Novel melt-spun liquid-core filaments for drug-release and similar applications

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Tailoring the properties of polymer fibers

**X-ray analytics**

**Raman spectroscopy etc.**

- Polymer treatment
- Production parameters
- Fiber treatment

**Properties**

**Structure**

**Applications**
Continuous LiCoF co-extrusion line
Hufenus et al., Materials & Design 2016, 110, 685
Industrial production of LiCoFs

First industrial-scale monofilament line up and running

Spinnereistrasse 10, 6020 Emmen, Switzerland
Why LiCoFs?

Functional liquids: essential oils/flame-retardant liquids

Physical/chemical properties of filaments

Dissolving active agents in liquid (reservoir/encapsulation)

Choice of material combinations

Bioinspired designs (induce movements)

Pressure-/diffusion controlled delivery
Applications of LiCoFs

What applications do we have in mind?

- Odorant
- Insecticidal
- Dilatant (Shear-thickening)
- Microhydraulic
- Optical
- Medical
- Flame-retardant
Towards a new generation of medical textiles

Drug-loaded liquid-core melt-spun fibers

- Controlled local drug-delivery
- Continuous or responsive release
- Reservoir of drugs
- Upscalability, weavability, flexibility, eco-friendly

- Heart valves
- Gauze
- Bandages
- Patches
- Band-aids
- Insulin pumps
- Hernia repair
- Stents
- Sutures
- Protective equip.
- Wound healing
- Pumping devices
Liquid-core fibers for medical applications

Drug-containing solution / polymer

Fossil-based

Biocompatible

$T_m \sim 60^\circ \text{C}$

$M_w = 50 \text{ kDa}$

➢ Possibility to offline exchange liquid core with other drug solutions.
Melt spinning of liquid-core fibers

Liquid-core materials

Carrier liquids:

- Glycerol (~10 Å) ✗
  ![Glycerol structure](Image)
- Polyethylene glycol (PEG) ✗
  Mw=200 Da
  Mw=750 Da (paste-like, melts close to 40°C)
- Polyethylene glycol methyl-ether (mPEG)
  Mw=500 Da
- Water mixed with 5wt.% PEG (Mw=200’000 Da) ✓

Drugs:

- Fluroescein sodium salt
  ![Fluroescein sodium salt structure](Image)
  $R_g = 5.0 \text{ Å}$
- Ibuprofen
  ![Ibuprofen structure](Image)
  $R_g = 3.2 \text{ Å}$
- Methylene blue
  ![Methylene blue structure](Image)
  $L \sim 13.8-14.5 \text{ Å}$
- Bovine serum albumin
  ![Bovine serum albumin structure](Image)
  $R_g = 27.6 \text{ Å}$
Mechanical properties
Monofilaments and liquid-core fibers

- Highest tensile strength for liquid-core fiber with mPEG500
- Molecular orientation seems to be affected by type of liquid core
- Fibers with small cores have higher tensile strengths than fibers with large cores

Liquid-core fibers: Outer $\phi \sim 185\text{-}195\mu m$

- Small core (sc) $\phi \sim 55\text{-}65\mu m$
- Larger core (lc) $\phi \sim 70\text{-}75\mu m$

PET for 6000m/min
UTS $\sim 440\text{-}570$ MPa
el. at break 45-65%
X-ray analytics
WAXD/SAXS

PCL monofilament
oriented
LiCoF (mPEG500f_lc)

➢ High tensile strength correlates indeed with high crystalline orientation
➢ Fibers with smaller core have a higher tensile strength due to higher crystalline orientation
Diffusion trials
Cut fibers / loops immersed in PBS

Possible drug-delivery mechanisms

Diffusion-controlled

Pressure-driven

Immersion for 24 hours at 20°C and 37°C.

Analytics:
• Fluorescence spectroscopy (fluorescein sodium salt, BSA-FITC)
• UPLC UV-vis (ibuprofen)
• UV-vis (methylene blue)
Diffusion trials
Cut fibers / loops immersed in PBS

Immersion for 24 hours.

➢ Temperature affects the diffusion rate
➢ Fluorescein sodium salt / Ibuprofen diffuses through PCL sheath
➢ Core-size influences the amount of diffused material after 24 hours (not shown)
➢ Structure of PCL influences the diffusion (not shown)
Diffusion mechanisms
For highly drawn LiCoFs:

- Small molecules
  - **PCL**
  - Fluorescein sodium salt
    - $R_0 = 5.0 \text{ Å}$
  - Ibuprofen
    - $R_0 = 3.2 \text{ Å}$

- Large molecules
  - Methylene blue
    - $L \sim 13.8\text{-}14.5 \text{ Å}$
  - Bovine serum albumin
    - $R_0 = 27.6 \text{ Å}$
Conclusions/Outlook

❖ **Successful melt-spinning**: Liquid-core fibers for medical applications with reasonable mechanical properties

❖ **Diffusion trials**: Diffusion rate depends on many factors:
Core size, sheath thickness, sheath structure, temperature, drug concentration, molecule size etc.

**Planned future work:**

❖ Melt-spinning with different types of drugs / solutions / polymers ($\varnothing < 150 \, \mu m$).

❖ Different diffusion trials (concentrations, types of drugs / carrier liquids / polymer materials).
Liquid-core melt-spun filaments
From research to industrial implementation

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- Innovation projects with implementation partners

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- Flagship Initiative

Innovation projects with international partners
- Projects of Swiss SMEs with international SMEs
  - Eurostars
- Cross-border innovation projects
  - Eureka
- Innovation projects with partner countries
  - Bilateral cooperation

What ideas do you have in mind?

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Thank you for your attention!