Polymer Fluids Group
Department of Chemical Engineering
New Museums Site
Pembroke St
Cambridge. CB2 3RA. UK

UNIVERSITY OF CAMBRIDGE

The invention and innovation of a novel plastic Microcapillary Film technology

Dr Bart Hallmark, in collaboration with Prof. Malcolm Mackley FREng

Summary

This poster describes a simple and exciting new plastic processing technology. The novel material, Microcapillary Film (MCF), is a flat extrusion-processed, flexible, plastic film containing an array of microcapillaries that run along its entire length. The precision engineered capillaries are effectively uniform and can range between 30 microns and 1 millimetre in diameter. Potential application areas are widespread and include its use as sensory equipment in the Formula 1 racing industry and in high-performance sailing, as a low-cost material for making domestic solar panels and, with further process development, as a material to create coloured fabrics without the use of chemical dyes.

1 The invention and its initial development

The invention

The MCF process combines ideas from fibre spinning, foam blowing and plastic film manufacture with the first proof of concept process being completed in late 2003. Figure 1 shows the early process and one of the first MCF products.

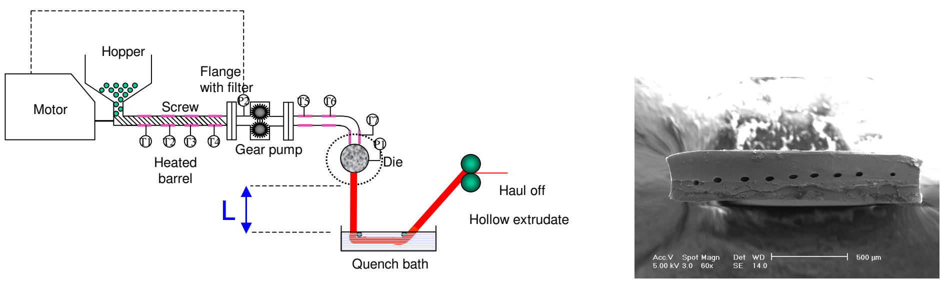

Figure 1. Schematic diagram of the MCF process (left) and an SEM of a very early MCF (right)

Process and product development

The MCF is a thin, flexible film containing capillaries that can range between 30 micron and 1 millimetre in diameter. A patent[1a] was filed to cover the invention and the process improved to make better quality product.

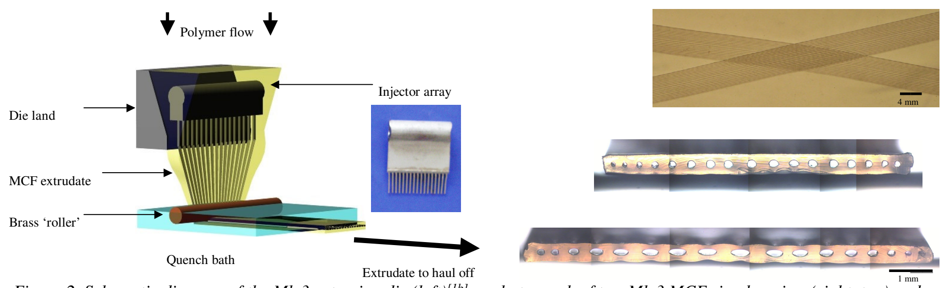

Figure 2. Schematic diagram of the Mk 3 extrusion die (left)[1b], a photograph of two Mk 3 MCFs in plan view (right, top) and cross-sections of Mk3 MCFs produced under differing process conditions (right, middle and bottom)

1a. Hallmark B. and Mackley M.R., EP1691964, 2006
1b. Hallmark B., Mackley M.R., and Gadala-Maria, F., *Adv. Eng. Mater.*, 7(**6**), 545-547, 2005

2 Process refinement and continued innovation

Process refinement

In late 2005, a precision-engineered die was fabricated using cutting-edge manufacturing methods. Additional new machinery was also added to the process. This allows us to make very high-quality MCFs (Figure 4).

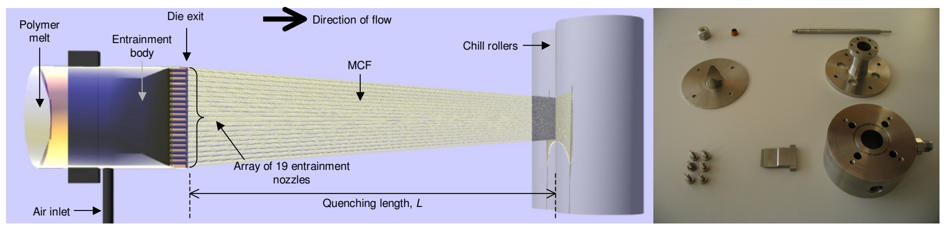

Figure 3. Schematic diagram of part of the Mk 4 extrusion line (left) and photographs of the Mk 4 die (right)

Early commercial interest and further innovation

In late 2005, a UK SME, Lamina Dielectrics Ltd., showed interest in MCF technology to manufacture microfluidic devices; license negotiations are almost complete.

MCFs have now been prototyped in a wide range of plastics and plastic-like materials; they can also be made to tear easily! This has resulted in a further patent application[2a] and a license to an American company.

Further development allows for high voidage within an MCF; this has resulted in a further patent filing[2b].

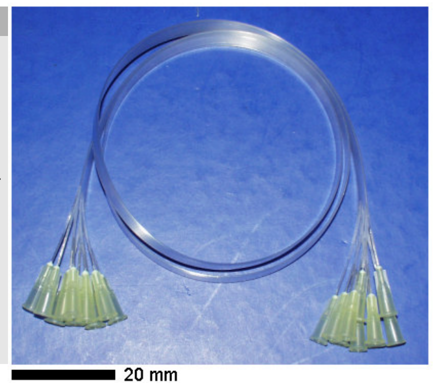

Figure 4. Photograph of an MCF with connectors (upper) and optical micrograph of a Mk4 MCF section (left)

2a. Hallmark B., Mackley, M.R. and Gadala-Maria, F., WO2006016128, 2006.
2b. Hallmark B. and Mackley M.R., UK patent application 0620246.9, 2006.

3 The science behind MCFs

Capillary formation

The capillaries in MCFs are formed by air being 'sucked' into the molten plastic through hypodermic needles. Finite element analysis is able to predict this and give us important design information (Figure 5).

Process stability

The MCF process isn't always stable! Figure 6 shows the window of stable operation.

MCFs with different cross-sectional geometries can also be created by simply manipulating process conditions[3a].

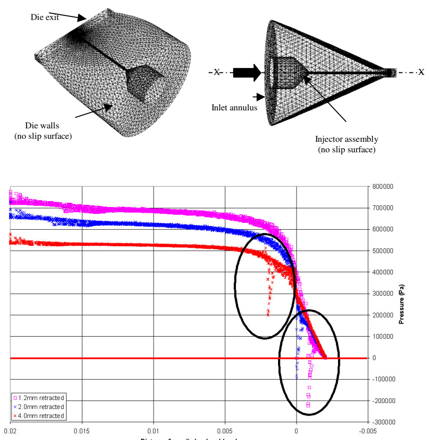

Figure 5. Finite element mesh of test die (above) and graph showing the pressure dip beneath the injectors that causes air entrainment (below)

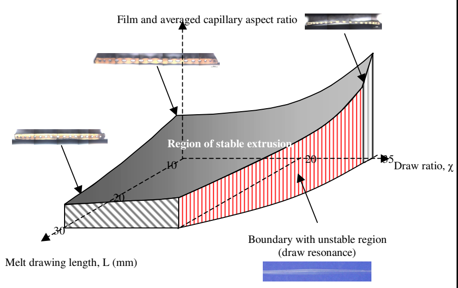

Figure 6. Stability map of the MCF process, determined from experiment, showing both the stable zone and the effect of processing conditions on final product

Product formation

Numerical modelling helps us to understand why slight changes to the operation of the process affect the final shape and form of the MCF product.

Cutting-edge computer codes are able to predict key features of the product (Figure 7)[3b].

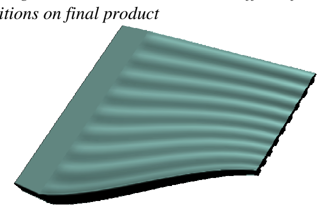

Figure 7. Finite element simulation of MCF deformation. Solution highlights the 'corrugated' structure that was experimentally observed

3a. Hallmark B., Mackley M.R., and Gadala-Maria, F., *J. Non-Newton Fluid.*, 128, 83-98, 2005.
3b. Hallmark B., *Submitted to Polym. Eng. Sci.*, 2006

4 Application development – creating end-user products

Formula 1 pressure sensing

Collaboration is ongoing with a Formula 1 team to evaluate using MCFs in pressure sensing systems.

MCFs may also be very useful for high-performance sail research. Collaboration is ongoing with a UK-based instrument manufacturer to trial this idea

Figure 8. MCFs are being evaluated for use in Formula 1 R&D

Low-cost solar heating

MCFs make excellent heat exchangers [4a]!

Collaboration is ongoing with a UK sustainable energy company investigating using MCFs in solar water heating to make a lightweight, cost effective and energy efficient domestic system.

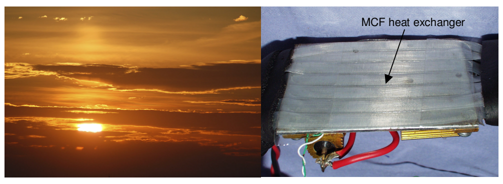

Figure 9. MCFs may be instrumental in the construction of low-cost, lightweight solar heating units

Dye-free coloured textiles

MCFs could be used to create dye-free coloured fibres!

In nature, many birds rely on diffraction effects, caused by nano-scale capillaries in their plumage, to generate colour.

If MCFs could be shrunk by a factor of 1000, this would be attainable. Commercial interest in this idea has been shown by a multinational chemical company.

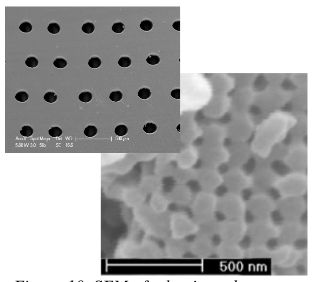

Figure 10. SEM of a laminated monolith of MCFs (above) and a SEM of a peacock feather barbule[4b]

4a. C.H. Hornung, B. Hallmark, R.P. Hesketh and M.R. Mackley, *J. Micromech. and Microeng.*, 16, 434-447, 2006.
4b. Zi J., *et al.*, *P Natl Acad Sci USA*, 100(**22**), 12576-12578, 2003..

Conclusions and Acknowledgements

A new process and product, Microcapillary Film (MCF), has been invented and patented. MCF is a novel material and has many exciting potential application areas. The MCF process has also been an interesting process to study and understand. Three MCF patents have been applied for (one is now filed in Europe, the USA and Japan), two licenses have been agreed and collaboration is underway with five companies who wish to evaluate MCFs in a number of interesting and diverse fields.

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