# Textile Structures with Active Ingredients

**Drug Delivery Systems.** Textile-based structures have been successfully used in medical applications for decades. The enhancement of these structures to include an active ingredient release function offers the possibility of improved treatment methods and new products.

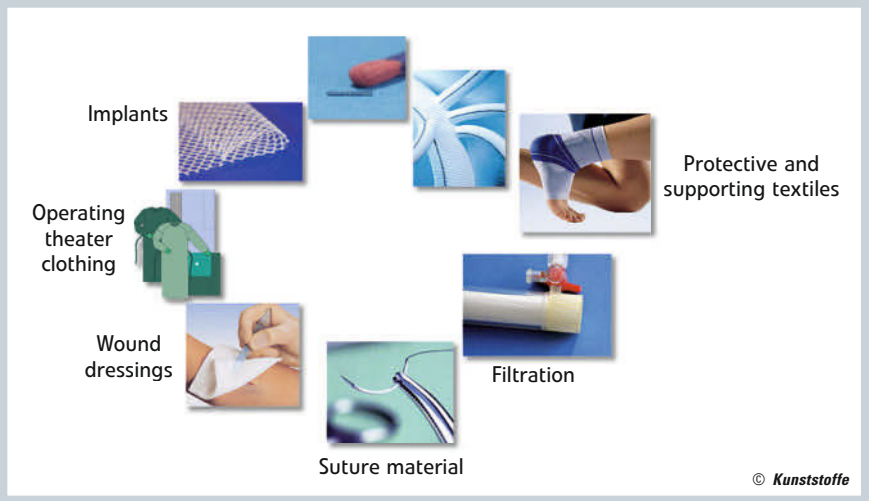


**Fig. 1. Examples of textile structures in medical applications** (source: ITA)

**PHILIPP SCHUSTER**
**STEFAN JOCKENHÖVEL**

Textile structures have been used with great success in medical technology for decades. Together with the development of new polymer materials and the advances in the field of textile production methods, textile structures also offer great potential for the future for the development of innovative treatment methods.

The advantages of textile structures derive i. a. from the possibility of producing two and three-dimensional structures, their good drapability, the possibilities of setting the mechanical and morphological properties at the micro and macro level, the very large specific surface area and the possibility of combining different materials in a variety of ways. Examples of the successful use of textile structures in medical technology are surgical suture materials, woven structures as wound dressings, microporous hollow fibers in oxygenators and dialysis filters, knitted hernia mesh implants, tubular vascular structures and braided stents **(Fig. 1)**.

A further field of application, in which the advantages of textile structures can be used, are active ingredient release systems, or "drug delivery systems", which enable the release of drugs over a prolonged period. Thanks to the local release of the active ingredient and the improved release kinetics, the use of drug delivery systems allows the dosing of the active ingredient to be significantly reduced compared with conventional, systemic medication. For the patient this has the advantage of reducing undesirable side-effects and of eliminating the risk of over-dosing.

## Drug-Releasing Fibers

The production of a fiber-based, drug-releasing implant starts with the production of fibers. Two different fiber production methods are essentially available here. During the melt spinning process, the polymer is melted to form the fibers. Although the process is superior to other fiber production methods from an economic point of view, it has one crucial disadvantage with respect to the incorporation of medical active ingredients. Due to the principle of the process, the temperature during melt spinning is always above the melting point of the polymer to be processed. The melting points of polymers typically lies in the range be- →

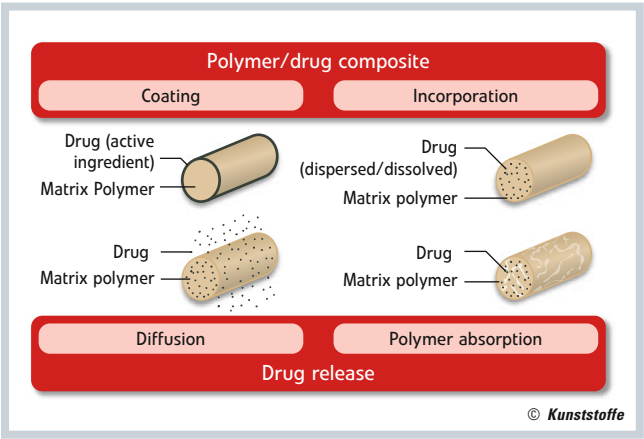


**Fig. 2. Possibilities of loading fibers with drugs and principles for the release of the active ingredients** (source: ITA)

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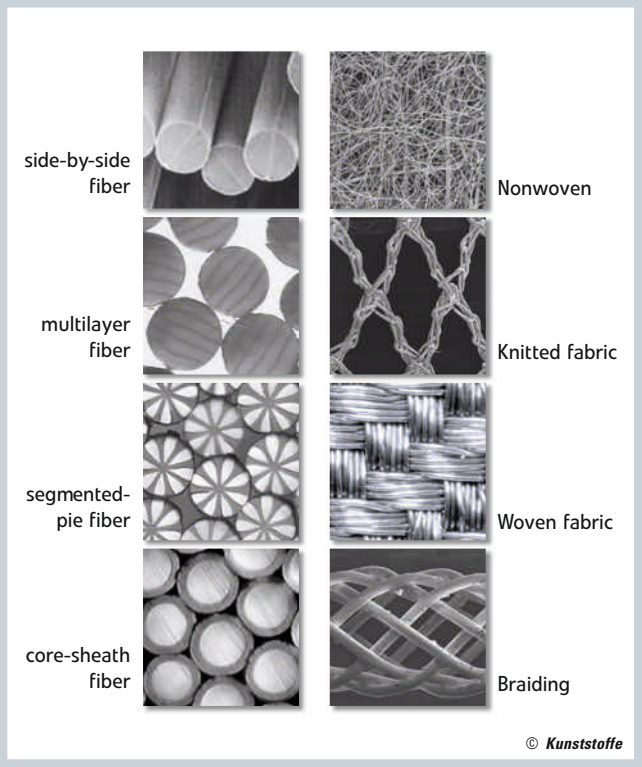


**Fig. 3. Drug combinations in fiber and structure** (source: ITA)

tween 160 °C and 250 °C. Due to the thermal instability of most active ingredients, the melt spinning process is not suitable for the production of drug-loaded fibers. A second method of producing fibers is the solvent spinning process (wet and dry spinning). In this process the polymer is dissolved in a suitable solvent to form the fibers. The process temperature with this method generally lies between RT and 60 °C. Even thermally unstable drugs can therefore be incorporated into the fibers with this method. Organic solvents such as chloroform or dimethylacetamide (DMAC) are frequently used as solvents. Due to their toxicity, these have a very low biocompatibility. Solvent residues in the fibers therefore have to be avoided at all costs. Gas chromatography is frequently used as a detection method for possible solvent residues. A special form of the solvent spinning process is the electrospinning process in which fibers with diameters of a few nanometers can be produced. It is not possible, however, to use the electrospinning process to produce endless filaments which can subsequently be further processed to form textile structures (knitted or woven fabrics).

The use of fiber-based structures opens up a wide variety of possibilities for the design of drug delivery systems. The drug can either be incorporated directly into the fiber (by solvent spinning), and/or it is applied to the fiber or a prefabricated textile structure in the form of a coating **(Fig. 2)**. A disadvantage of the coating method is the frequently non-trivial bonding (ionic, covalent) of the drug to the fiber surface. Furthermore, the duration of the drug delivery with coatings is generally shorter than for a polymer/drug composite with the drug dispersely distributed or dissolved over the whole fiber cross-section. The actual drug delivery with non-absorbable polymers is purely diffusive, while with absorbable polymers the delivery is dictated primarily by the degradation rate of the polymer [1, 2].

Systems in which more than one drug is to be delivered can also be produced using textile structures, with fibers bearing a single drug being combined in the textile structure. This is possible in all conceivable textile structures: Nonwovens, knitted and woven fabrics. If, in addition, different matrix polymers are employed, the release kinetics of the drugs can be matched to one another, with the delivery of both drugs starting simultaneously in each of the above cases. Bicomponent fibers represent a second possibility for producing a combined drug delivery system in a textile structure. In this way, different drugs can already be combined in a single fiber. In the case of side-by-side, multilayer or segmented-pie fibers, the delivery of the drugs starts simultaneously. With a core-sheath fiber, on the other hand, a delivery cascade can be created in which first only the drug in the sheath is released, and then later the drug in the core **(Fig. 3)**.

It should be pointed out that by contrast with the melt spinning process, the production of bicomponent fibers using

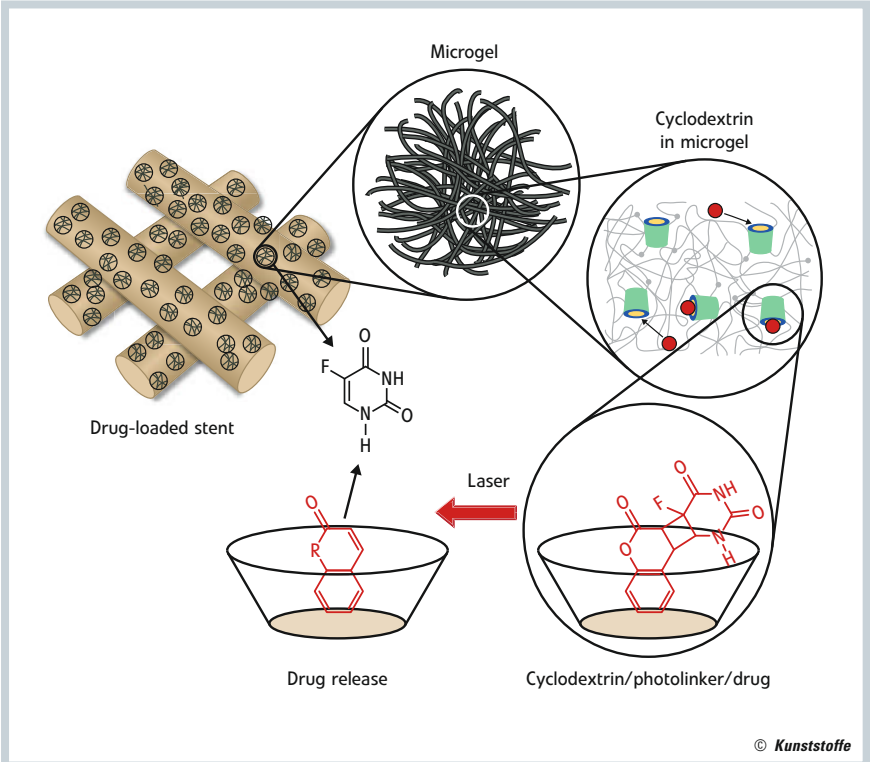


**Fig. 4. Concept of the "Photorelease" research project** (source: DWI)

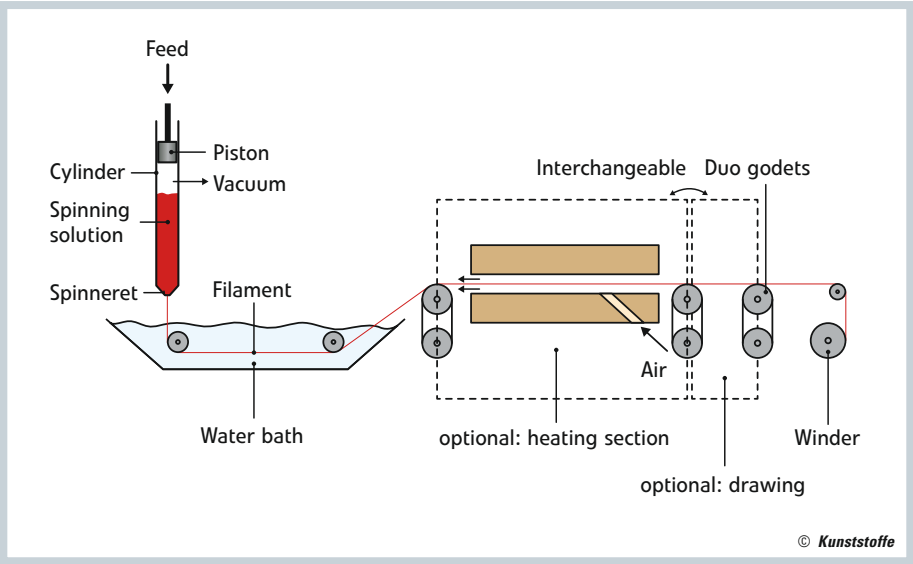


**Fig. 5. Layout of the KS33** (source: ITA)

the solvent spinning process is not yet state-of-the-art. In recent years, however, the working group headed by Prof. Jörg Lahann at Michigan University has succeeded in producing bicomponent and tricomponent fibers using the solvent electrospinning process [3]. In the light of this, this article illustrates the great potential and versatility of textile structures and processes for the development of innovative drug delivery systems.

## "Photorelease" Project

In the current "Photorelease" research project being conducted at the Institute for Textile Technology, Aachen, Germany, an innovative fiber-based drug delivery system is being developed in cooperation with partners from the fields of macromolecular chemistry, laser technology and medicine. This development targets the palliative treatment of metastasizing tumors in the gastro-intestinal tract. The state-of-the-art in such cases is to treat the tumor by chemotherapy and/or radiotherapy. However, this method of treatment places an additional burden on the patient due to the severe side-effects. If the tract affected is blocked by the tumor, the segment is frequently re-opened by means of a stent. It therefore makes sense to load the stent used here with a drug to allow a local treatment of the tumor. The concept of the project is illustrated in **Fig. 4.**

The drug 5-Fluouracil (5-FU) is bonded to a cumarin molecule by a photolinker. The application of laser radiation with a defined wavelength breaks down the bond between 5-FU and cumarin and the drug is released. In this way it is possible to adapt the course of the drug application to the actual course of the therapy. The cumarin 5-FU complex is encapsulated in a beta-cyclodextrin ring and embedded in a microgel. This microgel is incorporated into the fibers using the solvent spinning process, before the fibers are braided to produce the stent. The drug release is activated endoscopically.

On the basis of a requirement profile, a polycarbonate urethane (PCU) with long-term stability was chosen as matrix polymer. This is characterized by outstanding compatibility with human blood and tissue [4, 5]. Furthermore, it has elastic properties which is a further advantage in view of the peristaltic movements of the gastro-intestinal tract. The solvent used for PCU is N-methyl pyrrolidon (NMP). The installation used to carry out the spinning trials is a KS33 piston spinning plant (manufacturer: Fourné Polymertechnik GmbH, Alfter-Impekoven, Germany) **(Fig. 5).**

The spinning solution is poured into a hollow cylinder and extruded through the spinneret by a piston sealed against the walls of the cylinder. The resulting filament passes through a water bath (coagulation bath) in which the solvent diffuses out of the fiber. The filament is then optionally drawn and wound onto the winder. In the first step, process parameters for a stable spinning process were successfully identified. Fibers with a titer of 106 dtex, an ultimate elongation of 41 % and a tensile strength of 12 cN/tex were produced **(Fig. 6).**

Results achieved by the clinical partners have shown that 1–5 % by weight of drug-loaded microgel have to be incorporated into the spinning solution in order to achieve the desired cell response. It has recently been possible to produce fibers from a spinning solution with 6 % microgel in a stable spinning process. The next project steps are now the production of the braided stents and the evaluation of the release kinetics in cooperation with the clinical partners.

## Conclusion

The versatility and advantages of textile structures for use in medical applications have been illustrated. The incorporation of drugs into fibers here opens up, on the one hand, the possibility of sup- →

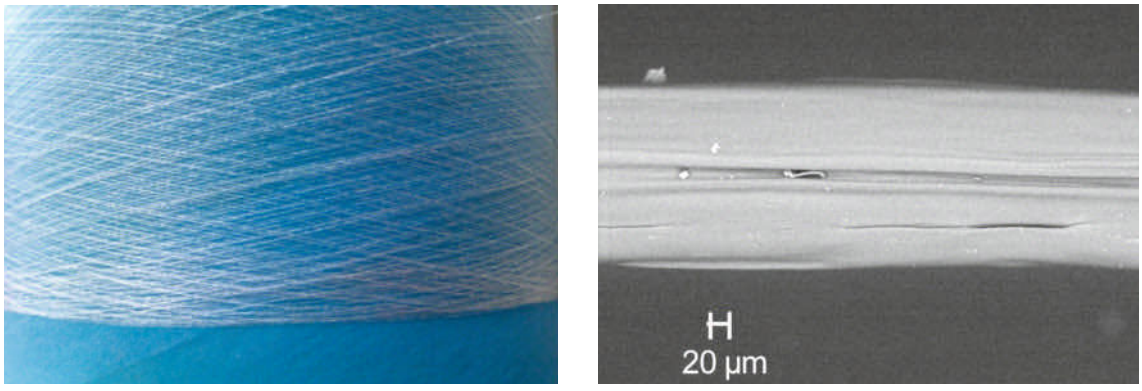


**Fig. 6. Solvent-spun PCU fiber (left) and REM image of a solvent-spun PCU fiber (right)** (source: ITA)

plementing textile-based medical products already established with a drug release mechanism, and on the other hand to develop completely new types of drug delivery systems. The project has shown that the interdisciplinary cooperation between medics, engineers and material scientists can enable innovative and highly promising products to be developed. ■

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**THE AUTHORS**

DIPL.-ING. PHILIPP SCHUSTER, born 1982, has been research associate at the ITA since 2009 and heads the "Fiber Systems Department" in the Life-science and Smart Textiles Faculty; philipp.schuster@ita.rwth-aachen.de

UNIV.-PROF. DR. MED. STEFAN JOCKENHÖVEL, born 1967, since 2011 Univ. Prof. for Tissue Engineering & Textile Implants at the RWTH Aachen University; member of the institute management of the Institute for Textile Technology Aachen (ITA) and Head of the Tissue Engineering & Biomaterials Department at the Institute for Applied Medical Technology (AME), Helmholtz Institute for Biomedical Technology at the RWTH Aachen University; jockenhoevel@hia.rwth-aachen.de



 