between the thickness values were not statistically significant.

**ACKNOWLEDGMENT**

The author is grateful to the company Fıstık Tekstil Örme Sanayi ve Tic. Ltd. Şti. for producing of the fabrics used in the study.

# Antibacterial Activity of Nonwoven Cleaning Materials Treated with Silver Nanoparticles after Newly Developed Repeated Washing Process

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**OBJECTIVE**

The aim of this study is to evaluate the antibacterial activity and washing durability of antibacterial property of nonwoven cleaning materials treated with silver nanoparticles with different concentrations and application methods. A new washing process was developed to simulate the washing of cleaning materials during daily use and the antibacterial effectiveness of unwashed and multiple washed samples were evaluated considering the silver nanoparticle concentration and treatment process type.

**MATERIALS AND METHODS**

80% viscose / 10% polyester / 10% recycled polyester needle punched and calendered nonwoven samples were used as material. Samples were washed as it is specified AATCC TM-135-200 test method before treatments and dried in room temperature. Nonwoven samples were padded through different concentration of bath 0.1%, 0.3% and 0.5% silver nanoparticles with 5% polyolefin dispersion (Dow Chemicals, Germany) at 30ºC, dried at 90ºC and cured at 110ºC for 5 minutes. Silver nanoparticles were obtained from Alfa Aesar, USA with particle size 20-40nm and 99.9% purity. The fabric pick up was determined as 146% during padding process and the padding process was conducted using a laboratory pad-mangle. Additionally, homogenous 0.5% silver nanoparticle and 5% polyolefin dispersion bath was prepared separately and applied on both sides of the samples by spraying method. Sprayed sample was also dried and cures as padded ones. Treated samples were washed 10 and 20 times with new developed washing procedure (Figure 1). The antibacterial effectiveness of unwashed and washed samples was determined according to ASTM-E2149-01 against to gram negative bacteria *Escherichia coli.* The other properties of treated nonwovens such as areal weight, thickness, water absorbency capacity, abrasion resistance were measured by following standard test methods for nonwovens.

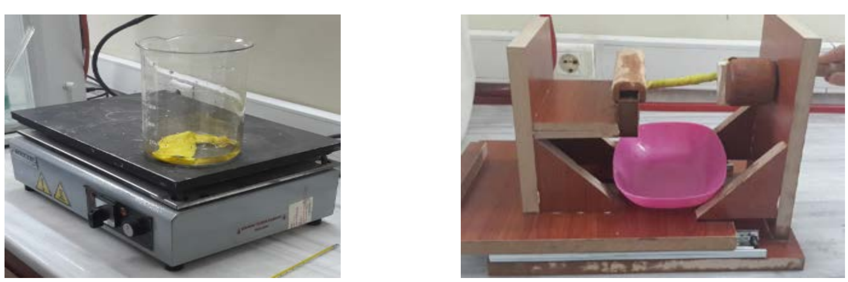

Figure 1. New developed washing procedure for simulation of washing during use.

**RESULTS**

As a result of experimental study, applying silver nano particles enhanced the antibacterial activity against to gram negative bacteria *Escherichia coli.* However, nanoparticle application process decreased the water absorbency capacity and abrasion resistance of samples.

It was shown that all the silver nano particles have not been transferred to the nonwoven material from the bath and also, the transferred silver nanoparticle amount increased when the bath concentration increased. Increasing silver nano particle in the bath concentration increased the antibacterial activity of the samples. The antibacterial activity of padded sample was higher compared to sprayed counterparts. Also, washing durability of padded samples was found to be better than sprayed ones.

# Tactile Feeling of Textiles: A Comparative Study Between Textiles Attributes of France, Portugal, and Brazil

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The sensorial comfort is the result of a complex series of sensory stimuli between the fabric and human skin when wearing or touching a garment. The sensory comfort is not influenced by the thermal equilibrium but by the feeling that the clothing provides the user with when in contact (mechanical or thermal) with the skin: the touch. Tactile properties are quantitatively evaluated through adaptations of sensory analysis methods, much exploited by the food and cosmetics industries. This assessment is the descriptive result of psychological and physiological responses of individuals. Before the evaluation of the textile comfort process it is necessary to develop descriptive terminologies of attributes that best define the characteristics of a product. Development of the attributes is made by a panel of selected volunteer assessor. Researchers from France (2004), Portugal (2011) and Brazil (2016) developed a set of touch attributes, which were classified and grouped. They followed the same methodology: ISO 11035, ISO 8586 and the Descriptive and Quantitative Analysis Method. Thus, the present study compares the textile quality attributes developed by these researchers. The attributes were grouped in Bipolar, Surface and Materials Attributes. The French and Portuguese researchers developed 15 terms and Brazilians developed 11 terms. It is possible to verify that seven terms are common in both countries; six terms are common among French and Portuguese people, one term in common between the Portuguese and Brazilians. Of the rigid and flexible bipolar attribute only the hard term was considered by Brazilians, however when evaluating this attribute, we can consider that Brazilians evaluate as a bit hard a fabric that presents to be flexible. The Portuguese bipolar terms Sleek - Rough and Smooth-Rough were grouped differently by Brazilians. The French introduced terms such as Greasy and Grooved and the Brazilians presented Dry - Humid. Therefore, we can consider that the seven common attributes are the most cited among consumers and offer higher subsidies for improvement in the development of innovative clothing, resulting in greater comfort to the consumer worldwide.

| | FRANCE | PORTUGAL | BRAZIL |
|---|---|---|---|
| BIPOLAR ATRITUTES | Light- Heavy | Light- Heavy | Light- Heavy |
| | Thin- Thick | Thin- Thick | Gross- Fine |
| | Cold- Warm | Cold- Warm | Fresh- Hot |
| | Supple- Rigid | Supple- Rigid | |
| | | Sleek – Rugoss | Rough- Flat |
| | | Rough – Smooth | |
| | | | Dry- Humid |
| SURFACE ATRIBUTES | Soft | Fluffy | Soft |
| | Pilous | Pilous | Plushy |
| | Granulous | Granulous | |
| | Sticky | Sticky | |
| | Slippery | Slippery | |
| | Greasy | | |
| | Grooved | | |
| | | | Rugged |
| MATERIALS ATRIBUTES | Elastic | Elastic | Elasticity |
| | Falling | Falling | Falling |
| | Responsive | Shape Recovery | |
| | Crumple-Like | Crumple | |
| | | | Rigid |

Table 1 : Final attributes of the French, Portuguese and Brazilian evaluators

# Determination of the Heat Dissipation of Sport Bras Using Thermal Manikin and Thermography

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## INTRODUCTION

Activity by practicing sport is one way of keeping shape and achieve general wellbeing, being recommended that every adult should do some physical activity every day [1]. There are a multitude of sports and probably the most popular is running, due not only to its simplicity but also to the economics factor. The thermal interaction of human body and the environment during running activity is an important mechanism that may affect the athlete's performance [2]. For this reason, the cloth an athlete uses play an important role since it should provide comfort and should protect him from all environmental impacts, and thus with a benefit in the performance and efficiency of the athlete [3].

In this work we compare five commercially available models of sports bra specifically conceived for running and analyze the heat dissipation using a thermal manikin in a controlled environment. Due to the differences in raw material, finishing and knitted structure, the team expects to obtain different behaviors and thus understand which should be the most favorable candidate for this specific sport.

## MATERIALS AND METHODS

The five sport bras present several differences, from the construction to the structure level as one can observe in Table I. In this study, all specimens use mainly polyamide combined with elastane at different percentages as raw material and most of them were produced using seamless full jacquard knitting machines, which allowed to combine different weft knitted structures without using seams to bind the different parts of the bra. There are specimens with two structures used in the entire bra, as well as bras with up to seven different structures, in different regions, not only for proper support and tight fit to women's body as well as for thermal comfort purposes. Figure 1 illustrates the five sport bras.

Table I. General characteristics for the five sport bras studied.

| Code | Composition | Layers | Number of Structures |
|---|---|---|---|
| BRA 1 | Polyamide 96%, Elastane 4% | Two layers with different structures inside an outside | Three, distributed in different regions, as in the front, the welt, between the breasts and in the back |
| BRA 2 | | | |
| BRA 3 | | Two pieces, one brassiere (inner layer) and top bra (outer layer) | |
| BRA 4 | Polyester 43%, Polyamide 38%, Elastane 4% | Two layers, the inner layer with neoprene covered with weft fabric | Two, one in front and other in the back |
| BRA 5 | Polyamide 96%, Elastane 3%, Polypropylene 1% | One single layer | Seven different structures in distinct regions |

For this particular study, a dry thermal manikin TM 3.2/R 110 of PT-Teknik, Denmark with 20 different segments was used inside a climate chamber, and the tests were carried out with an average temperature of 19ºC and 45% humidity, corresponding to winter conditions for a specific region in Brazil – Paraná. Since the thermal manikin does not have enough sensing segments in the chest area, a Testo® 885 320x240 sensor thermographic camera was used to record the temperature variability for the different regions of the manikin's chest covered with the sport bras. The thermal manikin was adjusted for PI control and a target temperature of 33ºC. The measurements were made after proper stabilization of target temperature.

Bra 1 Bra 2 Bra 3 Bra 4 Bra 5

Figure 1. Images of the five sport bras used in this study.

**RESULTS AND DISCUSSION**

The resulting thermal images of the five sport bras studied in this work are presented in figure 2 and in each image the thermal footprint is superimposed to the sport bra in order to better understand the possible influence of the combination of raw material and structure on the heat release. By observing the thermal images one can see that Bra 3 and Bra 4 present lower surface temperatures than the others, namely in the breast region. This may be explained by the second layer of these Bra: while Bra 3 is made of two different pieces, being the inner one a brassiere, Bra 4 presents an inner layer made of material similar to neoprene, covered by the same knitted structure as the outer layer. These combinations most probably result in more difficult path to dissipate heat. In fact, while Bra 3 shows a similar thermal pattern excepting on the welt region, Bra 4 shows different patterns, due to a net structure between breast and sleeve, as well as below the breast. The region with lower temperature is where the inner layer is located.

On the other hand, for Bra 1 the two structures present in the breast and below seem not to influence the heat release, while the structures used in Bra 2 and particularly on Bra 5 seem to result in changes in temperature. It is important to note that Bra 5 has only one layer, but a coarser yarn than the remaining ones.

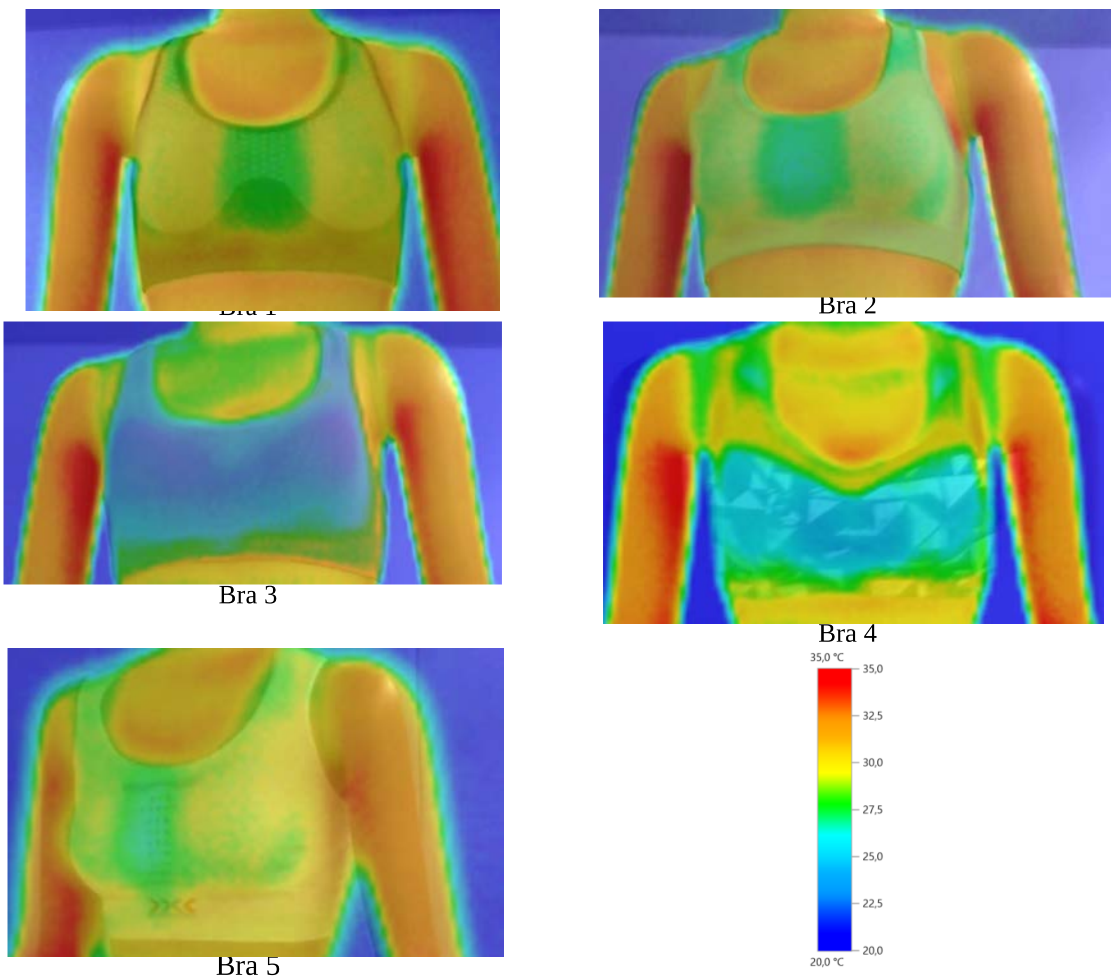


Figure 2. Thermal images of the five sport bras tested in this work.

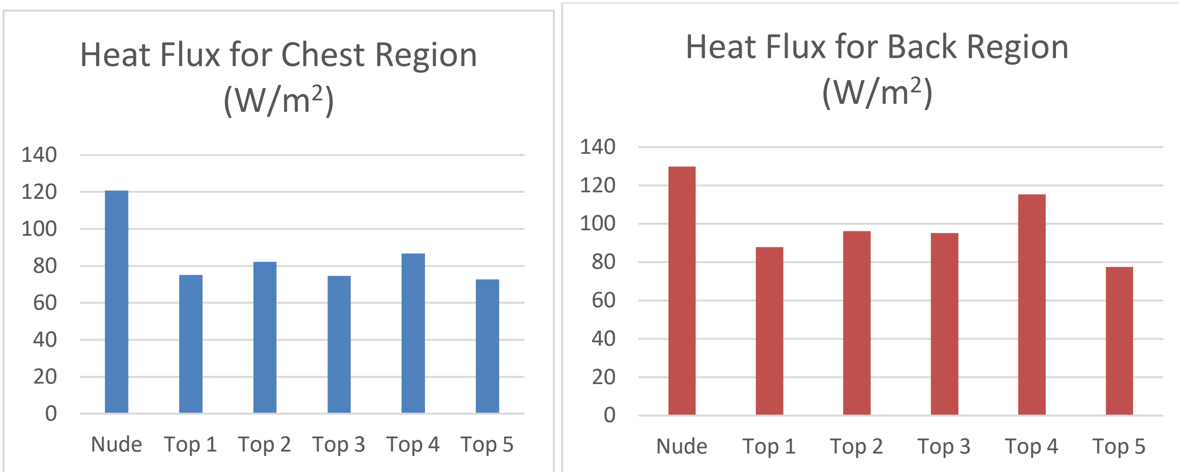


Figure 3. Chest region heat flux and back region, obtained by thermal manikin analysis, adjusted for PI control method and target temperature of 33ºC for five sport bras tested in this work.

The thermal manikin allowed to determine the heat flux for the two regions where the sport bras are. It can be observed that the bra 5 presents the lowest overall heat flux and the bra 4 the highest heat flux. Although in the chest region the difference is not so evident, the same does not happens at the back. This is due to the structure used in Bra 4 in that region, which is similar to an open net. On the other hand, it is important to note that bra 5 has only one layer, but a coarser yarn than the remaining ones.

## CONCLUSIONS

The selection of specific structures for specific regions seems to have influence in the release of heat and thus in the sports bra's breathability. It was also observed differences on surface temperature, which are due to the selected structures. This may ultimately result in a reduction in the skin temperature and thus contribute for an improved comfort for the wearer.

In the future, the research will focus on testing a new prototype to optimize the behavior between heat loss and breathability of the sport bras, oriented mainly on the different knitted structure. An objective and subjective evaluation of the proposed bra with commercially available products (in vivo) will also be conducted.

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## ACKNOWLEDGMENT

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# A Study to Improve Drying Property of Towel Fabrics


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The purpose of this study is to investigate the effect of core-spun yarn on quick dry property of towel. For this aim, five different raw materials (modal, cotton, polyester, bamboo, viscose) which are the most used in towel production was preferred. Seven different core yarns and 5 different conventional yarns were produced with these fibers in the ring spinning machine (Table I). These yarns were used in the weft direction to produce the towels having 400 g/m$^2$ (48 pile length), and 550 g/m$^2$ weight (66 pile length) and non-pile fabric samples. Same ground warp yarn and pile warp yarn were used for all samples. The towels were also subjected to the constant dyeing conditions.

After production, the quick-dry properties of samples were tested according to method improved by the researchers by taking the opinions of experts in the field. The samples were subjected to washing and free drying processes under the same conditions for determine the quick dry abilities. The decreases in the amount of water on the towel samples and accordingly the drying amounts in % percentage were calculated and compare to each other. The same process was applied for all samples. According to quick dry tests results; usage of the core yarn in towel production has provided certain amount improvement in the quick drying ability.


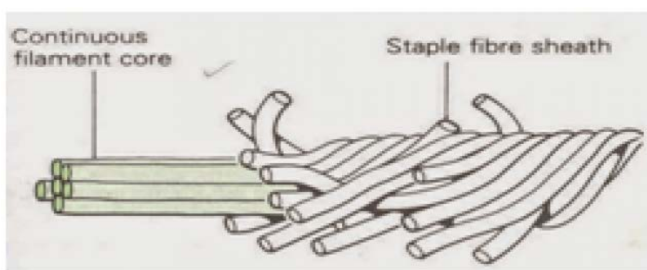


Figure 1. Typical core-spun yarn [www.functionyarn.com]

Table I. Properties of conventional and core yarns

| Code | Raw Material | Yarn Type | Number (Ne) | Core number |
|---|---|---|---|---|
| Co | COTTON | Conventional | 14/1 | - |
| CoC | | Core-spun | 14/1 | 75 Denier (PES) |
| CoC55 | | Core-spun | 14/1 | 55 Denier (PES) |
| V | VISCON | Conventional | 14/1 | - |
| VC | | Core-spun | 14/1 | 75 Denier (PES) |
| VC55 | | Core-spun | 14/1 | 55 Denier (PES) |
| B | BAMBOO | Conventional | 14/1 | - |
| BC | | Core-spun | 14/1 | 75 Denier (PES) |
| M | MODAL | Conventional | 14/1 | - |
| MC | | Core-spun | 14/1 | 75 Denier (PES) |
| P | POLYESTER | Conventional | 14/1 | - |
| PC | | Core-spun | 14/1 | 75 Denier (PES) |

# 3D Knitting Using Large Circular Knitting Machines

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The advantage of flat-knit technology lies in its possibility of great pattern variety up to defined three dimensional structures. The production using flat knitting technology is limited in productivity by the discontinuous movement of the carriage and the amount of feeding systems (4-6). In comparison to flat knitting machines the productivity in terms of m²/min is higher due to the continuous movement of the needles as well as due to the higher amount of feeding systems (up to 144). As a result, large circular knitting machines are used for mass production in industry in order to produce e.g. Tshirts or mattress covers. In order to realize the final product, the textile is produced as a fabric roll. The material is then cut and sewn in a downstream process in order to get the final ready-to-wear product.

So far, three-dimensional products cannot be produced by large circular knitting technology. Three-dimensional weft knitted fabrics can be realized by the use of flat knitting machines. The research at the division of knitted fabrics at the Institut für Textiltechnik of the RWTH Aachen University, Aachen focuses the development of three-dimensional knits in a more productive way by the use of the benefits of large circular knitting machines.

The combination of high productivity with an increased flexibility will lower costs in production of final knitted products for industrial applications (sports industry, medicine, automotive, air and aerospace sector).

The oral presentation will show a worldwide first prototype of a three dimensional knit by the use of large circular weft knitting machines (patent application).

As a result, we have shown that 3D knitting is possible using common large circular knitting machines. Possible applications face e.g. the medicine, automotive, the sport textiles as well as the air and aerospace sector.

# The Measurement of Textile's Warm-Cool Feeling


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## INTRODUCTION

Textile's warm-cool feeling is an important part of the comfort, but using subjective evaluation and the maximum transient heat $Q_{max}$ to characterize it is not reasonable. This study uses LDMG-1 insulation tester and LD-1 clothing thermal insulation tester to indicate the parameters of textile's warm-cool feeling, which compensates for the defects.

## METHOD AND MATERIALS

In this study, 8 bedding samples and 2 apparel samples with different fabrics are tested. The typical thermal power curve is shown in Figure 1. In order to find the start time $t_0$ and end time $t_1$ of cool feeling time, the curve is smoothed. Then $t_0$ is the time when the curve up to the steady period's average power $\overline{Q}$ and $t_1$ is the time when the curve down to the $1.2\overline{Q}$, as shown in Figure 2. What's more, we've resershed three parameters to indicate warm-cool feeling as follow:

a. Cool feeling time $T$ (in seconds) is defined as the peak of thermal power curves or severely non-steady periods of the heat transfer, as shown in Figure 2 (b) and Equation (1).
b. The total amount of heat $W_1$ (in Joule) is defined as the total energy coming from the sample's per unit area in the cool feeling time, as shown the shaded area in Figure 2 (b) and Equation (2).
c. Pure amount of heat $W_2$ (in Joule) is defined as the energy which is due to the different temperature textiles transfer to the skin, as shown the slashes area in Figure 2 (b) and Equation (3).

$T=t_1-t_0$ (1)  $W_1=\int_{t_0}^{t_1} Q(t)dt$ (2)  $W_2=W_1-\overline{Q}T$ (3)

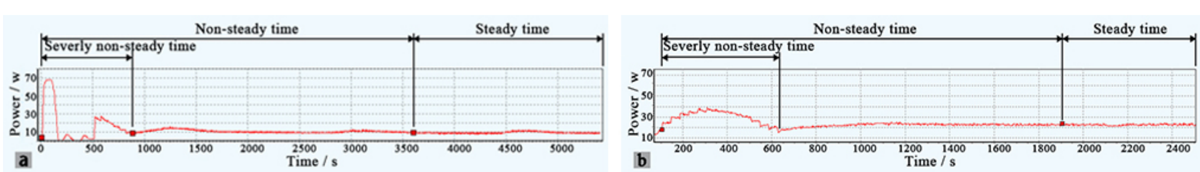


Fig.1. (a) The thermal power curve of the gray duck down quilt tested by LDMG-1 insulation tester. (b) The thermal power curve of the woolen sweater tested by LD-1 clothing thermal insulation tester.

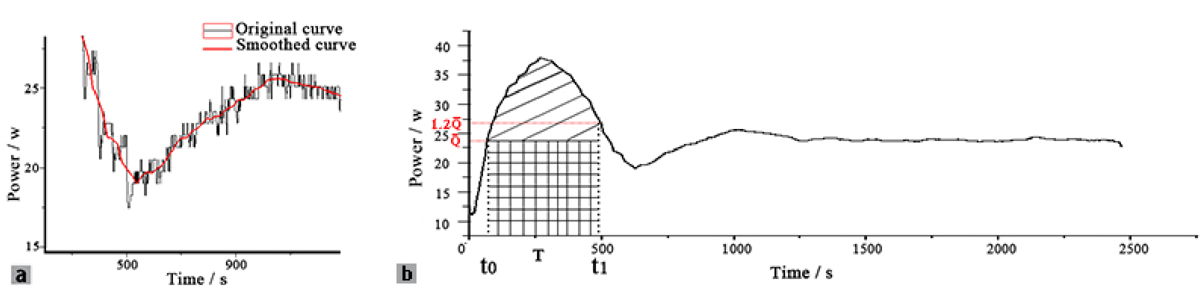


Fig.2. (a) Smoothed and local amplified thermal power curve. (b) The ketch of three cool feeling's extraction.

## RESULTS AND DISCUSSION

In this study, there is a clear reaction to the warm-cool feeling of textile in thermal power curves of test board. Besides, the warm-cool feeling of textile should be characterized by warm-cool feeling time and amount of heat. The Amount of heat includes the total amount of heat $W_1$ and pure amount of heat $W_2$. What's more, the latter is more comparable than the former. The longer the $T$ is, or the bigger the $W_2$ is, the stronger cool feeling will be.

# Radiant Heat-protective Performance of Fabrics Used in Firefighters' Clothing: A Scientific Study

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## BACKGROUND

The analysis of radiant-heat protective performance of fabrics is critical to develop a firefighter's protective clothing. Although many researchers have contributed in this area, a comprehensive knowledge of protective performance of fabrics under radiant-heat exposures is still scanty and ambiguous. Therefore, this study aims at analyzing the protective performance of a set of fabrics under radiant-heat exposures of different intensities.

## METHODS

Single- and multi-layered fabrics (shell fabrics, moisture barriers, and/or thermal liners) were selected for this study, and their properties (weight, thickness, air permeability, thermal resistance, and evaporative resistance) were measured according to ISO standards. These fabrics were tested under radiant-heat exposures of low (10 $kW/m^2$), medium (40 $kW/m^2$), and high (80 $kW/m^2$) intensities according to ISO 6942:2002 standard (Figure 1). The Heat Transfer Levels (HTL1 and HTL2: times to reach wearers'/firefighters' skin temperature increase of 12°C and 24°C, respectively) through these fabrics were measured, and the HTL2 was considered as Radiant-heat Protective Performance (RPP) of fabrics. The effects of fabric parameters (e.g., fiber contents, weave designs), structures, properties, and radiant-heat intensities on RPP were analyzed, and fabric properties that significantly affected the RPP were statistically identified. Employing these significant properties, mathematical models (multiple linear and logarithmic regression models) were constructed and compared to effectively predict the RPP.

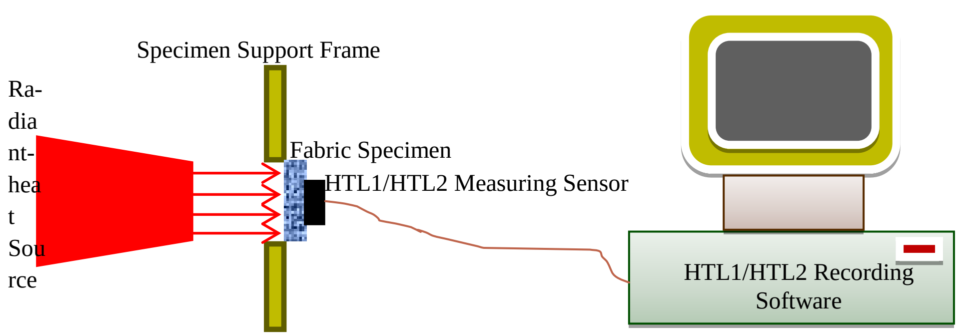


Figure 1: Radiant-heat exposure test according to ISO 6942:2002

## RESULTS AND DISCUSSION

Fabric parameters, structures, and properties considerably contributed to the radiant-heat transfer through fabrics and affected the RPP. Notably, Proban® treated cotton, twill weave, and thick thermal liner based fabrics showed higher RPP. Fabric properties namely weight (W), thickness (T), thermal resistance (TR), and evaporative resistance (ER) positively and significantly affected the RPP. As found, a multiple linear regression model (Equation 1) can be used to effectively predict the RPP from significant fabric properties.

$$(RPP) = 3.02 + 0.02 \times W - 7.9 \times T + 0.29 \times TR + 1.27 \times ER \quad \text{......Equation 1}$$

## CONCLUSION

The model developed can be used in industries for fast and effective prediction of radiant-heat protective performance of fabrics. Overall, this study should help textile and material engineers to select and/or design a high performance fabric for firefighters' protective clothing.

# Airflow Characteristics During Rotor Spun Composite Yarn Spinning Process

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Rotor spun composite yarn show a compound performance combined by staple fibers and filaments, such as excellent hand feeling, extremely elasticity or strength. Air characteristics including pressure and speed are critical factors of rotor spun composite yarn spinning process. In this paper, air flow pressure and speed in spinning unit of rotor spun composite yarn are simulated and analyzed by ANSYS, and verified by experiments. The results show that under the same conditions, static pressure within the filament guide tube is lowest as -9810Pa and around -5631Pa in rotor. The airstream accelerates from the transfer channel inlet to the outlet with the decrease of the pipe diameter, and reaches the largest value to 386m/s at the outlet. As the impact of airstream from the transfer channel outlet against rotor slip plane, the airflow is divided into two strands in opposite direction, one clockwise and one reverse direction, which joined together after circling around the rotor, and then following circular motion around the outlet face of filament guide tube, as showed by Figure 1. As the rotor speed increases, the airflow velocity increases and the static pressure decreases, breaking strength and CV of composite yarn increase, while the breaking elongation and hairiness decrease according to the experiment results.

**KEYWORDS:** Rotor spun composite yarn, simulation, airflow, performance

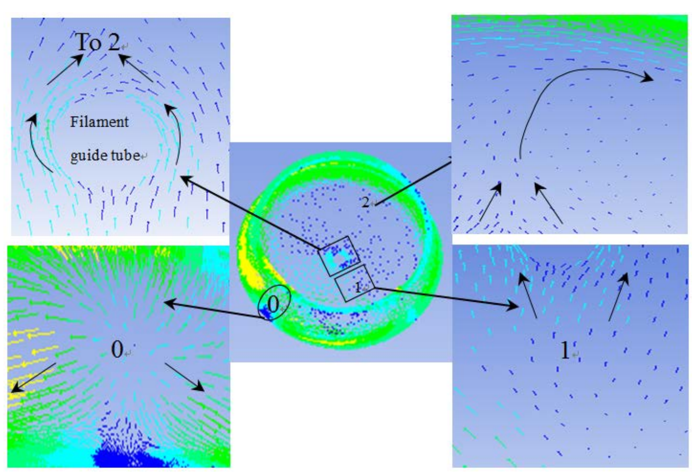


Figure 1. Airflow in rotor

**ACKNOWLEDGMENT**

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# Twisting Robustness in the Ring Spinning System with Single Friction-belt False-twister

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Recently, friction-belt false-twister adopted on a ring spinning frame has been developed for producing yarns with unique structure and properties.[1,2] In this study, special attentions have been focused on twisting process because it is of great importance to determine the structure and properties of resultant yarn. Uniform twists inserted into the yarn ensure even features and good yarn quality. Twist variation in the spinning process may results in poor spinnability as well as uneven features or imperfections of the resultant yarns, such as strength deterioration, diameter irregularity and wrapping fibers along yarn length. On the other hand, for a stable process or product, it should permit a certain tolerance for the system variation or error.

Therefore, it is crucial to investigate the impinge of twisting robustness in the spinning process as well as evaluation of the yarn quality subject to external perturbations. Based on twist kinematics, equations are derived to evaluate the twist variations subject to external perturbations. Although several basic simplifying assumptions have been necessary in order to make the analysis manageable, the findings have given a clear indication of the significant twist levels that can develop in the zones of the machine. The model is then verified by the experimental observations and a good agreement has been made. It has been proved by the experiment that with ±10% periodic variation in false-twisting rate, the yarn properties are not significantly affected. In another words, the current configuration and system parameters are stable and robust as well as have a high tolerance for twist variations.[3]

The main purpose of this study is to assess the stability and robustness of the modified technique as well as comprehending the effect of system parameters on dynamical twist redistributions. At the least, the results should give rise to a better comprehending of the mechanism of false-twister adopted in a ring spinning frame and provide method of calculating the practical levels of twist control required to reduce certain remarkable yarn faults.

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**ACKNOWLEDGMENT**

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# Development and Characterization of a New 3D, Nonwoven, Pleated Shockproof Product Inserted in Clothing for Body Protection

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The objective of this work is the development and the characterization of an anti-shock 3D non-woven fabric prepared by a new manufacturing process. Indeed, this single-layer, made of 3D non-woven fabric, is a combination of 3 components: a core and two skins. The core consists of the new 3D pleated non-woven called vertilap® [1] which can be used in several areas of application. In our case this core is covered by 2 skins made of nonwoven or woven fabrics. It has the advantage of offering products with high breathability, good thermal and acoustic insulation properties and interesting properties in compression and resilience. Unlike foams, it has a better durability due to its recyclability

In our studies, the core absorbs energy at impact and both skins maintain the pleats vertical and disperse energy contributing the increase of the impact resistance. The combination of these three anti-shock components could be used in different types of application where human body protection is required such as protective clothing for civil engineering, sport and so on. Every day, human may be subjected to many impacts of very different nature and intensity; these impacts typically result from the fall of a tool or from the percussion of debris.

In order to properly evaluate the behavior of this product against shocks, a device, based on the principle of free fall, was developed [2]. Thanks to this device, the product was tested on a large range energies and impact ball radius. This technique of product characterization [3] relies on upon the use of an impactor, mounted on an electromagnet system electrically powered by a current transformer. Drop of the impactor on the product is tested (flanged in the punch) from a desired height and at variable load by adding weights (fig: 01).

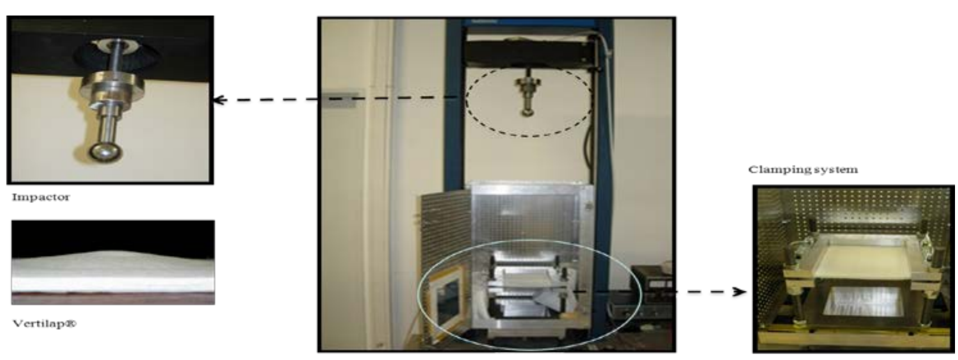


Figure 1: Experimental system

To visualize the shock at the impact's moment, a fast camera, a light source for a proper illumination of the test chamber and a microcomputer are used. The video recorded impact sequences are processed thanks to eye-motion software. In a second step of this work, impactor will be instrumented. The obtained results have led to understand the contribution of each product's components and allow us to link these components and the impact resistance of the developed products.

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# Modeling and Simulation

# An Optimized Yarn Geometric Model for Knitted Material Simulation

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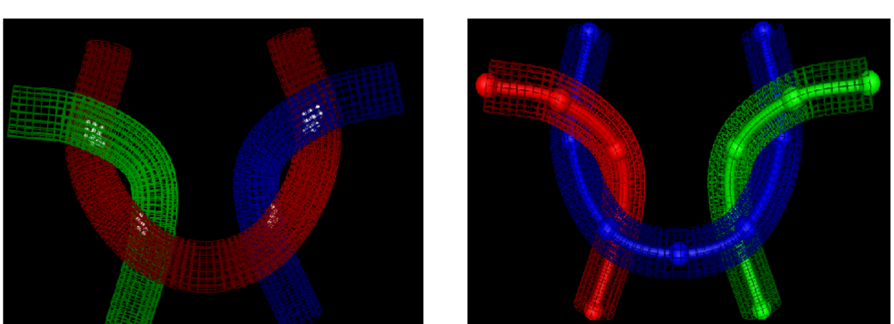
Finite Element Modeling (FEM) simulation is becoming increasingly more important for evaluation of the mechanical properties of knitted materials. The results of these simulations may be utilized to direct and optimize design parameters, when specifying the stitch architecture of a knitted material to achieve particular performance criteria. One of the critical inputs to an FEM analysis is the geometric model of the structure to be simulated. There have been numerous papers describing geometric models that define spline curves that represent the shape of individual yarns in a knitted material. The shortcoming of these models is that they have only been geometric in nature. The previous work in this area has mostly provided the control points or formulas for these "tubes in space". While these models have been parameterized in order to accommodate fabrics with different macroscopic properties, e.g. course/wale densities and loop width/height, they have ignored critical low-level issues that would extend the models from being only geometric to truly physical. One of these critical issues is yarn overlap/intersection. It is obvious to state that two pieces of yarn cannot exist in the same location in space. Therefore in order to specify yarn geometry of knitted materials that is consistent with actual physical yarns, the spline tubes representing the yarns should not interpenetrate. This interpenetration constraint is also required for proper FEM simulations based on the yarn geometries.

We have formulated the task of generating physically accurate yarn geometries that do not interpenetrate as an optimization problem. The functional that is minimized to produce the desired result consists of three components,

$$E_{Total} = \alpha E_{Distance} + \beta E_{Bending} + \gamma E_{Length}.$$

$E_{Distance}$ is defined in such a way that it is at a minimum when the distance between the spline tubes is zero, i.e. the yarn geometries are not intersecting, and are just touching. $E_{Bending}$ defines the bending energy (as a function of curvature) of the yarn and ensures that the yarn geometry maintains a natural-looking shape. $E_{Length}$ is the term that ensures that the yarn spline tube does not significantly change its length during optimized. $\alpha, \ \beta, \gamma$ are weights that allow for the modification of the strength of each term and give us the ability to adjust the importance/contribution of each component to the final result. The desired yarn geometry result is produced by minimizing $E_{Total}$ through manipulation of the control points that define the yarn tube's spline centerline. The optimization is computed with a quasi-Newton method. Our approach has been employed to generate the yarn-level geometry for a knitted material consisting of an $n \times m$ array of knit stitches. We are currently extending this work in order to produce an arbitrary $n \times m$ array of knit and purl stitches. The figure below shows the results of our optimization technique on the loop unit cell that we utilize to produce an array of knit stitches. The left figure presents spline tubes (an offset surface from a spline centerline) specified completely geometrically (parameterized control points). The white spheres highlight where the tubes intersect each other. The right figure presents the results of our optimization. The large, colored spheres are the control points of the yarn centerline. They have been adjusted to remove the intersections between the yarn offset surfaces. Note the white spheres have been removed.

(a) (b)



# Modeling Approaches for 3D Woven Composites: Potential and Limitations

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Weaving near-net shape preforms out of three-dimensional (3D) woven textiles enables manufacturing cost effective composites. The objective of this study is to explore the capabilities of different software available for predicting 3D woven composites' mechanical properties in the linear and non-linear regimes. The investigated software include, but not limited to, WiseTex with TexComp and TexGen with Abaqus CAE. The 3D woven architecture designed in this research is referred to as multilayer plain weave architecture. The schematic design of the architecture, as a cross-section and 3D unit cell, is shown in Figure 1.

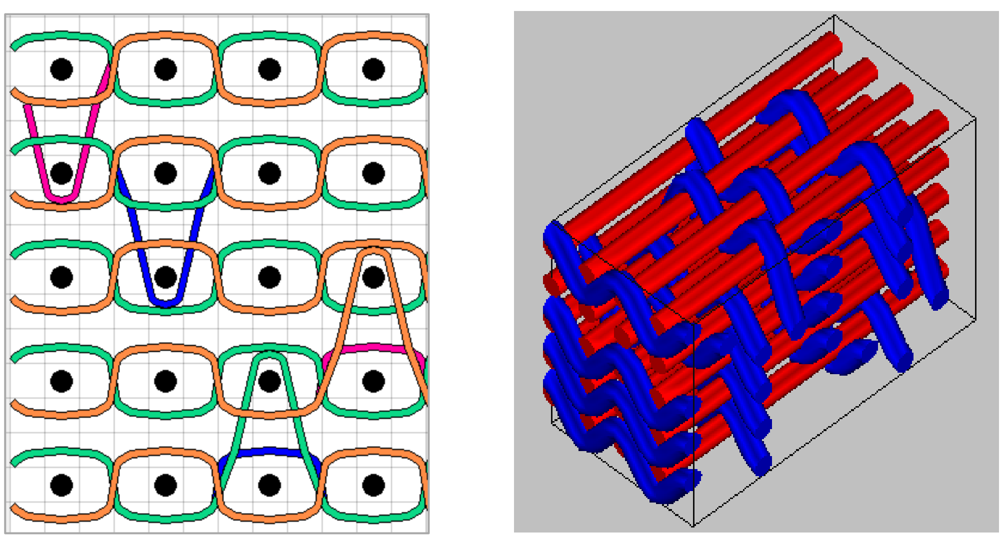

Figure 1. A Schematic of the  multilayer plain weave architecture: Cross-section (left) and 3D unit-cell view (right).

The manufactured composite samples were physically characterised (via optical microscopy and volume fraction analysis) and mechanically tested (in tension, compression and in-plane shear). The experimental results obtained are then used to validate the simulation software and provide recommendations along with limitations for the existing tools available in the market. The proposed software are evaluated based on their geometrical capabilities to generate complex 3D woven architectures and account for manufacturing process distortions, the simulation algorithm, the computational cost and deviation from the experimental results. The validation process demonstrates a clear potential for the proposed simulation software with a high level of accuracy and confidence in predicting the linear elastic mechanical properties of complex 3D woven textile architecture with less confidence in predicting the damage evolution and the non-linear behaviour up to final failure.

**ACKNOWLEDGMENT**
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# Internal Structure of the Bundle Manufactured by Friction Method

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## INTRODUCTION

Yarn formation method by using the surface frictional force is adequate process for manufacturing multipurpose engineering yarn due to its simple working principle and high production rate but usage of friction spun yarn in industrial field is interfered by its relatively low strength caused by irregular under structure. In this study, to understand the structural characteristics of friction spun yarn, we introduce the mathematical model that describing the twists that are inserted in the yarn during the friction bundling process based on the bundle thickness dynamics and delineate the traits of the inner twist structure.

## THEORETICAL MODEL (STEADY STATE)

- Bundle Surface twists

$$T_w(x) = \frac{(1-S)\cdot v_d}{2\pi\cdot R(x)\cdot v_y} = \frac{(1-S)\cdot FR}{2\pi\cdot R(x)} \qquad (1)$$

- Twists generated by torque

$$v_y \cdot \frac{dT_T(x)}{dx} = -\frac{(1-S)\cdot v_d}{2\pi}\cdot\left(\frac{d}{dx}\frac{1}{R(x)}\right) \qquad (2)$$

- Twists generates at the take-up zone

$$T_{take-up,0} = \frac{FR}{2\pi}\cdot\frac{1-S}{R(t,L)} \qquad (3)$$

- Radius of bundle in friction zone

$$R(x) = \sqrt{\frac{v_f\cdot D_{f0}}{\pi\cdot v_y\cdot K}\cdot x + {R_0}^2} = \sqrt{\frac{v_f\cdot D_{f0}}{\pi\cdot v_y\cdot K}\cdot x + {R_0}^2} \qquad (4)$$

where,
$v_d$: linear velocity of drum surface.
$v_y$: bundle delivery speed.
$\rho_f$: volume density of feeding fleece.
$\rho_y$: volume density of in-process bundle.
$D_f$: thickness of feeding fleece.
K : $\rho_y/\rho_f$
S : slippage ratio between drum surface and bundle.
FR: friction ratio.

## RESULTS

The inner structure of yarn based on the theoretical model turned out that at the delivery end yarn has uniform twists distribution along the radial direction but residual twists are canceled out during the passing through the take-up zone, so output yarn has theoretically zero twists distribution along the both of axial and radial direction (Fig. 1d).

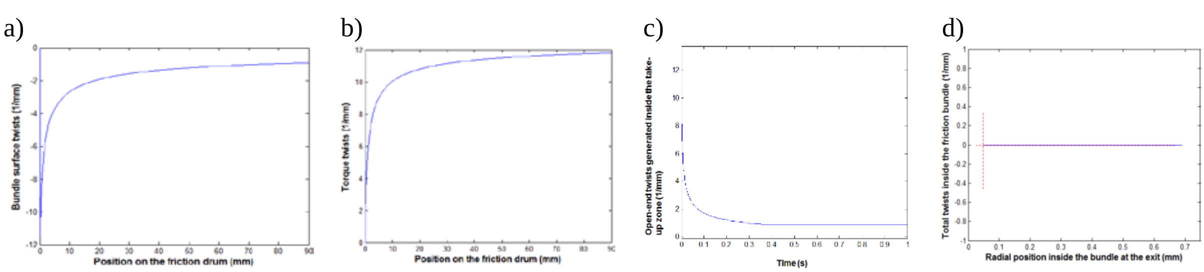


Fig. 1. Generated twists during the friction bundling process. (a) twists generated by fiber arrangement, b) twists generated by torque, c) twists generated at the take-up zone, d) total twists distribution of output bundle)

## ACKNOWLEDGMENT

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# Effect of Staple Length on the Sliver Dynamics in Roller Drafting

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**INTRODUCTION**

This study is to investigate the characteristics of the sliver thickness variation in the roller drafting process by simulation on the basis of a theoretical model. Especially, the staple length effect on the sliver thickness through roller drafting process is examined, since slivers are composed of staples that have a length distribution. Influence factors are fiber length distribution, inter-fiber friction, roller gauge length. Fiber length distribution is described in forms of a beard diagram and the linear density profile of the output sliver is obtained numerically.

**BUNDLE FLOW MODEL**

Denoting the average linear density of the sliver and average speed of the staples at time $t$ and position $x$ as $l_b(t,x)$ and $v(t,x)$, while $f(t,x)$ is the force developed by sliver deformation,

- Continuity equation: $\dfrac{\partial\{l_b(t,x)\}}{\partial t} = -\dfrac{\partial\{l_b(t,x)\cdot v(t,x)\}}{\partial x}$

- Equation of motion: $\dfrac{\partial}{\partial t}\{l_b(t,x)\cdot v(t,x)\} = -\dfrac{\partial}{\partial x}\left[l_b(t,x)\cdot\{v(t,x)^2 + Var[v_i(t,x)]\}\right] - \dfrac{\partial f(t,x)}{\partial x}$

where $Var[v_i(t,x)]$ stands for the variance of the speed of individual staples at $(t,x)$.

- Constitutive equation : $f(t,x) = -\mu\cdot l_b(t,x)\cdot\dfrac{\partial v(t,x)}{\partial x}$

where $\mu$ is the kinematic viscosity of the sliver, which is formulated as $\mu \propto h(x) = \mu_0\cdot h(x)$.
$h(x)$ denotes the shape function of $\mu$ and $\mu_0$ is a proportional constant.

- Auxiliary equation : $Var[v_i(t,x)] = C_V(x)^2\cdot v(t,x)^2$. where $C_V(x)^2$ represents the *C.V.* of the ratio of the individual staple speed with respect to the average staple speed at *x*.

- Beard diagram: $\gamma(x) = (1-k\cdot x/L)^n$, $0\le x\le L$ $(n\ge 1)$, where $k = L/l_{max} > 1$. $l_{max}$ denotes the maximal staple length, $L$ is the roller gauge length. $h(x) = (\gamma_b(x)+\gamma_f(x))$ and $C_V(x)^2 = a_0\cdot(1-h(x))^2/\max$.

**RESULTS**

a) b) c)

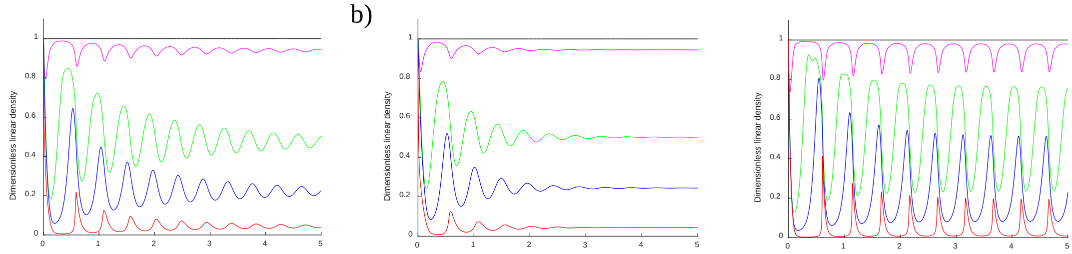


Fig. 1. Dynamic behaviors of the sliver thickness at various positions in the draft zone under the conditions such as; a) mu=30, n=1, k=1.3, DR=30, b) mu=30, n=2, k=1.3, DR=30, and c) mu=$3.0\cdot 10^2$, n=2, k=1.1, DR=30.

Figures show that the roller drafted sliver can be characterized by the fact that there are different dynamic behaviors in the linear density; a fixed point (asymptotically stable) or a limit cycle (periodic changes with specific wave lengths). Even when the input sliver has a uniform thickness, fluctuations in the thickness of the output sliver occur under certain process conditions. This characteristic is investigated in this research.

**ACKNOWLEDGMENT:** This research was supported by Korea-Germany Mobility Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2013K1A3A1A04075431).

# Modeling of Some Mechanical Properties of Cotton Fibers

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## INTRODUCTION

Cotton is one of the most important cellulosic fibers [1, 2]. Researchers have determined not only that the quality of cotton products is directly related to fiber's one, but also that yarn strength is determined by the fiber's (single or bundle) strength and interactions [3, 4, 5].

## APPROACH

The aim of the whole research is to elaborate a relationship between fibers' mechanical properties and yarns' ones by studying their relative behavior and the relationship between single and bundle cotton fibers. For this purpose, twelve different types of cotton fibers were studied. These cottons were chosen to cover a large panel of varieties and physical properties (maturity, fineness, micronaire, length, *etc.*) (Figures 1 and 2).

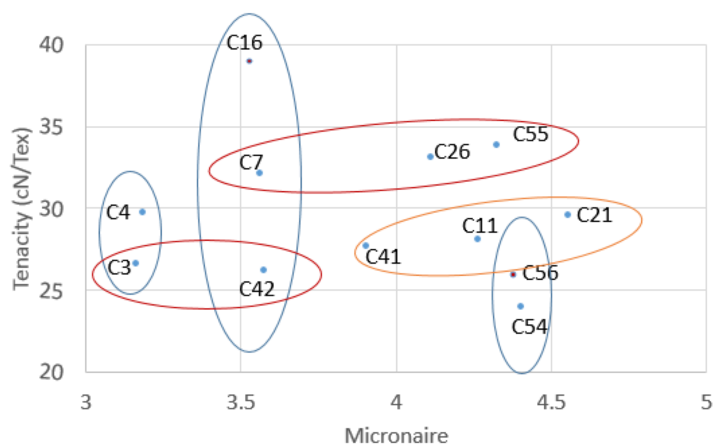



Figure 1. Tenacity vs. Micronaire for the 12 cottons

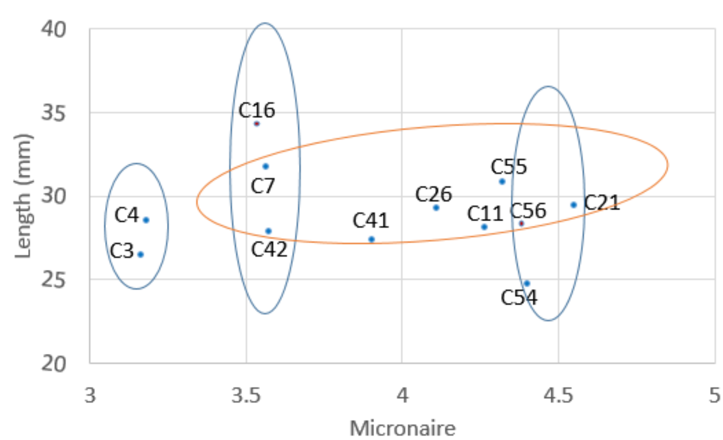



Figure 2. Length vs. Micronaire for the 12 cottons

Prior to testing, all cotton samples were conditioned for at least 48 hours in standard conditions (HR% = 65±4%, T = 20±2°C). A MTS machine (Tensile Strength Machine) was used for testing the fibers' single and bundle behavior after tensile, creep, relaxation and fatigue tests. In addition, FAVIMAT [6] was used for testing the tensile behavior of single fibers after determining their linear densities. Sensors used for the single and the bundle fibers testing were respectively 2N and 2kN. The gauge length used for all the tests was 15 mm and the tests have 5mm/min speed.

**RESULTS AND DISCUSSIONS**

Some results for single fiber tensile and creep tests of some samples are shown in figures 3 and 4.
After carrying tests with Favimat and MTS devices, data is processed with R [7] and RStudio softwares to draw the corresponding tests curves and to determine some other parameters such as:

- Work of rupture: The energy required to break a fiber determined by the area under the load-elongation curve;
- Extension at break: The percent change in fiber length at breaking force. It means how much the fiber will extend from its initial length for the break to finally occur;
- E: The initial modulus determined form the tangent of the initial stress-strain curve;
- η: viscosity determined from the creep test, it is equal to E.t where t is the intersection point of the two tangents.

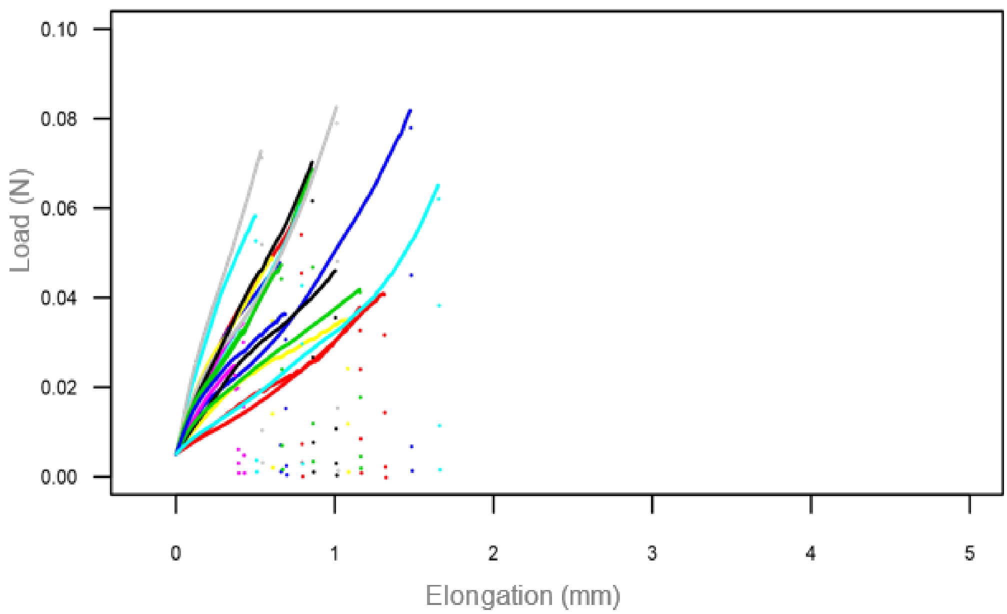



Figure 3. Single fiber tensile tests for cotton 55 (one trace per tested fiber)

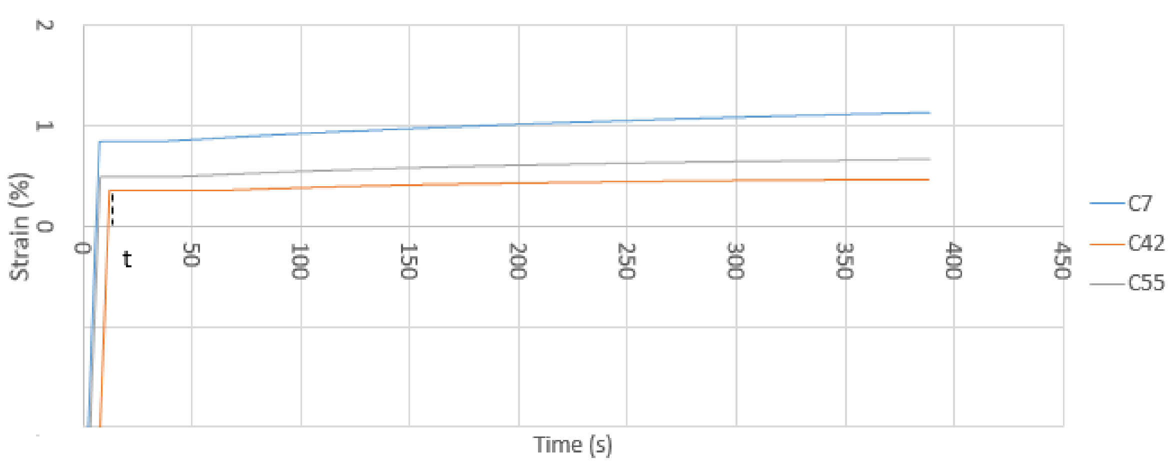



Figure 4. Single fiber creep test for cotton 7, 42 and 55

As cotton is viscoelastic, its response to creep test can be modelled to Kelvin-Voigt model in which a spring (representing the elastic element) and a dashpot (representing the viscous element) are connected in parallel.

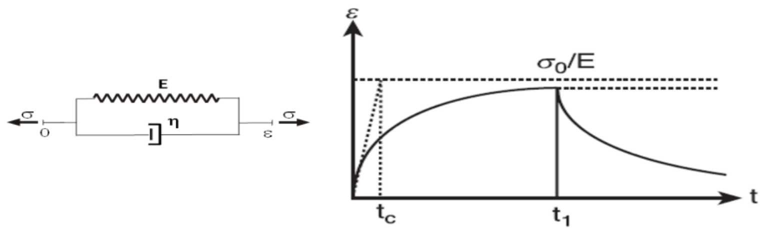
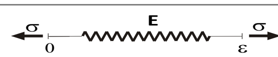
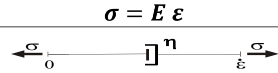



Figure 5. Kelvin Voigt model and response to creep test

Table I. Standard linear solid models [8]

| Analogical model | Mechanical element |
|---|---|
|  $\sigma = E\,\varepsilon$ | Spring |
|  $\sigma = \eta\,\dot{\varepsilon}$ | Dashpot |

This response is characterized by a fast-increase part explained by the fact that the stress is at first carried entirely by the viscous element. The second part, characterized by a very slight increase explains the implication of the elastic element in the continuous elongation of the viscous element (Figure 5, table I).

## CONCLUSION

Creep tests have shown an analogical response. The other mechanical tests will be carried out for the rest of the samples in both single and bundle cases, in order to find the relationship between fibers and yarn structure taking all the phenomena that may exist (such as friction between the fibers) into account.

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We would like to thank the team of CETELOR France for their kind help in carrying out the tensile tests for single fibers on the Favimat machine.

# Composites

# Enhanced Damping of Carbon Fiber-Reinforced Composites by Novel Liquid-Core Fibers

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We demonstrate the continuous production of liquid-core thermoplastic filaments in a stable melt-spinning process at the pilot plant scale, using an adapted bicomponent melt-spinning approach. Different polymers and liquids could successfully be combined over a wide range of core-sheath dimensions. The ability to produce a continuous liquid-core fiber (LCF) is attractive since post-filling of a hollow fiber with similar dimensions is not practical. We characterized the mechanical properties of the LCFs with particular attention to their damping properties. A LCF can exhibit significantly enhanced damping properties compared to plain polymeric filaments of same dimensions. Low frequency bending tests suggest that pressure propagation along the incompressible fluid core combines with damping properties of the polymer sheath at a distance. Significant damping factor increases observed at higher frequency suggest that this effect can be further optimized with suitable liquid/polymer combinations. This new type of filament could find future applications in the enhancement of the damping factor of fiber-reinforced lightweight structures. In a feasibility study we could improve the vibration damping characteristics of carbon fiber-reinforced epoxy composite materials. For this purpose, a novel fibrous grid composed of liquid-core thermoplastic filaments was introduced in the interlaminar regions of the composite. As a result, structural vibration damping of the carbon fiber-reinforced composite could be increased up to 4-fold at high frequencies.

# A Novel Automated Method for Manufacturing of New Semi-finished Photo Composites

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**ABSTRACT**

According to European Union Directive for environmental issues, automobile manufacturers have to reduce vehicles weight in order to decrease the $CO_2$ average emissions to at least 30% before 2020. Substitution of traditional metals in vehicles chassis by lighter and more efficient composite materials is one of several solutions to meet this matter. Moreover, manufacturing methods used in the production of such composite materials have to ensure high production rates, which are required for automotive sector. The current work exposes a new method which was developed to meet these requirements. This method is based on a laying-up head equipped with a bobbin of flexible and sticky pre-impregnated composite. The head is moved by an automatized robot (Figure 2), in order to lay-up prepregs on a mold surface, according to a programmed trajectory. When the laying-up step is finished, prepregs are irradiated by means of an ultraviolet source to consolidate the prepregs (photo-polymerization), and hence to transform them into a final composite piece. The photo-polymerization technology allows having a very short polymerization time of resin (30 to 60 seconds) due to its specific properties. During the robotic laying-up process, the quality of the obtained composite part is related to the correct conditioning of the prepregs bobbins. Accordingly, it is vital to design and manufacture an automated manufacturing machine, to produce such bobbins. This machine enables to adjust and control various manufacturing parameters such as: percentage of Ultraviolet radiations, number of prepregs layers, etc...These parameters which achieve the better prepregs quality are experimentally defined so that, they have to be taken into account for industrial production phase. Moreover, in comparison with other composite manufacturing processes, the proposed technology doesn't cause any health effects since there is no thermal polymerization source, and subsequently no toxic emissions happen during this process.

Figure 1. Prepregs manufacturing machine

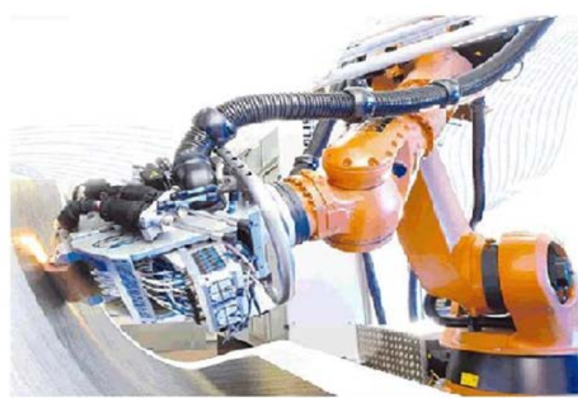

Figure 2. Laying head (depositing head) with its robot

**ACKNOWLEDGMENT**

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# Metal Composite Yarn Production with Commingling Technique and Properties of Textile Surfaces Obtained from These Yarns

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Intermingling is an alternative technique for yarn blending process. Yarns having different features can be combined by feeding the same intermingling jet. This process is defined as commingling. Intermingling machine's unit and commingling process diagram are shown in Figure 1.

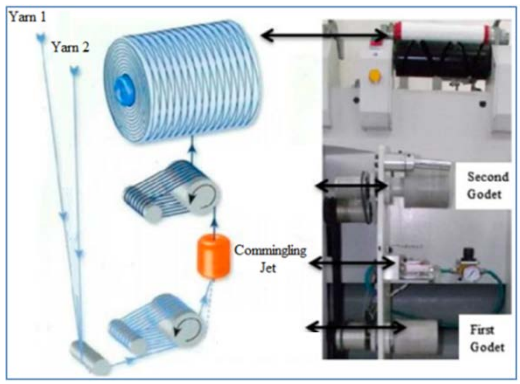


Figure 1. Intermingling machine's unit and commingling process diagram

In this study, for the production of metal composite yarns, standard textured polyester yarns were commingled with different silver, copper, stainless steel metal wires and metalized (silver) polyamide filament. Then, woven fabrics were produced with 4 different placements of these composite yarns. Different fabric structures produced in this study can be seen from Figure 2.

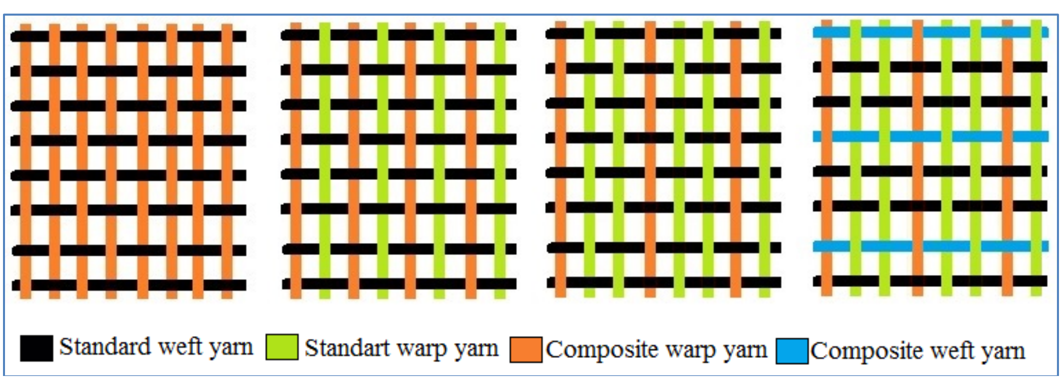


Figure 2. Different fabric structures

Antibacterial-antifungal activity, surface resistivity and electromagnetic shielding effectiveness tests were applied to produced samples according to relevant standards. It has been identified that the carried application provides antibacterial-antifungal activity, antistatic and electromagnetic shielding properties to the samples.

# Strategies for Improving Durability of Vegetable Fiber-reinforced, Cement-based Composites

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Apart from the well-known use of vegetable fibers to reinforce polymeric materials, during the last few years, there has been a growing interest in the use these fibers to reinforce cement based composites for applications on the construction industry. In this sense, although the reinforcement of building materials with vegetable fibers has been applied since ancient times, the need for eco-friendly construction products has led to a "revival" of these materials [1].

The role of vegetable fibers (VF) as reinforcement for brittle matrix is basically to improve the ductility, flexural capacity of the post-cracked composite. Compared with the common synthetic fibers used as reinforcement for cement based composites, VF are nonhazardous, renewable, and biodegradable, allowing the development of more sustainable and ecofriendly materials for the building industry.

Despite all the aforementioned advantages, one of the main drawbacks of these composites is their low durability to aging under wet/dry cycles [2]. This lack of durability due to changes in the environmental moisture which induce dimensional changes in the cellulosic fibers is further increased by the effect of the calcium hydroxide present on the cement Portland matrix, which causes a degradation of the fibers.

To overcome these problems, the research community basically applies two strategies: the modification of the composition of the matrix (using additives or other matrix different to Portland cement) or the physical and/or chemical modification of the fibers to make them less sensitive to the matrix composition and water absorption.

The aim of this research is to evaluate and compare the effectiveness of several strategies to improve the durability to accelerated aging of cement based composites. On the one hand, it will be explored the effect of previous chemical and physical treatments of the vegetable fibers as well as combinations of both treatments. On the other hand, for a fixed treatment of the fibers it will be analyzed the effect of the cement matrix composition.

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# Basalt Fiber as Technical Textile Material

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Mobiltech technical textiles are the most important group of the technical textile with the %20 share. The main products of this area : seat belt, air bags, upholstery, carpets, pre-assembled component, cords, tyres, curtains, hoses, ropes, filters and compozites. %33 carpets, %18 upholstery, %14 pre-assembled component, %12,8 tyres, %8,8 seat belts and %3,7 air bags are the technical textiles which are used in automobile sector. Basalt originates from volcanic magma and flood volcanoes. It has good hardness and thermal properties. Basalt is a major replacement to the asbestos, which poses health hazards by damaging respiratory systems. As it is made of basalt rock is really cheap and has several excellent properties (good mechanical strength, excellent sound and thermal insulator, non-flammable, biologically stable, etc.). Basalt also has good mechanical power, noise and temprature isolation, Incombustibility, high elasticity module, Impermeability. Basalt is also a great vibration isolater. The moisture content of final fiber is less than 1%. In this study, it was investigated the use of Basat Fiber as Technical Textile Material. The fiber, basalt was also compared with glass fiber and carbon fibers at the using of other industrial applications.

**KEYWORDS:** Basalt, Mobiltech, Technical textile

# Reinforcing Structures

# Characterization of Warp-knitted Reinforcing Fabrics and Cement-based Composites: Influence of Yarn and Stitch Types on Mechanical Performance

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Different types of textile fabrics are used for reinforcing concrete structural parts. This paper presents a technique for producing warp-knitted reinforcing fabrics from high-performance rovings for applications in textile reinforced concrete. Three types of warp-knitted fabrics composed of glass and carbon yarns with different stitch patterns (tricot, cord, and pillar), as well as cement composites based on these fabrics, were produced. The mechanical properties of the developed cement composites were determined by a four-point bending test. Experimental studies demonstrated that the material of a reinforcing fabric, as well as the design of the fabric, has a significant impact on the properties of cement composites. The stitch type of warp-knitted fabrics was found to significantly affect the properties of the fabrics and cement composites based on them. In general, fabrics with tricot stitch show better strength characteristics as compared to fabrics with cord and pillar stitches. Fabrics with pillar stitch provide very high bonding between the fabric and the cement matrix, which leads to the instantaneous fracture of the cement composite under bending.

**KEYWORDS:** cement-based composites; warp-knitted reinforced fabrics; stitch type; mechanical performance; reinforcement efficiency

## INTRODUCTION

Fibrous materials have found widespread application in the reinforcement of structural composites in recent years [1]. In particular, textile fabrics representing a reinforcing structure composed of continuous filament yarns or rovings have attracted considerable attention [2]. Moreover, in the last two decades, textiles have been widely used to reinforce cement composites, representing a combination of textile-reinforcing fabrics and the cement matrix. This combination has led to the development of a new type of structural material — textile-reinforced concrete (TRC). TRC finds diverse applications, ranging from a variety of concrete architectural elements to load-bearing structural members. It is an excellent building material in terms of sustainability, disaster control, and retrofitting of existing structures [3, 4].

## MATERIALS AND METHODS

### Reinforcing fabrics

Alkali resistant (AR) glass rovings and three types of carbon rovings with different mechanical characteristics were used for manufacturing the fabric samples. The fabric samples were produced on a 6 gage warp-knitting machine (MALIMO/c/P2-2S, Karl Mayer Textilmaschinenfabrik GmbH) at the Institut fuer Textiltechnik (ITA) of RWTH Aachen University. AR-glass and carbon rovings were used as the warp inlay yarns, while the weft yarns were AR-glass rovings only. The samples contain three rovings per inch of fabric width. The characteristics of the knitted fabric samples are listed in Table I. Polyester multifilament yarn (16.7 Tex) was used as the knitting yarn.

Table I. Characteristics of the knitted fabrics.

| Series | Raw material | Surface density, $g/m^2$ |
|---|---|---|
| 1 | AR-Glass rovings | 620 |
| 2 | Carbon rovings, 24K, PAN-based, 1600 tex | 510 |
| 3 | Carbon rovings, 24K, PAN-based, 810 tex | 415 |
| 4 | Carbon rovings, 12K, PAN-based, 1560 tex | 500 |

**Fabrication of cement composite samples**
Fine-grained concrete with a maximal sand fraction of 0.6 mm was used to manufacture the cement composite samples. Two samples of the reinforced fabrics were placed in the tension and compression areas at a distance of 7.5 mm from each edge of bottom and top of the concrete sample. The test samples were stored for 28 days at 23°C and 95% RH before testing.

**RESULTS AND DISCUSSION**
Fig. 1 shows the stress-deflection curves of bending for specimens of reinforced cement composites with different stitch types. From the curves, it is clear that the behavior of the samples varies and depends strongly on the type of reinforcing roving and the stitch. In samples with the tricot and cord stitches, after reaching the first peak, failure occurs stepwise, thereby achieving a high residual load capacity. In samples with the pillar stitch, an instant destruction occurs, primarily because of the high adhesion of reinforcement and matrix due to the open grid fabric structure. The initial part of the stress-deflection curve of each sample is characterized by linear properties, with subsequent transition to a part with a slight non-linearity. Following this, there is a first transverse crack corresponding to the maximum peak in the curve. Then, an increase in bending strength due to the resistance of the reinforcing rovings occurs. This process progresses in steps with the formation of several additional peaks. This effect is well pronounced for the tricot and cord stitches and less for the pillar stitch. However, as seen from the curves in Fig. 1a, the first peak in the graph is achieved at very high stresses of bending for the tricot and cord stitches. The strength at the first peak in these two patterns is almost equal (over 0.95 $\sigma_{max}$) to withstand peak sample.

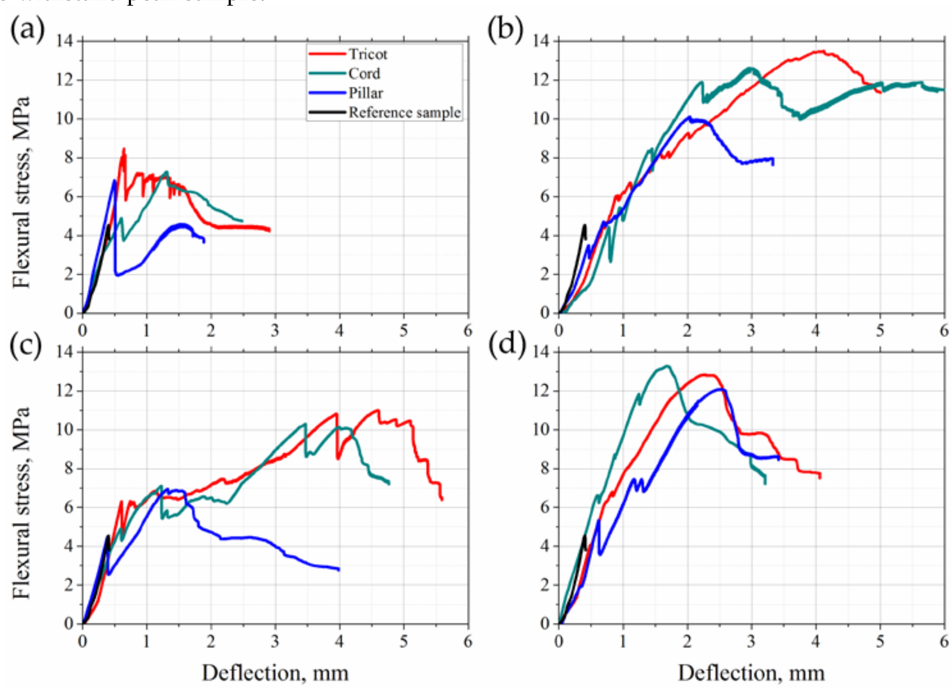



Figure 1. Stress-deflection curves of cement composites with different fabric stitch types.

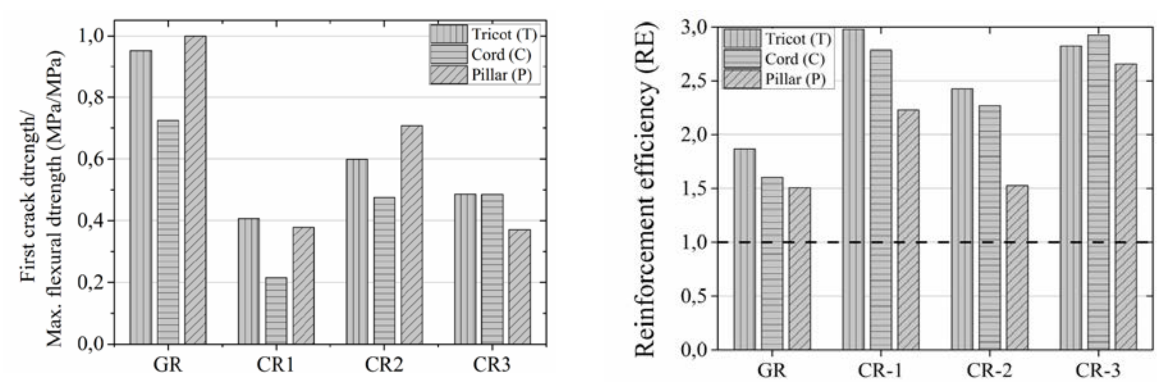
The sample of cement composite with glass yarn and pillar stitch was destroyed at the first crack because of strong bonding between the fabric and matrix. Samples of cement composites of carbon rovings achieve a value of the first peak of about 0.4–0.6 $\sigma_{max}$. Further, with increasing deflection, load increases because of the resistance of the rovings. In this behavior, the stitch plays a significant role in achieving the maximum breaking strain. In the case of the tricot and cord stitches, the reinforced concrete matrix continues to resist much longer compared with the pillar stitch. This is clearly seen in Fig. 1b and 1c, where the maximum deflection is more than 4 mm. This capacity of maintaining the form and performance without fracture at very large strains can be utilized in critical application areas, such as those associated with the seismic resistance of buildings and constructions. Samples with the pillar stitch show the worst properties, such as in the flexural strength and the capacity of bearing a load at high strains. It should also be noted that the sample of carbon roving CR3 based on the pitch-based yarn elicits a slightly different behavior from the previous samples (Fig. 3c). However, this sample has minimal tensile elongation when compared with others. The relationship between the first crack and concrete flexural strength depending on the stitch type is shown in Fig. 2a.

In order to evaluate the reinforcement efficiency of the investigated materials, the coefficients that show an increase in composite properties relayed to original material may be used. The reinforcement efficiency was calculated as

$$RE = \frac{FS_R}{FS_O}, \tag{1}$$

where $FS_R$ denotes the flexural strength of a cement composite in MPa and $FS_O$ denotes the flexural strength of the reference non-reinforced specimen in MPa.

Fig. 2b shows the coefficient of reinforcement efficiency with respect to the original non-reinforced cement sample. As can be seen, the data samples of fiberglass reinforcement have minimum efficiency by a factor not exceeding 1.86. For the carbon samples, the reinforcement efficiency factor was greater than 2.5 in the case of fabrics with tricot and cord stitch made of CR1 roving and for all three stitch types of cement composites with CR3 roving. The cement composite reinforced with CR2 roving showed the lowest strength efficiency, although this roving possessed the highest Young's modulus. The obtained results indicate a significant improvement in reinforcement efficiency. In addition, some positive effect can be found in deformation behavior of cement composites.




(a) (b)

Figure 2. Relationship between first crack strength and maximum flexural strength of concrete (a) and reinforcement efficiency (b).

## CONCLUSIONS

Experimental studies have clearly showed that the type of reinforced yarn structure as well as the design of the fabric has a significant impact on the properties of TRC. In order to improve the load-carrying capacity of TRC, warp-knitted fabrics made of AR-glass and carbon rovings were developed and produced. It was observed that the stitch type of warp-knitted fabrics significantly affects the properties of the fabrics and cement composites based on them. In general, fabrics with tricot stitch show better strength characteristics as compared to fabrics with cord and pillar stitches. However, the flexural behavior of the different stitch types varies considerably. Cement composites reinforced with fabrics with tricot and cord stitches demonstrate very high residual strength and low first-crack strength.

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# In-Plane Permeability Characterization of Reinforcing Fabrics Based on Radial Flow Experiments: Comparative Studies

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**ABSTRACT**

In liquid composite molding (LCM), dry preforms of reinforcing fabrics are placed in a mold and then impregnated with the liquid polymer matrix material. The impregnation process plays a key role as insufficiently saturated regions directly affect the mechanical properties of the final component. In order to avoid elaborate and expensive impregnation trials, filling simulations can be accomplished. These simulations strongly rely on accurate and trustworthy permeability values. A well-known approach to determine 2-dimensional permeability values of reinforcing fabrics is based on the observation of radial flow experiments (see Figure 1). There, a three-stage data evaluation procedure is followed: (1) acquisition of specific sensor data during the actual experiment, (2) evaluation of the sensor data to determine the flow front advancement with time and (3) calculation of the 2D permeability values from these characteristics.

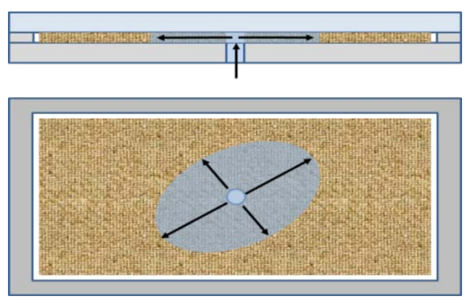

Figure 1: Schematics of a radial flow experiment.

In this work, two different approaches for capturing the flow front during the radial flow experiments are addressed: an optical and a capacitive measurement technique. Due to their respective built-up both approaches go together with major sources of deviations. The paper at hand focusses on experimental work to investigate these sources of deviations. This work was elaborated by two European research institutions in a joint initiative: The Processing of Composites Group (LVV) of Montanuniversität Leoben in Austria and the Institut für Verbundwerkstoffe (IVW) Kaiserslautern in Germany.

**TESTRIG DESCRIPTION**

Figure 2 (left) shows a picture of the optical testrig available at LVV. On top of the working table, the metal mold half is mounted. The security glass plate forming the upper mold half is made from two glass plates, each 19 mm in thickness, separated by a 0.76 mm thin polymer foil. The glass mold half is framed with metal profiles in order to connect it to a hinge system on the back side of the test rig. A pneumatic cylinder finally provides for the flapping motion. The actual mold cavity is specified through the cavity frame showing an inner dimension of 300 mm x 400 mm. After placing the reinforcing structures inside the cavity, the mold is closed and the glass plate is tightened with the lower mold half using a metal clamping frame and a set of screws. The radial flow experiment is then executed by injecting the test fluid into the cavity through a central injection point in the metal bottom mold half. The optical approach relies on a camera system focusing on the reinforcing fabric, which is positioned in a cavity with an optically transparent mold half, i.e. a glass plate. As the optical technique requires a glass plate, the structural stiffness of the mold is significantly lower than in the capacitive setup, where a full-metal mold is used. As a result, the load acting on the glass plate, which is a combination of the preform compaction pressure and the pressure field of the injected test fluid, causes a deformation of the cavity.

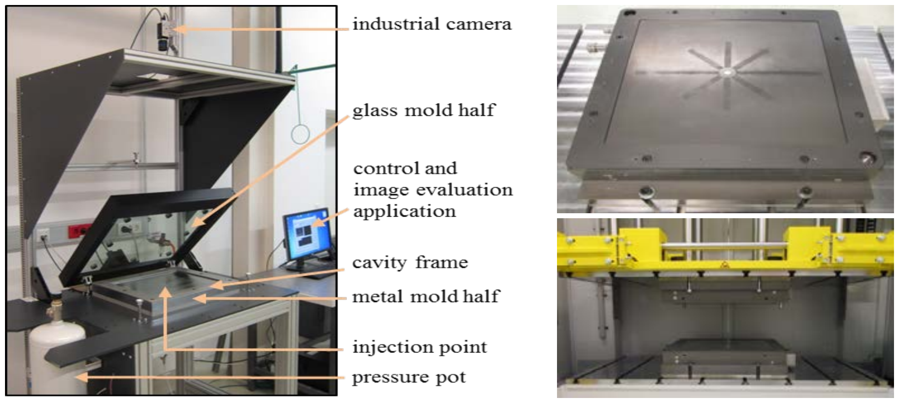


Figure 2: Optical permeability measurement system (left) as well as lower mould half of the capacitive permeameter with eight linear capacitive sensors (top right) and mounting of the two metal mould halves in a hydraulic press (bottom right).

The capacitive measurement system, designed and manufactured by PMB - Präzisionsmaschinenbau Bobertag GmbH (*pmb-bobertag.de*), involves two metal mould halves, each being 150 mm thick, mounted to a hydraulic press or mould carrier taking on the load resulting from preform compaction and fluid injection. A set of eight linear capacitive sensors is embedded in the lower mould half (see Figure 2, right) in a star-like scheme around the central injection point, whereas the test fluid is injected through a central injection opening in the upper mould half. The sensors show a length of 185 mm (East and West sensors) and 105 mm (all other sensors) as well as a sensitive width of 5 mm. They capture the change of capacitive equivalent representing the dielectric properties of the material covering their sensitive areas. The flow front position is linearly related with the level of sensor saturation and thus, can be reconstructed from the sensor signals. The methodology was developed and patented by the IVW [1].

For both techniques, the flow front is finally reconstructed to an elliptical geometry model by data interpolation or approximation strategies, respectively applied to the captured flow front data. The timely flow front advancement is finally obtained in terms of the major and minor axes length characteristics, respectively.

## COMPARABILITY OF IN-PLANE PERMEABILITY DATA

Although many authors reported on permeability data obtained from observation of radial flow experiments in the past [2-9], comparability of these values is not covered in the literature up to now. This is the focus of systematic investigations elaborated by LVV and IVW [10-11], which address (a) the mechanical nature of the test rig mould, (b) the sensors used for flow front tracking, (c) strategies for fitting elliptical geometry models to the sensor data and finally (d) algorithms and strategies for computing the principal permeability values from the experimental data and material properties. Figure 3 shows an overview of the permeability characterization procedure together with the major sources of deviations as studied by the two institutions. The results of this work lead to an initiative for an international benchmark exercise (*jeccomposites.com/knowledge/international-composites-news/international-textile-permeability-and-compressibility*), which is currently elaborated on two different types of centrally supplied fabrics as well as a common test fluid by 22 participants from all over the world.

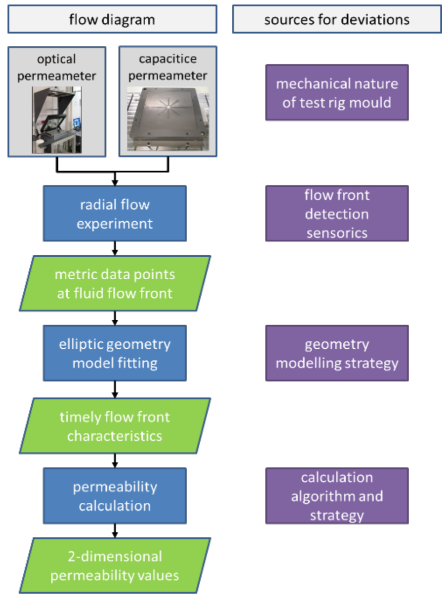


Figure 3: Flow diagram representing the permeability characterization procedure together with major sources for systematic deviations inherent to results gained with the two permeameter systems.

## ACKNOWLEDGMENTS

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# Investigation of the Production of Hollow Carbon Fibres

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The modern legislative demands improved resource efficiency and a reduced CO2-emission of motor vehicles. This leads to an increased research and development trend of lightweight construction in the automotive and aerospace industry. In contrast to this, the rising requirements for safety and comfort of motorized vehicles result in a higher weight of cars and airplanes. In order to resolve this conflict of interests more and more carbon fibre reinforced plastics (CFRPs) are used as substitution classical materials like steel and aluminium. Especially thermoplastic CFRPs combine excellent mechanical properties with a low specific weight (specific strength thermoplastic CRFP: 2,350 NM/g, specific strength steel: 77 Nm/g). This leads to a rising market demand for carbon fibres in the next years. However, the production of thermoplastic CFRPs is time- and energy consuming (~ 30 €/kg). The main cost driver lies in the production of carbon fibres (~ 20 €/kg), which hinders a further market penetration of thermoplastic CFRPs.

The main goal of this research work is the development of ultra-low weight hollow carbon fibres. These fibres can be produced quicker than standard carbon fibres and have a reduced weight with comparable mechanical properties. These effects result in a minimized thermoplastic CFRP weight and increase the total cost efficiency. This research shows the production process of hollow carbon fibres in lab scale. The focus lies on the stabilization and carbonization process. For the stabilization and carbonization process parameters are developed, by which the hollow structure of the fibres is maintained. SEM microscopy is used to measure the change of surface properties during stabilization and carbonization. Figure 2 shows a picture taken by SEM microscopy of a carbonized hollow carbon fibre.

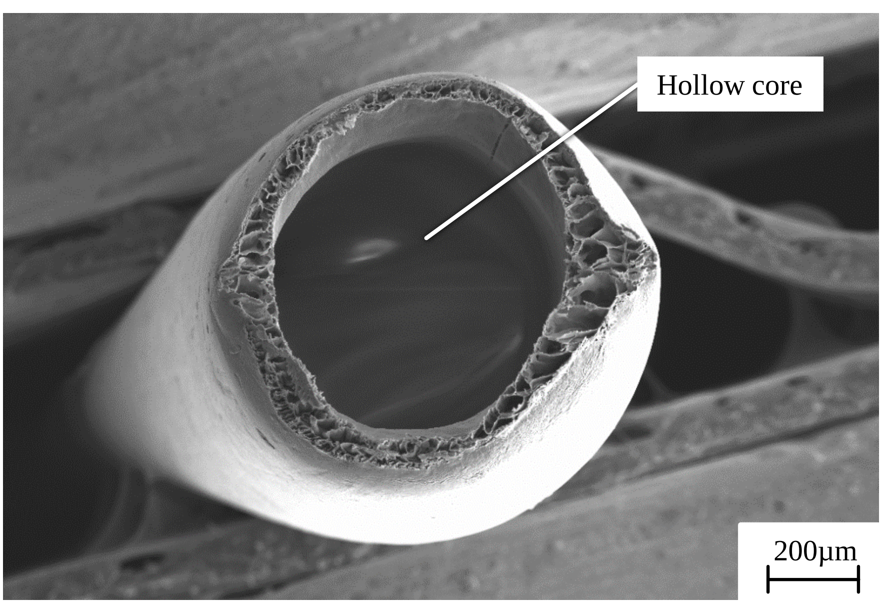


Figure 2. SEM microscopy of a carbonized hollow carbon fibre

FTIR and DSC are used for further analytics of the stabilization process. The stabilization and carbonization process of the hollow carbon fibres is compared to the stabilization and carbonization of “conventional” carbon fibres. The final product is a carbonized fibre with a hollow cross section.

# Analysis of Ceramic Fibre Processing with Braiding Machines for Two- and Three-dimensional Reinforcement Structures

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Structural materials with resistance towards multidimensional stresses for applications over 1000 °C in a corrosive atmosphere are key elements for the development of traffic engineering and metallurgy. Oxidic fibre composites are appropriate for these applications. Oxidic reinforced composites can resist damage under high temperatures and temperature gradients. In the research project “fibre reinforced oxide composites” a porous matrix is reinforced with a load capable optimised three-dimensional ceramic fibre structure.

In order to process brittle ceramic fibres with the 3D braiding process, tribological adaptions of the 3D braiding machine are crucial. As the highest damage of ceramic fibres occurs during braiding on the braiding bobbins, new bobbins have to be developed. The scientific background for the development of new bobbins is systematical tribological characterization of braiding bobbin parameters. The braiding process is analysed by the use of the 5-Step-Tool for systematic tribological investigations. In the first step of the analysis all contacts between braiding yarn and braiding machine components are identified. As a result, eight relevant influence factors have been identified. Six tribological systems are modeled on a tribological test bench called Tribometer. Firstly the number of contacts between yarn and machine elements and the resulting wrap angle are evaluated. Secondly different bobbin elements and recently existing bobbins are compared regarding their filament breakage rate. Process parameters are tested to identify the operation point for ceramic fibre processing. As 3D braiding requires dynamic yarn storage for flexible bobbin movements, the cylinder diameter of the bobbins is investigated to minimise fibre breakage during constant on and off winding of fibres. Ceramic fibres have to endure friction stresses to it. Thus fibre/fibre friction is examined.

With all these trials fundamental information for choosing a braiding bobbin concept is given. For further reduction of ceramic fibre breakage during processing, different coatings for yarn guiding elements are tested. This tribological study is used for three dimensional braiding of highly brittle ceramic fibres. Based on this study specialized bobbin prototypes are developed and constructed. Three dimensional braided and reinforced prototypes can be manufactured.

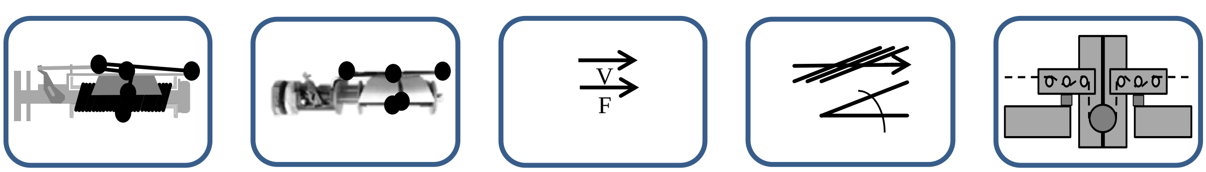


Figure 1: Evaluation of braiding bobbins and braiding process based on a 5 step tool tribological analysis.

**ACKNOWLEDGMENT**

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# Fiber Formation, Structure, and Properties

# Crystallization and Melting Behaviors of Polypropylene Blend Fibers Consisting of High and Low Stereo-regularity Components

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**ABSTRACT**

Isotactic polypropylene (IPP) is one of the most commonly used polymers in the world due to its reasonably good properties and low cost. Recently, IPP with extremely low but controlled stereo-regularity developed applying the metallocene catalysts was commercialized. The newly developed low stereo-regularity/low molecular weight IPP (LPP) is being applied either as the resin modifier for improving the processability of high stereo-regularity/high molecular weight IPP (HPP) or as the major component of spun-bonded elastomeric nonwoven fabrics. However, neither the exact mechanism for the improvement of spinnability of HPP/LPP blend nor its crystallization behavior have not been clarified yet. Therefore, with the aim of elucidating the effect of mutual interaction of HPP and LPP for crystallization and melting behaviors, blend fibers of various HPP/LPP compositions were prepared through the melt spinning process. In the spinning process, on-line measurement of the fiber diameter was carried out along the spinning line at various distances from the spinneret to analyze the thinning behavior. Differential scanning calorimetry (DSC), temperature modulated DSC (TMDSC) and wide-angle X-ray diffraction (WAXD) analyses were carried out during heating process for clarifying the crystallization and melting behaviors of individual components. On-line diameter measurement of the spinning line revealed that the blending of LPP into HPP caused the shift of solidification point to downstream. This result indicated the lowering of the crystallization temperature of HPP by the addition of LPP. Through the TMDSC analysis, re-organization of the crystalline structure through the simultaneous melting and re-crystallization was detected in the cases of HPP and blend fibers, whereas re-crystallization was not detected during the melting of LPP fibers. In the WAXD analysis during the heating of fibers, amount of alpha-form crystal was almost constant up to the melting in the case of single component HPP fibers, whereas there was a distinct increase of the intensity of crystalline reflections from around 100 °C, right after the melting of LPP, in the case of blend fibers. These results suggested that the crystallization of HPP in the spinning process as well as during the conditioning process after the spinning was hindered by the presence of LPP.

# Tungsten Wire Fabrics Used in Tungsten Fibre-reinforced Tungsten Composites

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The ideal material for highly loaded areas in a future fusion device needs to combine properties such as low sputter yield, high melting point, high thermal conductivity and moderate activation. Tungsten, as a promising candidate for such structures, has in addition also a high strength and creep resistance at elevated temperatures. However, the inherent brittleness below the ductile-to-brittle transition temperature and the embrittlement during operation, e.g. by overheating and/or neutron irradiation are the main drawbacks for the use of pure tungsten. To overcome this limitation, tungsten fibre-reinforced tungsten composites (Wf/W) were developed which utilizes extrinsic mechanisms to improve the toughness similar to ceramic fibre-reinforced ceramics [1]. As an integral part of this novel composite system tungsten wire used as reinforcing fibre has been part of intensive research work [2-8].

In this contribution we give an overview on this new composite material and its intended use in a fusion reactor. The focus will be on the review of conducted work on tungsten wire with a focus on microstructure and mechanical properties as well as textile processing. Tungsten wire shows a very high strength [2] and in contrast to conventional bulk tungsten large ductility [3] even at room temperature. The elongated grain structure was identified as the key parameter for the ductility [4]. Used in a composite the ductile deformation significantly contributes to the toughening [1,5]. By using potassium as doping material, the microstructure and properties of the wire exhibit excellent thermal stability [6]. To utilize these wires for the use in composites different textile techniques have been established i.a. weaving [1] and braiding [7]. To improve the textile process ability investigations on the production of tungsten based yarns thin filaments is ongoing [8]. In a powder metallurgical manufacturing approach wire pieces are used as random orientated short fibre reinforcements [9]. Further, this contribution will critically discuss the prospects of W wire to be used in composites in general and give a short outlook of the next steps in the development of Wf/W composites and the characterization of W wire.

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# Numerical Analysis of Non-steady State Melt-blowing Process Based on a Particle Method

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## INTRODUCTION

The non-woven materials with fine fibers are strongly required in this field to improve both of high filtration accuracy and low pressure drop. Melt-blowing process is well developed process for produce non-woven materials with fine fibers. The non-woven materials which has a mean fiber diameter 1 micron or finer has already been developed commercially. However, fiber formation behavior in melt-blowing process has not be well understood yet.

Basic numerical model of melt-spinning process and calculation method for that model in the 1960's. This model could describe spin-line deformation very well. The model was described in Eulerian coordinate system, so it was simple and powerful model for calculate steady-state spin-line. On the other hand, application of this model on melt-blowing process caused difficulty in calculation stability. In this study, numerical model and calculation method based on a particle method was developed and fiber formation behavior in melt-blowing process was investigated using this model.

## THEORY

Spin-line was described by particles connected in series with each other and movement of each particles solved in Lagrangian coordinate system. The basic formula for melt-spinning was described in Lagrangian coordinate systems as below.

Equation of continuity: $$\frac{\partial}{\partial t} m = 0$$

Equation of momentum balance: $$m\frac{\partial V}{\partial t} = F_{rheo} + mg + S\tau_f$$

Equation of energy balance: $$\frac{\partial T}{\partial t} = -\frac{Sh}{mC_p}(T - T_s)$$

Constitutive equation: $$F_{rheo} = \frac{A\eta}{L}\frac{\partial L}{\partial t}$$

Here, $g$ is acceleration of gravity, $\tau_f$ is air friction coefficient, $h$ is thermal transfer coefficient. The variables of each particle ($m$ : mass, $V$ : velocity, $T$ : temperature, $A$ : cross-sectional area, $S$ : surface area, $L$ : length, $x$ : position) are functions of particle number and time : $t$. When there were $N$ particles, $N$ equation could be described for each particle. Solving these simultaneous equations with $N$ variables, movement of the particles could be traced.

## RESULTS AND DISCUSSION

Fiber formation behaviors in melt-blowing process was calculated by numerical model based on a particle method. Stability of spin-line was quite good without considering surface tension. However, periodic change was observed with considering surface tension and low through-put. This periodic behavior was similar to the behavior which was observed by high-speed camera in melt-blowing experiment.

# Strength Improvement of Polypropylene Fine Fibers by Increasing Beta-crystal Content

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**ABSTRACT**
The commercial polypropylene is mostly isotactic with moderate crystallinity. Crystalline polypropylene is in alpha, beta and gamma crystal forms along with in the smectic form in an amorphous state. The triclinic gamma form rarely forms under regular processing conditions. Isotactic PP generally crystallizes into a stable monoclinic alpha form under standard process conditions, sometimes with a very low content of the hexagonal beta form. The presence of high levels of beta crystals can sharply improve the impact strength and toughness.

Commercial isotactic alpha PP has a melting point ranging from 160 to 166 °C, depending on crystallinity (atactic contents) while beta PP and syndiotactic PP with a crystallinity of 30% have a melting point of 150 and 130 °C, respectively.

Polypropylene (PP) is the most widely used polymer especially for meltblown application because of its processability, rapid crystallization and easy to drawing into fine fibers. Since, high melt flow index (MFR) grade of polypropylene has been used in producing fine fibers, it is important to increase the strength of individual fibers due to the softness of polypropylene short molecular chains.

The Wide Angle X-ray Scattering (WAXS) pattern of a sample web without water spray shows a typical α-form while sample webs with water spray appears to be in a transition phase toward ß-form. DSC results also support this transition.

The WAXS patterns of sample web with 2% Hindered Amine Light Stabilizers (HALS) + 98% PP with water spray shows the maximum peak shifting much closer to the beta crystal peak indicating increased amount of beta crystals.

The tensile strength and percent elongation to break along both MD and TD of sample webs with water spray and 2% HALS were higher than those without water spray. It appears that HALS additive seems to enhance the strength of polypropylene fine fibers.

# Wet-spinning of Silk Fibroin-based Conductive Core-Sheath Fiber

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As one of the most promising two-dimensional (2D) nanomaterials, grapheme has been widely applied to fiber sensors, owing to its exceptional electrical conductivity, flexibility and mechanical properties. In spite of the low electrical resistivity, the surface-coated graphene shows a crucial problem of charge transport due to the contaminant adsorption. Protective polymer coating, such as PMMA[1] and SiN[2], becomes the only approach to tackle this challenge.

Silkworm silk has attracted great attention for its superior mechanical properties due to its unique protein chain sequence, and is known in textile industry for thousands of years. In the recent decades, regenerated silk fibroin-based materials with desired properties are of considerable interest among the field of polymer science. Regeneration of silk fibroin (SF) fibers has been successfully prepared via wet spinning. Wet spinning technique enables the fabrication of high strength microfiber with a high degree of molecular orientation from liquid crystalline silk fibroin.

The current study aims to identify the feasibility of co-axial wet-spinning of SF-based conductive microfibers. Calcium chloride-formic acid ($CaCl_2$-FA) is used for dissolving SF in the sheath phase, and aqueous carrageenan solution containing different loadings of reduced grapheme oxide (rGO) as a dispersant, is used as the core phase. The outermost SF sheath can serve as a protective layer for the sensitive core rGO from the external stimuli.

Investigation will be conducted to analyze in detail the morphology, structures, conductivity and the mechanical performances of the as-spun fibers using scanning electron microscopy (SEM), Fourier-transformed infrared spectroscopy (FTIR), resistance tester, and universal tensile machine.

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# The Evolution and Formation Mechanism of Gradient Structure During Melt Spinning of Blend Fiber

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**OBJECTIVE**

The evolution of PS droplet in PP/PS blend fibers during melt spinning is investigated based on morphology analysis. Delaby's droplet deformation model was used to simulate and explain the formation mechanism of gradient structure. A quantitative relation between the temperature and deformation of polymer in elongational flow was established and used to calculate the radial temperature at different zones.

**APPROACH**

The cross and longitudinal sections of PP/PS blend fibers was scanned by SEM. These SEM micrographs were performed by binarization operation and partitioned into 5 zones from the center to the surface along radial direction, and the diameter, the length of major axis L and minor axis B, and the number of dispersed phase were automatically measured by image process software.

The temperature, velocity and elongational rate of running strand were obtained from basic dynamic equation for melt spinning. The rheologic property was investigated with a capillary rheometer.

**RESULTS AND DISCUSSION**

The average diameter *D*, the average number *n*, number average volume *V* and number average aspect ratio *L/B* of PS droplets in different radial zones at various taken-up velocities along the spinning line were obtained to study the evolution of the gradient structure. Results show that PS droplets experience large deformation under extension stress, and there is non-uniformly distribution of *L/B*, *n* and *D* for PS droplets along the radial direction. Droplets in center area experience larger deformation than those in the surface area.

The deformation of PS droplets was considered to be affine based on Taylor's deformation theory and Huneault's criterion. Delaby's deformation model $(\lambda_d - 1)/(\lambda_m - 1) = 5/(2p + 3)$ was used to describe the deformation of droplets along the spinning line. Delaby's model shows the deformation of droplet was attributed to $p$ which is determined by the temperature under the specific elongational strain rate. The higher temperature in the center of melt filament leads to lower interfacial tension than the surface, which makes the deformation of center dispersed phase easier.

A quantitative relation between the temperature and deformation was established based on Delaby's model and Arrhenius equation. The radial temperature along the spinning line was calculated utilizing dispersed phase as an indicator.

# Spinnability of Polyacrylonitrile Solution Research Based on Dry-Jet Wet Spinning Dynamics Simulation

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**ABSTRACT**

During the process of dry-jet wet spinning extrusion, it was found that sticking phenomenon happened if raised the spinning temperature, however, disappeared while improved the pump capacity and the PAN solution could be able to extrude out smoothly. At the same time, spinnability was generally judged subjectively or by an intuitive empirical criterion according to the experiment results in the actual spinning process. To put forward a criterion for extrusion spinnability of polyacrylonitrile (PAN) solution in dry-jet wet spinning, dynamics simulation calculation has been done according to the critical extrusion conditions of spinning experiment and measurement parameters of spinning dope. The results showed that only spinneret pressure had little difference, about 6MPa under the conditions of extrusion spinnable after comparison of the relevant engineering parameters: the liquid flow rate, flow velocity gradient, spinning solution viscosity, spinneret pressure, filament diameter, die swell ratio etc. Therefore, the pressure of spinneret was chosen as a criterion for judging the extrusion spinnability. Then, based on the criterion and the dynamics simulation model, we provided reliable theoretical basis for the design of spinneret orifice size. The pressure of spinneret orifice as a criterion for judging the extrusion spinnability could be generally applicable to other dry-jet wet spinning system and the results of simulation can provide favorable theoretical guidance for the control of the industrial production process.

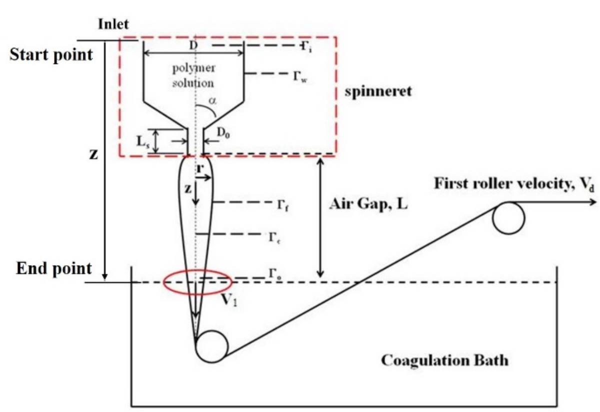


Fig. 1. Model of dynamic simulation along spinning-line (from start point to end point) in dry-jet wet spinning.

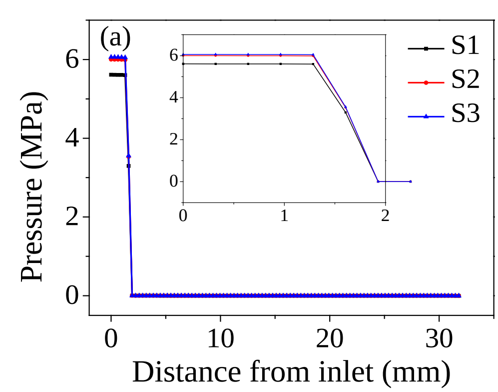


Fig. 2. Spinneret pressure distribution along spinning-line under the critical extrusion spinnable conditions during dry-jet wet spinning process (W=2.341 g/min, $T_0$=40°C, $T_{amb}$=20°C, L=30mm, $\lambda$=1.5).

**ACKNOWLEDGMENT**

This work was supported by the National Natural Science Foundation of China (11079015 and 51273039), Chinese Universities Scientific Fund (CUSF-DH-D-2016044), and State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, Donghua University (LK1506).

# Increase of the Adhesion Property of CFRP and CFRTP Materials and Preparation of New FRP Using Modified Fiber

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Carbon fiber reinforced plastic (CFRP) materials are useful for the lightweighting of cars and aircrafts. They are adhered each other with epoxy resin adhesives, and the adhered CFRP boards are reinforced by riveting or bolting. We have studied the modification of chemically stable polymeric material fibers such as polyolefin, silicone resin, fluorocarbon resin, and found a useful novel technique. We tried to modify CFRP and CFRTP (CF reinforced thermo plastics) boards to increase their adhesion property, applying the process. In addition, the modification of several stable fibers was examined to prepare new type FRPs.

Polymeric materials (fibers, boards) were used after washing with methanol. Commercial chemical reagents were used after a simple purification. Porous aluminum alloy boards (having nanometer size pores; Taisei Co. Jpn,) were used. Poly(vinylpyrrolidone) (PVP), wood-use bond, cyanoacrylate (CA), CA-primer set, a film type epoxy resin adhesive (3M-AF163-2), etc. were used. Polymeric materials were activated by oxidations and energy irradiations. The activated polymeric materials were coated with chemical reagents. These techniques were named as “DHM (durable hydrophilic modification) process”. Adhesion strengths of materials were measured by a tensile tester, Shimadzu AGS-H5KN. IR spectra were observed by a Shimadzu IRPrestige-21. XPS was observed by an Ulvac PHI 5000 VersaProbe II.

The following results were obtained:
1) The tensile shear strengths of non-modified CFRP adhered to non-modified CFRP boards, plasma-CFRP/ plasma-CFRP boards, and DHM-processed CFRP/DHM-processed CFRP boards are given in Table I. The DHM-processed CFRP boards showed a durable adhesion property.
2) Unmodified CFRP or modified CFRP boards adhered to aluminum alloy or porous aluminum alloy boards were compared each other. The DHM-processed CFRP adhered to porous Al board gave a maximum adhesion tensile strength (see Fig.1).
3) DHM-processed CFRTP (PEEK resin) adhered to DHM-processed CFRTP boards gave the shear strength, 25MPa. Unmodified CFRTP gave no significant adhesion strength.
4) FRP boards were prepared using unmodified or modified PET fibers and epoxy resin. The FRP made with DHM-processed PET fiber gave a high strength and a unique breaking behavior, as compared with FRPs made with unmodified or plasma treated PET fiber and epoxy resin.

Table I: Adhesion tensile shear strength of CFRP-CFRP boards adhered with film epoxy resin adhesive.

| Adhered CFRPs | Adhesion strength (MPa) |
|---|---|
| Unmodified CFRPs | 25 |
| Plasma-discharge processed CFRPs | 35 |
| DHM-processed CFRPs | 52 |

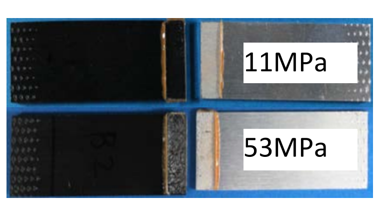


Figure 1: Adhesion of CFRP board to aluminum alloy board (upper; tensile shear strength=11MPa), and that of modified CFRP board to porous aluminum alloy board (lower; tensile shear strength=53MPa).

# Grafting β-cyclodextrin on Cotton Fabric


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**ABSTRACT**

Cyclodextrins (CDs) are macrocyclic compounds built from D-glucose units linked by α - (1, 4)-glycosidic bonds and due to the hydrophilic exterior and hydrophobic interior of these compounds. CDs can incorporate a variety of hydrophobic compounds in their cavities, via host-guest complexation. So, there were many attempts to permanently fix CDs on the cotton fabrics. In this study, ceric ammonium nitrate (CAN) was applied to generate free radicals on the surface of the fabrics and acrylic acid and (AA) with β-cyclodextrin itaconate (CDI) were permanently bonded to the pretreated fabrics. The characterisation results of modified fabrics with CDI suggest that the application of CDI can improve the performance of cotton fabrics. It was found that, despite of a reduction in the mechanical strength and physical properties of cotton fabric due to the oxidation of CAN, graft copolymerisation of AA and CDI could compensate these properties and improve the performance of the samples. The performance of β-CD fixed onto the surface of cotton fabric was evaluated by a new quantitative method. In this method a hydrophobic guest such as cyclohexane in the vapour phase was included in the cavity of CD onto the surface of the modified cotton fabric. Hence, by measuring the amount of the released cyclohexane via gas chromatography (GC) the quantitative determination of the maximum accessible content of CD onto the surface would be possible. The results showed that although the grafting rate indicated the amount of anchored CD onto the cotton fabric, the correlation between the grafting rate and the accessible content of CD confirmed the performance of the modified fabric. Therefore, this analytical method seems to be appropriate to estimate the maximum accessibility of CD cavities for molecular encapsulation on the surface of the modified cotton fabrics using β-CD and different crosslinking agents.


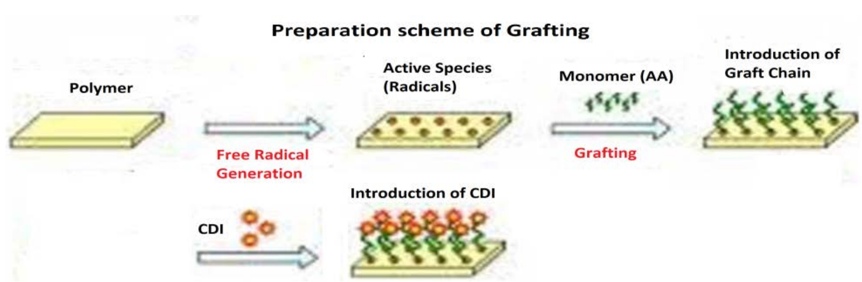


Fig 1. Graft Polymerization of AA/CDI on to cotton fabric.

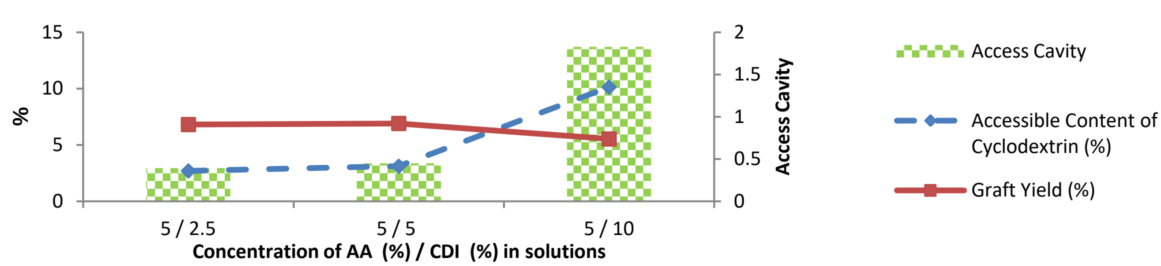


Fig. 2. Graft yield (%), accessible content of cyclodextrin (%) and access cavity of CDs for the fabrics modified with AA (5%) and different concentration of CDI.

# Posters

# Design of Freestyle Machine Embroidery

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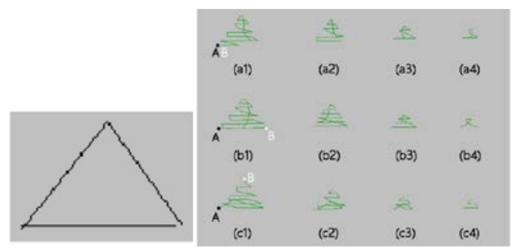
Compared with diversity of hand embroidery, the pattern of the machine embroidery is relatively simple and rigid, because design of machine embroidery is restricted to machine and software capability. In order to change this situation, this paper attempted to vary ordered stitches in machine embroidery into disordered stitches to simulate hand embroidery, through using the existing embroidery machines and software, and to develop the freestyle machine embroidery products with a mixture of reality and vitality and elegant and unique features. Studies on freestyle machine embroidery could not only inherit the essence of traditional manual disordered stitches, but also reduce costs and increase production efficiency of creating embroidery products with disordered stitches on the machine. In the paper, stitch combination, parameter setting, needle position, color overlay, yarn selection and embroidery combined with printing were studied by using WILCOM embroidery software. The methods and design experience of creating freestyle machine embroidery products were conducted.

Figure 1 shows Chinese traditional handicraft disordered stitches, which breaks the regular principles of pattern design, and extends the effect of traditional embroidery, is known as the Chinese fifth embroidery.

1. Chinese traditional hand embroidery with disordered stitches



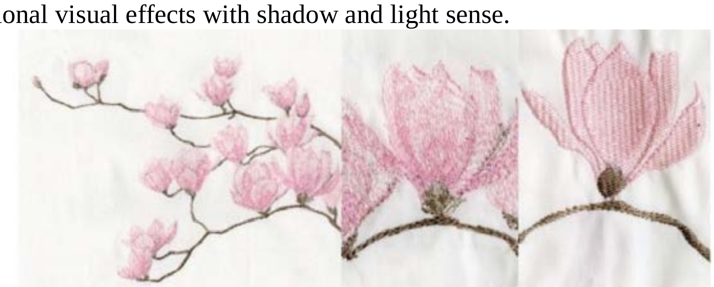

2. Experiment design of basic stitch unit

As shown in Figure 2, the study intended to imitate the pointillism, and use points as the basic unit to constitute complex patterns. According to the characteristics of hand embroidery, in the experiment, a triangle shape stitch was designed as the basic point, and the different triangle shapes were studied to explore the combination method for creating embroidery patterns.

As shown in Figure 3, the stitch density could directly affect the performance of freestyle machine embroidery, so this study investigated the stitch distances by changing design parameters and machine settings to achieve the best embroidery effects.

3. The experimental samples of freestyle machine embroidery by different stitch density

As shown in Figure 4, in contrast to the conventional machine embroidery, freestyle machine embroidery shows obvious three-dimensional visual effects with shadow and light sense.



4. Comparison between conventional and freestyle machine embroidery effects

# Flame Retardant Activity of Fabrics Based on Aluminosilicate Coatings

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## OBJECTIVE

The aim of this research was to apply the mixture of different aluminosilicates in the form of a very fine powder on three structurally different fabrics, i.e. according to pad-dry-cure procedure with or without crosslinking agent (DMDHEU) in order to modify fabrics surfaces and consecutively their functionalities without essentially affecting the fabrics' whiteness.

## MATERIALS AND METHODS

Three industrially-bleached fabrics in plain weave were used in this research, i.e. 100% cotton (CO), 100% polyamide (PA) and mixture of cotton/polyamide (CO/PA - 50/50). The source fabric was washed at 40 °C for 30 min using a neutral non-ionic washing agent, rinsed in warm and cold water and dried at ambient temperature. The aluminosilicates were synthesized and supplied by Silkem, Inc., Kidričevo, Slovenia, in the form of very fine powder; composed of 18.08 wt.% $Na_2O$, 29.24 wt.% $Al_3O_3$ and 43.73 wt.% $SiO_2$.

Aluminosilicates were analyzed using scanning electron microscopy (SEM) and X-ray powder diffraction (XRD). In addition, aluminosilicates were applied on fabrics according to the pad-dry-cure procedure. The samples were padded three times with a zeolite containing pad-liquor (30 g/L) using a laboratory pad-mangle, dried for 3 min at a temperature of 100°C (and then padded with DMDHEU and cured at 150°C). Coated surfaces were examined by SEM and FTIR, the flame retardancy by thermogravimetric/differential thermal analysis (TGA/DTA) and whiteness degree by spectroscopy.

## RESULTS

Selected results are presented in Figures 1 and 2.

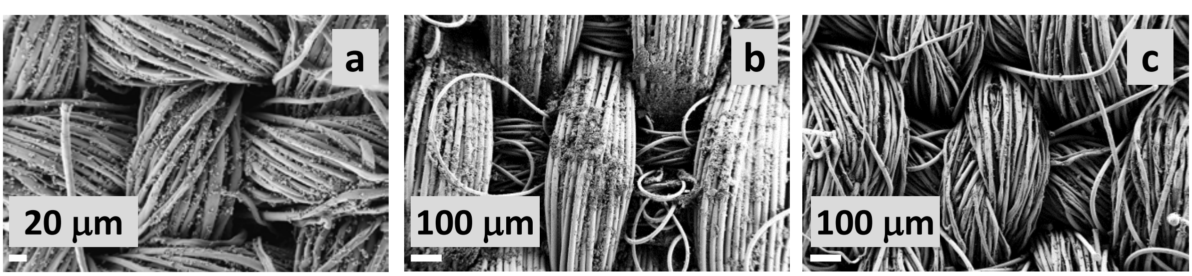


Figure 1. Selected SEM micrographs of aluminosilicate-DMDHEU coated fabrics: a) CO; b) PA; and c) CO/PA.

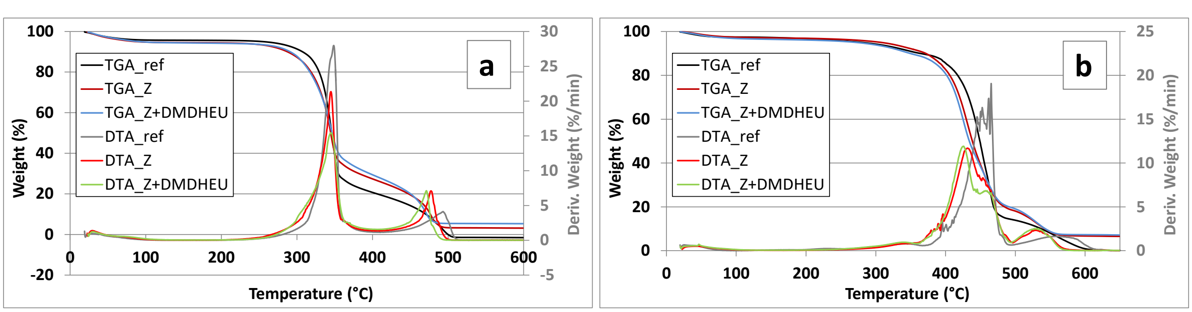


Figure 2. Selected TGA/DTA results of: a) CO; and b) PA.

# Determining the Effect of Different Washing Types on Tear Strength of Denim Fabrics

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Denim fabrics are currently used in many fields to produce trousers, jackets, shirts, blouses, working clothes and bags; furthermore, its production and consumption have constantly increased due to the comfort and durability of denim fabric and its ability to create diversity to satisfy different aesthetics and fashion sense. The purpose of some of the washing procedures applied to denim fabrics is to give variety to the denim.

The aim of this study is to experimentally determine the effect of different washing types on denim fabric's tear strength. In this context, two types of denim fabrics (one produced with elastane and the other without elastane) are selected as samples. The denim fabric constructions used in this study are given in Table I.

Table I. Properties of Denim Fabrics

| Constructions | Fabric Type | |
|---|---|---|
| | **Denim fabric with elastane** | **Denim fabric without elastane** |
| Weave pattern | 3/1 Z twill | 3/1 Z twill |
| Raw material | 98 % cotton, 2 % elastane | 100 % cotton |
| Weight (g/m$^2$) | 355 | 327 |
| Warp density (yarn/cm) | 33 | 40 |
| Weft density (yarn/cm) | 18 | 23 |
| Warp number (Ne) | 10 Ring carded slub | 14 Ring carded slub |
| Weft number (Ne) | 13 Ring carded+elastane (78dtex) | 13 Ring carded |

Then, three different washing processes (rinse, enzyme, and stone with enzyme) are applied to denim fabric samples. Afterwards, tear strength tests are performed according to two different methods by the related standards given in Table II.

Table II. Tear Strength Test Methods

| Test methods | Standard numbers |
|---|---|
| Textiles -- Tear properties of fabrics -- Part 1: Determination of tear force using ballistic pendulum method | TS EN ISO 13937-1 |
| Textiles- Tear properties of fabrics- Part 2: Determination of tear force of trouser- shaped test specimens (Single tear method) | TS EN ISO 13937-2 |

Finally, the tear strength test results of pre-washing and post-washing sample fabrics are evaluated and interpreted graphically and statistically.

# The Effects of Abrasion Process on Water Repellency Performance of Upholstery Fabrics

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The fabrics produced from chenille yarn are widely used in the upholstery industry, although they have low abrasion resistance. In this study, it was aimed to determine the effect of the abrasion process on the water repellency properties of the upholstery fabric produced by chenille yarn. For this purpose, six different upholstery fabrics woven with chenille yarns having three different raw materials (polyester, acrylic, and viscose) and two different pile heights were produced. For objective evaluation of the study; warp raw material, warp and weft density, second weft yarn and fabric pattern were kept constant (Table I). Water repellency finishing was applied to fabric samples in laboratory type foulard machine at two different liquid ratio values with impregnation method. Then, the samples were dried in laboratory type dryer at 150°C for different durations and fixed at 170°C, respectively. After this process, the fabric samples were subjected to abrasion according to related standard with Martindale test equipment. Water repellency values of samples before and after abrasion were measured and the results were evaluated.

Table I. The Properties of the Sample Fabrics

| | Sample codes | | | | | |
|---|---|---|---|---|---|---|
| **Properties** | **N1** | **N2** | **N3** | **N4** | **N5** | **N6** |
| **Chenille Material (Pile Yarn)** | %100 PES | | %100 Acrylic | | % 100 Viscose | |
| **Pile Height** | 0,8 mm | 1,2 mm | 0,8 mm | 1,2 mm | 0,8 mm | 1,2 mm |
| **Chenille Material (Chain Yarn)** | %100 Cotton | | | | | |
| **Chenille Yarn Twist (turns/m)** | 900 turns/m | | | | | |
| **Chenille Yarn Count** | Nm5 | | | | | |
| **Warp Yarn Material** | %100 PES | | | | | |
| **Material of Second Weft Yarn** | %100 Cotton | | | | | |
| **Weaving Construction** | Plain Weave | | | | | |
| **Weft Density** | 18 yarn/cm | | | | | |
| **Warp Density** | 70 yarn/cm | | | | | |

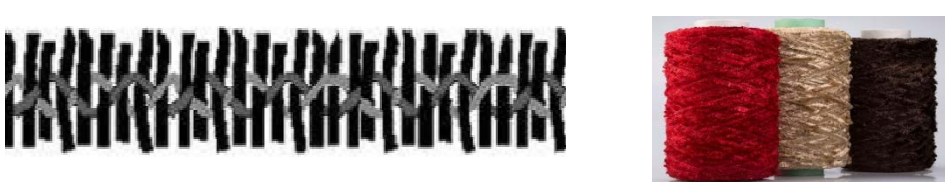

Figure 1. Chenille Yarn Structure

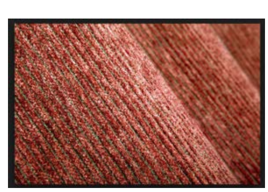

Figure 2. Sample Fabric from Chenille Yarn

According to the test results, the water repellency values of samples decreased after abrasion as expected. But, after 500 rpm abrasion, water repellency values of samples having different raw material were determined as ISO4 and ISO3. These values are the acceptable values for upholstery fabrics. It was also found that the impregnation rate was not a significant effect in maintaining the effectiveness of the water repellency property. However, the effect of pile height and pile raw material on the water repellency property after abrasion was investigated.

# Micro- and Nanoscale Polyester-based Hybrid Acoustic Insulation Materials

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Acoustic insulation materials should fulfill the requirements: high efficiency, low cost and low environmental impact. A hybrid structure combined of micro and nano fibers is an ideal material to meet these requirements. Hybrid polyester fiber mats were prepared by electrospinning PLA porous fibers onto carded PET fiber mats. Ina systematic study, electrospinning parameters of the nanofiber mat as well as fineness, cross-section and crimp of the PET microfibers were evaluated.

Acoustic performance of the insulation mats was investigated, and the relevant parameters of the nanofiber layer structure that affect sound insulation performance were identified. Results showed that the number of nanofiber layers, diameter of PET microfibers and their bulk density and porosity were key elements for good acoustic insulation properties. Maximum sound absorption coefficients of 0.5 and 0.8 were achieved at 500Hz and 1000Hz, respectively. However, the thickness of nanofiber layer showed little attributes for the acoustic insulation properties.

# Preparation of Polyamide 6/Zeolite Composite Filaments

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## OBJECTIVE

The main goal of this research was to incorporate industrially-synthesized zeolite into a polyamide 6 (PA6) masterbatch, from which PA6/zeolite filaments were spinning in an industrial scale, in order to impart different functionality to PA6 yarn and, at the same time, replace the fillers without affecting optical and mechanical properties of knitted fabric.

## MATERIALS AND METHODS

4A zeolite particles were industrially-synthesized and supplied by Silkem, in the form of very fine powder. Zeolites were characterized by scanning electron microscopy (SEM) and X-ray powder diffraction (XRD). Additionally, the PA6/4A masterbatch containing 10% (mass fraction) of zeolites was prepared and dried for 5 hours at 90°C. As-prepared masterbatch was used as a filler to prepare PA6/4A composite filaments during melt spinning process using industrial spinning line (AquafilSLO) for the production of a partially oriented yarn. The total amount of zeolites was fixed to 2 wt.% with an aim of minimal effect on the yarn' mechanical properties. The morphological and chemical characterization of PA6/4A composite filaments was accomplished by SEM and FTIR techniques, the flame retardancy by thermogravimetric/differential thermal analysis (TGA/DTA), diffuse reflectance spectra (DRS) profile by spectrophotometry, and selected mechanical properties by means of a Textechno statigraph M test machine according to standard ISO 2062:1993.

## RESULTS

Selected results are presented in Figures 1 and 2.

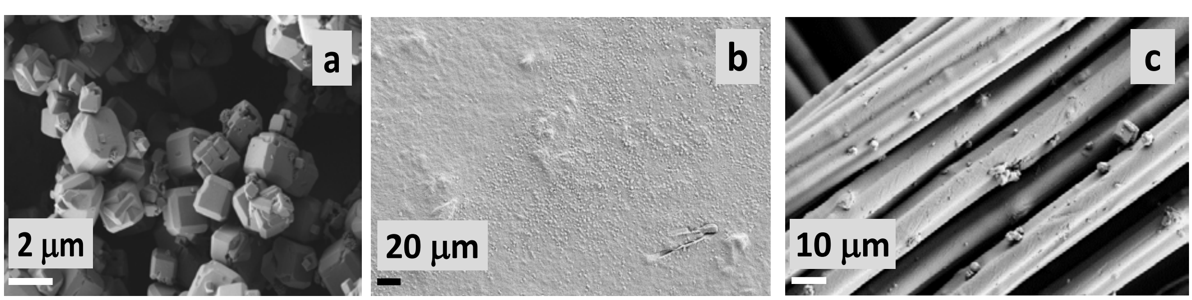


Figure 1. SEM micrographs of: a) 4A zeolite particles; b) PA/4A masterbatch (90/10); and c) PA/2% 4A knitted fabric.

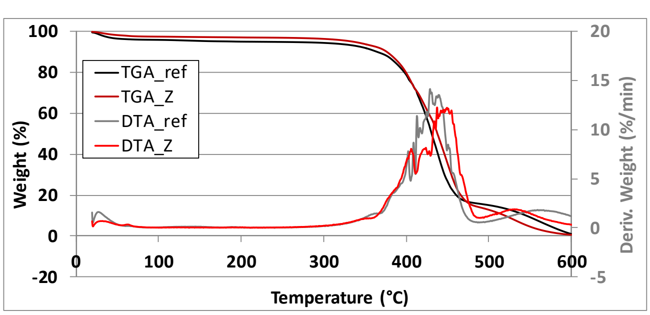


Figure 2. TGA/DTA of PA/4A knitted fabric.

Table I. Selected mechanical properties.

| Sample | Elongation (%) | Force (N) | Tenacity (cN/tex) |
|---|---|---|---|
| PA6 | 45.91 | 1.40 | 16.82 |
| PA6/4A | 40.24 | 1.36 | 16.39 |

# Photo-Catalysis Properties of Electrospun Ceramic $TiO_2$ Nanofibers with Different Structures and Morphologies

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**ABSTRACT**

The unique properties and wide variety of potential applications of ceramic nanostructures in future nanoelectronics and functional nanodevices, such as optoelectronics, photonics, cosmetics, health, bioengineering, sensors, mechanics, and catalysis make theses nano-materials as one of the interesting research topics in recent years. It is necessary to fabricate these one-dimensional structures in uniform way. Electrospinning seems to be the simplest and the most versatile method, also inexpensive technique to achieve this aim, compared with other methods. The electrospun nanofibers are continuous, and also relatively easy to align, assemble, and process into desired applications.

In this study, we fabricated some different types of high porosity ceramic $TiO_2$ nanofibers created with sol-gel electrospinning technique with subsequent heat treatment process. The anatase-phase titanium oxide ($TiO_2$) has attracted extensive research interests in the recent years, because it has a wide variety of applications such as environmental remediation, electronics, sensor technologies, solar cells, and photo-catalysis applications.

Morphologically controlled fabrication of $TiO_2$ with different structures such as nanorods, hallow porous sheets, nanofibers and hallow, porous, mono-core hallow nanofibers were produced in this study. The electrospun $TiO_2$ nanofibers with diameters being hundreds of nanometers to about 60 nanometers, and consisting of anatase-phase $TiO_2$ crystallites with sizes of about 10 nm, particularly the porous structures with relatively high specific surface area were fabricated. The crystal structures, morphologies, specific surface area and photo-catalysis properties of the $TiO_2$ nanostructures were investigated using X-ray diffraction, scanning electron microscopy, Brunauer–Emmett–Teller analysis and UV spectrophotometer, respectively. The results indicated that electrospun anatase-phase $TiO_2$ nanofibers with special structures and relatively high specific surface area increase the performance of their photo-catalysis properties in these materials.

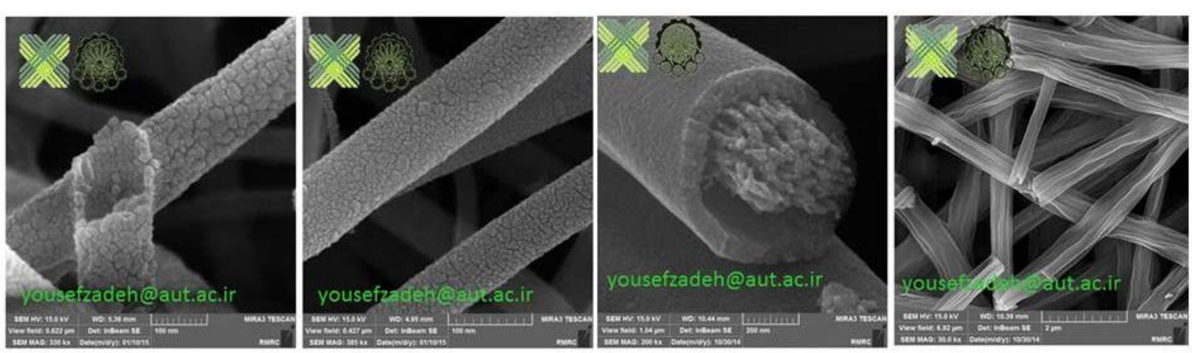


Figure 1: Some of the different $TiO_2$ nanofiber structures that were produced in this study.

# Potential of POF Sensors for Structural Health Monitoring of Fiber Composites

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**ABSTRACT**
Lifetime calculations of fiber composites are currently evaluated conservatively, as no exact models exist. Since maintenance is offline, this results in high downtime und maintenance costs. Structural Health Monitoring refers to the long-term and reliable surveillance of potential damage in structural components during operation by direct implementation of non-destructive testing systems on or into the structure. So, real lifetime can be exhausted by recognizing damage before failure of the composite, reducing weight by decreasing safety coefficients and by lowering the maintenance effort by condition-based maintenance instead of time-based.

A short summary of the most important SHM techniques will be given and evaluated in regards to their suitability for the application in fiber reinforced plastics (FRP). Special attention will be paid to the use of polymer optical fibers (POF) regarding their good sensorial properties (high failure strain and small bending radius) as well as their easy and direct integration into reinforcement textiles. Three different concepts are evaluated and whereof the most suitable are implemented in FRP-specimen to test their processability. The results are compared to commercially available glass optical fiber (GOF) sensors. By now, GOF are used mostly. However, these fibers have a low elongation at break, with a maximum of 1 %, and a high bending stiffness which complicates the processing, positioning und measurement of high elongations. Polymer optical fibers show minor attenuation characteristics. Thus, potential transmission distances are shortened to approx. 100 m. On the other side, POF can be stretched over 30% and placed in smaller bending radii.

To meet the high standards needed for SHM systems, the following requirements have been found out to be fulfilled by POF: A small fiber diameter has large impact on good textile processing and on homogenous stress distribution within the laminate. Nevertheless, a compromise has to be found between a small diameter for a good processability and a large diameter for easy manual handling. Additionally, processing characteristics also depend on the material. Beside PMMA-POF, elastomers with good optical properties may be taken into account. This is currently examined at ITA.

The principle of SHM with POF is shown in Figure 1.

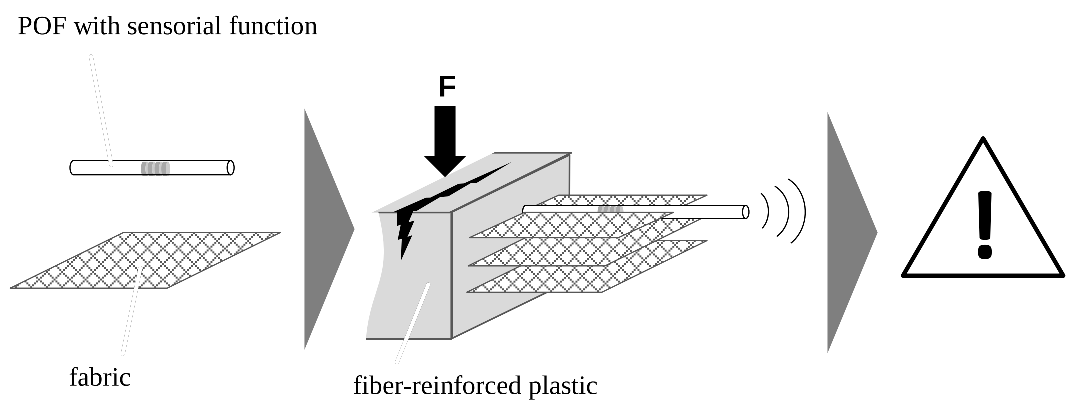


Figure 1: Automatic online-monitoring of fiber reinforced plastics by sensorial, optical polymer fiber integrated into the textile.

# Dual-beard Algorithm for Fiber Length Histogram

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## INTRODUCTION

Dual-beard is a novel type of sample for fiber length measurement, which is prepared by perpendicularly clamping a uniform sliver and combing the unclamped fibers away. As each fiber's probability of being clamped only relates to its length, dual-beard is closer to Hertel's intention about length-biased sample than Fibrograph beard. The dual-beard can be scanned into a transmission grayscale image which is converted by our special optical algorithm into relative linear density curve for further calculation, as shown in Figure 1. This study focuses on the algorithm for computing cotton and wool length frequency histogram based on this curve.

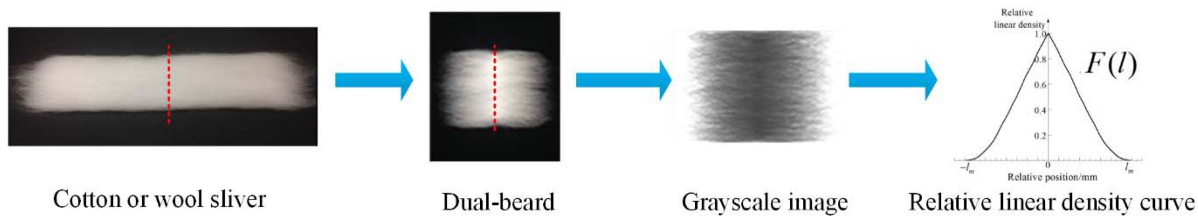



Figure 1. Procedure of obtaining relative linear density curve in dual-beard image method

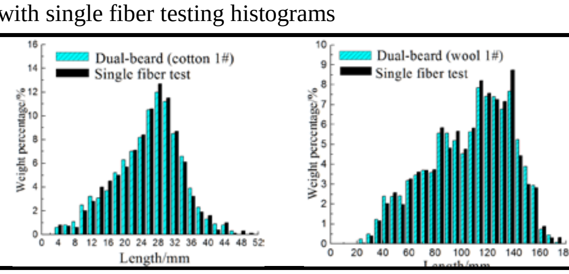
## METHOD AND MATERIALS

In the previous study, we presented a formula for calculating short fiber content by weight ($SFC_w$, i.e., the weight percentage of fibers shorter than a fixed length threshold which is 1/2 inch in US and 16 mm in China) based on the curve $F(l)$, as shown by Equation 1 where $\alpha$ is the length threshold. By replacing $\alpha$ with an arithmetic progression using 0 as first term and $k$ as tolerance, we obtained a series of formula listed in Table I, which are capable for calculating the weight percentages of fibers shorter than a series of length thresholds. It is obvious that subtracting $SFC_w(3k)$ by $SFC_w(2k)$ will give the weight percentage of fibers whose lengths are between $2k$ and $3k$, similarly, the data of successively subtracting each formula in Table I by the prior one will finally generate a length frequency histogram by weight, using $k$ as interval. In order to test this algorithm, 24 cotton and 12 wool are measured by dual-beard image method, the computed histograms and mean length values are compared with those from reference methods.

$$SFC_w(\alpha) = F(0) + 15.5[F(\alpha) + F(-\alpha)] - 16[F(\tfrac{31}{32}\alpha) + F(-\tfrac{31}{32}\alpha)] \quad (1)$$

Table I. Algorithm formula and the computed histograms compared with single fiber testing histograms

| $\alpha$ | Formula for cumulative weight percentage |
|---|---|
| 0 | $SFC_w(0) = 0$ |
| $k$ | $SFC_w(k) = F(0) + 15.5[F(k) + F(-k)] - 16[F(\frac{31}{32}k) + F(-\frac{31}{32}k)]$ |
| $2k$ | $SFC_w(2k) = F(0) + 15.5[F(2k) + F(-2k)] - 16[F(\frac{31}{32}\cdot 2k) + F(-\frac{31}{32}\cdot 2k)]$ |
| $3k$ | $SFC_w(3k) = F(0) + 15.5[F(3k) + F(-3k)] - 16[F(\frac{31}{32}\cdot 3k) + F(-\frac{31}{32}\cdot 3k)]$ |
| … | … |




## RESULTS AND DISCUSSION

The histograms and mean lengths in Table I and Figure 2 display that the measurement results of dual-beard algorithm have highly agreement with those from manual test of 1000 single fibers, AFIS and Almeter. The algorithm enables dual-beard image method to provide comprehensive and accurate fiber length information.

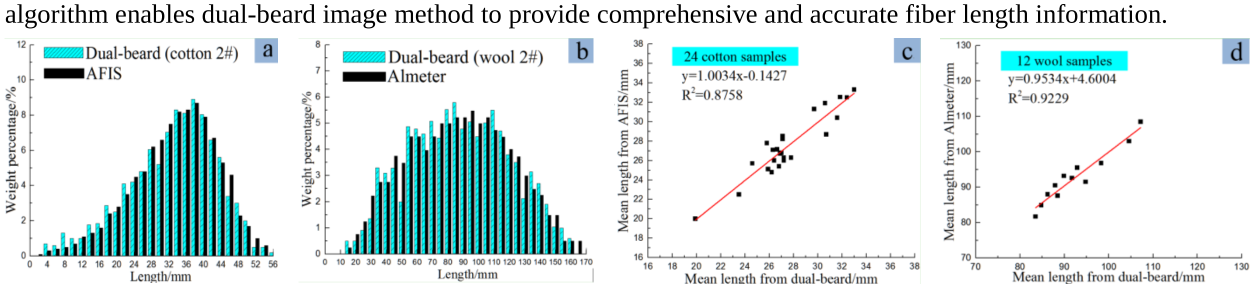



Figure 2. Comparison between the measurement data of dual-beard algorithm and reference instruments (AFIS and Almeter)

# A Study of 3D Auxetic Textile Reinforced Composite

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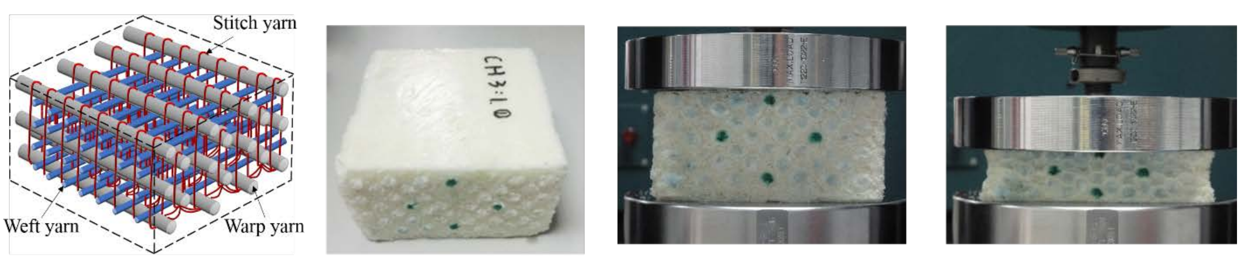
**ABSTRACT**

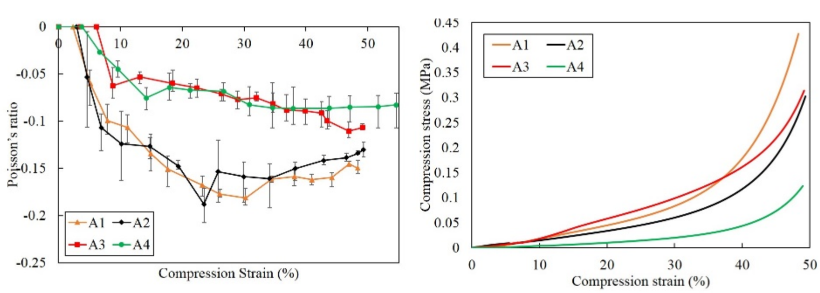
In recent years, auxetic composites have attracted considerable attention. Due to their unique performance compared with non-auxetic materials, auxetic composites have potentially shown enormous suitable applications in various areas. However, auxetic materials are substantially less stiff than the solids from which they are made and this causes limitations on their structural applications. In this work, a new kind of auxetic composite was fabricated by using 3D auxetic textile structure (Fig. 1(1)) as reinforcement and conventional polyurethane foam as matrix. The produced sample is shown in Fig. 1(2). Due to the special arrangement of warp yarns in 3D textile structure, the fabricated 3D composites display very good auxetic behaviour under quasi-static compression (Fig. 1(3)-(4)). The testing results also shows that the auxetic behaviour of the composite increases with increasing the compression strain (Fig.2 (2)). Among all the evaluated structural parameters of auxetic composites (Fig.2(1)), the diameters of warp yarns obviously affect the auxetic behaviour and the density arrangements of weft yarns affect the compression properties (Fig.2(3)). It is expected that this study could pave a way to the development of innovative 3D auxetic textile composites for different potential applications such as impact protection.




(1) (2) (3) (4)

Fig. 1 (1) The schematic presentation of 3D auxetic textile structure; (2) auxetic composite produced; (3) unloaded state; (4) under compression.

| Structure type | Structure No. | Warp yarn: Diameter r1(mm) | Warp yarn: Arrangement method | Warp yarn: Spacing Sx (mm) | Weft yarn: Diameter r2(mm) | Weft yarn: Arrangement method | Weft yarn: Spacing Sy (mm) | Diameter of stitch yarn (mm) | Fabric structure thickness (mm) |
|---|---|---|---|---|---|---|---|---|---|
| Auxetic | A1 | 6 | In the form of one in and one out | 15 | 2 | full-arranged | 3.7 | 0.5 | 50 |
| | A2 | 6 | In the form of one in and one out | 15 | 2 | half-arranged | 7.5 | 0.5 | 50 |
| | A3 | 4 | In the form of one in and one out | 15 | 2 | full-arranged | 3.7 | 0.5 | 46 |
| | A4 | 4 | In the form of one in and one out | 15 | 2 | half-arranged | 7.5 | 0.5 | 46 |




(1) (2) (3)

Fig.2 (1) Structural parameters of 3D auxetic textile reinforced composites; (2) auxetic behaviours; and (3) compression cuves.

**ACKNOWLEDGMENT**

This work was supported by the Research Grants Council of Hong Kong Special Administrative Region Government in the form of a GRF project (no. 515812).

# Negative Poisson's Ratio Behavior and Pore Characteristics of Woven Fabric Made of Auxetic Plied Yarn under Tension

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## ABSTRACT

The basic configuration of the auxetic plied yarn structure involves two soft yarns and two stiff yarns to achieve negative Poisson's ratio (NPR) behavior (Fig. 1). Compared with the existing helical auxetic yarn (HAY) based on a double helix structure to generate auxetic effect with a different auxetic mechanism, the 4-ply auxetic yarn has the advantages of being more stable and capable of producing immediate auxetic effect upon stretching. Auxetic plied yarns are not only suitable to use exclusively, but also feasible to fabricate textile fabrics with auxetic effect. This paper presents an experimental study of the NPR and pore characteristics of woven fabrics made of auxetic plied yarns with a 4-ply helix structure. Six kinds of macro-scale 4-ply auxetic yarns were made by different combinations of soft yarns, stiff yarns and twist directions. The yarn samples were then incorporated into a range of woven fabrics with different yarn contents and weaving structures. For a comparative purpose, HAY- and 6-ply auxetic yarn- woven fabrics were fabricated as well. The fabric samples were subjected to tensile testing (Fig. 2) and characterized in terms of their auxetic behavior and open pore properties (Fig. 3) throughout the entire tensile process.

The study shows that NPR effect of the 4-ply auxetic yarns is still promoted in the fabric samples under tensile load (Fig. 4). Porosity changes for varying woven structure, while design parameter of the 4-ply auxetic yarn is found to be the factor that has the most significant effect on the auxeticity and open pore properties of the fabric samples. Besides, auxetic fabrics made of 4-ply auxetic yarns display a larger auxetic effect and porosity variation than those made of HAYs and 6-ply auxetic yarns during extension, which is an attractive feature to be utilized in a wide range of engineering applications.


Fig. 1: 4-ply auxetic yarn: (a) at rest; (b) under tension; (c) at different states in cross-section view.

Fig. 2: Photograph of the tensile as testing system.

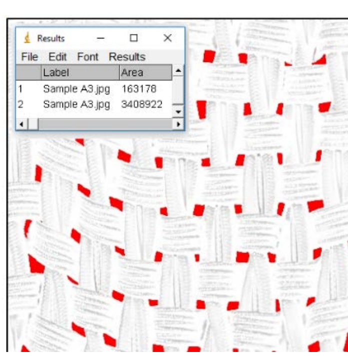


Fig. 3: Image analysis of sample A3 at given strain.

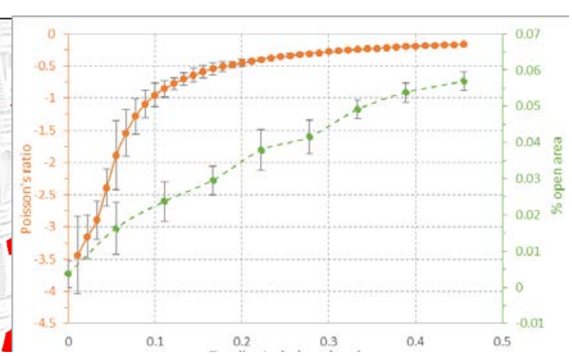


Fig. 4: Poisson's ratio and percentage of open pore area as function of tensile strain for sample A3.

## ACKNOWLEDGMENT

This work was supported by the Research Grants Council of Hong Kong Special Administrative Region Government (grant number: 515713).

# Tensile Property of PTFE under Different Conditions


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## INTRODUCTION

Polytetrafluoroethylene (PTFE) as engineer materials has excellent physical and chemical properties, such as outstanding thermal stability and toughness at low temperature, low thermal conductivity and chemical resistance. The tensile properties of PTFE woven fabric exposed to different temperature were studied in this paper.

## MATERIALS AND METHOD

PTFE fabrics used in this study were supplied by Changzhou XCF Polymer Materials Co., Ltd, and the yarns in the fabric are constructed by twisting PTFE sheet which is slit and further stretched. The warp and weft density of fabric is 342 threads/ 10cm and 300 threads/ 10cm, respectively. The temperature dependent tensile properties were investigated using Instron 5966 with a chamber in the temperature range of 25-300$^{o}$C. And the tensile properties of PTFE fabric with different heat treatment were tested at ambient temperature to serve as a contrast.

## RESULTS AND DISCUSSION

As shown in figure 1(a), higher temperature and longer time of heat treatment have little effect on the mechanical properties of PTFE fabric achieved at room temperature, which shows that PTFE fabric has good heat resistance. However, the tensile curves in Figure 1(b) show that break strength decreases quickly with the increase of temperature, and higher temperature leads to greater break extension. Seen from the curve of 85$^{o}$C, there is a long platform stage where the load is almost unchanged while the strain keeps increasing. And this large deformation below Tg is may due to the less relaxation time of polymer chain along the direction of external force when elevating temperature. While at 170$^{o}$C, the longer platform stage is owing to the slippage of ribbon-like crystalline structure of PTFE under the interaction of heat and force above Tg. The Td (decomposition temperature) was defined as the point at which the mass loss was 5% and the Td of PTFE fabric was 508.6$^{o}$C. According to the previous statement, we can draw a conclusion that although PTFE is a kind of thermostable material, there will be a large deformation under the interaction of high temperature and large force.

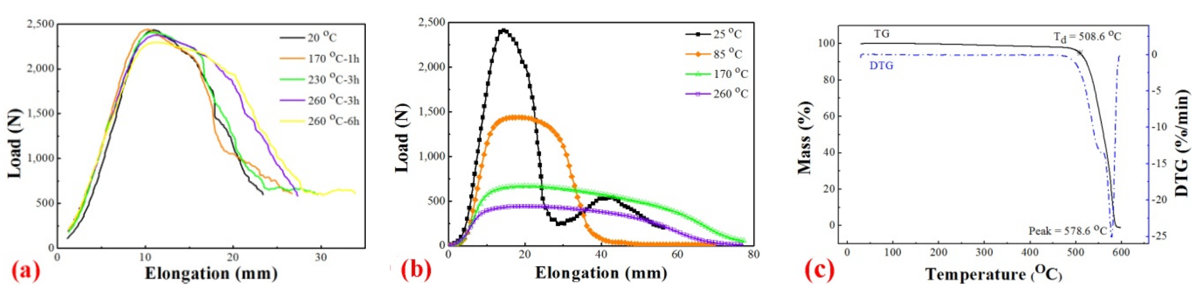


Figure 1. (a) Warp tensile curves of PTFE fabric tested at room temperature after heat treatment, (b) tested at different temperature, (c) TG curve of PTFE fabric.

# Synthesis of Monodisperse and Porous Ag Nanoparticles/Polystyrene Microcomposite Particles by Seeded Suspension Polymerization

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In recent years, silver nanoparticles (Ag NPs)/polymer composites have attracted much interests because of their numerous potential applications. Especially the porous polymers are now widely used because of its high specific surface area, which is very improtant in the field of energy storage and catalysis.

In our research, monodisperse and porous polystyrene (PS) microspheres with homogeneous and uniform dispersed Ag NPs embedded were obtained in a two-step seed swelling polymerization. This procedure is involving precipitation polymerization synthesis of PS seed particles, swelling of seed particles with monomers, crosslinker, Ag NPs, plasticizer, initiator and porogen, and polymerization of those substances inside the swelled PS seed particles. In order to keep high dispersity of Ag NPs in the porous PS matrix and to have strong combination between the Ag NPs and the matrix. An organic-soluble Ag NPs capped with double bond were synthesied previously and used during the polymerization. The Ag NPs can be well dissolved in the monomer, crosslinker and plasticizer, so they can be easily swelled into the PS seed together with monomers during the swelling step. In addition, the double bond on the surface of Ag NPs can be reacted with styrene monomers and divinylbenzene crosslinkers to firmly trap Ag NPs into the PS network by covalent attachment. In the experiments, the reaction temperature, the amounts of Ag NPs, the ratio between the monomer and the crosslinker, the kinds of porogen were changed to investigate their effects on the structure and morphology of Ag NPs/PS porous composites. FTIR, SEM, XRD, TEM, BET and TGA methods were used to characterize the composite, structure, mophology, specific surface area and Ag NPs loading amount, respectively.

Herein, a method to synthesize monodisperse and porous Ag NPs/PS microcomposite particles is studied. In view of the high specific surface area of porous PS and excellent catalytic activity of Ag NPs, the catalytic properties of this kind of composite will be further explored in the future. As Ag NPs/PS microcomposite particles can be a functional particles, it is possible and meaningful to produce crosslinked and highly porous Ag NPs/PS composite fibers in the next step.

**ACKNOWLEDGMENT**
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# Investigation on Air Suction Phenomenon for a Rotating Flyer

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Compact yarn spinning is a technology to condense the fiber bundle effectively to reduce the spinning triangle so that the qualities of spun yarns can be improved, particularly in terms of yarn hairiness and strength. This study treats on a novel technology to produce compact yarns based on a flyer system which works in principle on the phenomenon of air suction from the top of the rotating flyer.

Air pressure difference due to centrifugal force in revolving flyer derives air flow inside of the flyer, which leads to sucking in the air around the flyer top placed below the front roller pair of the draft bank. Therefore, the edge fibers poking out of the spinning triangle are sucked with air into the flyer so that the spun yarn hairiness can be reduced and the yarn quality improved.

In this research, a CFD model based on the conservation equation for laminar air flow has been designed and simulated by FVM (Finite Volume Method) to investigate the air flow pattern inside the flyer and on the periphery of the flyer top as well. To describe the turbulence effects and the rotation of flyer, Reynolds stress model and MRF (Moving Reference Frame) method were used, while the air flow in room temperature was considered in 3-dimensional incompressible steady state.

Simulation results revealed that the air flow field was generated inside the flyer by the rotating flyer and the phenomenon of air suction occurred around the flyer top. Variables representing the air suction such as air flow rate, air velocity and air pressure were influenced by the dimension of flyer and the rotational speed of flyer.

Under the simulation conditions given in Figure 1, the air velocity at the flyer top was about 50 m/s and the effective range of the air suction(faster than 0.5 m/s) was covered up to 45 mm high from the flyer top. As for the air pressure distribution, the relative static pressure decreased abruptly form 0 Pa(reference value) to -3,300 Pa near the flyer top, which meant that the performance of the air suction by a rotating flyer was comparable to that of the pneumatic compact spinning systems already obtainable commercially.

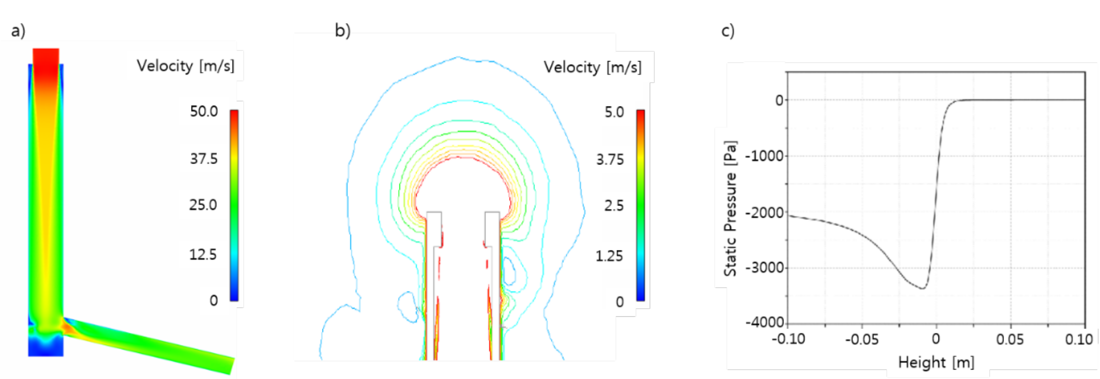


Figure 1. Analysis of air suction in the flyer spinning system:

1) air velocity inside the flyer; 2) surrounding air flow pattern; 3) relative static pressure near the flyer top(x=0) (Flyer main cylinder: 200 mm long, 15 mm in diameter, Flyer arm: 110 mm long, 11.25 mm in diameter, Rotational speed: 5,000 rpm)

**ACKNOWLEDGMENT**
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1A6A3A11933946).

# Polymer Blends for Textile and Composite Applications

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## MOTIVATION

Polymer blends can be of great interest for processing in textiles and composites since a remarkably broad spectrum of properties can be obtained without having to develop a new polymer. By blending, it can be possible to outperform the existing homopolymers or develop materials with tailored properties. In addition, introducing a cheaper polymer may reduce the cost of the final product. Thus potential of PP/PET, PP/PA6 and PET/PA6 blends were studied for textiles and composites.

## RESULTS

### *PP/PET blends*

The presence of PET microfibrils in PP can increase the modulus of the monofilaments, certainly when a compatibiliser is added. High PET concentrations can easily be added during monofilament extrusion, but this higher PET content did not result in an additional positive effect.  Shrinkage and creep of the monofilaments did not further decrease when increasing the PET concentration above 30%. PP multifilaments reinforced with PET microfibrils can be dyed using disperse dyes result-ing in deeply dyed filaments with a good water and light fastness.

When processed to composites, a PP plate with PET microfibrillar reinforcement is produced, having properties in the same range as self-reinforced composite materials. For unidirectional composites, an optimum is reached at 50% PET, while for bidirectional composites, the highest performance is realised at 30% PET.

### *PP/PA6 blends*

In general PP/PA6 blends showed to be less promising than PP/PET blends. Presence of PA6 microfibrils inside PP does not lead to an increase in mechanical properties.

### *PET/PA6 blends*

Finally, also for PET/PA6 blends, it was proven that they can be easily processed to textile filaments, without affecting the mechanical properties. Again, this shows the potential for the easy recycling of plastic waste. Moreover, the addition of PA6 to PET improves the dyeability of PET and might have a positive influence on the wearability. For this blend combination, the full textile processing chain has been evidenced going from filament extrusion, through textile processing (twisting-knitting-weaving) and finally to dyeing.

## CONCLUSION

In conclusion, the use of polymer blends can be an interesting route to improve the properties of yarns and composites and can give valuable insights for the reprocessing of plastic waste.

## ACKNOWLEDGMENT

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# PU Nanoweb Transmission Lines Coated with Non-oxidized Graphene for Smart Clothing

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The purpose of this study is to impart electrical conductivity to polyurethane (PU) nanoweb by coating with non-oxidized graphene for transmission lines of smart clothing. The 2wt% non-oxidized graphene dispersed in aqueous binder was diluted using distilled water in order to have concentration of 1.4wt%, 1.6wt% and 1.8wt% of the graphene. PU nanoweb was dipped in each diluted graphene concentration and the original 2wt% concentration for 5min and dried in a thermo-regulating chamber at 50℃ for 60min. Electrical resistance of specimen was measured by a RCL meter (Fluke PM6304) after clamping both end of the specimen with a forceps for stable contact. Scanning electron microscopy (SEM) was used to analyze uniformity of graphene coating applied on the nanoweb and to observe the microstructural changes of them. Fourier transform infrared (FT-IR) was employed to detect chemical information of the specimen, and high resolution x-ray diffractometer (HR-XRD) was used to investigate the crystallographic properties of it. Electrical resistance of treated specimen decreased from 1439Ω to 152Ω as the graphene concentration increased, which means that the electrical conductivities of the graphene coated specimens increased as graphene concentration increased, and that the graphene coated PU nanoweb can be used as transmission lines for smart clothing. SEM images presented the non-oxidized graphene was coated on the PU nanoweb more evenly as the graphene concentration increased. FT-IR data revealed the peak band at $1727cm^{-1}$ ~ $644cm^{-1}$ in untreated PU nanoweb and the relatively narrow peak band at $1219cm^{-1}$ ~ $554cm^{-1}$ in the treated. HR-XRD diffraction patterns(2θ=20~80°) presented that some peaks faded after 50°, and the peaks were gradually disappeared with the graphene concentration increased. This means that the higher the concentration of non-oxidized graphene, the more uniformity applied to the nanoweb surface, indicating a loss of PU nanoweb peaks. The results of this study are expected to be helpful for developing electronic textiles for smart clothing.

**ACKNOWLEDGMENT**
Acknowledgment: This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. NRF-2016R1A2B4014668) and the Brain Korea 21 Plus Project of Dept. of Clothing and Textiles, Yonsei University in 2016.

# Textile Energy Storage

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**ABSTRACT**
It has seen recently remarkable development in smart textile field and that is required a source of energy to provide the electricity for electronic elements and devices which use in this textiles. There are different types of textile energy storage to supply the electronic devices with energy such as supercapacitors and batteries especially lithium ion batteries but this energy storages should fabricated with special specification to suit the fabrics like safety, gel/solid electrolytes, long term cyclability, wearability etc.

Our study will focus on producing a wearable li-ion battery that provide energy to sensors inside the yarn.

**KEYWORDS:** textiles, energy storage, batteries, lithium ion

# Recyclability of Carbon Fiber-reinforced Concrete Structures

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**ABSTRACT**
In recent years, big markets for composite materials and constructions have developed in the construction sector. One example is textile reinforced concrete (TRC), which was awarded with the "Deutscher Zukunftspreis 2016" by the German Federal President.

While construction, reconstruction and dismantling of buildings create the major amount of waste compared to all waste generation (60 % of resource consumption, 35 % of energy consumption as well as 50 % of waste production in Germany), potential for separating, recovering and recycling of the innovative composite material TRC has not been investigated so far.

For this purpose, carbon fibre textiles were coated with different polymers to analyze its effect on the recoverability of textile reinforcement from TRC. TRC specimen containing the coated textiles with epoxy resin, styrene-butadiene rubber and potassium silicate solution were destroyed with a jaw crusher. All failure modes were collected and compared. The crushing has shown clear results. Textiles coated with epoxy resin were regained from the concrete matrix with minor defects. Small remains of concrete can be removed manually and without damages. Styrene-butadiene coated textiles have shown major damages on the textile. Remains of concrete cannot be removed. In both cases the knitting yarn turns out to be the textiles weak point. It detached from large parts of the textiles causing unfastened and detached weft threads. With both coatings, textiles were recovered with few cracks in the rovings. Textiles coated with a potassium silicate solution could not be recovered from the concrete matrix. There are major remains of concrete and damages on the textile.

The reinforcement's layer in the concrete matrix has not shown a clear effect on the recoverability. Textiles under a lower concrete cover have shown slightly better results.

Additionally, particle-size distribution of the crushed fine grained concrete matrix was determined and compared to standard distribution curves of mortars. With those results potential applications for reuse of the concrete as well as the textile reinforcement can be made accessible.

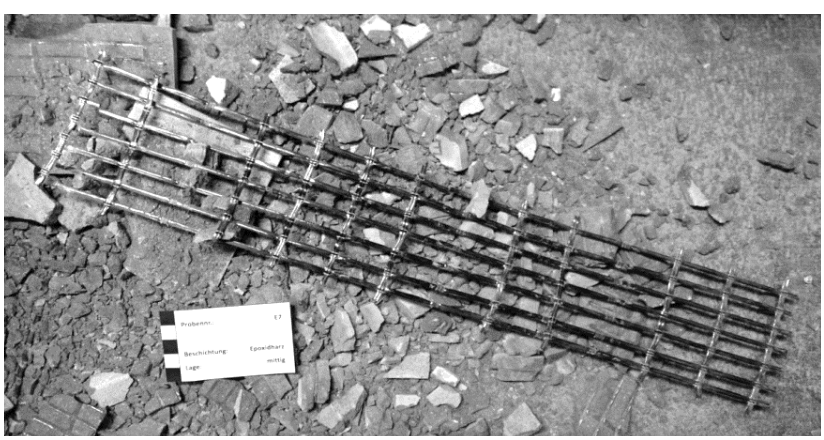

Figure 1: Separated carbon concrete sample after targeted destruction

**ACKNOWLEDGMENT**
The author is member of the PhD-programme "Verbund.NRW," supported by the North Rhine-Westphalian funding scheme "Fortschrittskolleg" by the Ministry of Innovation, Science and Research.

# Interactive Learning Systems for Textile Technology

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**INTRODUCTION**

The advancing technical development enables the design of interactive media-based learning. Interactive teaching and learning scenarios are used both in formal and informal learning possibilities. In the following, the implementation of media-based learning in the formal context of university teaching and in the informal context of work-integrated training in textile technology will be presented.

**E-LEARNING IN HIGHER EDUCATION**

E-learning tools have the potential to increase motivation among students and thus lead to better learning sequences. Lectures, however, remain a firm and important part of academic teaching. On the contrary, e-learning offers serve as a supplement to presence events. It is no longer a question of e-learning, but of "blended learning". At the Institut für Textiltechnik der RWTH Aachen University (ITA), the lectures are supplemented by flexible virtual learning units based on interactive learning cards. The interactive learning cards are used in the lectures for presentations; on the other hand the students use the learning cards for independent preparation and follow-up. In compact units, the most important terms, definitions and connections are presented, as well as further advanced teaching contents. On the individual pages of an interactive learning card, various elements such as texts, graphics, images, tables, animations and videos are integrated. Students also have the opportunity to reflect their learning level by e-tests with different types of tasks, such as multiple-choice, assignment and order tasks (drag and drop) or cloze tasks. The acquired content and gained knowledge could also be used in adult education, e.g. for work integrated learning.

**LEARNING TOOL FOR INDUSTRIAL WORKING**

By creating and providing diversity-driven workplaces, technical tools, and mobile information technologies, companies can provide their employees with individual assistance in the exercise of their activities. Steadily changing action situations with technical changes demand the competence development of the staff. Informal learning is necessary to maintain the effectiveness of employees and to qualify them target-group-specific. The interactive learning cards, as an element of a learning tool, provide adaptive problem- and task-oriented learning modules. For integration of learning tools in the daily work, it is included into an assistance system for industrial textile work environments.

**ACKNOWLEDGMENT**

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# Tailored Warp Knitted Reinforcing Textiles for Construction Applications

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**ABSTRACT**
The use of reinforcing textiles is indispensable in today's building industry and represents the state of the art. Textile reinforcements made of materials such as PVA, PES, carbon, glass and basalt fibres meetthe growing requirements for corrosion-free and high-strength structures in the building industry. With increasing properties, such as strength and stiffness, the price is also rising for such materials. In order to safe resources and make high strength materials competitive to conventional materials it is necessary not to place them in regions where the strength is not needed. Today's most common textile reinforcements are biaxial grids with uniform properties in each direction.

With the exact knowledge of the maximum affecting forces and their location in the component, textile-reinforced structural elements can be designed accordingly. This is why tailored reinforcements can lead to weight reductions and to economic and ecological savings. The textile manufacturing process of warp knitting allows changes within the production process and to substitute single threads as well as changes in stitch type during production. This makes warp knitting suitable to achieve the goal of tailored reinforcing textiles.

This paper will give an overview on how materials can be used in tailored textiles with varying properties and how they can be treated during the warp knitting production process. Within the application area for tailored reinforcing textiles in road construction, which size grows steadily, it is shown that the use of tailored textiles can save up to 20 % material and 50 % of cost related to the reinforcement. Tailored textile reinforcements are an answer to the requirements for sustainable mobility as well as an environmentally and climate-friendly, socially responsible and economically efficient infrastructure concerning road construction.

**INTRODUCTION**
The reinforcing textiles in construction applications offer many promising advantages. One advantage, for example is a high corrosion resistance. Textile reinforced concrete (TRC) elements allow very filigree and thin-walled constructions of up to 10 mm. Furthermore, these elements can be produced with a high drapability, which stands for numerous design possibilities.

Compared to conventional steel reinforced concrete elements, TRC elements have an outstanding sustainability as large quantities of cement can be saved during the production. A reduction of the necessary cement quantity and the linked reduction of up to 80% $CO_2$ emissions during the production of TRC elements show the ecological advantage of this technology.

The lower proportion of the necessary cement has an effect on the transport of the components since, compared with conventional reinforcement methods of concrete, textile reinforced elements achieve weight reductions of up to 70%.

**DEVELOPMENT OF LOCALLY AND ELASTICALLY ADAPTED WARP KNITTED TEXTILES FOR CONSTRUCTION APPLICATIONS**
The main concept behind the project of locally adapted warp knitted textiles is that textiles with different stitching patterns are possessing different material properties. In Figure 1 three different types of stitching patterns of warp knitted textiles are shown.

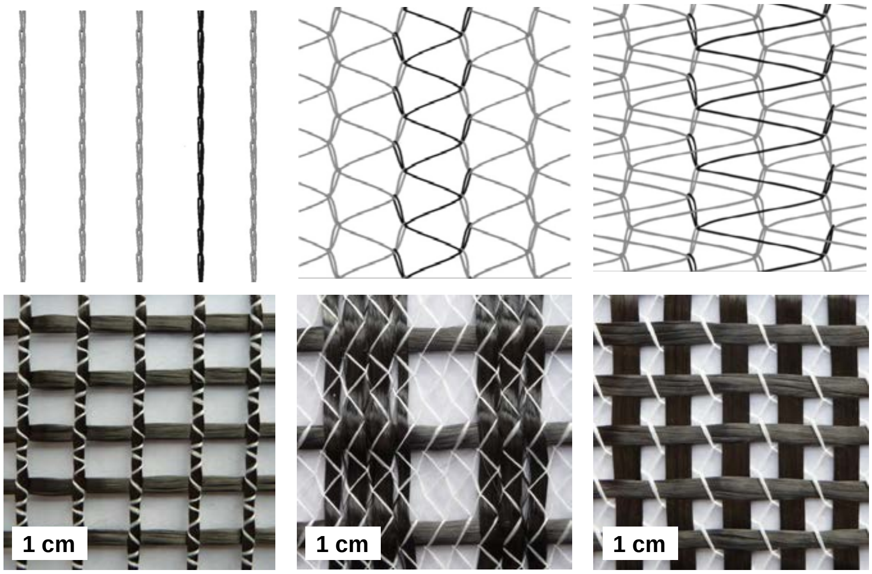

Figure 1: Different types of stitching patterns of warp knitted textiles: pillar, tricot, plain (from left to right)

The first goal of the research was to create a locally adapted warp knitted textile, which can be used as a reinforcement that locally adapts to the forces which affects the construction element. Therefore different types of stitching patterns need to be combined to generate a foldable but also stiff textile, which has the ability to resist high local forces. In Figure 2 a locally adapted biaxial warp knitted textile is shown.

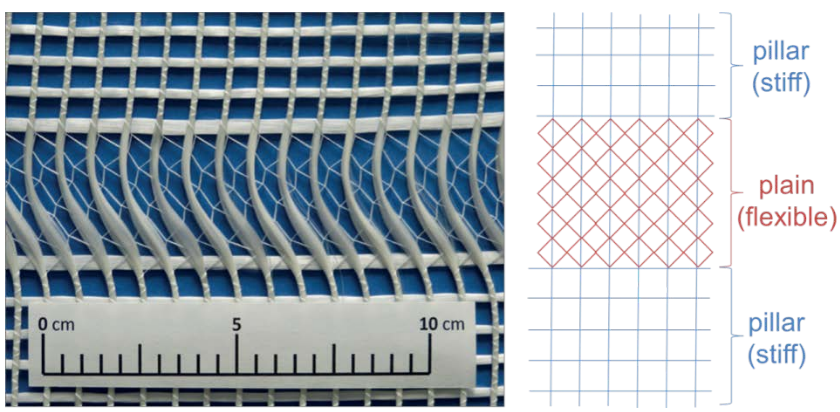

Figure 2: Locally adapted biaxial warp knitted textile

The bending stiffness of a textile varies with its stitching pattern which means that folded construction elements are producible. As shown in Figure 3 the bending stiffness of a pillar stitched textile is higher than the bending stiffness of a plain stitched textile.

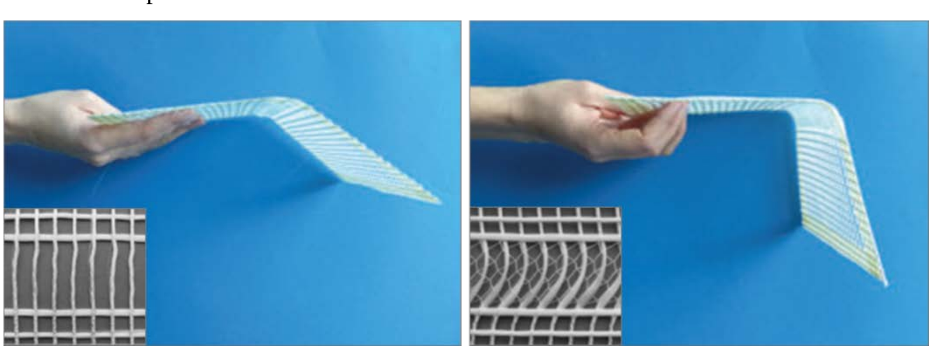
Figure 3: Bending stiffness of a pillar stitched textile (left) and of a plain stitched textile (right)

Due to elastic textiles a high drapability of textile reinforcements can be realized and double curved construction elements are producible. Figure 4 shows an elastically adapted unidirectional warp knitted textile made of glass rovings and silicon fibers.

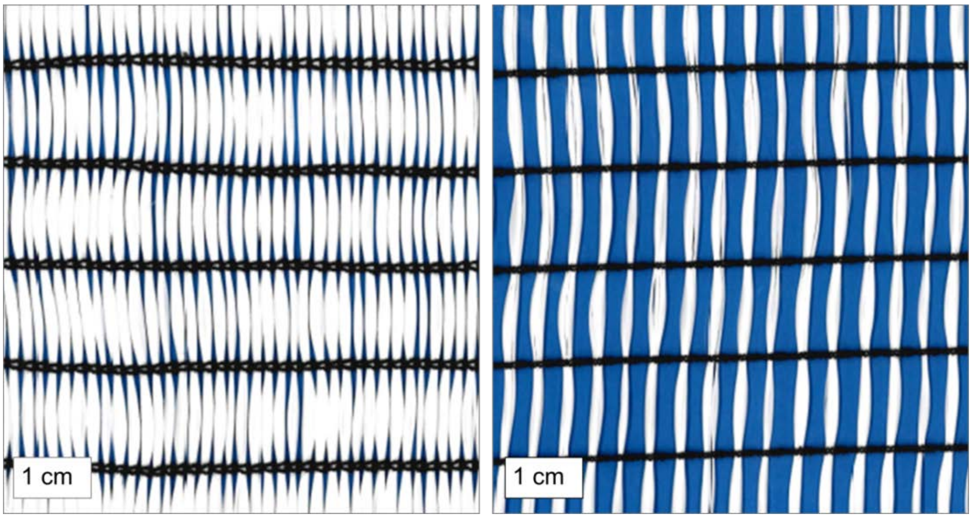


Figure 4: Elastically adapted unidirectional warp knitted textile made of glass rovings and silicon fibers: neutral state (left) applied tensile force 100 % elongation (right)

The textiles with very high qualities are used in very large masses within construction applications, which is not economical due to high production costs. To develop tailored warp knitted textile structures the exact knowledge of the location of the force within the component and the maximum affecting forces are necessary.

**CONCLUSIONS**

Generating tailored warp knitted reinforcing textiles for construction applications needs three different material properties. One of them is an adjustable bending stiffness which can be realized during the warp knitting process of the textile through different stitching patterns. Another important property is the adjustable drapability of the reinforcing textile which will be achieved by the application of elastic knitting yarns. The last important property feature is an adjustable load assumption which is gained by the warp knitting of different roving materials to hybrid textile structures.

# Development of an “Anti-bug” Bicomponent Fibre

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Nowadays, crop spraying is mostly done with pesticides, which harm crop enemies, but can also interfere with the human body. Silica particles ($SiO_2$) in the nanometer and micrometer scale offer a physical way to combat insects without harming humans and other mammals. Thereby, they allow to forego pesticides, which can harm the environment. As silica particles are supplied as a powder or in a suspension to farmers, the silica use in large scale agriculture is not sufficient due to erosion through wind and rain.

When silica is implemented in a textile’s surface (uncovered by polymer), particles are locally bound and do resist erosion, but can function against bugs. By choosing polypropylene as a matrix polymer, the production of an inexpensive agritextile with an “anti-bug” effect is made possible.

In the Symposium the results of
1) preliminary experiments from lab scale extrudered filaments (Figure 1 and 2) and of
2) compound development and investigation as well as selection and furthermore
3) the fibre manufacturing on a pilot scale melt spinning line and fibre investigation will be shown.

For the compound manufacture, a selected number of investigated silica particles are shown (3 out of 8, different sizes in the nano and micron range: small, medium and large) and results of filler content and filter testing are portrayed and explained. In the following, one particle type is selected for the fibre manufacture in a semi-industrial scale. In a melt-spinning process, bicomponent fibres are manufactured. These fibres consist of a virgin polypropylene core and a functionalized silica sheath. In the Symposium both the manufacturing characteristics and varied parameter will be shown as well as their influence on the fibre characteristics are investigated.

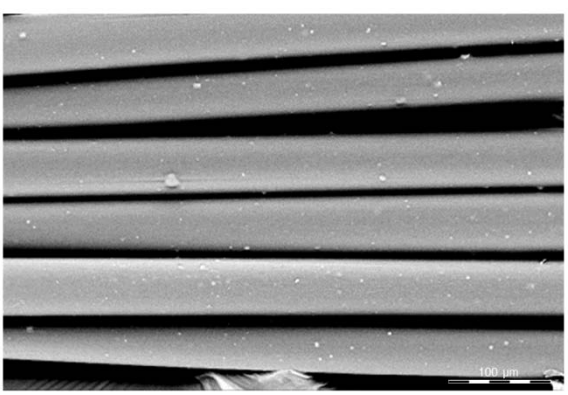


Figure 1: PP fibre with 5,2 wt.% Aerosil R812

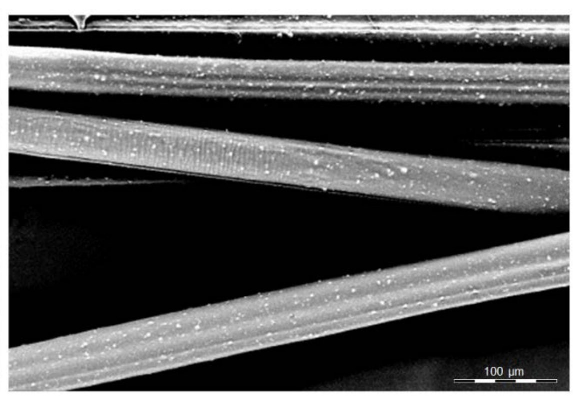


Figure 2: PP fibre with 4,5 wt% Syloid 244

# Modeling Dynamic Fiber Behavior in a Meltblowing Die Utilizing FSI

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## INTRODUCTION

Current research shows an interest to expand the possibilities of fiber production using meltblowing. Meltblowing is becoming an increasingly popular and cost effective process, with research showing that this process can be used to make extremely fine fibers, classified as nanofibers (less than 1000nm diameter). The aim of this research is to model a representation of a polymer fiber in a meltblowing die to better understand phenomena such as fiber whipping and attenuation.

Previous research has focused on simplified approaches utilizing beam and viscoelastic elements or mathematical approaches to find specific parameters as well as Computational Fluid Dynamics (CFD) simulations of airflow through the die. This research aims to expand previously gained understanding with a novel modeling approach. The fiber is modeled as a 3D meshed body and coupled with a turbulent airflow simulation. This approach is known as a Fluid Structural Interaction (FSI) simulation, combining both the airflow as well as large strain deformation of the fiber.

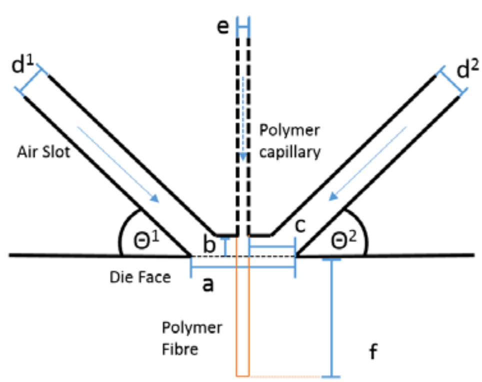


Figure 1 - Meltblowing Die with Polymer Fiber

## MODELING PROCESS

As can be seen in Fig. 1, a section of a typical Exxon style meltblowing die is modeled with a representation of a fiber emerging from the polymer capillary. The die parameters are taken from previous case studies to allow for comparison of results. This geometry is then modeled in 3D utilizing the Multiphysics software package ADINA.

Multiple models are examined, showing the differing fiber behavior due to changes in die geometry. During the simulation movement of the fiber in 3D is observed, showing the influence of turbulence on the fibers path.

## FUTURE WORK

The long-term aim of this research is to expand on this initial simplified model by introducing both a flow rate to the fiber i.e. having material emerge and be attenuated as in the real scenario, as well as investigating thermal effects, thus modeling cooling and recrystallization of the fiber. Finally, the model building will be controlled by a GUI, allowing faster, simple, generation of case studies for use by the layman.

# Fabrication of Ultrasensitive $CO_2$-responisve Nanofibers via Post-polymerization Modification for the Visual Detection of $CO_2$

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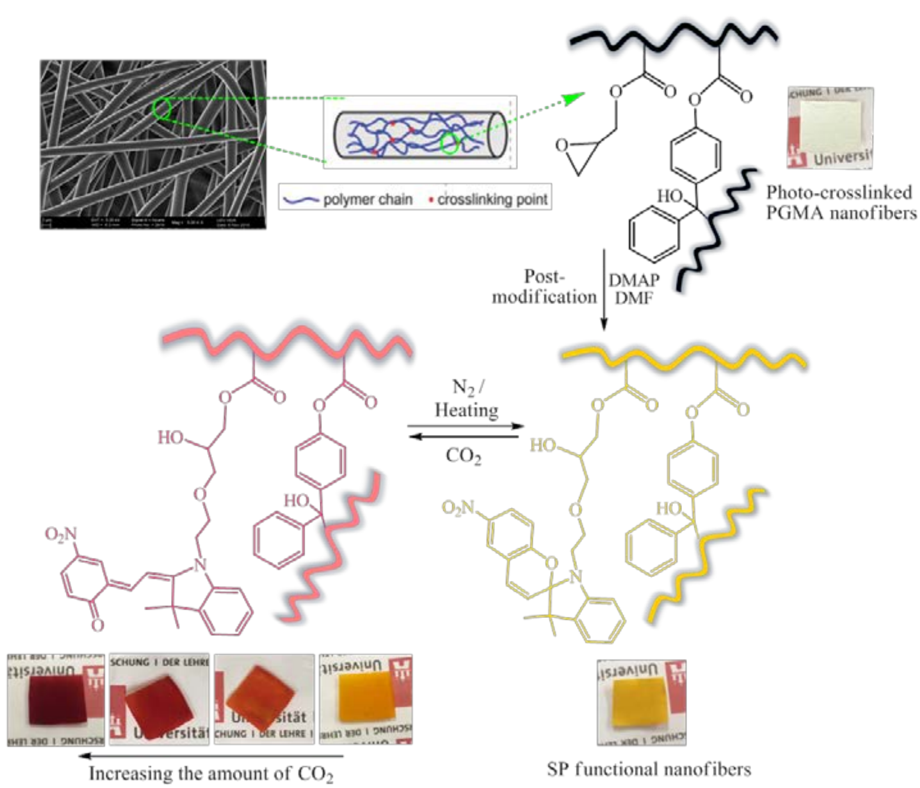
Photo-crosslinked poly(glycidyl methacrylate) (PGMA) nanofibers with reactive epoxide groups were fabricated as versatile precursor nanofibers. Owing to the reactive character of epoxide groups, $CO_2$-sensitive spirospyran side groups were introduced via nucleophilic ring-opening reaction. It was found that these nanofibers can quickly respond to $CO_2$ in aqueous solution or wet environments by exhibiting a visual color transition of the incorporated spirospyran (SP). Moreover, the intensity of color of SP nanofibers is strongly depending on the amount of $CO_2$, by featuring a change from yellow over orange and red to dark red with increasing exposure of $CO_2$. Noteworthy, this color change of SP nanofibers is fully reversible and can be altered by addition of $CO_2$ and removal $CO_2$ via purging with $N_2$ or heating. Hence, these SP functional nanofibers are expected to be employed as a $CO_2$ sensor for the visual detection of $CO_2$.




Scheme 1. Illustration of fabrication process of SP functional nanofiber mats via post-polymerization modification and visual detection of $CO_2$ behavior as $CO_2$ sensor.

# A Novel Dynamic-Crosslinking-Spinning Technology for Scalable Fabrication of Hydrogel Fibers

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Advances in hydrogel design are yielding new generation hydrogel materials with diverse specific macroscopic topological structures. Among which hydrogel fiber has been considered as a significant one dimension material with spatiotemporal properties such as anisotropic structure, high length/diameter ratio, flexibility and knittability. Several techniques have been established to fabricate hydrogel microfibers, including electrospinning, extrusion, 3D printing, wet spinning and microfluidic template. However scalable production of hydrogel fiber from monomers and oligomers, which are the common functional and structural element of hydrogel, presents many specific and complicated challenges due to the contradiction between time-consuming polymerization of hydrogel and instantaneous fiber-forming process.

Recently, we have successfully established a novel dynamic-crosslinking-spinning (DCS) technology for fabricating hydrogel fiber in a large scale with controllable diameter. In a typical process, the PEGDA oligomer solution was extruded into a water bath. The extruded solution formed a fiber-shape aggregate due to the viscoelasticity of the oligomer. The fiber-shape phase was rapidly solidified by UV irradiation. As a result, a continuous fiber was formed along with the extrusion of solution dynamically. The fiber could be collected on a roller outside the bath. The diameter of hydrogel fibers can be mathematically controlled by concentration of solution, extrusion rate and winding speed. Furthermore, by using a subtle coaxial spinneret, a series of PEGDA-GO/PEG core-sheath fiber and PEGDA-rGO hollow hydrogel fiber with graphene inner wall were obtained, which demonstrated that the DCS technology is effective for core-sheath and hollow fibers by adjusting extrusion ratio of core and sheath solutions. Moreover, the dimension of core and sheath could be well controlled by changing the extrusion rate of solution. All the fibers obtained above could be could be further weaved by typical textile instruments.

In conclusion, the large-scale hydrogel fibers with multilevel structures (solid, core-sheath and hollow) were successfully fabricated with controllable dimension by a novel dynamic-crosslinking-spinning technology. It provides us new materials for reconstruction of hierarchical multi-structured devices with considerable application opportunities in the area such as biomaterials and sensors, etc.

# Cribellate Spiders: a Biomimetic Inspiration for Processing and Handling Nanofibers

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**SPIDERS AS A BIOLOGICAL MODEL FOR NANOFIBER PROCESSING**

Spider silk has been intensively investigated especially with respect to its mechanical properties. Despite the mechanical properties of the silk itself, an often overlooked skill of the spider is the production and handling of fibers in general. Cribellate spiders carry this ability to an extreme: They have the capability of processing more than three different types of silk to one functional thread only due to the movement of their spinnerets. Within its production, some spiders can even produce, process and handle up to 40.000 nanofibers, a task not yet imitable within the production of technical fibers. Hence, the thread production of cribellate spiders should be a perfect inspiration for innovative approaches to process and handle nanofibers.

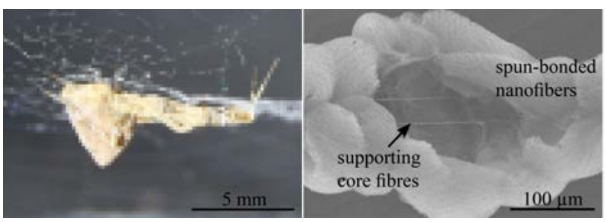


Fig.1: The cribellate feather-legged lace weaver (*Uloborus plumipes*) and a produced capture thread with opened mat of spun-bonded nanofibers revealing the surrounded larger fibers (SEM image, sample coated with carbon).

When analyzing the simplest cribellate capture threads' structure, we found the nanofibers organized in a spun-bonded nanofiber fabric, enclosing a fiber system with two parallel larger supporting fibers (Fig.1). To combine the spun-bonded fabric with the supporting fibers into one functional thread, the spider uses a third fiber system emerging from elongated spigots. This third silk connects the former ones with a sewing-like bonding by a highly coordinated movement of the spider's spinnerets. In a technical application, such a stable unit could be used e.g. for easier handling of the nanofibers themselves without detaching from a supporting fiber during processing, or to functionalize a basis fiber by coating it with nanofibers.

**BIOMIMETIC TRANSFER TO A TEXTILE APPLICATION**

Based on this biological model, our aim was to abstract the process and transfer the principles to a technical proof-of-concept. In a first approach, we replaced the spun-bonded fabric of nanofibers with a microfiber nonwoven. This nonwoven can be dawn onto larger supporting fibers by a third connecting the former fiber system (Fig.2). We thus reproduce the capture thread of cribellate spiders and build a stable thread out of a nonwoven enclosing a larger core fiber. Our results demonstrate that the cribellate thread production suits a biomimetical abstraction process and can in follow up research facilitate the processing and handling of nanofibers, increasing their potential field of application.

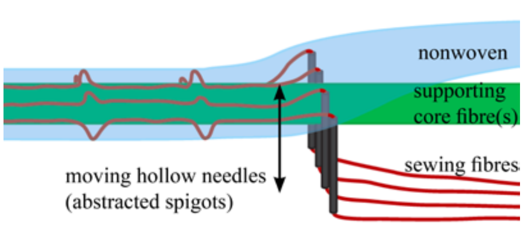


Fig. 2: Sketch of the biomimetic setup for sewing a nanofiber nonwoven on supporting fibers.

**ACKNOWLEDGMENT**

Many thanks to Peter Bräunig from the Institute of Biology II for supporting this study.

# PVC-based Synthetic Leather with Thermal Comfort for Automobile Applications

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Increasingly consumers are demanding cars to be comfortable even for more economic commercial segments. Thus, the development of materials with thermo-regulation properties assumed renewed interest. An attempt has been made to prepare multi-layer PVC-based synthetic leather with paraffinic PCM´s to be applied on car seats. The thermal behaviour of the material was analysed using a thermal manikin combined with an Infra-Red camera, monitoring the temperature development as in a real situation and comparing the results with Alambeta apparatus that test bi-dimensional fabrics regarding thermal properties. The viscosity of each PVC paste was analyzed (20+/-2ºC) and compared with similar formulation without PCMs (fig 1). It is not observed viscosity changes even when 10% of PCMs concentration was used. So the process ability wasn't influenced by PCMs incorporation on polymer formulation.

DSC is used to observe melting temperature and latent heat of PCM (free or in material) during the exothermic or endothermic phase transition process. The typical DSC curve for synthetic leather without PCMs was present in figure 1a, while figures 1b and 1c shown the DSC thermograms of PCMs and synthetic leather with PCMs.

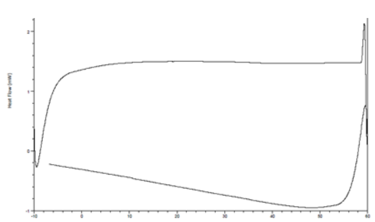

Figure 1a: Synthetic leather thermogram

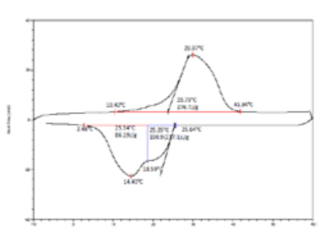

Figure 1b: PCMs thermogram

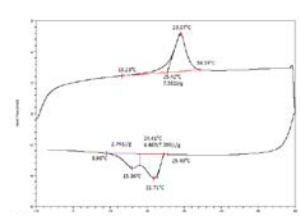

Figure 2c: Synthetic leather with PCMs thermogram

The latent heat of PCMs was confirmed to be around 276J/g (fig 2b), higher than most other PCMs in this phase change temperature range. Therefore, the melting temperatures of PCMs and synthetic leather with PCMs were measured at 29.97ºc and 29.07 ºC respectively. This phase change temperature is appropriate to the application as it is comfortable to human body.

The obtained results demonstrated that the synthetic leather with PCM´s feels cooler and it takes longer to react to the environmental temperature variations than material without PCM´s incorporation. Globally, the new material allowed greater thermal comfort to the automobile´s user.

# Comparative Analysis of Wearable Respiration Sensors Based on PU Nanoweb/PDMS Treated with AgNWs and PPy

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This study suggests two types of wearable strain sensors for respiration monitoring employing polyurethane (PU) nanowebs and polydimethylsiloxane (PDMS). Two different treatment methodologies were utilized to impart electrical conductivity to PU nanowebs; pour-coating of PU nanowebs using ethanol containing dispersed silver nanowires (AgNWs), and in-situ polymerization of polypyrrole (PPy) with pyrrole monomer after soaking PU nanoweb into an aqueous bath containing ammonium persulfate (APS) as oxidant and 2,6-naphthalenedisulfonic acid, disodium salt (NDS) as additional doping agent. Both of them were cut as 2 x 10 cm, and snap buttons were attached to the two ends. PDMS was coated on the surface. Each sensor was attached to stretchable fabrics and connected to a designed fabric belt. The belt was worn by a human subject, while the signal was transferred and processed by analog circuit, MP150 and the Acqknowledge. RSP 100C amplifier with respiration belt transducer was employed to monitor the signals as reference. The human subject repeated inhale/exhale for five times at rates of 40~80 bpm. Although the initial electrical resistance of the specimen treated with AgNWs (398 Ω) was lower than PPy (3.33 kΩ), both respiration sensors showed curves and peak values according to the respiration. Moreover, PPy sensor showed highly similar graph morphology and statistical correlation to the reference electrode at 40 bpm while AgNW sensor showed higher statistical correlation than PPy sensor at 60 bpm. The three sensors showed only peaks without the unique curve morphology at 80 bpm and less correlation. This implies that the nanoweb based strain sensors can be developed as wearable respiration sensors by intrinsically conductive polymers as well as metallic nanomaterials.

**ACKNOWLEDGMENT**
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. NRF-2016R1A2B4014668) and the Brain Korea 21 Plus Project of Dept. of Clothing and Textiles, Yonsei University in 2017.

# Insight into the Relationship Between Creep Behavior and Structure of Polyester Industrial Yarns

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In order to investigate the relationship between the creep behavior and structure of poly(ethylene terephthalate) (PET) industrial yarns, the typical samples such as high tenacity (HT), high modulus low shrinkage (HMLS), low shrinkage (LS) and super low shrinkage (SLS) polyester yarns were selected to evaluate the creep properties at different temperatures and applied load. And the creep rate was used to illustrate the deformation rate as a function of time. The structure of fibers was characterized by wide angle X-ray scattering (WAXS), small angle X-ray scattering (SAXS), and birefringence. The results showed that a great initial creep deformation of these fibers occurred when the load applied, however, the deformation rate with load during the creep process showed different tendency. For HT and HMLS yarns, the creep rate increased continually with the increase of applied load, while that of LS and SLS decreased first and then increased. Based on the structural information, it can be found that the different creep behavior is mainly related to the amorphous structure, because these four kinds of yarns have similar crystallinity. Compared with LS and SLS yarns, the HT and HMLS yarns have higher amorphous orientation and less molecular entanglement, resulting in the chain slippage at higher load and the creep rate increase. In contrast, the LS and SLS yarns had disorder amorphous structure and serious molecular entanglement. The disordered molecular aggregates was stretched first at a certain rang of load, which can weaken the chain slippage and decease the creep rate. At higher load, the molecule disentanglement occurred and accelerated the chain slippage, leading to the increase of creep rate. In addition, when the temperature rises from 25 °C to 140 °C, the evolution of creep rate for HT and HMLS stay unchanged, increased continually with the applied load. However the temperature make entangled molecular chains of SLS and LS become easier to straight, in case that the decline degree of creep rate at small load become slighter.

# Economical and Technical Investigation on the Recycling of Polyacrylonitrile(PAN)-containing Waste

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The production of PAN fibers for textile materials is about 1,9 mio tons per year. The production capacity in Europe is about 525,000 tons per year (including Turkey). During the production of PAN fibers nearly 1 % of the applied raw material (PAN Polymer) arises as production waste. In the processing of PAN fibers to textile products like sweat shirts or blankets, the arising production waste is even about 6 %. In most cases the arising production waste will be dumped (not in EU) or used for thermal combustion. In the latter case greenhouse gas as well as toxic and carcinogenic gases occur. Consequently, both methods cause an environmental damage. In some cases the PAN based production or end consumer waste can be used for the fabrication of textile lobes, which is seen as downcycling. However, the goal is to develop an economical recycling process for PAN-containing production waste.

The waste arising during the production and processing of PAN fibers is not efficiently used for the purpose of sustainability. There are about 25.000 tons of PAN production wastes in Europe each year. With a market price for PAN fibers of approximately 2,00 €/kg there are unused PAN secondary raw materials having a value of 50 mio € per year. To overcome this deficit, a resource and cost efficient recycling system is needed. Therefore the Institute of Textile technology of RWTH Aachen University develops a conditioning and fiber spinning process for the recycling of PAN containing textile waste in cooperation with industry and research partners.

In Figure 1 the process and value chain for the recycling and upcycling of PAN containing textile waste including intermediate and end products are shown.

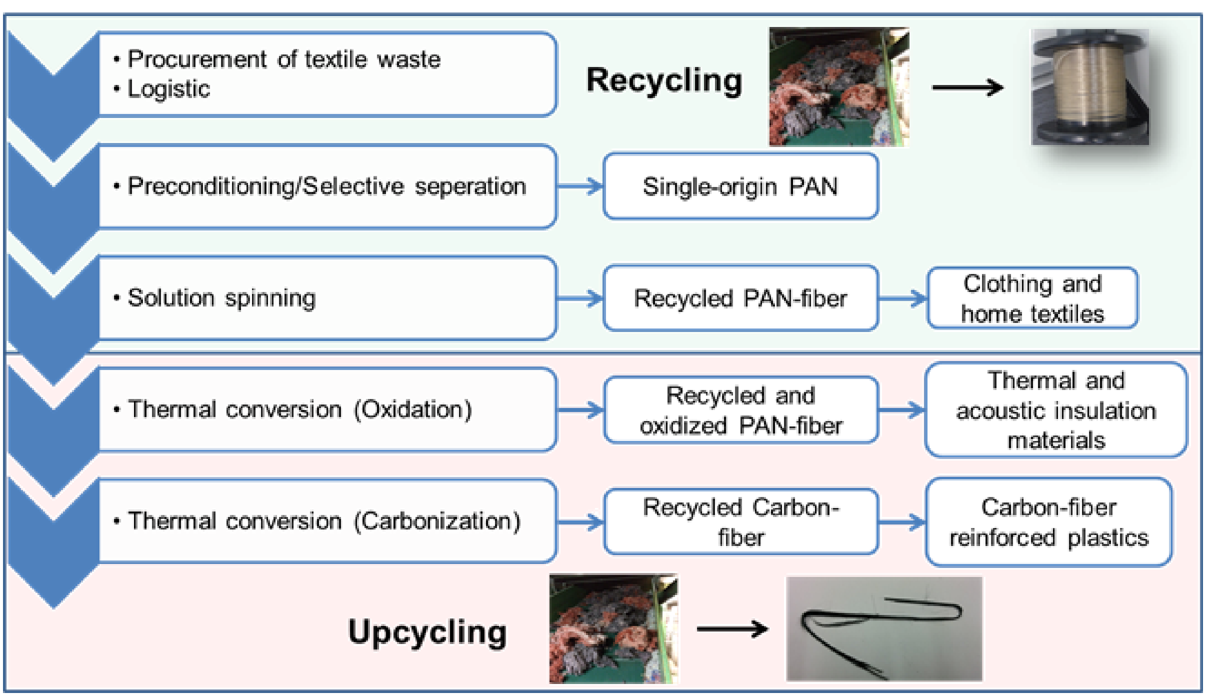


Figure 1: Process and value chain for the recycling and upcycling of PAN containing textile waste including intermediate and end products

# Shape Memory Alloys Applications on Weft Knitted Fabrics: Toward a Compression Sock for Venous Disease

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**INTRODUCTION**

Shape Memory Alloys (SMA) are currently used in several areas [1], namely in health applications, such as cardio-vascular diseases [2], and it is possible to identify applications in textiles, as fashion and artistic expression [3]. The unique properties of this called smart materials can also be used in other areas involving textiles as compression, and examples can be found in literature [4]. The study presented here intends to contribute for a better understanding about the behavior of SMA in textile structures, namely on weft knitted fabrics. Two Nitinol filaments are characterized and used with a base yarn of polyester in different combinations of jersey based structures for different loop lengths and then characterized in terms of loop dimension changes and thermomechanical behavior.

**MATERIALS AND METHODS**

For the purpose of this experiment, two Nitinol (NiTi) monofilaments were used, with a 0.02” (0,51 mm) diameter and an austenitic nominal transition temperature of 70ºC and 30ºC. These monofilaments are equivalent to a textile yarn of 11,0 tex (approximately 99 den) and were selected in order to be knitted in a seamless weft knitting machine from Merz, model MBS, gauge 28E, diameter 13” and 1152 latch needles. The base yarn used was 100% polyester. The objectives of this preliminary study were to observe the possibility of embedding SMA monofilaments in textile structures, namely weft knitted fabrics, and the effect of their presence in the textile fabric. The study was then organized in the following steps: the characterization of the nitinol monofilaments, embedding the SMA yarns in a weft knitted structure; the characterization of the weft knitted fabrics; the analysis and discussion of the results. The characterization of Nitinol was performed using X-ray microanalysis (EDS - Energy Dispersive Spectrometer and thermal analysis by DSC (Differential Scanning Calorimetry). The thermomechanical properties of Nitinol and the weft knitted fabrics were evaluated using an Hounsfield Dynamometer equipped with a climatic chamber. Loop dimensions were determined by means of a stereoscopic lens with image processing, using a fixed amplification of 16x, 12.5x, 10x, and 7.1x in relaxed state and right after heating the sample.

**RESULTS AND DISCUSSION**

**Monofilament characterization and analysis**

Figures 1, 2 and 3 illustrate the basic characterization performed on one of the two nitinol monofilaments, namely for the yarn that is activated at 30ºC. It is possible to observe the high purity of the alloy and the homogeneous distribution of the main elements in the monofilament’s structure on figure 1. The DSC characterization was performed with a temperature interval from 18ºC-45ºC for ascending as well as descending temperature. It can be observed in figure 2 that the transition temperature is estimated as 29.57º C. The transition phase is estimated to start in the temperature range of 26.12ºC-32.18ºC. From the thermomechanical tests, both SMA’s showed a decrease in elongation and small increase in the maximum applied force when submitted at the transition temperature (both for 28ºC and 45ºC).

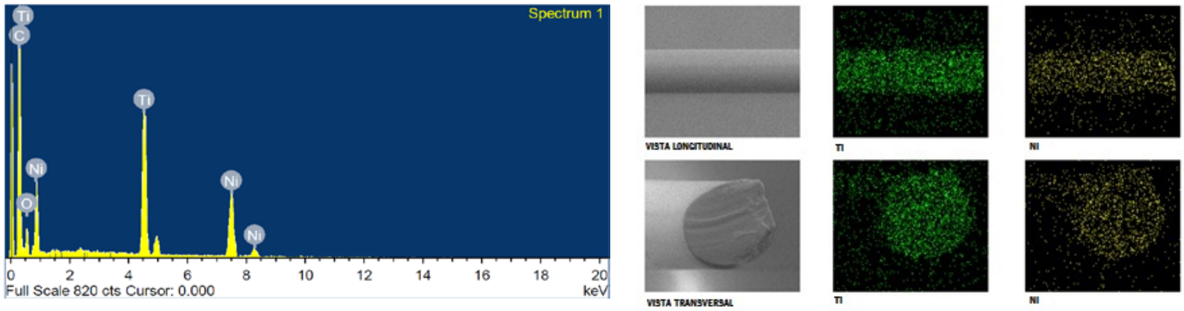


Figure 1. X-ray spectrum (left) and X-ray map with element identification made in SEM with 20kV voltage (right), for Nitinol filament activated at 30ºC.

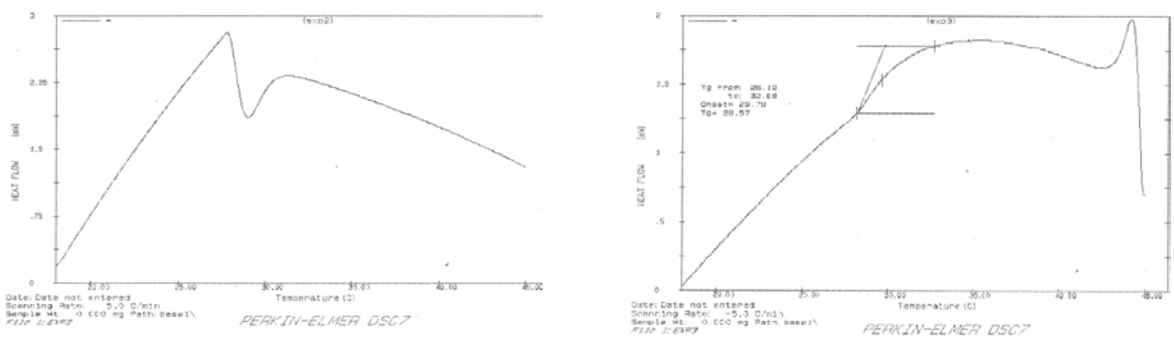


Figure 2. Thermal analysis by DSC for Nitinol filament activated at 30ºC.

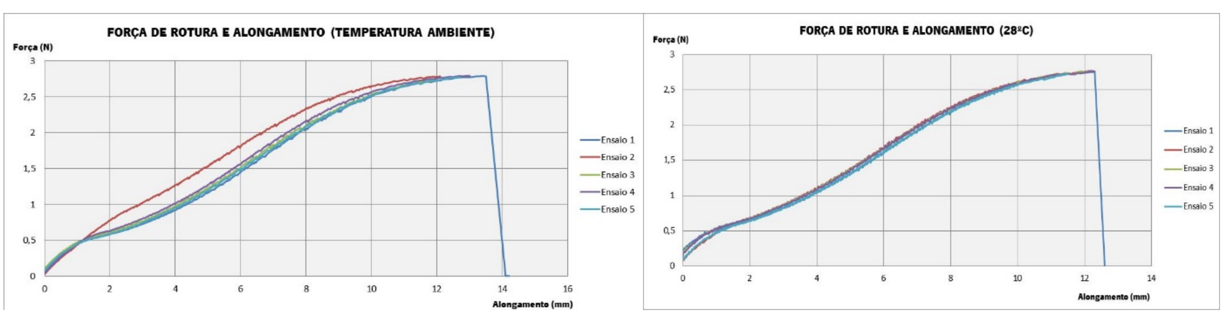


Figure 3. Thermal analysis by DSC for Nitinol filament activated at 30ºC.

**Fabric Characterization and analysis**

Weft knitted fabrics were produced with different loop lengths and different basic structures, namely jersey, single pique and single locknit. It was also produced jersey fabrics with only one, two and three courses of Nitinol surrounded with polyester yarn. From the observations and measurements made using the microscopic lens and after submitting the fabric to the transition temperature, one can say that the loop length has an influence in the width and height of the loop length. When the Nitinol is submitted to the activation temperature, the loop suffers a decrease in width and an increase in height. However it was not possible to observe an influence that could be related with the number of consecutive courses of Nitinol. The structures become more irregular in terms of appearance as the number of consecutive courses of nitinol are used, probably being due to the filament’s rigidity. Single pique and single locknit structures also showed a high irregularity. From the different combinations of weft fabrics, the research team selected as the best candidate the jersey structure where the odd courses were knitted with Nitinol and the even courses knitted with the polyester.

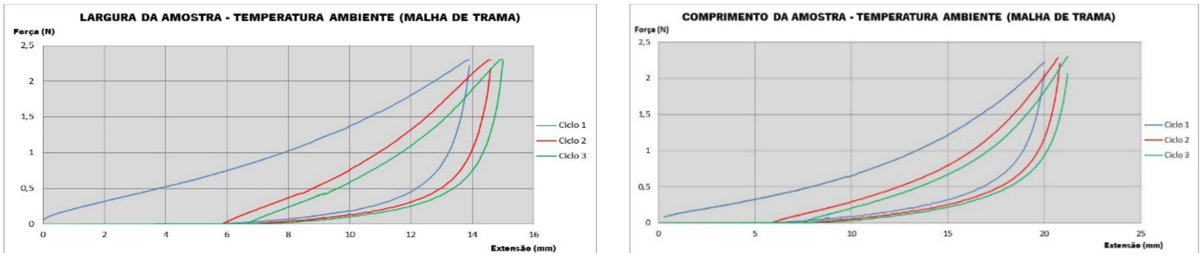


Figure 4. Thermomechanical tests for weft knitted fabric with Nitinol activated at 30ºC, when submitted at environment temperature.

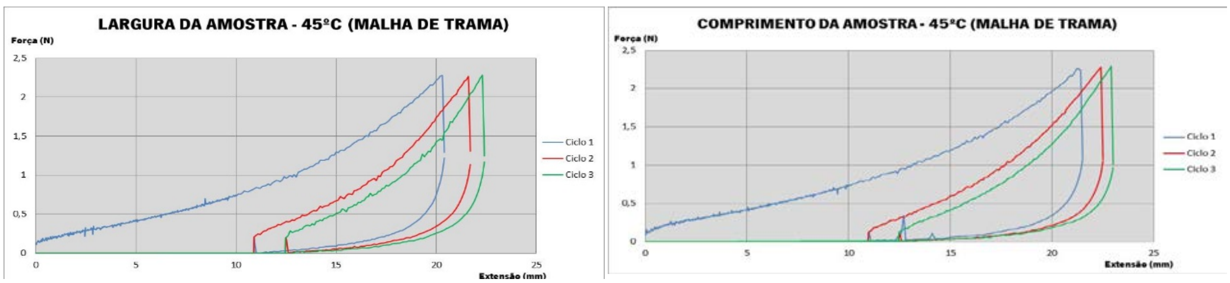


Figure 5. Thermomechanical tests for weft knitted fabric with Nitinol activated at 30ºC, when submitted at 45ºC.

Figure 4 and 5 illustrate the thermomechanical cyclic tests performed on the selected structure. It is observed a significant change in dimensions, particularly in the width direction when the structure is submitted to the transition temperature. There is also a change in the height direction, although is not so significant. It is also observable that the fabric made with Nitinol degrades its mechanical behavior with consecutive cycles both at room temperature as well after Ts. The superelasticity characteristic of nitinol is then observable in a fabric through the change in size dimension.

**CONCLUSIONS**

From the study made one can conclude that although it is possible to knit Nitinol in small gauges, most the fabrics resulted irregular in aspect. The effect of reducing the elongation and increasing the force in the SMA yarn due to the memory effect does not present a significant effect in the fabrics possibly due to the modification of the loop geometry. Laying in the Nitinol yarn possibly will maximize the reduction in elongation and ultimately result in a higher compression effect.

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**ACKNOWLEDGMENT**

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# Identification of Specific Animal Hair Fibers Using Forensic Science

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Species identification of biological specimens such as blood stains, hairs, tissues, and bones is one of the most important aspects in forensic science. There are more researches using forensic science technics to identify humans via their DNA types and it now also is being used increasingly to characterize animal materials in forensic cases. In this study, two systems for species identification will be developed based on scanning electron microscope analysis (SEM) and new molecular (real time PCR) methods. Although the species identification using conventional microscopic hair characteristics is a common method, the value of hair evidence to species characterization/identification (for pig, goat, horse and cow hairs) using mitochondrial DNA typing and SEM in comparison with the microscopic characteristics was investigated. The latest DNA-based technologies today make it feasible to identify single individuals by DNA typing from only trace amounts of their genetic material (see fig 2). The differences in the sizes of the polymerase chain reaction (PCR) products and respective primers are able to permit us to characterize/identify species.

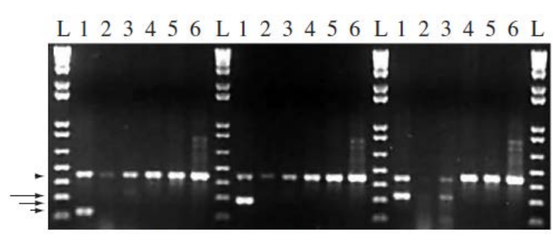


Fig 1. Electrophoresis results

# Storefactory — Customizable In-store Textile Production

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**INTRODUCTION**

Today the fashion industry is facing an increasing customer demand for individual and customizable products in addition to short delivery times. These challenges are passed down to the textile and clothing industry decreasing batch sizes and production times. Conventional clothing production cannot fulfill those demands especially when combined with more and more individual or customizable designs. Hence new production concepts have to be developed.

**CONCEPT DEVELOPMENT FOR IN-STORE FASHION PRODUCTION**

Aim of the STOREFACTORY project is the development of an in-store fashion production. Flat knitting is chosen as the main production process, as it offers the possibility to produce clothing without using joining technics, which is often referred as knit-2-wear production. As the fashion product a sweater is selected.

The in-store user-experience consists of a bodyscanner and design stations, where the customer creates their individual fashion products. These processes are supported by a software-system, which transfers the individual body-measurements and the design into the necessary machine data. The production itself takes place on flat-knitting-machines followed by thermosetting as well as finishing equipment for the statutory labeling.

**CONVERTER UNIT**

To guarantee a perfect fit for the customer, the acquired thermosetting results have to be taken into account before the knitting process starts. Hence the shrinkage data is fed into a database. The so called Converter Unit describes a software solution to apply the shrinkage on the individual body measurements. In addition the Converter Unit solves the task of transferring the body measurements into knitting machine data.

Different approaches have been analyzed of which two have been methodically developed, implemented and tested. The results do not differ in terms of accuracy. However the approaches show different results regarding look and surface feel. Based on those criteria, the best results have been archived adjusting yarn-tensions directly on the machine.

**CONCLUSION AND OUTLOOK**

Within the STOREFACTORY project, an in-store fashion production line for individually designed and shaped woollen sweater has been successfully set up. With an approximately production time of four hours from scan to fully finished products, the concept shows great potential facing the increasing customer demand for individual and customizable products.

# Double-doped Polymer Optical Fibers for Fluorescent Fiber Applications

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The high absorption coefficients of organic dyes can be combined with the long wavelength emission of organometallic materials to produce luminescent hybrid systems. These hybrid complexes could provide a suitable luminescent material for, as an example, fluorescent fiber solar concentrators, combining the advantages of organic and inorganic dopants to utilize the solar spectrum more efficiently. Moreover, the cylindrical waveguide structure of the POFs has a number of benefits. On the one hand, they are light-weight, thin and flexible, which permits an easy manipulation. On the other hand, they can easily be attached to transparent optical fibers for light transportation, which allows spatial separation between the light harvesting system and the final system placement. The latter leads to a positive feature for solar concentrator applications since no precise tracking system is required, overcoming one of the traditional Si-cell harvesting system limitation.

In this work we have drawn different fluorescent polymer optical fibers from double-doped PMMA. For this purpose, methyl-methacrylate (MMA) has been polymerized combining two different organic and metal-organic dyes in a bulk process. Applications in the field of fluorescent fibers, such as highly efficient Fluorescent Fiber Solar Concentrators (FFSCs) are targeted.

**ACKNOWLEDGMENT**
We gratefully acknowledge German Federal Ministry for Economic Affairs and Energy (BMWi) for funding the LiLa-POF project (20E1510). The work carried out by I. Parola has been funded by a research grant given by the Departamento de Educación, Política Lingüística y Cultura del Gobierno Vasco/Eusko Jaurlaritza for her PhD thesis.

# A New Shape Factor Method for Profiled Polyester Fibres

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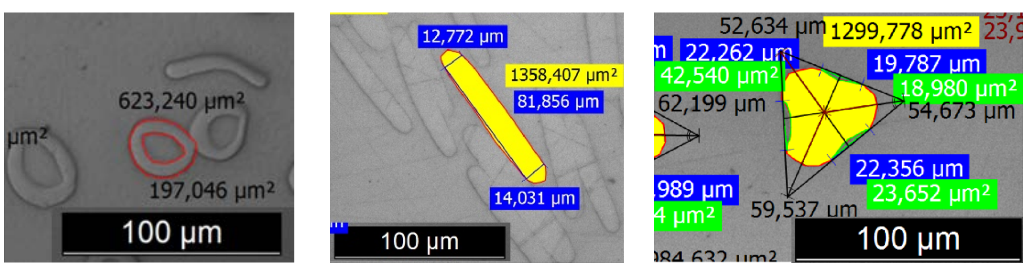
**ABSTRACT**
Profiled fibres may have cross-sectional shapes which are non-circular. It influences the properties of fibres, yarns and fabrics which are produced of them. Significant properties may be moisture transport, heat insulation, weight, luster or UV protection. However, each process step in a production chain of synthetic fibres can cause a deformation of the intended fibre shapes which consequently affects the textile's properties and finally its quality. Accordingly, a detailed analysis of the fibre shape deformation is crucial for the optimization of each particular process step.

In particular, the analysis of trilobal, hollow and flat cross-sectional fibre shapes is focused on. In order to proof the accordance between the real and the intended cross-sectional shape, there are some measurement methods existing so far. All of these are referred to as shape factor methods. In recent publications, the shape factor is usually defined as an indicator for the "non-circularity" of the fibre's cross-section. However, it turns out that most of the available measure methods are impractical to point out fibre deformations in a meaningful manner.




(a) (b) (c)

Figure 1. Image processed microscopic captures of hollow, flat and trilobal fibres

In this paper, new measurement methods are proposed which are based on a geometrical analysis of the particular cross-sectional shapes. Thereby, the characterization is performed by the simplification of each fibre cross-section to a composition of geometrical sub-shapes enabling a more practical analysis. Figure 1 presents image processed microscopic captures of hollow (a), flat (b) and trilobal (c) fibres' cross-sections. For each of those cross-sections an individual shape factor allowing a specified analysis of the particular fibre cross-sections is developed.

# Influence of Alkaline Treatment on Surface Roughness and Wetting Property for Hydrophobized Silk Fabrics

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The purpose of this research was to develop silk fabrics with dual-scale surface roughness, hydrophobicity, and self-cleaning properties. The surface roughness of 100% raw silk fabric was controlled by varying the temperature and time of degumming with NaOH solution to adjust the extent of sericin dissolution. Hydrophobization was carried achieved by depositing n-dodecyltrimethoxysilane on the silk fabric.The surface morphology, chemical composition, weight loss, tensile strength, luster, and color change of the fabric were measured, and the surface wettability was evaluated by water contact and shedding angle measurements.It was observed that the sericin on the fiber surface dissolved in the alkaline solution and formed nanoclusters. Consequently, because of the nanoscale roughness induced via the alkaline treatment, the contact angle increased from 0° to 152° after the hydrophobization, and the shedding angle decreased from 90° to 15°, indicating the superhydrophobicity of the resulting fabric. Therefore, alkaline treatment of silk fabric at 70 °C for 10 min was determined as the optimum condition for developing a self-cleaning silk fabric with an outstanding superhydrophobicity. The physical properties such as tensile strength, luster, and color were found to be the same even after the treatment.

# Analysis of PET Fiber Deformation in High-speed Melt Spinning by Using 2-way On-line Diameter Measurements


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## INTRODUCTION

Over the past few decades, many researcher groups have been studied to reveal the mechanism of structure evolution of fibers in melt-spinning and drawing processes, and various on-line measurement methods have contributed much to obtain valuable results. In this study, by using improved 2-way (XY-axis) high-precision on-line diameter measurement system (On-line DMS), we investigated the correlation between fiber deformations and spinning conditions in high-speed melt-spinning line of PET in more detail, and analyzed neck-like deformation behavior with obtained high-resolution data.

## EXPERIMENTAL

PET was melted using single-screw extruder and the melted PET was extruded through spinnerets by gear pump at the different spinning temperature. The high-precision On-line DMS were composed of two optical on-line diameter measurements to scan XY-axis diameter of running PET fiber, auto-tracking stage to position the running fiber at the center of two diameter measurements, and Z-axis elevator to adjust height of these measurements. The diameter profiles of PET fiber were measured between nozzle and winder by changing the position, and sampling rate of optical diameter measurement was over 10 kHz.

## RESULTS & DISCUSSION

The On-line DMS were conducted into high-speed melt-spinning process of PET fiber, and could measure XY-axial diameters of PET fiber simultaneously and more precisely up to high-spinning velocity of 6km/min. Overall diameter profiles obtained in the spinning line showed that typical correlation between neck-like deformation and spinning conditions such as molecular weight, spinning temperature and spinning velocity in more detail. The change of profile of neck-like deformation, which accompanied strain-induced crystallization by spinning conditions, could be obtained with high-resolution data.

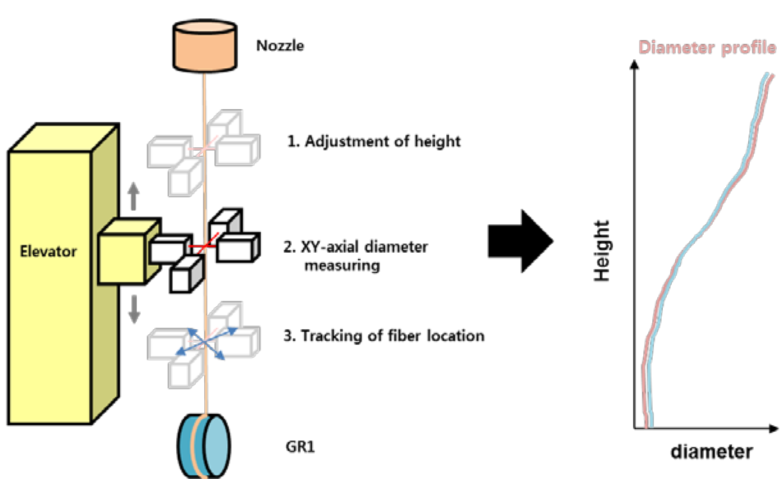


Figure 1. Schematic of 2-way on-line optical diameter measurement

# Nanoparticle Modified Polymer Melts and the Theory of Similarity

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## NANOCOMPOSITES AND THE MELT SPINNING PROCESS

Using Carbon Nanotubes (CNT) to make chemical fibers conductive can lead to problems during the melt spinning process. Exceeding a certain fraction, the nanoparticles cause the pressure in the spin pack to increase quickly. Different explanations such as the nanoparticles' tendency to agglomerate, the orientation of CNT with respect to the fiber axis, and the possibility of unintentionally filtering out the nanoparticles were given. None of them have been experimentally verified yet. Moreover, it is still not clarified whether the pressure increase is caused by nanospecific effects (agglomeration, Brownian motion) or by simple geometric factors in the nanoscale.

Based on the assumption that nanospecific effects do not influence the pressure in the spin pack, a model including geometric, process and material variables is to be built. This model should serve to compare the results of experiments with nanosuspensions and suspensions with macroscale particles. The method of choice is the theory of similarity.

## SIMPLIFICATION AND MODELLING WITH THE THEORY OF SIMILARITY

For a first model the given situation is simplified in two ways. The model refers to a rotational rheometer instead of the spin pack, enabling the determination whether the assumption of neglected nanospecific effects is true or not. Additionally, experiments will be run with Carbon Black (CB) nanoparticles instead of CNT because CB can be treated as spherical particles. Considering these simplifications, the following list of nondimensional numbers can be derived:

Table II: Nondimensional numbers

| | |
|---|---|
| $\pi_1 = K/\left(\dot{\gamma}^{2-n} \cdot {D_P}^2 \cdot \bar{\rho}\right)$ | shear thinning particle Reynolds number |
| $\pi_2 = b/D_P$ | length ratio |
| $\pi_3 = n$ | flow behavior index |
| $\pi_4 = \Phi$ | volume fraction |

Table I: Variables

| | |
|---|---|
| K | flow consistency index |
| $\dot{\gamma}$ | shear rate |
| $\bar{\rho}$ | suspension density |
| b | rheometer gap width |
| $D_P$ | average particle diameter |

Since polymer melts are shear thinning fluids, the factors flow consistency index K and flow behavior index n replace the viscosity η. The Ostwald–de Waele relationship uses these two variables to describe η as a function of $\dot{\gamma}$. It happened to correlate well with experimental measurements of a polypropylene (PP) melt, both with and without CB.

The requirement of similar systems is: each nondimensional number needs to have the same value, respectively for the real system and the model system. In the given case, this leads to experiment instructions concerning the model fluid. According to the theory of similarity, a suspension of buttermilk with particles of 55 µm diameter at a shear rate of 1 $s^{-1}$ is to be reacting similar to a PP-CB-nanocomposite with 15 w% of CB at 260 °C at a shear rate of 10.000 $s^{-1}$.

# Prediction of Yarn Properties by Inline Measurement and Numerical Modeling

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**ABSTRACT**
The properties of man-made yarns heavily depend on the filaments structure. During the melt spinning process the orientation and crystallization process is influenced by the temperature and stress profiles. Thereby, the local cooling and the strain behaviour of the filaments are defined by the cooling and haul-off conditions.

A lot of research has been performed on possibilities to model the spinning process and to determine the influences of the different process variables on the fibre structure. However, these models are rarely applied for industrial applications due to a lack of confidence in the computational results. Furthermore, the verification of these results is costly since the measurement equipment is usually not embedded in modern spinning plants. Nevertheless, there is a high potential to reduce costs of the process design and to increase the quality of the products by using additional measurement technologies and numerical simulation during the design of the process.

Within this work, measurement technologies are embedded into the melt spinning plant to collect data of process variables that are significant for the formation of the filament. Therefore, existing measurement technologies are evaluated and tested in accordance with their suitability for the measurement of the fibres structure during the melt spinning process. Furthermore, a numerical model is developed that describes the fibre formation in the multifilament melt spinning process and predicts influences on the properties of the product. Based on the achievements of this work, a tool which combines the collected measurement data and the developed model to obtain an assisted process design is set up.

**ACKNOWLEDGMENT**
This work is supported by a cooperation of national and international partners, which are interested in basic research on application-related topics in the field of melt spinning. This cooperation between companies and the Institut für Textiltechnik of RWTH Aachen University is called Industry Research Group (IRG) Meltspinning. The members represent industrial sectors as for example fibre production, plant engineering and plant component manufacturing. The current members of the IRG Meltspinning are INVISTA Performance Materials, Heberlein GmbH, DSM Engineering Plastics B.V., Kuraray CO. LTD, Oerlikon Textile GmbH & Co. KG, Reifenhäuser Reicofil GmbH, Schill + Seilacher GmbH, Technip Zimmer GmbH, Trützschler GmbH & Co, Van de Wiele Group and Zorlu Textile Group.

# Stability of Basalt Fibers in the Alkaline Environment

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Under the cooperation project financed by the Federal Ministry of Education and Research (BMBF) was alkaline resistance of basalt fibers the object of investigation. Similar to the glass fibers is the main structure of basalt fibers made of $SiO_2$. This structure is easily attacked in the alkaline solution, which leads to the porosity of the fiber. Main advantage of the basalt fibers produced by DBF GmbH is high amount of network building elements ($Al_2O_3$, MgO, $TiO_2$ etc.) compared to the glass fibers. Due to these circumstances basalt fibers have better mechanical properties and more alkaline stability compared to E-glass fiber. As the state of the Art is “Alkaline Resistant Glass fiber” used for the concrete reinforcement, because of the $ZrO_2$ in the chemical composition. Contrary to AR-Glass fibers, Basalt fibers has no $ZrO_2$ in the structure. They way to make Basalt fibers alkaline stabile leads to sizing application on the fiber.

DBF GmbH has evaluated lot of different sizing types in order to save the structure of basalt fiber against alkaline attacks. Promising result were reached in the past year. Investigations of the fibers were done by ITM TU Dresden. Basalt Fiber Samples with the sizing type BZFC and the linear density of 2400tex were binned in the 3-ionic water solution (NaOH, KOH, $Ca(OH)_2$) and in pore solution (pH 12,48). Scanning electron microscopie images was done after 7 days in respective solutions in order to see the morphology of the fiber surface. As shown in the images below (1-4), there are no significant changes on the surface, despite of the alkaline attack. After 28 days, the tensile strength of samples was measured after ISO 3341(Figure 1). Compared to the initial tensile strength of the fiber (above 1000MPa) 30% less tensile strength was measured after the alkaline environment. Conclusively, basalt fibers produced by DBF GmbH are alkaline resistant fibers due to sizing application and alkaline resistance could be increased with additional coating materials.

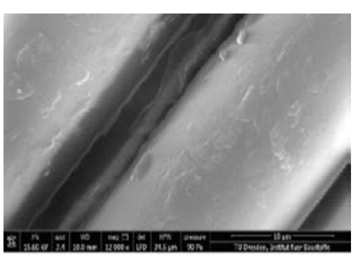

Image 1: reference, not binned

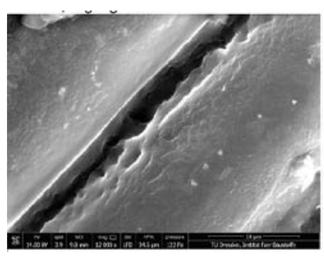

Image 2: binned in water at 80°C

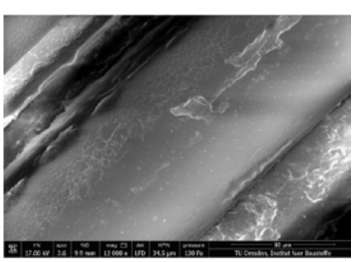

Image 3: binned in pore solution at 80°C

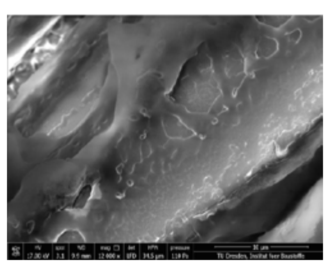

Image 4: binned in 3-ionic solution at 80°C

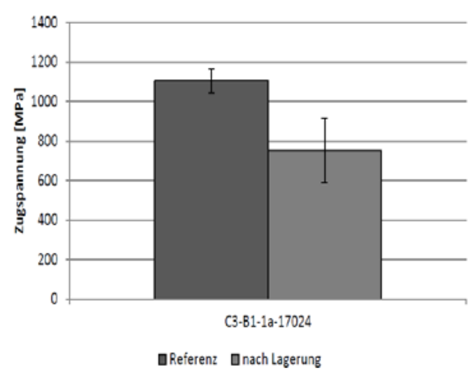


Figure 1: tensile strength before and after alkaline attack (ISO 3341)

**ACKNOWLEDGMENT**
This research was partially supported by the Federal Ministry of Education and Research(BMBF). Many thanks also to the project executing organisation PTJ Jülich.

# Investigation of the Spinnability of Polymers with a High-speed Rheometer

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The spinnability results from a complex relationship between polymer composition and structure, flow properties and viscoelasticity, molecular weight, molecular weight distribution, molecular topology, and thermal and chemical resistance. Some of these relationships are known above all from semi-empirical investigations. However, these findings are not sufficient to predict the spinnability or the quality of the thread formation of a new polymer.

Drawback of this approach is the time consuming and costly way needed to develop a polymer to a spinnable material which is suitable for large variation in textile applications diminishing significantly the interest of the polymer producers to develop new polymer grades for the melt spinning process. Furthermore the development costs for new spin polymers is higher in fibre applications than for other extrusion applications. In addition polymer fibres market is smaller in comparison to other plastic applications. Therefore most polymer manufacturers refrain from a polymer redevelopment. With shorter development times the interest for the development of new spin polymers can be greatly intensified.

The aim of the here presented project is the assessment, quantification and visualization of the melt-spinnability of polymers for high-performance industrial processes avoiding material waste and loss of production by filament breaks. Therefore a rheometer making studies of the spinnability of polymers under real spinning conditions possible is developed. This rheometer-system includes the development of a highly sensitive force sensor allowing for the first time the high resolution measurement of thread haul-off forces at high haul-off velocities. Thereby an optical sensor will enable the measurement of the extruded profile or swell in thread haul-off direction. This rheometer-system will allow, next to conventional rheological characteristics, statements about the maximum force on the melt strand, its elastic limit and defects that occur at the melting line.

In here the rheometer development including the versatile applications which this system offers as well as the actual test results which were obtained previously by using this new system are presented.

# A Study in Flame Retardancy of Flavonolignans Composition in Polypropylene Filaments

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Polypropylene (PP) has a high heat of combustion; about 46.4 kJ.g-1, and it has no char forming feature and a limiting oxygen index (LOI) of about 18%. PP has a high heat release peak and a rapid production of smoke which is hazardous. Processibility, UV stability and cost-effectiveness are the key issues for flame-retardant (FR) PP fibers. Recent advances in FR technology have improved the processing, but UV stable formulations which are economically feasible have not yet been achieved.

The goal of this research is to incorporate a novel FR into polypropylene, to provide flame-retardant properties with excellent thermal and UV stability, without use of halogenated aromatic compounds.

In this work we use *Silymarin*, which is a flavonoid compounds extracted from the blessed *milkthistle silybum marianum,* and *α-naphthoflavone.* These are used in the PP fibers in combination with NOR116® which is a commonly used FR additive. The PP fibers were produced by melt-spinning, and their flame-Retardancy was investigated.

The compound granulates were manufactured in a mico-compounder and further they were processed in a piston melt-spinning machine to produce polymer filaments. Furthermore, a punch-card knitting machine was used to produce fabrics. Thermogravimetric analysis (TGA) was used to determine the temperatures at the maximum weight loss rate and matrix decomposition temperature. Melting temperature, crystallization temperature, heat of fusion and crystallization heat were obtained by differential scanning calorimetry (DSC) method and the degree of crystallinity for the PP matrix was obtained by related equation. Vertical flame test (UL-94) was performed to observe flammability. LOI value was determined according to ASTM D2863. Finally a cone calorimeter method was carried out to measure heat release rate.

The PP compounds containing *silymarin* decompose in a higher temperature than the other prepared compounds. Moreover, the compounds containing α-naphthoflavone have better thermal stability. Results show that the crystallization rate for PP is greater than other flame-retardant composition. The LOI test results show that the presence of both *Silymarin* and *α-naphthoflavone* in the PP polymer matrix increases the LOI value. Furthermore, *α-naphthoflavone* has a significant fire extinguishing effect while *silymarin* deacelerate the fire extinguishing, by expanding the flame behavior.

# Modification of Chemically Stable Polymeric Materials 90: Increase of the Adhesion Property of Chemically Stable Polymeric Materials and Preparation of New FRP Using Modified Fiber

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**Abstract** Silicone resin materials and other chemically stable polymeric materials were modified by a novel hydrophilic treatment. Well-modified silicone resin sheets could be adhered strongly to other materials, using double coated adhesive tapes. Fluorocarbon resin materials and other chemically-stable polymeric materials were also modified well. The modified property gave a high durability, as compared with plasma-discharge process. Modified PP, PET and PPS were useful for the preparation of light and strong polymeric composites. CFRP boards made with modified CF and epoxy resin gave a high strength and no separated breaking in the bending test. The obtained hydrophilic property was not lost for several years.

## INTRODUCTION

Polymeric materials such as polypropylene (PP), polyethylene (PE), ultra-high-molecular-weight PE (UHMWPE) and poly(methylpentene) (PMP), silicone resin and fluorocarbon resin are chemically stable and their durable modification is not easy. The plasma-discharge process is not useful for some polymeric materials such as PMP and PEEK resin. In addition, plasma-discharge processed materials have to be used quickly for the subsequent process. We found that a combination of some techniques (DHM-process) was effective for the modification of these polymeric materials. We studied the modification of CFRP and CFRTP to increase the adhesion property. In addition, we prepared new type FRPS using DHM-processed fibers.

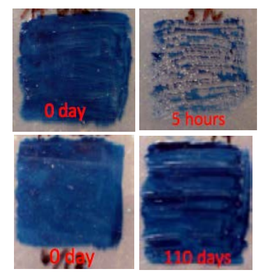


Fig. 1. Water-based paint coated silicone resin sheets; upper two: plasma-discharge processed ones and lower two: DHM-processed ones; the number gave the

## EXPERIMENTAL

**Materials:** Polymeric materials were used after washing with methanol. Commercial chemical reagents were used after a simple purification.

**Adhesives:** Poly(vinylpyrrolidone), wood-use bonds, cyanoacrylate (CA), a film type epoxy resin adhesive (3M-AF163-2), etc. were used.

**Treatment:** Polymeric materials were activated by chemical oxidations and energy irradiations. The activated polymeric materials were coated with chemical reagents. The treatment conditions were considered for each material. These techniques were named as "DHM (durable hydrophilic modification) process"

**Adhesion strength and analysis:** Adhesion strengths of polymeric materials were measured by a tensile tester, Shimadzu AGS-H5KN. IR spectra were observed by a Shimadzu IRPrestige-21 equipped with an ATR accessory. XPS of materials were observed by an Ulvac PHI 5000 VersaProbe II.

Fig. 2. Adhesion of PTFE film and aluminum board with PVP glue.

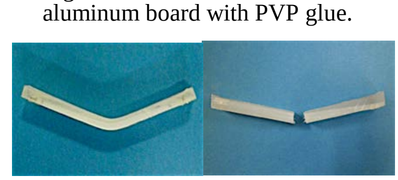

Fig. 3. FRP of plasma-discharge processed PET/epoxy resin (left) and FRP of DHM-processed PET/epoxy resin (right).

## RESULTS AND DISCUSSION

**1) Water-based paint coating:** Plasma-discharge processed silicone rubber sheet was coated with water-based paint soon after the treatment, but it was not coated with the same paint five hours after the treatment. But, DHM-processed silicone rubber sheet was coated with the same paint even 110 days after the process (see Fig. 1).

**2) Adhesion of poly(tetrafluoroethylene) (PTFE):** PTFE was not modified by the plasma-discharge process. But DHM-processed PTFE sheet was adhered to aluminum board using usual PVP glue (see Fig. 2)

**3) Preparation of new type FRP:** PET or CF fibers were treated by the plasma-discharge treatment and the DHM process. FRPs were made by the modified PET or CF fibers and epoxy resin. In the T-type strength test, the plasma PET or CF-epoxy resin FRP boards were broken separately, but the DHM-PET or CF epoxy resin boards were not separated after the breaking (see Fig. 3).