DEUTSCHE INSTITUTE FÜR
TEXTIL+FASERFORSCHUNG

ANNUAL REPORT 2018

TEXTILE FUTURE

DITF.de

OPEN THE WINDOW
INTO THE WORLD OF TEXTILE

TAKE A LOOK INTO THE DETAILS OF OUR RESEARCH, IN IDEAS AND INNOVATIONS FROM THE GERMAN INSTITUTES OF TEXTILE AND FIBER RESEARCH DENKENDORF

DEUTSCHE INSTITUTE FÜR
TEXTIL+FASERFORSCHUNG

ANNUAL REPORT 2018

FOREWORD

Dear readers,

We followed the Südwesttextile's campaign "Textil kann viel!" (Textile does it all) with much joy, which created plenty of attention in 2018 since it also showcases our convictions and achievements. The products and procedures we develop at the DITF Denkendorf are innovation drivers for many industries. They provide impulses in sectors like lightweight construction, medical and environmental technology, regenerative energies, resource efficiency, mobility, but also in traditional areas like clothing and home textiles. The DITF supports people working in these application fields and shapes the future with practical applications as well as ideas.

Our diverse R&D activities throughout the last year highlight the broad applications and enormous potential of fiber-based materials and textile technologies. The annual report invites the reader to discover new topics and projects. We report on research highlights and visionary developments, from molecule to finished product.

"Textil goes digital"

The topic "Textil 4.0" is, among other themes, the focus of numerous research projects in the year under review. Digitization as cross-sectional technology permeates nearly all other research sectors and poses substantial challenges for the textile industry. The digitization of the industry encompasses products, processes, as well as business models and will fundamentally modernize all sectors.

The laboratory and demonstration environments at the DITF institutes provide opportunities to experience digitization first-hand. The DITF opened the showroom "Digitales Engineering" in the Mittelstand 4.0-Kompetenzzentrum *Textil vernetzt* (competence center for mid-sized companies, networked textiles) in 2018 for that purpose. It presents a novel digital process chain in the area of clothing and home textiles, next to smart textiles and lightweight construction.

The DITF showcased how digitization works in practice during a labTour for the textile industry; moreover, in cooperation with other digital experts at the first symposium "Textil goes digital" of the competence center *Textil vernetzt*. The various activities also received much praise from the public authorities. Thomas Strobl, Minister of the Interior, Digitalisation and Migration of Baden-Württemberg, visited the DITF within the context of the campaign "Digitalisierung: Läuft!" (digitization succeeds) and was impressed by the commitment and current state of research at the DITF.

Go ahead international

The exchange with leading competent players worldwide is a necessary condition for research excellence. It is with this knowledge in mind that the DITF further expanded their international activities in 2018 and enhanced their worldwide innovation partnerships. Participation in major international textile trade fairs is a critical component of that.

In 2018, the DITF made their first appearance at the two major textile trade fairs in America – the Techtextil North America in Atlanta and the IFAI Expo in Dallas. Further trade fairs on the agenda included MEDICA, Jec World

and Index, which offered an ideal marketplace for making the developments and research results known internationally. Additionally, the DITF, as co-organizers of the ADD International Textile Conference, supported the exchange at both national and international levels.

Collaboration with distinguished partners – at the national and international levels

Digitization and internationalization are changing the nature and pace of research, innovation, communication as well as cooperation. Knowledge-based and value-added networks are thus becoming increasingly important. As a result, the DITF rely on both regional, trust-based relationships as well as national and international networking. Innovation today is teamwork. The DITF institutes pursue this approach across industries and disciplines, and they are involved in various knowledge-based and innovation networks, as well as clusters.

Cooperation with research communities focused on industrial research at the state and federal level plays a vital role for the DITF who wish to promote greater effectiveness of mid-tier research in Germany. We have established valuable partnerships with the institutes of the Innovation Alliance Baden-Württemberg (innBW) and the Zuse-Gemeinschaft. The innBW scientist gatherings and numerous project meetings allowed us to boost further exchange and cooperation in 2018.

We thank our customers and partners for their trusting cooperation during the past year and look forward to future challenges as well as the ongoing dialogue with you. This annual report shall provide you with an insight into the details of our research, as well as the ideas and innovations by the German Institutes for Textile and Fiber Research Denkendorf.

The DITF Board

Prof. Dr. rer. nat. habil. Michael R. Buchmeiser	Prof. Dr.-Ing. Götz T. Gresser	Peter Steiger

TABLE OF CONTENTS

Documentation separate from the annual report provides an overview of

> DITF points of contact

> Publicly funded research projects

> Published final reports, publications, lectures, press releases

> Dissertations, awards

> Events, trade shows, exhibitions

> Patents

> Bodies, scientific advisory councils

Orders: info@ditf.de

DITF

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

GERMAN INSTITUTES OF TEXTILE AND FIBER RESEARCH DENKENDORF

THREE RESEARCH FACILITIES. ONE BRAND.

Three research facilities are united under the umbrella of the DITF. These include the Institute of Textile Chemistry and Chemical Fibers, the Institute of Textile and Process Technology and the Center for Management Research. Each has its own research focus and its own expertise. Their potential lies in their close connection under the DITF umbrella brand. Together they form Europe's largest textile research institution and cover the entire production and value creation chain for fiber-based materials.

GERMAN INSTITUTES OF TEXTILE AND FIBER RESEARCH DENKENDORF

We think in textile systems. They are the key to innovation in many important industries and high-tech sectors.

The DITF form the largest textile research center in Europe

With more than 300 scientists and technical employees, the DITF cover the entire production and value creation chain in textiles as the only textile research institution in the world. We have been covering all the important textile topic fields since 1921. We count among the leading research institutions in our field of work worldwide.

Application-oriented research from molecules to products

We carry out application-specific research over the entire textile production chain. Our technology-oriented innovations as well as modern management concepts contribute to the competitiveness and safeguarding of both the German and European economy.

Industry partners

The DITF are partners with numerous local and international enterprises. They take part in public research processes or issue direct research assignments to the DITF. The DITF support and advise companies in the most important industrialized nations worldwide.

R&D services

We are an important R&D partner for industrial and service companies in fields ranging from ideas to material research, the development of prototypes and industrial processes, from pilot production to testing. We are an important supplier of innovative expertise, especially for small and medium enterprises that do not have their own R&D departments.

Technology and knowledge transfer in practice

We quickly transfer sustainable research results into economic exploitation and application. Our most important goal is the conversion of scientific knowledge into market-ready processes, products and services.

Teaching and practical further training

As one of the leading European research institutions in the field of textile technology, the DITF have a special responsibility to encourage young scientists. Therefore, training and further education are among the DITF's central tasks.

Numerous lecturing and research collaborations have been formed with regional universities. A collaborative research and lecturing association with Reutlingen University exists through the Center for Interactive Materials (CIM) and a shared professorship. The DITF also have a close connection with the University of Stuttgart in the form of three professorships as well as courses in other study subjects.

Professorships at the University of Stuttgart

Professorship in Macromolecular Substances and Fiber Chemistry – Institute of Polymer Chemistry
Prof. Michael R. Buchmeiser

Professorship in Textile Technology, Fiber-Based Materials and Textile Machinery – Institute of Textile and Fiber Technologies
Prof. Götz T. Gresser

Institute for Diversity Studies in the Engineering Sciences
Prof. Meike Tilebein

FROM MOLECULE TO MARKET – WHAT WE OFFER

We support you – starting from brainstorming through material research, development of prototypes and production processes, pilot manufacture and testing to advice on new business models. We orient ourselves to the needs of the industry and create market-ready products, processes and services for it.

Denkendorf Future Workshop

Innovations are rarely created by coincidence or simply by intuition. A structured innovation process is essential for creating new, market-ready and implementable ideas. The Denkendorf Future Workshop can help with this. It offers companies targeted and systematic support for brainstorming.

Applied research and development

We invest in preliminary research, make the latest results from fundamental and application-oriented research available to the textile sector, operate joint research, contract research and development on commission. From the molecule to the finished product and its entry onto the market we research and develop along the entire textile value creation chain and in the process, also develop business processes and models.

Testing services

Since their foundation the DITF have had test laboratories and offer a comprehensive service catalog for testing fibers, yarns, surfaces and textiles. Hardly any other institution offers such comprehensive technology for the research and testing of fiber-based materials and textiles. State-of-the-art analysis and testing techniques are available for examining textile-technical, chemical, biological and sensory testing processes.

Pilot factory

We operate a pilot factory in which all the important technologies along the process chain are implemented. With this pilot factory we offer the industry a unique opportunity in the textile market for zero and small series manufacturing. Experienced staff, combined with the existing machinery park and well-equipped technical facilities guarantee optimal framework conditions for contract manufacturing.

Prototype construction

We have in-house development and construction facilities for prototype construction. Well-trained personnel use the modern equipped workshop and the electronics laboratory to develop new ideas for testing and production processes for the textile industry. In this way we offer the textile industry the opportunity to test and optimize at specially built test stands.

Please ask us!

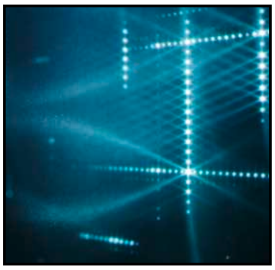
DITF RESEARCH FIELDS

The six strategic research fields of the DITF use the unique feature of textile vertical integration for knowledge-based innovations. As the only textile research institution in the world the DITF cover the entire production and value creation chain of textiles.

From the molecule to the finished product

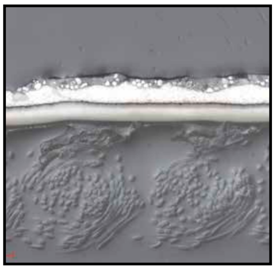
High-performance fibers and yarns

Development of high-performance fibers and yarns on the basis of synthetic polymers and sustainable raw materials



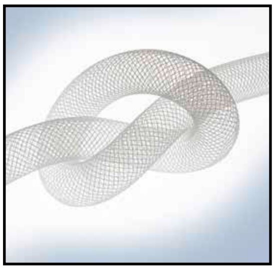
Smart textiles

Integration of existing technologies for the development of more active, more adaptable, more sensory and shinier textiles



Textile finishing and coating

Development of functional technical textiles with new environmentally friendly technologies

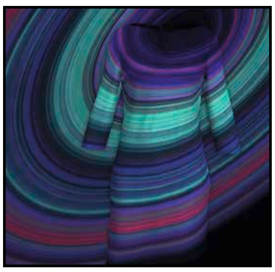


Medical technology

Biologization of medical textiles and implants with active substance delivery systems and more active surfaces

Composite fiber and lightweight construction

Development of end-contour 3D-components with composite fiber technology



Textile 4.0

Digitization, process development, value creation and knowledge management in the textile and clothing industry

FIELDS OF APPLICATION

We encounter the textile world everywhere. Textile development and products are the key to innovation in many important industries and high-tech sectors. Fiber-based materials are among the most important materials of the 21st century. Multi-functional, cost-efficient and sustainable, they are recommended for more and more fields of application. We have carried out diverse research projects for industrial as well as public clients in the following fields of application:

Architecture and construction

Construction materials with textile components, fiber-based materials

Energy, environment and resource efficiency

Energy technology, environmental technology (e.g. water treatment, geo- and landscape protection, recycling of high-performance fibers), intelligent energy management

Health and nursing

Textile implants and regeneration medicine, wound treatment products, diagnostic and monitoring systems, smart textiles, depot and therapy systems

Production technologies

Process engineering and technology for higher productivity, quality and energy efficiency, automation

Mobility

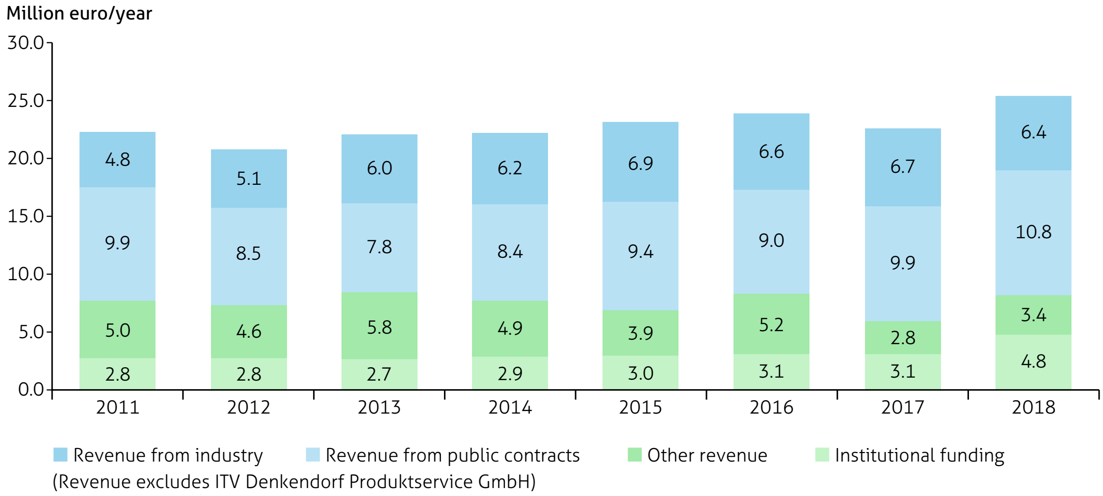
Fibers, structures and products e.g. for the automotive industry and for aviation and space travel technology

Clothing and home textiles

Functional clothing, climate-regulating textiles, light textiles, sound technological textiles, smart textiles

FIGURES – DATA – FACTS

DITF Revenue 2011–2018



Stable revenue performance

The total revenue from ordinary business activities amounted to 25.4 million Euros in 2018, and is therefore significantly higher than the results achieved in 2017. As in the previous year, revenue from public contracts increased sharply. The additional increase in income was enough to fully compensate the slight decline in the number of industrial projects.

Institutional funding by the Ministry of Economics, Labor and Housing Baden-Württemberg increased enormously in the past year. At 4.8 million Euros, it was well above the figure from the prior year.

When it comes to industrial revenue, the small and medium-sized enterprises play a special role for the DITF. The industrial revenue generated through SMEs (Small and Mid-sized Enterprises) amounted to 50% in 2018. The focus on SMEs is further highlighted by the large number of ZIM projects, which accounted for 24% of revenue from public contracts during the period under review.

Employees as of 31.12.2018

DITF
248 employees
127 scientists and engineers
121 non-scientific employees
11 doctoral candidates
1 scholar
82 students
(bachelor, master, graduand/degree candidate)

ITV Denkendorf Produktservice GmbH
54 employees

Quality management

Selected DITF laboratories and the ITV Denkendorf Produktservice GmbH test laboratory are accredited according to DIN EN ISO/IEC 17025:2005.

The area of Biomedical Engineering, PET yarn production area and PGA fleece, as well as the ITV Denkendorf Produktservice GmbH are certified according to DIN EN ISO 13485:2012 in the field of design and development, production and sale of absorbable and non-absorbable surgical sutures, implants and wound dressing materials.

NETWORKS AND COLLABORATIONS

Networks help us to drive innovation faster and to operate more successfully in the market. For that reason, we actively promote networking and collaborations – across industries, nationally, and internationally.

Combined expertise

In addition to having close links to the business and science community, the DITF are intimately involved in the activities of a wide range of associations, organizations and thematic networks of excellence, which serve as a platform for cross-system, interdisciplinary research.

Applied research

One crucial task of the DITF is the support of SMEs through applied research together with the successful transfer of technologies. Networking and collaboration with other business-related research institutes help to reinforce the mid-tier research capacity in Germany. Accordingly, DITF engage with the most significant research communities concentrating on industrial research at the state and federal level.

innBW INNOVATIONSALLIANZ BADEN-WÜRTTEMBERG

The DITF are part of the Innovation Alliance Baden-Württemberg (innBW), a group of 13 non-academic, business-related research institutes with a total of 1,150 employees. The institutes carry out result-oriented contract research in areas relevant for the future of the state. With around 4,700 industry projects per year, the innBW is an important partner, particularly for SMEs.

ZUSE-GEMEINSCHAFT

DITF co-founded the German Industrial Research Foundation Konrad Zuse e.V. This association represents the public interests of non-profit industrial research institutions in Germany and is open to all technologies and sectors. Its members include independent research institutions from all over Germany. They promote innovations in all sectors, from agriculture to medicine to mechanical engineering and shipbuilding.

ARCHITECTURE AND CONSTRUCTION

Fiber-based materials and processes for the construction industry. Improved aesthetics, greater sustainability, functionality and innovation. For temporary and permanent buildings.

> Textile facade elements

> Light-guiding textiles

> Smart textile construction elements

> Pneumatic textile actuators

> Autonomous living walls

> Textile moss walls for particulate reduction

> MucorPrevent: heating textile material to prevent mold

> Flectofin: smart, lightweight building shading

> Sonic textiles

> New membrane materials for textile construction

Architecture and construction

The construction industry needs innovative approaches to develop their future tasks. We must address the challenges associated with the increasing scarcity of housing space and growing density of urban development, as well as the improvement of ambient air quality and optimization of resource use to fulfill statutory requirements. Metropolitan areas have an increasing need for solutions involving qualitative redensification of the available space. Such solutions should also help to develop commercial potential conducive to social redensification to create affordable housing.

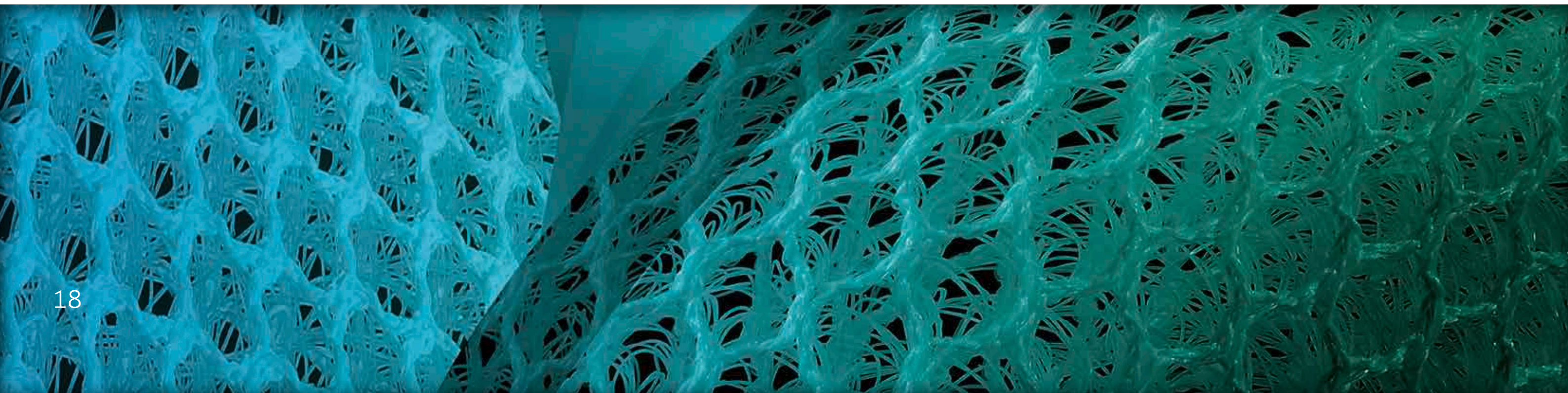
Functional, smart building textiles

Textile solutions for addressing these issues can be found, for example, in the development of new materials and structures that can be integrated into new products and components. Few components today fulfill only a single function. Accordingly, they will often protect from exposure to climatic influences as well as sound and light. Materials and components must fulfill structural, energetic, and design functions. Fiber-based materials prove their worth especially in the context of such multiple demands. The DITF develop feasible and efficient solutions for this, which ideally address the issues of redensification.

Textile solutions for redensification

The Denkendorf research cube allows us to develop ideas; moreover, test and demonstrate new approaches, which then results in the rapid introduction of new products. New shading textiles achieve optimum light distribution in the interior of a building because even though they reduce glare, they direct so much valuable daylight into a room that artificial lighting becomes unnecessary. Integrated textile sensors measure the illuminance as well as control textile-based actuators that adjust the shading depending on the position of the sun. Such smart and active building textiles cannot only be used in the smart home but also present an ideal basis for the realization of so-called smart districts, where entire streets are interconnected in a smart network. The aim is to manage issues relating to energy production and consumption as well as water supply and wastewater disposal in increasingly paved areas across all districts.

Building facades also hold excellent potential for solving problems of redensification. Textile facade systems can be produced to be lightweight, flexible, and highly functional. Attached vertical greenery systems (living walls) not only improve the quality of the air and life in densely populated city centers, but their water retention capacity also makes them suitable for urban water management. Even textile roof constructions in the form of membrane structures have long become a part of permanent buildings. Accordingly, thanks to their low weight and flexibility, textile materials allow the roofs of stadiums, train stations, and airports to be versatile like no other material.



Fiber-reinforced composites in construction

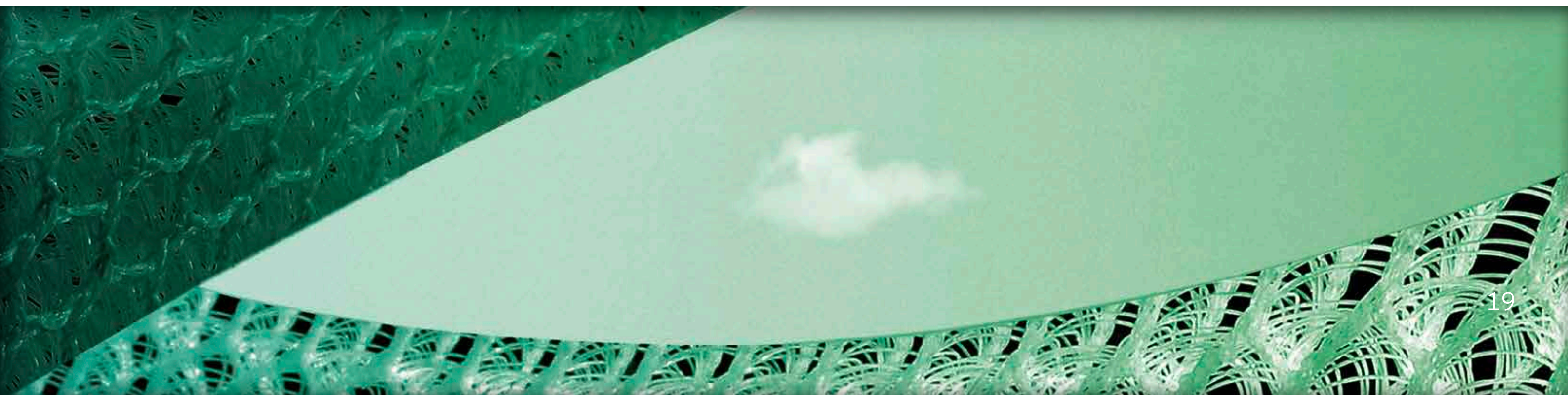
Fiber-reinforced composites have industrially relevant properties as a result of their great specific strength and rigidity; subsequently, they are becoming increasingly important for use in construction. Moreover, the orientation of the fibers, adhesion at the fibermatrix interface, as well as the many possible combinations of fibers and polymeric matrices, make it possible to adapt the material properties to various applications. The emerging digital transformation of everyday life and industry increasingly demands complex materials that, in addition to their usual intrinsic characteristics, have additional features such as artificial "sensory organs" to remain competitive in an ever more interconnected environment.

Adaptive covers and structures for the built environment of tomorrow

The integration of sensors into fiber-reinforced composites within the context of the Collaborative Research Center (CRC) 1244, among other things, will generate a complex component that will detect deformations and a partial failure of building envelopes or concrete structures.

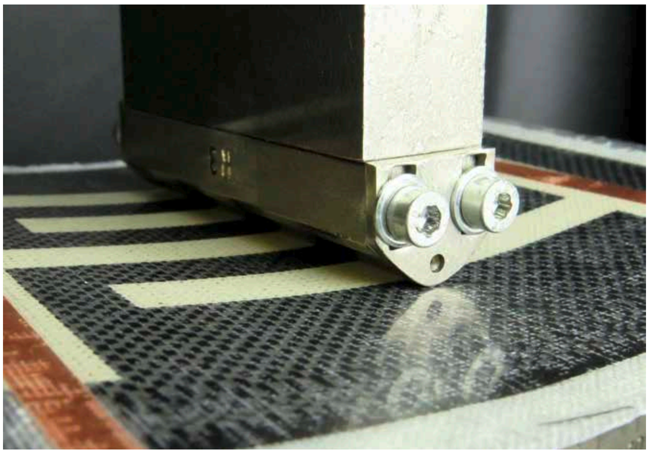
Aside from the identification of suitable fibers, along with the independent development of polymer-based resins, which are employed as cured thermosetting matrix composites, the selection of sensors is another crucial step. The sensor structures are printed on the fabric in a screen printing process using a conductive paste (e.g., carbon black, silver). The DITF have the relevant experience and knowledge needed to produce fibers (primary spinning) and the conductive pastes based on electrically conductive particles and binders. Of crucial importance for the production of sensors in fiber-reinforced composites is the expertise needed to treat (textile) supporting structures with sensor-active materials as well as the use of coating techniques such as inkjet and screen printing.

Following the sensor printing, these fiber-based sensors are to be fitted with electrical connectors and covalently embedded in a suitable polymeric matrix.



Sensors for fiber-reinforced composites

Fiber-reinforced composites have become much more relevant in recent years since they are lightweight, withstand high mechanical loads, and are corrosion resistant, unlike metal-based materials. They are used in lightweight construction, particularly, in automotive engineering and aircraft construction, as well as in the creation of rotor blades and wind turbines. Affixed strain gauges or piezoelectric sensors serve to monitor and control the mechanical deformation as well as the damage to fiber-reinforced composites. A disadvantage is that large areas and surfaces outside the measured regions are not taken into consideration.



Load tests on sensory composite

Large-scale printed sensors

As part of a current research project, large-scale textile sensor technology was developed. Its size can be adjusted as needed for the production processes. The required pastes and inks were developed for this purpose specifically. Electrically conductive inks are used to print so-called interdigital structures onto the reinforcement fabric. These structures serve as electrodes, which conduct the measurement signal. Coating or printing the interdigital structure with sensor active inks/pastes creates a textile-based sensor that, for example, changes electrical resistance when pulled or pressed. Tests showed that even minimal mechanical loads can be measured reliably. The results of the project permit the continuous monitoring of large-scale components since mechanical deformations and damage can be measured on the entire composite.

Development of a textile-based heat exchange panel for utilizing heat from wastewater

The heat dispersed from wastewater is a sustainable, long-term, and renewable energy source. The heat supply is available throughout the year, but its energetic potential has found little use so far. As a result, Germany produces 5-6 m³ billion wastewater each year. Extracting only about 3 Kelvin heat energy from the wastewater would yield approximately 20 TWh annually. Theoretically, this energy could be used to provide eco-friendly heating to 5 % of all buildings in Germany.

The aim of the project was the development and testing of textile-based Heat Exchange Panels (HEP) to reclaim energy from wastewater. It will be installed into the wastewater system while the sewers are built; or fitted into smaller cross-sections during their refurbishment. The heat exchange panels are made from spacer fabrics, whose open sides were sealed to be liquid tight. The heat transfer medium flows through the spacer fabric and absorbs the heat from the wastewater. Specifically designed knitted fabrics permit an optimized heat transfer. Compared to systems currently available on the market, the textile heat exchange panel can dissipate significantly more energy through the HEP thanks to micro-turbulent currents.

The heat exchange panel is installed at the saline area of the sewer. The wastewater temperature ranges between 8 °C and 15 °C on average throughout the year. The heat exchange takes place between the wastewater and fluids of the HEP. The fluid warms up in the HEP and is forwarded to the heat pump. The heat pump raises the temperature to approximately 40 °C to 70 °C and makes it available for heating.

A heat exchange panel within a two-piece sewer pipe

Light management using textiles

Light technology architectural textiles developed at the DITF offer novel possibilities for lighting in buildings. Sun protective textiles with selective angle and light directing characteristics guide natural light into the interior in an optimized fashion. New adaptive technologies make it possible to react to changing daylight situations and change room illumination accordingly. The optimized integration of lightweight textile structures can save a significant amount of energy used for lighting.

Daylight measurement in the research KUBUS

Individual adaptation of the photometric properties

The flexible mass production of textiles opens structural and material parameters thanks to individual settings, whose unique properties can be adjusted to each building individually. Using the appropriate textile structure at the right place requires determining numerous and complex correlating parameters. A unique challenge is the interaction of craftsmanship, customer, and industry. The craftsman on-site must communicate the customer's expectation regarding the final product and the actual lighting conditions to the industrial partner in a way that allows the industrial partner to create an individualized product that satisfies client expectations after installation by the craftsman. Digital interconnectedness, in the sense of Industrie 4.0, allows the determination of the required parameters, concerning the specification of such technically superior systems, by the craftsmen, and, therefore, the exact requirements specified. The knowledge the DITF have built up over the years at the light laboratory and the ForschungsKUBUS is ideal for testing and exchanging the results.

Textile moisture management for greenhouses

The DITF is developing new textile structures for water and heating systems in greenhouses, that, with the help of circulatory systems, help to save resources. Specialized plants serve as a source of ideas for the development of textiles with specific tasks.

Processes for evaporation, condensation, distribution, and capillary transport are designed for water circulation. The local water system of the rainforest was the inspiration for this closed-loop water cycle. The system is powered by solar energy, which is collected by solar collectors, which, in turn, generate demineralized water. The demineralized water is transported to the plants as humid, oversaturated air, where it condenses into nonwovens and is made available to the plants. The adapted storage volume and capillary transport into nonwovens ensure an adequate water supply to the plant's roots.

Innovative perspectives

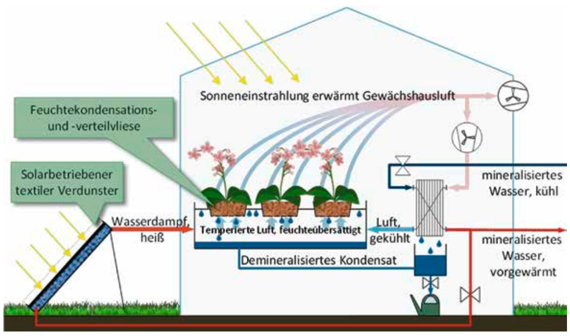
This novel system and its components provide innovative perspectives:

> The largest surface creates ideal conditions for an effective transition from water to gas.

> Novel humidity absorbing plant substrates dispense the collected moisture to the plants as demineralized water.

> Biodegradable textile substrate components for moisture storage permit harmonized growing systems with low energy and water usage as well as extended watering intervals.

> The innovative way of transporting water as humid air complements the methods previously used in urban agriculture: aeroponics, hydroponics, and drip irrigation.



Textile modules for the closed-loop humidity system in the greenhouse

HEALTH AND CARE

Textile materials, products, and processes concerning innovative applications for the medical care of people.

- > Resorbable polymers and bio-materials
- > Implants
- > Cell scaffolds for regenerative medicine, biohybrid artificial organs
- > Closure device for blood vessels and nerve guidance conduits made from biopolymers
- > Drug delivery systems: capsules containing therapeutic agents and coating systems
- > Ceramic fibers for bone replacement
- > Bioactive coatings, for example as wound dressings
- > Sensory textiles for telemedicine
- > Personalized orthoses
- > Physiologically optimized stockings
- > Wound dressing materials
- > Hospital and surgical textiles
- > Antibacterial textiles

Health and care

People have always attached very high importance to medical topics. The increasing life expectancy is also due first and foremost to the enormous advances that medicine, and notably medical technology, has achieved over the past decades. All the same, many diseases still take us to the limits of medical knowledge and technical capability, while at the same time offering an almost inexhaustible potential for research and development opportunities. However, medical technology is currently still facing significant problems: In its efforts to ensure high standards of patient safety, the EU introduced a new medical device regulation in mid-2017, which must be implemented by 26.05.2020. Not only does this regulation make the approval of new medical devices much more difficult, but it must also be applied to existing products. The implementation of regulatory requirements will overwhelm many companies and even established companies will reduce their product range considerably, resulting in incalculable consequences for medicine.

Product development under certified conditions

By contrast, the DITF institutes are well situated in this field. We have been researching and developing fiber-based medical devices from polymers to implants or hospital textiles for more than 40 years. The DITF and its subsidiary, ITV Denkendorf Product Service GmbH (ITVP), are already certified according to the new ISO 13485:2016. The certification allows us to produce prototypes for use in humans in the cleanrooms of the institutes and their subsidiary, ITVP. Finally, ITVP also makes its production facilities available on request. Thus, partners of DITF and ITVP, who collaborate with them on new products, not only benefit from the know-how and the experience of the institutes but also conditions for research, development, and production that meet all current legal requirements. The following pages offer an example focusing on nonwovens that the DITF develop and manufacture for medical purposes according to customer requirements. In some instances, the comprehensive experience with the technologies established here even makes it possible to launch new products relatively quickly in this complex and strictly regulated field.

Recognizing and utilizing development potential and potential for development

Medicine continuously makes discoveries that lead to the replacement of established materials and structures. Polycaprolactone (PCL) -based medical devices represent an excellent example of such discoveries. On the one hand, PCL is attracting more widespread attention in the development of absorbable medical devices because it demonstrates higher biocompatibility compared to the established polymers polylactide and polyglycolide, which can produce high, local acid concentrations during degradation. On the other hand, the ITVP was able to utilize the discovery to develop a new suture material, which no longer requires knot tying for wound closure but anchors in the tissue with the help of small barbs. This advancement shows that even the most simple, established products still have the potential for development.

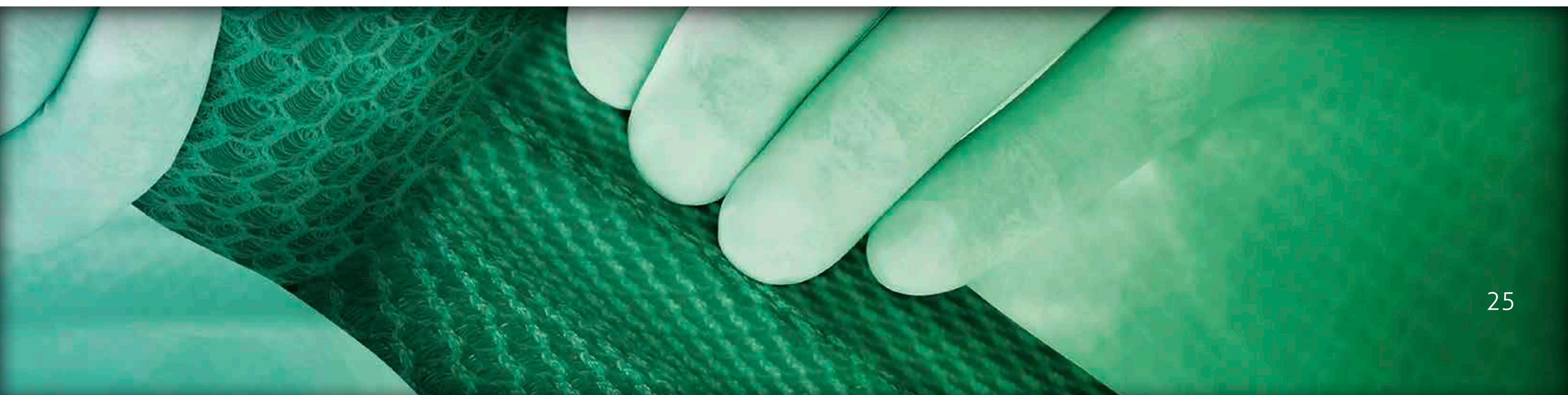
Functionalization of medical products

Functionalization represents a significant movement, especially in the textile industry. To an increasing extent, medical devices are gaining additional functions, for example through combination with medication. The primary purpose of a wound dressing so far was to protect the wound from contaminants and germs; other than that, the wound healing process was supposed to progress as undisturbed as possible. As described in the report on porous fibers, in the future, these dressing materials will actively target the wound healing process, accelerate and improve healing through the time-controlled release of therapeutic agents.

From symptomatic treatment to prevention

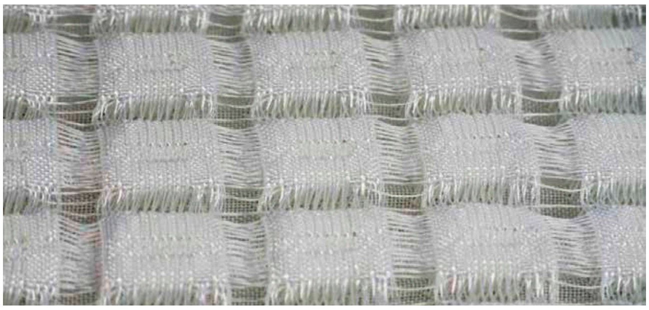
Protectors showcase that health care research at the DITF institutes does not focus on addressing treatment only after a patient has already fallen ill. Suitable preventive measures can avoid many adverse health effects. This is the case not only for athletes but also for ordinary people, such as elderly persons with osteoporotic bones. New composites made from 3D textiles with specially adapted foam structures can contribute to maintaining health.

Not only is medical technology at the DITF state of the art, and in line with regulatory requirements, the institutes also offer the entire spectrum of innovative medical device development from polymer development to biomaterial processing and functionalization to prototype production under certified conditions. This array also includes cell biological and microbiological tests for functional testing in vitro.



Personal protective components with improved impact behavior

Integrating load-oriented textiles into protective helmets has significantly reduced the impact and penetration forces of powerful blows. The conventional hard particle foam is replaced by a combination of materials encompassing a mold-adapted spacer fabric, which has the particle foam embedded in its internal spacer layer. This sandwich construction disperses the impact load encountered by the outer shell of the helmet over a larger surface of the upper fabric layer and transmits the forces via numerous spacer fibers to the foam particles. The result is an improved force distribution in the protective layer of the helmet, which provides for more uniform energy dissipation. In the case of the ski helmet, for instance, the optimized interaction of textile fibers and foam material allowed shock absorption to be increased by 30 %.



Spacer fabric that is filled quickly with foam and adaptive to bends

Adapted textile foam composites

Utilizing specially adapted textile foam composites can even improve the protective effects of back protectors. This particular application includes the use of flexible foams, which follow body movements more readily and thus provide greater wearing comfort. While the pure foam protector demonstrates excellent protection at room temperature, its protective effect deteriorates significantly during standard testing at 40 °C. The support structure of a spacer fabric, which has been adapted employing a particular bonding technique, in combination with softer filling foam, extends the usable work applications of the protector across a broader temperature range.

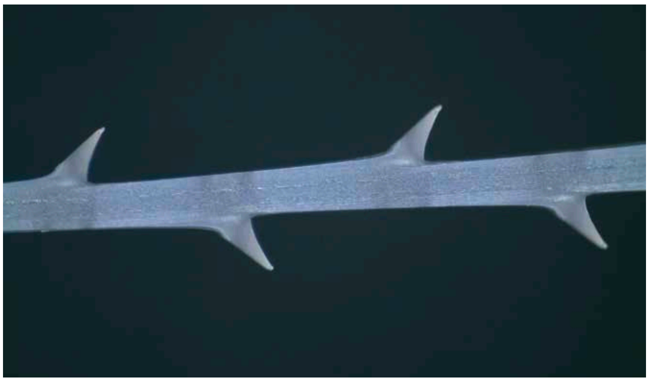
The possible result is either a significant increase in the protective effect of personal protective components or a reduction in the wall thickness of protectors while maintaining the same level of protection.

Polycaprolactone-based medical devices: New developments from ITVP

Polycaprolactone (PCL) is a synthetic, long-term absorbable polymer whose degradation half-life of about one year significantly exceeds that of polylactides. Even though the biocompatibility is excellent and the acid release rate during the degradation and absorption phase is lower compared to polylactides, there were only a few PCL-based medical devices available on the market for a long time. There has been an upsurge in interest in PCL-based orthopedic and cosmetic applications in recent years, which has led the ITVP to develop a range of PCL-based products. It now includes the medical-grade polymer, high-strength monofilaments, and multifilaments, as well as barbed sutures for knotless wound closure and thread lifting.

Optimum molecular weight – High strength – Unique barbed geometries

The PCL polymer developed and manufactured by ITVP has a viscosity range of 1.6 dl/g to 2.2 dl/g, ensuring an excellent processing capacity of the polymer in thermoplastic processes in combination with the highest tensile strengths of monofilaments and multifilaments. ITVP produces monofilaments with resistances of up to 800 N/mm², which are ideal for absorbable meshes and also used for molded barbed sutures at larger diameters. Our high-strength PCL multifilaments open up new possibilities for product developments in areas such as orthopedics. ITVP also uses the unstretched PCL monofilaments to produce unique barbed sutures with particular barbed geometries employing a patented process. This method provides high anchoring forces in the tissue with less pointed anchoring structures, thus resulting in less irritation.

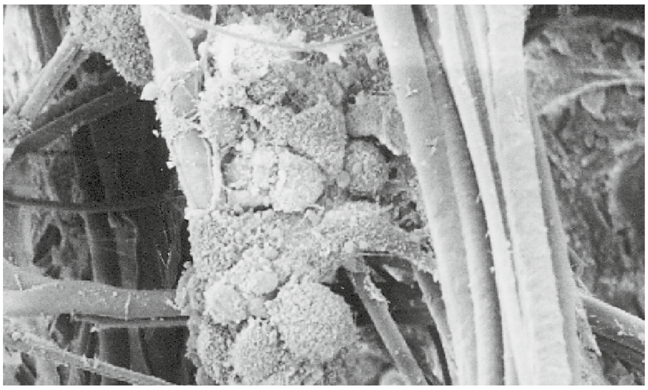


Long-term absorbable PCL-based barbed suture used for thread lifting and wound closure

Nonwovens with medical properties

Denkendorf has been developing nonwovens for more than 40 years. The dry spinning technology for the production of elastic nonwovens was invented at the DITF institutes and carried over into industrial application for meningeal repair. Tissue engineering, which arose in the 1990s, required voluminous nonwovens. The spinning technology for absorbable polymers was initially set up in the cleanroom for this purpose, before being replaced by the more flexible carding technology. On this footing, a small biotech company in the country has been providing bio-functionalized nonwovens for cartilage regeneration for more than ten years.

Joline GmbH & Co. KG, an SME from Baden-Württemberg, Germany turned to DITF with a call for help: "We lost a supplier – can you supply us with nonwovens as soon as possible?" As soon as possible in medical technology translates into successful sampling, followed by validation of all process steps, the preparation of the production documents, as well as a detailed risk analysis. The DITF institutes solved this task in record time within half a year. At the end of 2018, the order received authorization for production.



Cartilage cells in the nonwoven fabric

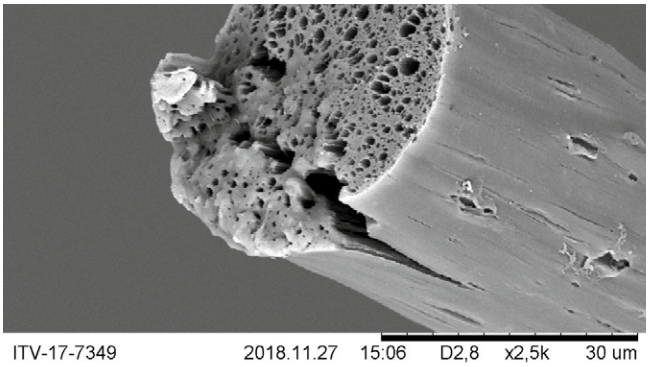
Digitized nonwovens

The DITF institutes produce fibers for implants certified to ISO 13485:2016. These are also processed into carded nonwoven scaffolds. Here, the intricate relationships from fiber production to nonwoven production to cell reaction cannot yet be derived entirely. That is why the state of Baden-Württemberg subsidizes the digitization of manufacturing process up to the analysis of cell reaction via the "alliance for innovation of Baden-Württemberg" (innBW).

Porous fibers for the release of therapeutic agents

Wound dressings and implants that release therapeutic agents can add significant value to the medical device by supporting and regulating wound healing as well as reducing side effects.

For example, the combined release of therapeutic agents is successfully used on coronary artery stents to decrease the risk of restenosis. The possible side effects of implants also include inflammatory reactions, which can be diminished by delivering anti-inflammatory drugs.



SEM image of the cross-section of a porous fiber for therapeutic agent release

Time defined targeted release of therapeutic agents drug delivery

Another application is the controlled release of growth factors from wound dressings; the objective of a recent development at the DITF institutes, which aims to support the healing of chronic wounds. The challenge lies in delivering the therapeutic agents directly from the wound dressing into the wound bed in a timely and targeted fashion. To that end, the DITF institutes participate in a publicly funded project (AiF 19523 BG) to develop porous polymer fibers, which release the therapeutic agent with a delay.

They are based on extruded fibers made from various polymers compounded with a water-soluble component. After washing out this component, the fibers exhibit interconnecting pores, which are filled with a carrier that contains the therapeutic agent using a negative pressure procedure. The substance carrier, a hydrogel based on a polysaccharide, conserves the agent's activity and, at the same time, serves as a diffusion matrix. The characteristic of releasing the substance depends on how the gel is crosslinked as well as the porosity of the fibers.

MOBILITY

The world of mobility is undergoing drastic changes. Textile innovations by the DITF assist in shaping this process; while always keeping an eye on the current requirements for comfort, functionality, energy, and the environment.

> Fiber-based composites for lightweight construction

> Carbon fibers from renewable resources

> Technologies for carbon fiber recycling

> High-quality semi-finished products made from recycled carbon fibers for structural applications in automotive engineering and aircraft construction

> Ceramic Matrix Composites (CMC) for turbines in aircraft engines

> Load-converting textiles

> Economical and environmentally sustainable materials for fuel cells

> Cellulose-based filter materials

> Functionally integrated lightweight construction

> Further development of airbags and protective textiles

> Smart interior textiles for interaction with users

> Energetic concepts

Mobility

Fiber-reinforced composites (FRP) are successfully applied in the most diverse areas of technology. Their advantages include superior structural robustness and rigidity combined with low weight, high resistance to corrosion, as well as outstanding fatigue strength. Apart from the expensive carbon fibers, which are mainly used in aircraft construction and the sports sector, the long-established inexpensive glass-fiber composites are still finding additional areas of application. The high cost of raw materials and production for carbon components act as an obstacle, the primary aim here is the so-called hybrid (mixed) construction employing steel, aluminum, magnesium, and FRP. The goal is to achieve optimal performance and costs.

An example is the roof rail of the new BMW 7 Series, which is manufactured by way of composites construction from woven CFRP (crash performance, weight) and steel (crash performance, connection of the spar to the car body). The use of new weaving, multiaxial and braiding techniques enables the production of highly integrated textile preforms that supersede the joining of individual fiber layers and exhibit superior crash characteristics as a turbine blade for instance.

Improved matrix systems

A wide variety of improved matrix systems are being developed and characterized alongside the advancement of highly integrated textile reinforcements. The goal is to design matrix systems that are safe to process and produce favorable mechanical properties. The project "Fast Matrix" developed a thermoplastic matrix, which polymerizes very quickly in situ displaying excellent wetting of the fibers.

ARENA2036

The DITF have been working closely with the OEM, computation companies and suppliers in the automotive sector for many years in the context of ARENA2036. The first four years of the joint project resulted in the development of a subfloor module equipped with battery box, which already integrates many additional functions in a single component, thus it is no longer necessary to add them in additional, expensive work steps.

The follow-up project strives for significant further improvements of the "digital fingerprint" and the "digital factory" in the area of design and calculation of fiber-reinforced plastics. A fiber-reinforced composite with specific strength and rigidity requires the construction and determination of the fiber orientation. Therefore, nowadays an FRP constructor must be able to design and calculate simultaneously. The team at ARENA2036 develops the necessary tools, databases, and programs, aiming for user-friendliness and the lowest level of complexity.

Exchange of results

Research results in the area of mobility can also be used in the field of construction – and vice versa. The DITF provides such transfer and cross-fertilization as part of the Collaborative Research Center Transregio TR141 "Construction and Bionics" by the German Research Foundation. As in mobility, the construction industry aims to reduce energy consumption in the production and operation of systems. Additionally, fiber-reinforced composites enable the creation of new delicate structures in forms that were hitherto impossible.

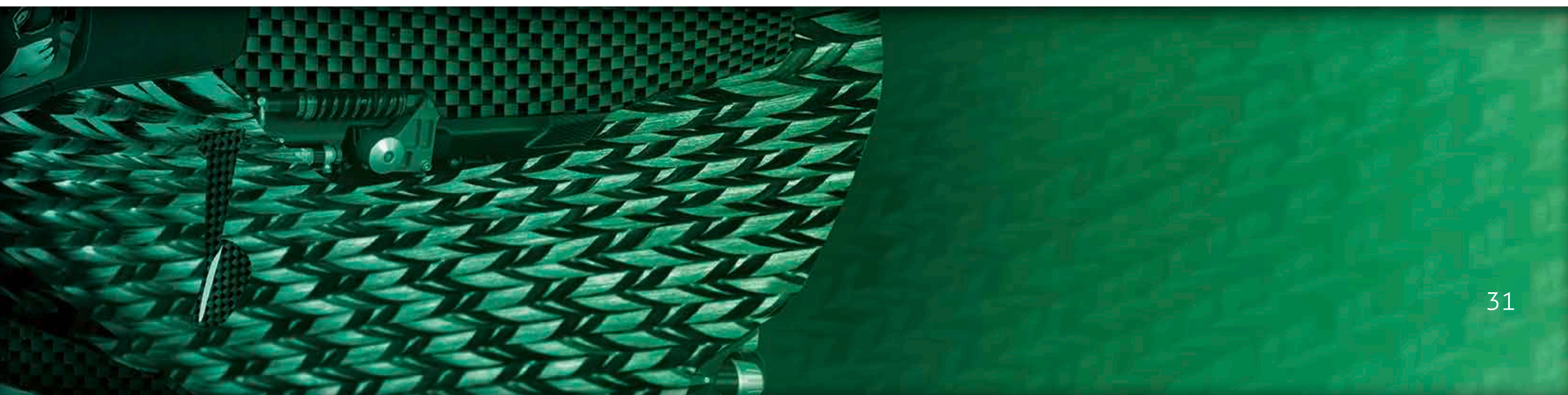
Primary objective: weight savings

The characteristics of carbon fibers include high stiffness and low strain. Various DITF projects push lightweight construction to extremes, instead of laying carbon fibers flat in the form of textiles, they lay them individually along the force lines. This approach reduces the weight by an additional 10 to 20%.

Recycling

Finally, residual fibers, textile clippings, pre-pregs, and end-of-life components require large-scale recycling. The DITF are right at the forefront of development owing to their creation of systems and products that have received global recognition. This proved to be highly popular in the recycling workshops organized by the DITF.

Exploiting the use of the favorable properties and outstanding environmental performance of fiber-reinforced composites further requires additional cross-cutting research and the participation of an interdisciplinary textile industry. The DITF are therefore closely involved with the Alliance for Fiber-Based Materials Baden-Württemberg (AFBW) as well as the Carbon Composites e.V. (CCeV) and thus unite the expertise of various faculties in workshops and conferences.



Cellulose composites as precursor for high-performance ceramics

Focusing on the sustainability of high-performance materials, the DITF have developed a new high-performance ceramic material based on the single-component material PURCELL, which consists of pure cellulose. This sustainable composite was then further developed as a precursor for the production of fiber-reinforced ceramics. The production of these ceramic composites was able to entirely dispense with the fiber treatment for good fiber-matrix adhesion and embedding resin as a matrix compared with the prior state-of-the-art carbon fiber-reinforced ceramics. Low-priced cellulose fibers replaced high-priced carbon fibers.

Compelling advantages

These new ceramic composites have excellent properties such as high specific strength, low thermal expansion, and high thermal shock resistance. It was possible to achieve mechanical properties within the range of commercial carbon-fiber-reinforced ceramics.

Another highlight of these ceramic composites is the simple and inexpensive production of different 3D structures, such as a Z-profile or a tube. The distinctive feature of the production of these 3D structures is that the single-component material is already incorporated into the desired 3D structure before ceramization and does not require alteration or repair during the manufacturing process until the ceramic composite is produced.

Fiber-reinforced ceramic composites made from pure cellulose composites in the shape of a Z-profile and tube

Mission support system for fire fighters to combat risks on seagoing vessels

Whenever a fire breaks out aboard a ship in port, the responsibility lies with the fire fighters on land. Emergency personnel generally do not have the relevant nautical training and are unfamiliar with the spatial or structural characteristics of ships. Entry from above, narrow rooms, along with pollution from unknown substances burning up further render the conditions more difficult. The DITF are working together with industrial partners to develop a mission support system that reduces the risk.

Land based fire fighters deployed during fires onboard ships in port

Development of a textile bus system

The institutes at the DITF are developing a textile bus system for this system, which provides the infrastructure for textile-integrated sensors while offering a comfortable fit.

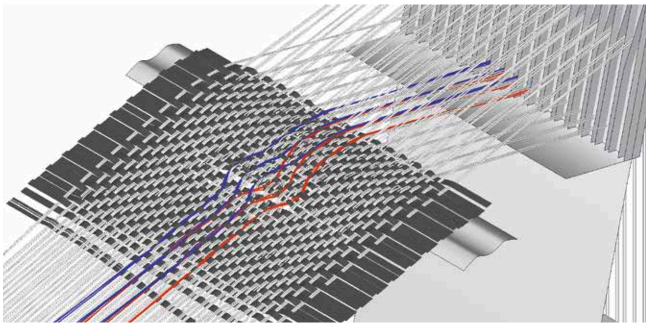
The bus system is fitted with internal temperature sensors for monitoring the body temperature, as well as pyrometry sensors for monitoring the ambient temperature via infrared detection and protected against any influence from the elements through silicone encapsulation. The sensor data are routed through the textile control system to a central communication unit and transmitted to mission control.

This information is the basis for optical signals that are communicated to the team member via a textile-integrated LED display, making it possible to warn personnel of imminent hazards. The insulating effect of modern firefighting suits presents risks both in terms of overheating as well as the incorrect assessment of environmental conditions since the emergency personnel lacks sensory information. The project development addresses both problems and thus increases operational safety.

ARENA2036 – project holistic digital prototype in lightweight design for large-scale production

The DITF and ARENA2036, the largest and leading research platform for mobility in Germany, have been partners since the beginning. The research program is rethinking and implementing the entire value-added chain of the fully digitalized vehicle of the future.

The objective of the project "DigitPro: Digital Prototype" within the framework of ARENA2036 was the development of a digital prototype based on a closed simulation process chain for integration in large-scale production. The virtual process chain is extended by computer-aided manufacturing (CAM) for the braiding and weaving, thereby increasing the predictive power of the simulation. A multi-scale approach advanced and validated the process-related and mechanical material analysis to enable optimized design in the future, from the fiber to the car component subjected to stress in a crash.



Weaving process simulation for process engineering and mechanical material analysis

Simulation of locally reinforced ORW textile

The production simulations of locally reinforced Open Reed Weaving (ORW) textiles formed a particular part of the task at the DITF, whereby a CAD/CAM interface was developed to gain insights from the process simulation for machine control. Numerous ORW hole reinforcement variants were produced as a practical demonstrator. Model verification was carried out with the help of high-resolution computed tomography established at the DITF. Semi-finished product models were developed to compute the mechanical properties and the draping properties of the material, which are now being used in the 5-year follow-up project of the Federal Ministry of Education and Research (Phase 2) "Digital Fingerprint". The DITF focus on the simulative consideration of textile-integrated or textile-based sensors along with their production.

ARENA2036 – project intelligent lightweight design with functional integration

As part of the joint project LeiFu (Intelligent lightweight design with functional integration), an integrated floor module is being developed by monitoring the production-technical aspects of the production processes. For this purpose, application-oriented fundamentals for the integration of single structural, thermal, sensory and electrical functions are being developed. The procedure for integrating various single functions into a highly integrated module is conceptually, constructively and methodically developed and tested using the example of a car floor module in fiber composite design. As one of the goals of this project, the DITF aim to produce the rear floor demonstrator using VARI (Vacuum Assisted Resin Infusion) technology.

Car floor module in fiber composite design

The rear floor consists of three separate functional parts – an upper housing, a lower housing, and a crossbeam. The upper housing consists of carbon fabric with metal inserts to enable the installation of the battery box and coolant connectors. The upper housing also holds the printed liquid sensor. The lower housing was produced from ORW textile. ORW technology enables the weaving of not only the main fibers but also the additional reinforcing fibers aligned with the flux of force, thus minimizing stress concentration within the component. The crossbeam has been laminated with carbon fabric and contains a foam core to improve NVH characteristics. The individual components were joined through adhesive technology.

Rear floor with integrated inserts, water supply and printed humidity sensor

ENERGY, ENVIRONMENT AND RESOURCE EFFICIENCY

The DITF institutes develop processes for improved energy, environmental and resource efficiency – with and for their industrial partners. The results are sustainable products and services for a variety of applications.

> Coatings made from renewable resources

> Polymer synthesis with biogenic polyethylene

> Solvent-free, energy-saving processes for coatings and textile finishes

> Minimal application technologies

> Heat recirculation and heat recovery in dryer systems

> Novel textile or textile-based heat exchangers for recovering heat energy from sewers

> Textile-based thermal solar collectors

> Energy generation through the use of technical textiles

> Economical and environmentally sustainable materials for fuel cells

> Textile materials for the extraction of drinking water from fog

> Irrigation systems based on capillary forces and suction power

> Filter materials for separating gases/solids/liquids

> Recycling technologies for high-performance fibers

Energy, environment and resource efficiency

Fibers have always been crucial components of nature. Especially in the plant kingdom, nature utilizes the properties of fibers to build a wide variety of structures and functions. Thus, it is not surprising that fiber-based materials hold many compelling and sustainable solutions for the requirements of energy efficiency and storage, resource efficiency, as well as environmental protection. Even though they are often invisible in the background and go unnoticed, fiber-based materials are indispensable to solving the problems in these fields of the future since they act as catalysts for increased efficiency, environmental protection, and reduced environmental impact.

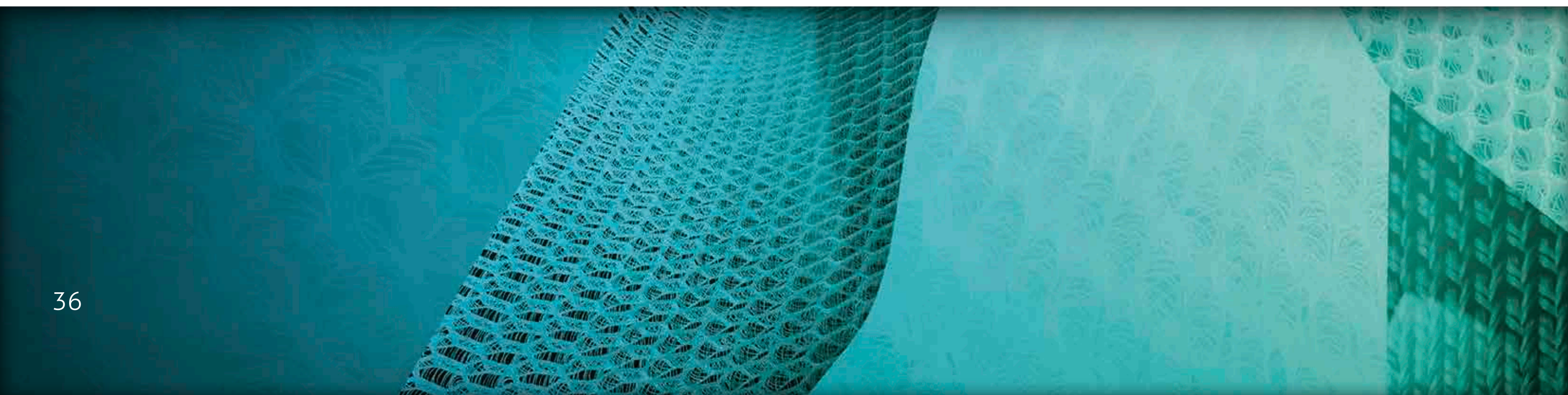
The development of processes for improved energy, environmental and resource efficiency – with and for their industrial partners – make the DITF essential research partners in this area. The results are sustainable products and services for a variety of applications. Filter and membrane materials for air and water purification, lightweight construction, insulators, sealants, as well as insulants for buildings and textile-based solar cells are just a few examples of the broad research portfolio at the DITF institutes. Current research topics focus mainly on material substitution, material efficiency, and recycling.

Renewable energy sources, energy systems

Technical textiles in Germany owe their success to the continuous development of new areas of application. Of particular interest in this context is the extraction of energy through the use of technical textiles, which is the subject of intensive research at the institutes in Denkendorf. Successes can be observed in solar thermal energy and thermal energy storage as well as in combinations thereof. Further developments include the recovery of heat energy from wastewater through novel heat exchangers, along with resource-saving and economical novel materials for fuel cells, as well as new electrical energy storage systems. Another significant contribution of fiber-reinforced composites is in the development of wind turbine blades.

Textiles for environmental protection

In the meantime, technical textiles significantly contribute to the mastering of environmental protection-related tasks in many industries. Accordingly, our research efforts include new filter systems, such as filters to extract particulates and pollen from the air, as well as isolate aerosols in cold and hot flue gas streams. We also develop textile supporting materials for biological organisms in vertical greenery, sewage treatment plants, and algae production. Currently, we are working on new irrigation and water storage systems for greenhouses and sports turf to improve plant growth. The advancement of acoustic absorption in the home and mobile sector continues to be a research topic.



The application of membranes in the wastewater treatment of the textile industry, as well as other manufacturing companies, has been a focus for years.

Sustainable fibers and composites

The sustainability of textile products is a central issue in our society. Given the discussion on microplastics in surface waters and oceans, our research on natural fibers and polymers from renewable resources, which are also readily biodegradable or recyclable, is of vital importance for the future. Such research entails working with the latest technology to process high-performance natural fibers into yarn, as well as new filter materials and composites made of cellulose and chitosan.

The production of cellulose composites creates lightweight, stable, aesthetic products that can be recycled or processed bioenergetically and lead to an overall reduced carbon footprint.

Self-healing materials that regain their properties after damage constitute a relatively new branch of bionic developments. Initial approaches employing particular filled hollow glass fibers in composites have yielded promising results.

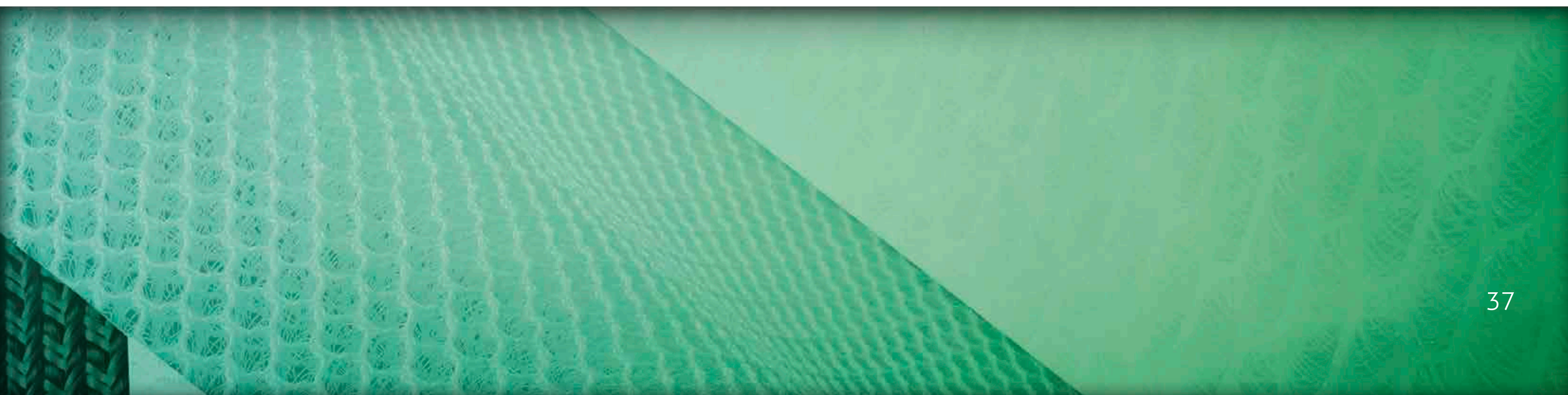
Often, these developments are accompanied by a lifecycle analysis to quantify both the consumption of our natural resources as well as the impact on the environment.

Energy consumption in textile manufacturing

Textile finishing and coating constitute the most energy-intensive process in textile manufacturing. Thus, there is a need to review new technologies for their energy-saving potential. Such review includes the commissioning of cross-linking systems of solids without solvents and reactive hot melts as well as minimal application technologies such as foam application methods.

Additionally, we are exploring the further development of dryer systems with more efficient heat-material transitions, heat recirculation, and heat recovery, as well as smart process control systems. New ways of interconnecting equipment and coatings result in energy savings and superior characteristics. These include curing through the use of electron-beam technology and ultraviolet light based on LED.

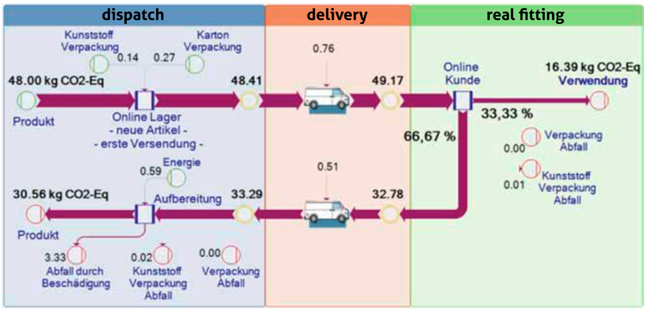
We achieved notable success with atmospheric- and low-pressure plasmas, which find increasing application in textile manufacturing.



Digitization as a way out of the returns trap

Those who enjoy online shopping often order several sizes or items to choose from – returns guaranteed. The transport to and from the customer, as well as the processing or even the destruction of the goods, are detrimental to the environment.

The DITF are partnering with Avalution GmbH and Assyst GmbH to develop a solution that no longer requires customers to order different sizes for trying on as part of the research project ECOmmerce by the German Federal Environmental Foundation (DBU). Instead, customers experience a virtual fitting of the clothing during the online ordering process, which generates a customer-specific recommendation for the right size.



Carbon footprint model of a return process

Distinct environmental benefits

Reducing the number of returns required by today's ordering process alone carries a significant environmental benefit. The assessment of these environmental impacts focuses on carbon footprint and water demand using the MFCA (material flow cost accounting) method and makes these transparent to customers in the ordering process.

The use of additional energy for the transport and the raw materials for the returned goods is considerable since these must be partially cleaned and repackaged or even destroyed immediately due to damage. Each order of three sizes of the same item results in about 30% additional CO_2 emissions (referring to the retained article).

The aim is to make customers aware of their order behavior since each additional return loop has a significant environmental footprint.

Low-pressure stabilization furnace for carbon fiber production

The exorbitant cost of carbon fibers prevents widespread use in many price-sensitive markets, especially among automotive manufacturers and the electromobility sector. Novel approaches are needed to meet the required prices for carbon fiber. No breakthroughs in cost reduction are currently expected for the precursor polyacrylonitrile; thus the particularly energy-intensive oxidation of the fiber is the best target for cost reduction in the manufacturing process of carbon fibers. The project Vakustab, which is funded by the Ministry of Economics, Labor and Housing Baden-Württemberg, is implemented in cooperation with the company Centrotherm International AG, Blaubeuren and aims to build a novel low-pressure stabilization furnace, which reduces the energy and material flow of such furnaces significantly. The furnace is being set up and optimized at the HPFC-fiber pilot plant of the DITF.

Numerous advantages over conventional processes

Use of a partial vacuum as a stabilizing atmosphere reduces the stabilization time of the precursors by 30% and, at the same time, requires up to 50% less energy than the conventional approach. The oven requires very little space and can be adjusted to an industrial scale easily. The resulting carbon fibers are much more homogeneous and reach the mechanical properties of carbon fibers from the conventional stabilization process already at atmospheric pressure. This approach improves process control without temperature jumps. Another advantage is the highly efficient production of carbon fibers from lignocellulose, which benefits from this new process considerably.

Novel low-pressure stabilization furnace at the DITF

Moss wall – A textile solution to reduce fine particulate matter

Supported by: ZIM Zentrales Innovationsprogramm Mittelstand; Federal Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag

Modular moss walls aim to make a targeted and sustainable contribution to reducing air pollution in cities affected by high levels of fine particulate matter: Ed. Züblin AG, Helix Pflanzen GmbH and the DITF have joined forces in the MoosTex research project as a step towards the implementation of this innovative idea. Ten modular moss walls have been subjected to intensive testing under different environmental conditions and sky orientations at four different locations in the Stuttgart region since November 2017.

Mosses help to reduce atmospheric particulate matter as they absorb water and nutrients from the atmosphere mainly through their leaves. The surface structure of moss plants is specially adapted to the absorption of particulate matter and up to 30 times larger than in vascular plants. Apart from these positive qualities, mosses also open up new creative possibilities for urban space.

Module of the moss wall on site at the DITF

Intelligent textile irrigation system

Moss walls require an actively regulated, textile-based irrigation system adapted explicitly to the moss to reduce fine particulate matter at the hotspots in a targeted manner. Textile properties are utilized for this purpose that enable a successful plant existence through a targeted construction and adequate use of material. In the hot and dry summer months of 2018, targeted active irrigation was used successfully to keep the moss panels of the test walls biologically active, even stimulating significant growth.

Insect chitosan for textile processing chemicals from European sources

The DITF have been working on the use of chitosan for textile production for several years. The excellent film-forming properties, high abrasion resistance and good adhesion to fibers make the product particularly attractive as a sizing agent in the textile industry.

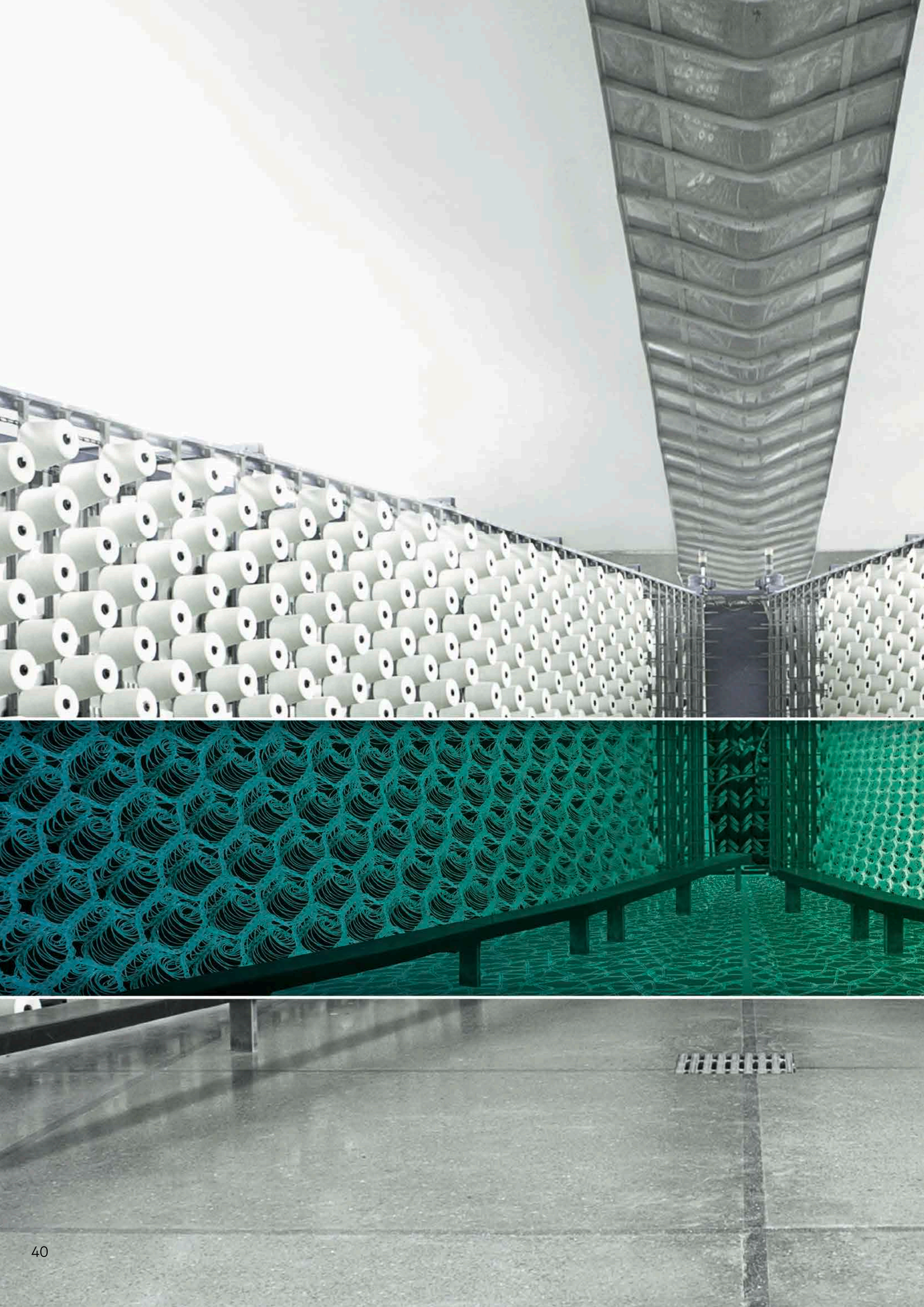
Effective raw material source for chitin: cocoons of fly larvae

Chitin is extracted in Asia, after sourcing and processing it from shells, chiefly from marine animals, through the removal of the proteins and decalcification. The chitin is converted into chitosan via chemical deacetylation using alkaline solutions.

The collaborative European research project "ChitoTex", funded by the Federal Ministry of Education and Research, aimed to develop insect chitin as a new and sustainable source of chitin for use as a functional surface coating. The project was carried out in cooperation with seven partners (DITF Denkendorf, Eucodis Bioscience, Fraunhofer IGB (Project Coordination), Lauffenmühle GmbH & Co. KG, Norwegian University of Life Sciences NMBU, Protix Biosystems, Textilchemie Dr. Petry).

The project successfully isolated the insect chitin from the cocoons of fly larvae. Chitin is produced in large quantities as waste for use as animal feed. The project thus developed a new and sustainable European source of raw materials for chitin delivering a constant quality, which can be used in various industrial applications. Environmentally friendly enzymes were tested to replace alkaline solutions for the deacetylation.

The results observed at the DITF technical center and by a textile manufacturer demonstrate that insect-based chitosans are a suitable replacement for synthetic sizing agents. It is even possible to employ methods that only use chitosan for warps and wefts.



PRODUCTION TECHNOLOGIES

The increase of innovative processes to ensure international competitiveness – new and improved technologies for the entire textile value chain.

- Smart process control systems
- Digital technologies for Industrie 4.0
- Functionalization of textiles with the help of robots
- Systems to bridge human-machine interaction
- Modeling and simulation technologies for textile industry processes
- Pneumatic textiles for factory automation
- Sensors and actuators printed on textile
- Efficient heat transfers in dryer systems

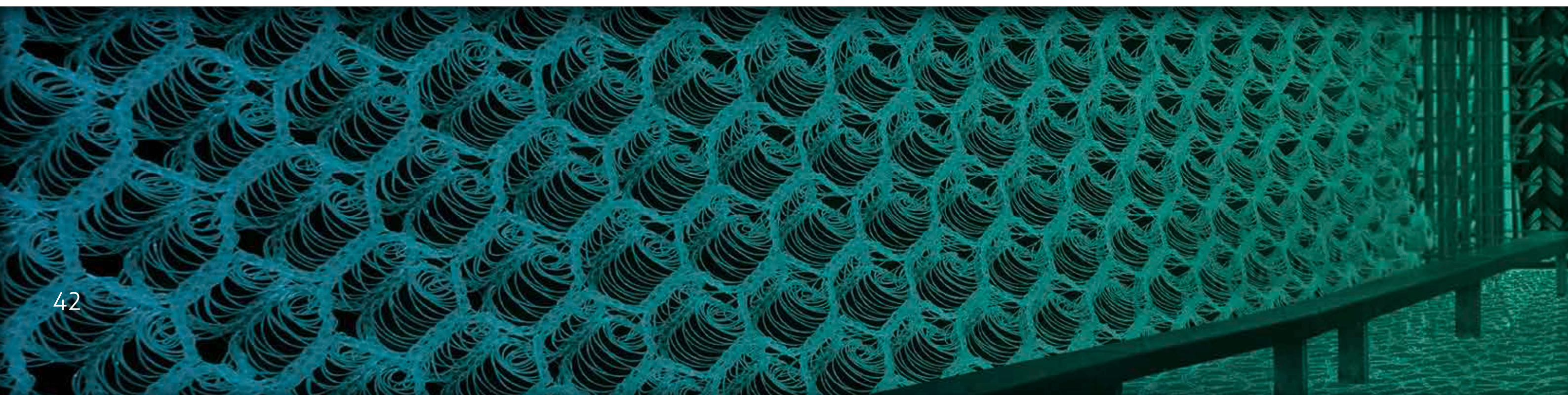
Production technologies

"Modern production technologies are essential for the industry. They are the driver for a 'smart production' and therefore a core factor for the competitiveness of industrial production". Thus describes the German Federal Ministry for Economic Affairs and Energy the importance of production technologies. German textile machine engineering, as well as the textile industry as a whole, have recognized the competition with Asia early on. Together, the industry has developed new process technologies for existing but also new applications, which, in turn, have increased competitiveness. Their success proves them right. Nowadays, textile machine engineering is a high-tech industry. Worldwide, every fourth textile machine comes from Germany. The German textile industry is highly specialized and leads Europe in the advancement of technical textiles. For nearly a century, the DITF institutes have been the leading partner of textile machine engineering as well as of the textile industry and have become the largest textile research center in Europe. Roughly a third of DITF research projects encompass production technologies, which make up the most substantial portion of applied research.

All stages of the textile value chain

Developing new process technologies in isolation is impossible. The development of yarn always comes with questions like how it behaves in its processed state, during finishing, or as the final product. The yarn will only prevail in the market by offering a different final product.

The DITF perform research at all stages of the value chain. They utilize the know-how of experienced specialists for individual processes; this results in the best possible solution for the customer. The foreground is always the holistic approach to research and development: all aspects, for example, technical, textile technological, and economic are considered. It is why the DITF experts come from different disciplines, such as textile technology, machine engineering, process technology, chemistry, physics, biology, cybernetics, computer science, and economics.



In keeping pace with industry-related processes

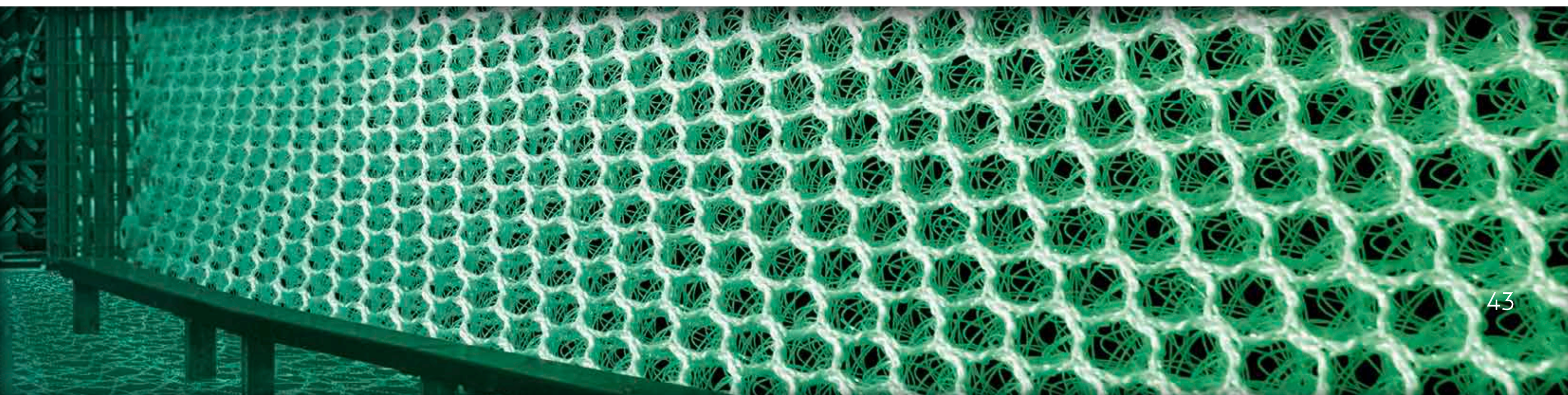
Applied research and development are only possible for processes that are close to the industry. The DITF have a research and production space of around 25,000 m^2, which permits a swift response to new production technologies and customer needs. We were able to equip industry machines with technology that has allowed us to conduct applied research and development in the areas of lightweight construction, complex 3D structures, digitizing, or the recycling of high-performance fibers. We can also cater for pilot or small productions. We develop and build prototypes in-house. We also support partners in the area of electronics and control. A state-of-the-art workshop and electronics laboratory serve specialized technicians to implement new ideas into testing and production procedures of the textile industry.

What will the future bring?

Broad research in the areas of process technology allows the early identification and promotion of trends and challenges.

Textile machines of the future are multifunctional, easy to operate, and connected. The flexibility of machines becomes more critical to increase production. Machines with flexible batch sizes require flexible approaches that can be adjusted swiftly and therefore permit a more significant application. For this, machine concepts based on individual drives are required. Modern machine parts are multifunctional, light, exchangeable, and reduce costs of production and maintenance. Sensors monitor the quality online and can intervene as well as correct if necessary. Smaller batch sizes will also lead to automation since personnel is unable to deal with the increased logistical complexity.

Industrie 4.0 has arrived in the textile economy. Each step within the process chain will be automated. Tailor-made mechatronic settings and automatic systems facilitate the process monitoring and control, which, in turn, improves manufacturing quality and reduces costs. It is beneficial for technical textiles, in particular, since production batches tend to be smaller and processes shorter. Technical textiles will continue to gain in significance and increase their market share.



Resource-efficient production of knitwear for clothing

By combining the spinning and knitting process in a single machine, the Spinit process represents a highly resource-efficient process for the production of knitwear. In this process, a twin-jet spinning unit and the corresponding yarn guide draw the fiber leaving the drafting system into a fine fiber bundle before its incorporation into the knitted fabric.

A recent project achieved a reduction in air consumption and thus energy savings of 20 %. For this purpose, flow simulation was used to examine the nozzle geometry, as well as the necessary yarn guides and other experiments were performed on a test stand and the Spinit machine.

Spinit 3.0 E machine from Mayer & Cie

The flow simulation determined that reducing the diameter of the thru-hole and the jet-hole surface yields the highest energy savings. The examinations highlighted that the first twist impulse applied to the fiber bundle is decisive for the running behavior and the final fabric quality. The jet-hole angle is a decisive factor in addition to the thru-hole diameter and the jet-hole surface. This requires a trade-off to be made between the twist effect concerning the fiber end and the transportation effect of the fibers.

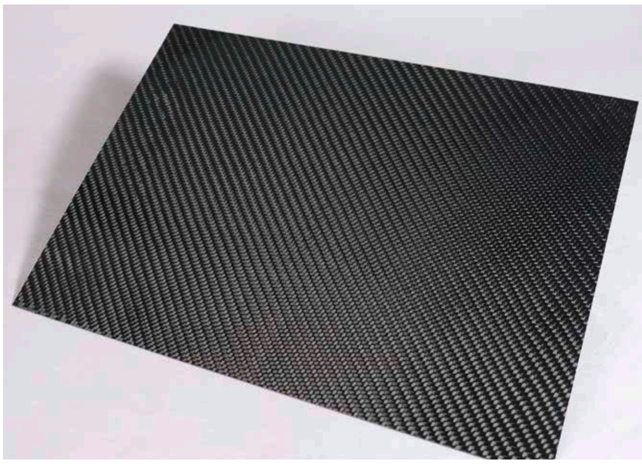
Modifications of the yarn guides were also able to demonstrate means, which would result in the improvement of the fiber grain in the direction of the knitting system and thus savings in raw materials.

The project was funded by the German Federal Environmental Foundation DBU (File number: 34028/01).

Fast epoxy systems – latent epoxy systems for more process safety

In recent years, continuous fiber-reinforced high-performance composites have increasingly found their way into industrial mass production. The decisive factor for further automation is, in particular, the technical reproducibility of the component taking into account high-quality requirements and short cycle times.

As part of a joint project between ITCF and ITV, existing quick-setting one-component (1-C) epoxies were optimized and adapted to modern processing methods. In contrast to two-component (2-C) epoxies already established as industrial processes, the use of one-component epoxies promises greater reliability concerning the reproducibility of material properties along with process technology that is easier to control. Thermosetting epoxies mixed with a latent catalyst can be stored and processed as 1-C latent epoxies. The actual curing occurs only after the heating of the epoxy through specified activation energy. It differs from the classical approach in that the fiber fabric is first infiltrated and then the polymerization is initiated through heat supply. The process parameters of the polymerization time are tailored to the manufacturing process.

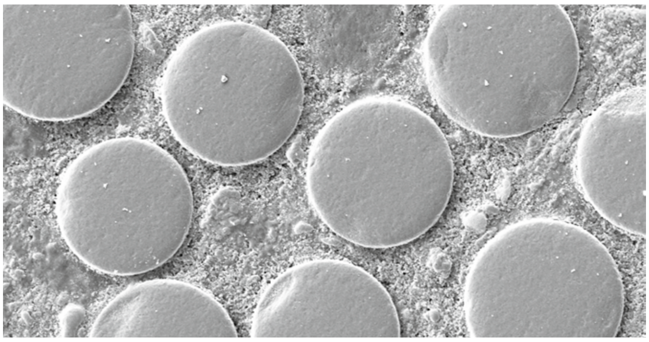


Four-layered carbon fiber-reinforced epoxy composite

The constant viscosity of the matrix system allows complete infiltration of the fiber and prevents undesired air bubbles. The project created glass fiber as well as carbon-fiber-reinforced composites with the help of Vacuum Assisted Procedures (VAP), hot pressing, and pultrusion. The resulting composite properties were assessed via a three-point flexural test, a tensile test, and the determination of interlaminar shearing properties.

Successful Manufacturing of ceramic fiber fabrics for ceramic composites

Oxide ceramic fibers are the most essential part of Ceramic Matrix Composites (CMC). The integration of fibers into a ceramic matrix creates construction materials with unique properties. Apart from the well-known temperature and corrosive resistance properties, these construction materials are also resilient against damage and do not become brittle. These characteristics open up new applications within high-temperature technology. Possible applications include aerospace (e.g., high-temperature lightweight construction in planes), energy technology (e.g., gas turbine parts), and furnace technology (e.g., burner nozzles, batch carriers, and oven linings).



Microsection of Oxide Ceramic Fibers (OxCeFi) in a Ceramic Matrix Composite (CMC)

Demanding production of CMC

Several fabric layers made from ceramic fibers, infiltrated by a ceramic slurry, can be used to manufacture CMC, which can then be formed, consolidated, and fired. Nevertheless, manufacturing woven fabrics from ceramic fibers is challenging since the fibers are susceptible to shearing. On the one hand, ceramic fiber rovings – made up of approximately 500 individual filaments, each with a diameter of 10 µm – are permitted to show little broken threads, on the other hand, the roving effect must be sized to make interweaving possible.

With the help of a specific weaving technique, we managed, in close collaboration with the institutes in Denkendorf, to process the OxCeFi fibers (corundum and mullite) into a ceramic fiber that serves as CMC preforms. Jacquard technology makes it straightforward to create fabrics by using various bonding types.

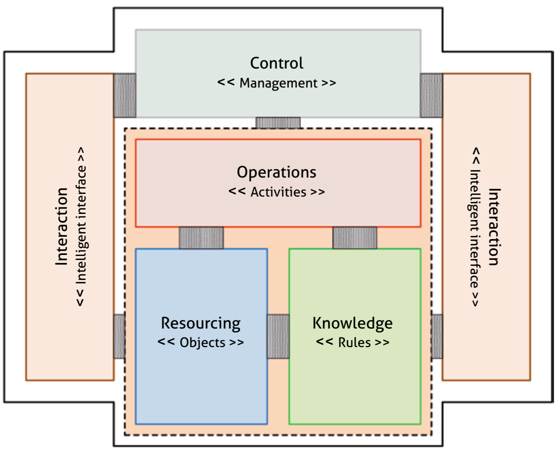
Initial strength tests on composites made from these materials confirmed the quality of the fibers and fabrics.

Digital twins and continuous digital engineering

Digitization makes continuous digital engineering with fully networked and integrated development as well as production chains possible. Digital engineering helps to reduce costs for materials and development times, permits swift and flexible reactions to market changes as well as trends. For this purpose, each product, activity, and machine requires a digital twin. A digital twin is a computer-assisted model of a tangible or virtual object that connects the physical with the digital world. Digital twins, just like their physical counterparts, must be considered in relation to each other. To that end, a graphical description language was developed as part of the research project futureTEX "Modeling of the future textile factory" by the Federal Ministry of Education and Research. It supports hierarchical structures, as well as the networking of independent units. The description language makes it possible to depict the horizontal integration at all stages of the value-added chain, as well as the vertical integration of production and planning systems. As a result, it becomes possible to design of continuous digital engineering processes.

Modeling the textile factory of the future

The basis for hierarchical and autonomous structures are models for digital representation, as well as relevant knowledge models designed to represent functions and resources. These are supplemented by additional models for interactions and adjustments to the environment. This type of modeling permits the implementation of continuous digital engineering in a company or entire networks and, therefore, creating the textile factory creation of the future.



Foundation for describing continuous digital engineering

CLOTHING AND HOME TEXTILES

New and further development of textiles and processes. For more comfort, aesthetics, and functionality.

- > New fibers and technologies to improve mechanical, haptic, optical, or acoustic properties
- > Bio-based fibers, additives, and (fluorine-free) finishing procedures
- > Thermal radiation selective textiles
- > Infrared reflective textiles
- > Finishes for UV protection and improved fastness
- > Compressive sports textiles
- > Vasomotor adaptive functional underwear
- > Energy-efficient functional textiles
- > Personal protective equipment (flame or vector protection)
- > Coated textiles, membranes, and laminates for comfort and security
- > Textiles for art and light applications
- > Sensor and actuator textiles through integration or printing on the respective circuitry, as well as fluorescent or electroluminescent colors and pigments
- > Digital coloring and functionalization of textile procedures
- > Textile lettering procedures for traceability and prevention of counterfeiting
- > Virtual product development and retailer feedback processes within the clothing industry

Clothing and home textiles

Continuous digital engineering and micro-factories

Digital technologies change the competitive environment and offer new chances to companies working in the apparel and household textiles industry. The DITF institutes have several laboratory and demonstration environments to show firsthand what digitization makes possible. The DITF showcase also presents "Digital engineering" at the Mittelstand 4.0-Kompetenzzentrum "*Textil vernetzt*", (competence center for mid-sized companies, "networked textiles"). It is a digital process chain in the area of clothing and home textiles. Continuous digital engineering from design to the final product is a milestone in digital transformation not only from a technical perspective. Fully integrated, automated digital process chains make even entirely new business models exciting and lucrative. They save material costs, development times and permit a swift but also flexible reaction to changes in the markets. It does not matter if they are micro-factories for regional or urban production of small batches or custom and unique individualized items – all of them address current market trends. Micro-factories also have substantial ecological advantages compared to conventional processes. The DITF institutes can incorporate the newest technology for digitally networked development and production processes into customized enterprise solutions.

Big Data, Smart Data, and Artificial Intelligence (AI)

With a focus on the customers, it becomes increasingly vital to integrate their needs systematically at all stages of the production chain. The basis for this requires comprehensive data analyses, which turn the vast amounts of data, collected at the various stages of the production chain, into meaningful information. Smart Data – decision-relevant knowledge derived from the analysis and interpretation of vast amounts of data – combined with interactive and virtual product design environments, fitting of apparel, as well as the simulation of materials, wearer comfort, and lifestyle has the potential to make product development highly flexible but also to address market requirements concisely and efficiently.

Together with European partners, we work on new technologies for systematic customer integration at all stages of the supply chain. To make this happen, sales data but also customer needs and preferences can be used to generate data-based services. Big Data and AI provide new approaches in that respect as well.

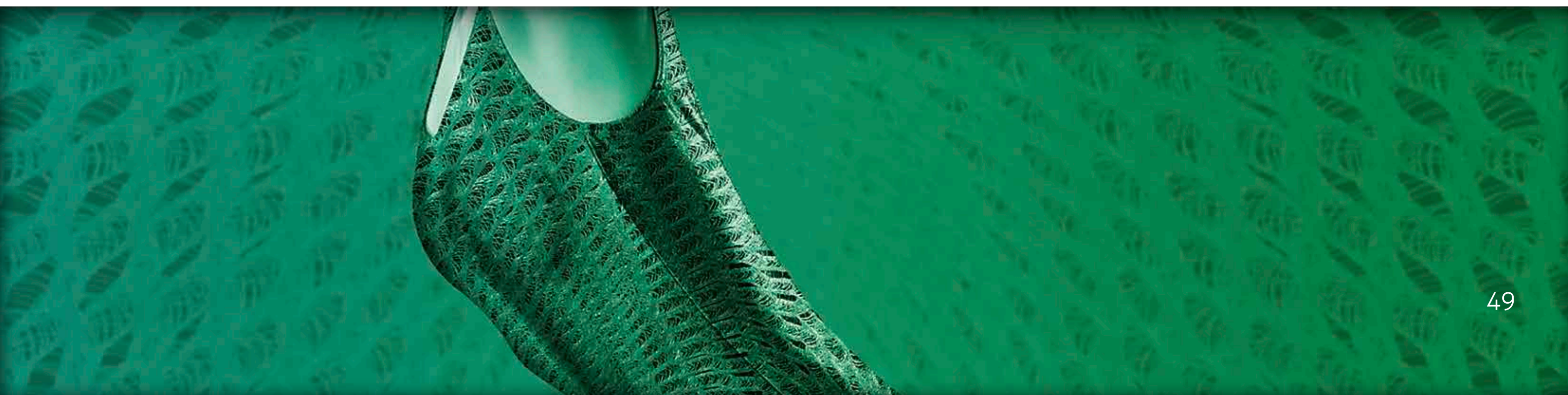
Interactive systems from production to trade

Production assistance systems can support employees with aggregated information and provide even more flexibility as well as robustness during processes while also contributing to individual and organizational learning. We also work with AI supported systems that permit the connection of information from machines and process data with staff knowledge and experience. Augmented Reality and Virtual Reality applications can help with implementation. These technologies, developed and tested during various projects at the DITF, offer new opportunities for information and interaction in the areas of production, job-related learning, or when used by the customers.

Sustainability and competitiveness

All environmental, economic, and social aspects of sustainability are gaining importance. Our expertise makes us part of the European initiative to create a broad network of companies in the textile industry with laboratories for innovation, service providers, and business consultancies. We want to provide alternatives to excess production and depreciation to regain production capacities in Europe, but also to bolster its competitiveness, and significantly decrease the ecological footprint of products. New value creation concepts like micro-factories appeal to the entire spectrum of the various dimensions of sustainability. In this context, the DITF institutes present works covering topics on traditional sustainability such as energy and resource efficiency. At the same time, we research materials made from renewables, the processing of high-performance natural fibers into threads, as well as the creation of cellulosic composites for practical applications. We study and analyze established as well as new materials, products, and processes in terms of sustainability based on a life cycle analysis but also the material flow cost calculation including diverse aspects of resource consumption and their costs.

First-class, technologically innovative, and sustainable products require the use of combined technology, innovative materials, and new processes, as well as appropriately qualified employees. Our expertise supports businesses in their area of specialization with needs-based, creative, and company-specific solutions at various levels of the entire value-added process, from creating the molecule to bringing a product to market.



Artificial intelligence in production

Production data are increasingly important within the context of Industry 4.0, particularly in terms of predictive quality and predictive maintenance. The ideal setup of machines is also a task that becomes increasingly more essential in times of flexible production and smaller batch sizes. The DITF are researching these connections with the help of machine learning and artificial intelligence in the framework of the AiF research project "WiMaH" – the development of a scientific method to determine case specific knitting machine settings, Industrial Collective Research No. 18844 N.

Practical examples

One company had its yarns, which they use for the production of sweaters, tested upfront in the laboratory. The yarn data was then analyzed along with the properties of the knitted fabric. This generated new insights, for example, about the connection between the yarn color, its mechanical properties, and the dimensions of the knitted fabric.

Another company records human experience and expertise in a case-based reasoning system. When receiving a request for a new article, the system searches the case database – the digital organizational memory – for similar articles produced in the past, taking into account similarity measures concerning material and bonding. This way, customer requests regarding new developments can be answered swiftly and efficiently. Calculations and process settings will be shared reliably from history.

	CO	Viscose	Poly-amide	Poly-ester	WW	Other synthetic fiber	Other natural fiber	Support material
CO	1	0.95	0.1	0.1	0.5	0.1	0.1	0.1
Viscose	0.95	1	0.1	0.1	0.5	0.1	0.1	0.1
Polyamide	0.1	0.1	1	0.6	0.5	0.1	0.1	0.1
Polyester	0.1	0.1	0.6	1	0.5	0.1	0.1	0.1
WW	0.5	0.5	0.5	0.5	1	0.1	0.1	0.1
Other synthetic fiber	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other natural fiber	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Support material	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Query of specific similarity functions of the materials used

Flame retardant polyamides – technological advantages through intrinsic flame retardancy in textile and plastics engineering

More stringent fire safety regulations drive the demand for flame retardant textiles, for example, for carpets, upholstered furniture, household textiles, but also in the areas of personal protective equipment (PPE), as well as technical textiles.

Novel flame-retardant polyamides where tested for their suitability in textile applications and plastics engineering as part of an ongoing research project in collaboration with the institute for plastics engineering (Institut für Kunststofftechnik, IKT) at the University of Stuttgart.

Horizontal fire test on a flammable fabric

In the textile sector, the majority of polyamide fibers are modified to become flame retardant through subsequent textile finishing. This type of retrospective textile finishing makes it challenging to combine effective flame retardancy with durability. Friction over time or washed out additives cause a reduction in flame resistance, which lessens quality and lifespan.

That is why, as part of the project, the flame retardant component was covalently integrated into the synthesis of the polymer chain of the polyamide 6. It was possible to spin the polymer analog to the unmodified polyamide 6, which permitted the creation of fibers with comparable textile mechanical properties. Textiles made from these polymers were self-extinguishing and showed excellent fire behavior – Limited Oxygen Index (LOI 35), V-0 following UL-94. The fire retardant fibers performed similarly to standard polyamide concerning skin tolerability, dyeability, and abrasion resistance. Wash tests showed an outstanding flame retardant durability.

Innovations in the manufacturing of ready-made clothing

In the past years, the development of superfine fiber, yarn, and mesh structures has brought substantial progress for the textile industry. This progress has led to garments becoming increasingly skin-tolerant but also well fitting, even for demanding body shapes. Delicate mesh structures do not go well with conventional stitched seams since they are too voluminous and stiff. Furthermore, cutting techniques based on craftsmanship are obsolete. That way, tension lines can arise that might lead to strain on the skin. The amount of effort extended on technical finishing is also problematic. For example, when producing the waistband and leg openings for panties, it makes up between 20 % and 40 % of the fabricating costs. There is an urgent requirement to further the development of manufacturing and finishing technologies in garment production.

Clothing without seems, runproof, and minimized load towards the borders

Seamless and runproof

Novel garment types that are seam free, runproof and show minimized load towards the borders were developed in a new research project by the ZIM (ZF-4060035CJ7). It developed specific mesh constructions and material compositions that, based on their bending as well as elastic properties, can become runproof as well as stretch-resistant, which enables the seam-free processing of the materials. Furthermore, an optimized, form-fitting cutting geometry was developed for the designed machines to ensure a harmonious force and stress curve as well as avoid stress to the skin caused by leading edges.

Wearable and innovative nonwovens

The DITF have developed the finest melt blown nonwovens for new wearable applications as part of public projects (The Federal Ministry for Economic Affairs and Energy, Industrial Collective Research 17563 and The Federal Ministry for Economic Affairs and Energy, Industrial Collective Research 19034 N) as well as industrial research.

Nonwovens for rain protection

The DITF have developed the melt blowing process for microfibers that are smaller than 1 µm. That way, melt blown nonwovens are promising as semi-permeable membranes for protective applications. One goal is to replace materials based on fluorine. Mangled polypropylene fabrics, with fibers that are approximately 0.6 µm, were also treated with fluorine-free polymer waxes. Tests showed convincing protection against rain and wind while retaining breathability.

Nonwovens for fashion: soft, elastic, and body-hugging

The MAS Intimates Ltd., Sri Lanka commissioned the DITF to develop an elastic polyurethane-based nonwoven. Suitable polyurethanes were processed into lightweight nonwovens by using melt blowing technology. All requirements like washing, draping, and drying properties, as well as fastness to color and light, were fulfilled. A specific treatment achieved a silky smooth fabric handle.

The DITF also supported the MAS in finding a manufacturer in Europe. New applications for outdoor clothing were developed and sold in the United States.

Fashionable apparel made from nonwoven based on polyurethane – LEVEZA by MAS

DITF BODIES

The DITF – founded in 1921 – are a non-profit research institution in the legal form of a foundation under public law. They fall under the jurisdiction of the Baden-Württemberg Ministry of Economics, Labor and Housing.

The supervisory body of DITF is the Board of Trustees. It advises the Management Board on questions of professional and structural orientation and includes representatives from science and business administration and representatives from the ministries of Economics, Labor and Housing as well as Science, Research and Art of the state of Baden-Württemberg. The scientific advisory committees of the research institutes provide topic-specific advice directly to the specific fields.

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Since its founding in 1961, the Association of the Sponsors of the German Textile and Fiber Research Institutes has supported business-related research and development at the DITF. Currently, 36 members from industry and textile industry associations are involved in the association. The development of new technologies is supported and innovative preliminary research is financed through their membership fees and donations.

In the last few years, funding went mainly to individual projects, such as the expansion of the textile laboratory, investment in a vacuum hot press, a 3D flat knitting machine and in equipment and test equipment for the development of high-performance fibers. These investments in the infrastructure of the DITF directly benefit business, especially SMEs.

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Join us!

Promote application-oriented research and development at the DITF and co-design the textile future!

Contact: Peter Steiger, peter.steiger@ditf.de

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