Polymer Interdisciplinary Research Centre

polymer IRC

2018

UNIVERSITY of BRADFORD

CONTENTS

Polymer IRC

2018

This booklet provides brief background information on developments in the world-class UK Polymer IRC, which was founded through an EPSRC grant in 1989. We have a vibrant, growing community of interdisciplinary researchers with world-leading facilities, and we lead an international community of research leaders, researchers and early career researchers, with a highly productive programme of Research Workshops and researcher exchanges, and three Joint International Research Laboratories.

A further extension of our capabilities in the healthcare technologies area is the EPSRC UK Centre for Innovative Manufacturing in Medical Devices, MeDe Innovation – a key grouping of five leading universities, of which we are a founder member.

All of our exciting progress is only possible because of an excellent team of like-minded, dedicated people, who are developing the capability and capacity of our research laboratories, which continue to pursue an upward trajectory, with local through to international impact.

We are always open to new opportunities, and welcome academic, industrial and clinical collaborations, so please do contact us!

WELCOME

The internationally recognised Polymer Interdisciplinary Research Centre (Polymer IRC) at the University of Bradford has a strong track record of warm co-operation in the UK and abroad, with academics, industry and clinicians across the area of advanced materials, especially polymers and polymer composites, and with an emphasis on healthcare technologies, ultraprecision processing and unique solid phase orientation processing of polymers.

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Director, Science Bridges China
International Science & Technology Co-operation Award of PR China (2017)
中国国际科学技术合作奖获得者
Famous Overseas Scholar, MoE China
中国教育部海外名师
Honorary Professor, Sichuan University
四川大学名誉教授
Honorary Professor, Beijing University of Chemical Technology
北京化工大学名誉教授

Polymer IRC Bradford leaders

Prof Phil Coates FREng
Director Polymer IRC
Director, Science Bridges China

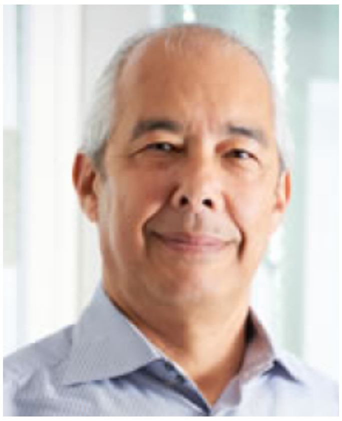
Prof Ben Whiteside
Director, Polymer Micro
& Nano Technology Centre

Prof Adrian Kelly
Manager, Extrusion

Dr Fin Caton-Rose
Manager Solid Phase
Processing & Modelling

Prof Anant Paradkar
Director, Pharmaceutical
Engineering Science

Prof Tim Gough
Manager Polymer
Characterisation



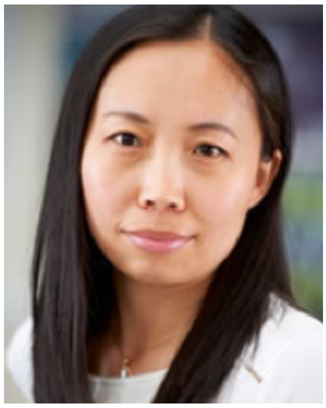
Prof Hadj Benkreira
Director Coating

Prof Steve Rimmer
Head, Chemistry & Biology

Prof John Sweeney
Polymer Mechanics
& Modelling

Dr Pete Twigg
Reader,
Medical Engineering

Dr Elaine Brown
Mechanical Processing



Xiaolei Wang
International Programme
Manager

Other Polymer IRC academic staff team members include:

- **Dr Max Babenko**, Polymer micro & nanotechnology
- **Dr Philip Drake, Lecturer Chemistry**
- **Dr Stephen Hickey,** Reader Physical Chemistry
- **Dr Maria Katsikogianni,** Lecturer in Biomaterials
- **Dr Mike Martyn**, Senior Lecturer, Polymer Engineering
- **Dr Pete Olley**, Senior Lecturer, Mechanical Engineering
- **Dr Raj Patel**, Head of Chemical Engineering
- **Dr Karthik Nair,** Microneedles, shape memory polymers
- **Dr Paul Spencer,** Polymer deformation
- **Dr Farshid Sefat**, Lecturer Medical Engineering
- **Dr Beverly Stewart**, Lecturer Theoretical Chemistry
- **Dr Tom Swift**, Lecturer Polymer Characterisation
- **Dr Brian Thomson,** Biomedical materials
- **Dr Cristina Tuinea-Bobe,** Senior RKT Officer
- **Dr Mansour Youseffi**, Reader in Biomaterials

Glen Thompson
Lab Technical Manager

Polymer Interdisciplinary Research Centre

The Polymer Interdisciplinary Research Centre at Bradford offers internationally leading Polymer Research; genuinely interdisciplinary, with major academic collaborations worldwide, and strong industrial involvement in our research.

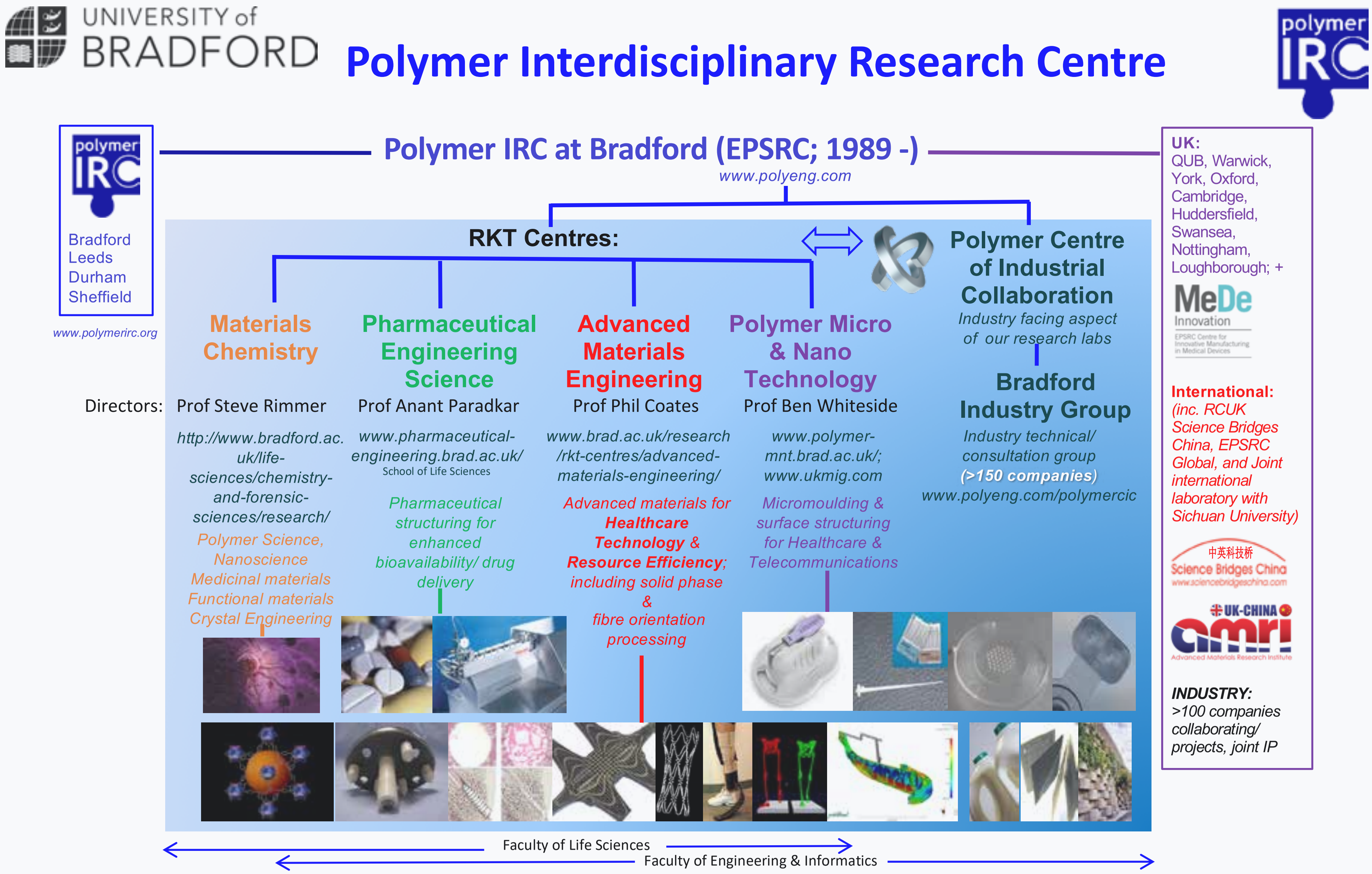
The Polymer Interdisciplinary Research Centre was founded in 1989 as a focal point for UK polymer science & engineering, supported by an EPSRC grant of £23m to the Universities of Leeds, Bradford and Durham, over its first 11 years. It formed a critical mass network of leading polymer scientists and engineers, with research interests across advanced materials including soft matter, nanocomposites, biomaterials, with strong UK and International links.

The world-class Polymer IRC research centre at Bradford has 16 processing laboratories (including a suite of 3 clean rooms), 6 materials preparation and characterisation laboratories, a computer modelling centre and large conference room. Processing capabilities include 10 injection moulding machines – emphasising ultraprecision moulding - over 20 extrusion lines, and 10 unique solid phase orientation processing lines; 10 3-d printers; electrospinning and cell culture. Materials characterisation includes TEM, AFM, X-ray, spectroscopy, rheometry, thermal and chemical techniques; product characterisation across the length scales includes surfaces via AFM, confocal laser microscopy, WLI, Raman surface mapping, and energy; physical properties from micro to macro scale – nanoindentation, micromechanical, micro CT, wear. In-process metrology features strongly, with many techniques pioneered in our laboratories, and includes precision optical and thermal imaging (both to ultra high speed).

Professor Phil Coates FREng is the overall Director of the Polymer IRC, based at Bradford in the Faculty of Engineering & Informatics, and Director of the Advanced Materials Engineering RKT Centre. Professor Ben Whiteside is Director of the Polymer Micro & Nano Technology RKT Centre, and Professor Anant Paradkar is Director of the Pharmaceutical Engineering Sciences RKT Centre (hosted in the Faculty of Life Sciences). Over 50 research staff at Bradford are involved in our programmes.

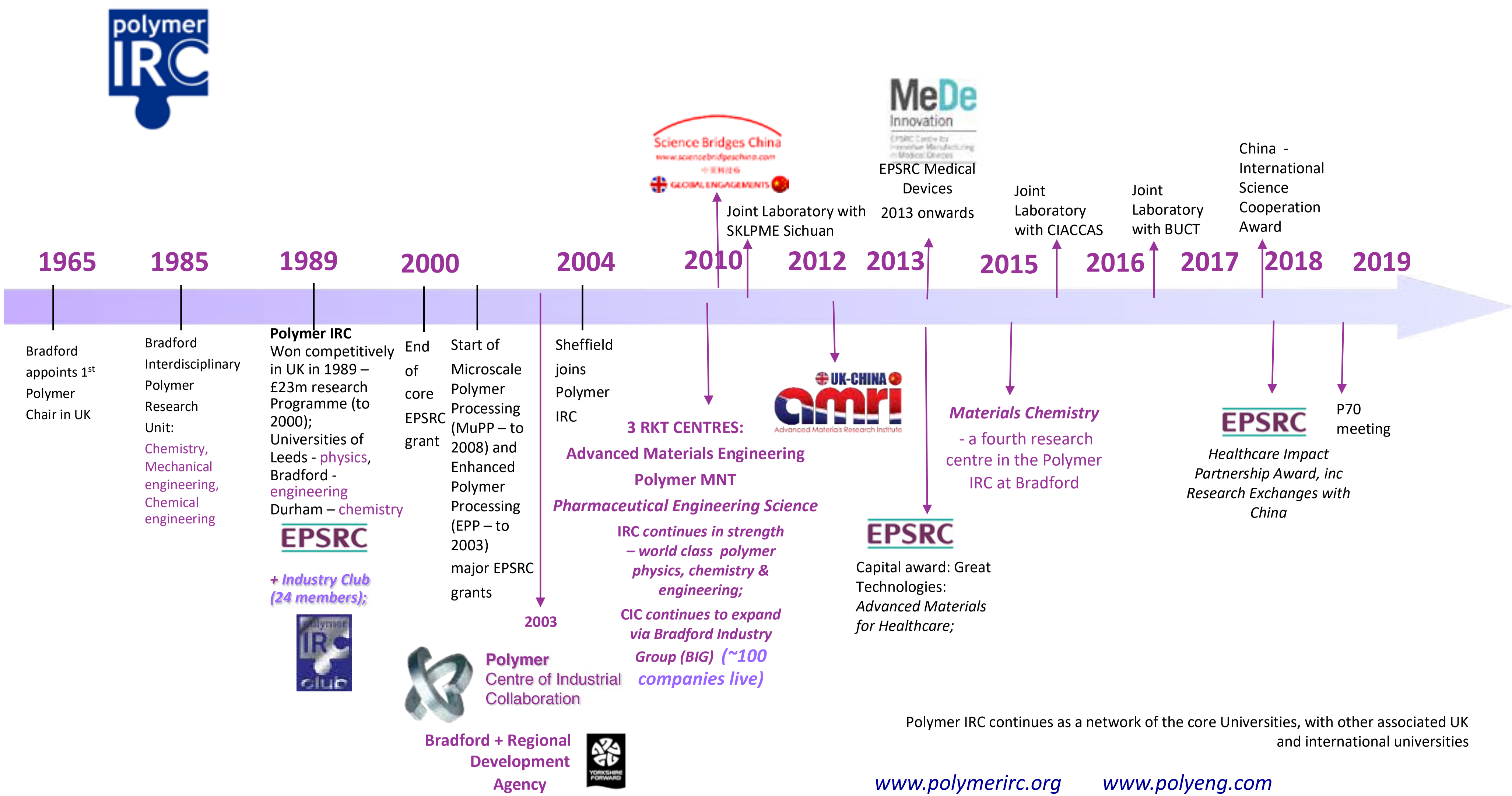
We are delighted to have taken the following major steps since 2014:

1. The ESPRC Capital grant (£3.42m, with a further £3.1m from industry and the University) for new processing and characterisation facilities for advanced materials for healthcare, early 2014.
2. Recladding and re-roofing of the laboratories, around £3m in 2014-15.
3. Materials Chemistry adding to the strength of the Polymer IRC in Bradford, summer 2015;
4. A Joint International Laboratory for Polymer Process Physics was formed in September 2015 between Changchun Institute of Applied Chemistry CAS and the Polymer IRC;
5. Xplore have placed a PM5 specialist compounding and film processing line in our laboratories, particularly for pharmaceuticals processing, in 2016
6. A significant donation of biomedical polymer equipment was made to our laboratory by Smith & Nephew Ltd, 2016
7. A Joint International Laboratory for Soft Matter Technologies between Beijing University of Chemical Technology and the Polymer IRC at the University of Bradford, was announced in December 2016
8. 3 major International Awards in 2017 and 2018.



A coherent, internationally leading Polymer Research Laboratory; genuinely interdisciplinary, with major academic collaborations worldwide, and major industrial involvement in our research

Polymer IRC science structure and some collaborative links



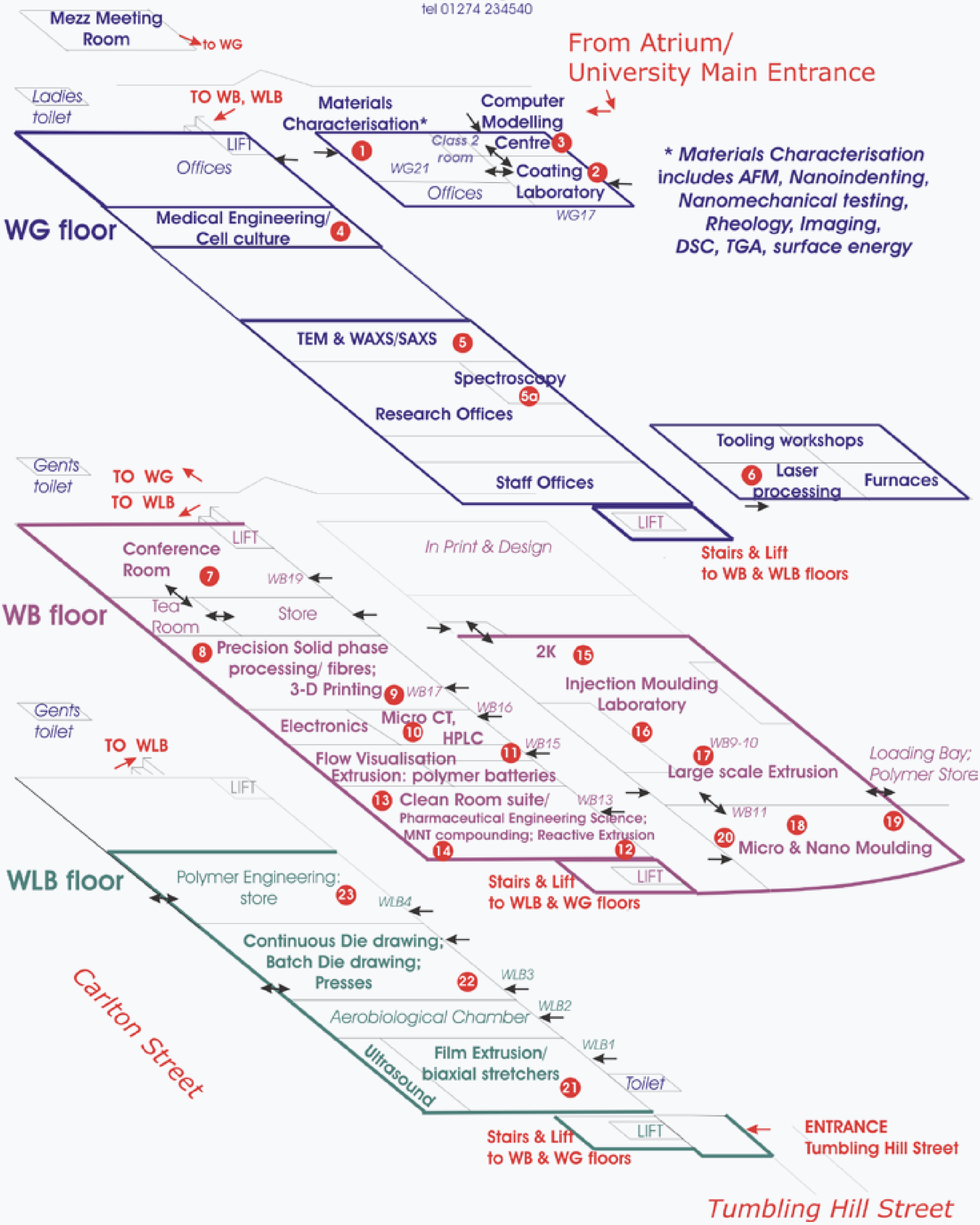
Polymer IRC timeline showing some major events to date

Polymer IRC

& Polymer Centre of Industrial Collaboration

RKT Centres:
Advanced Materials Engineering
Polymer Micro & Nano Technology
Pharmaceutical Engineering Science

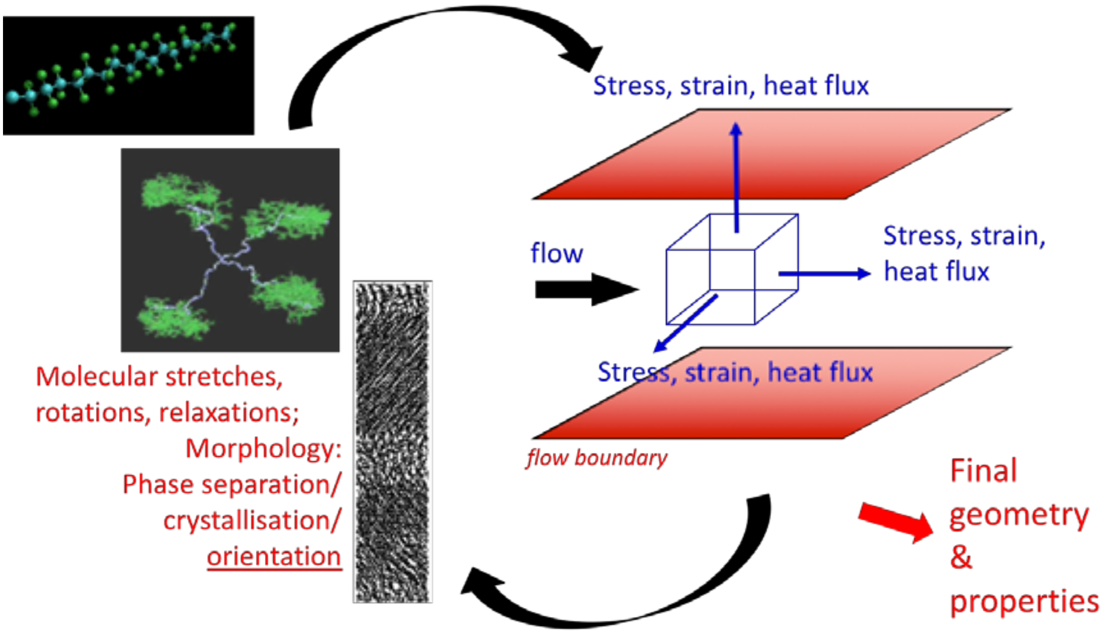
www.polyeng.com
tel 01274 234540



Research philosophy:

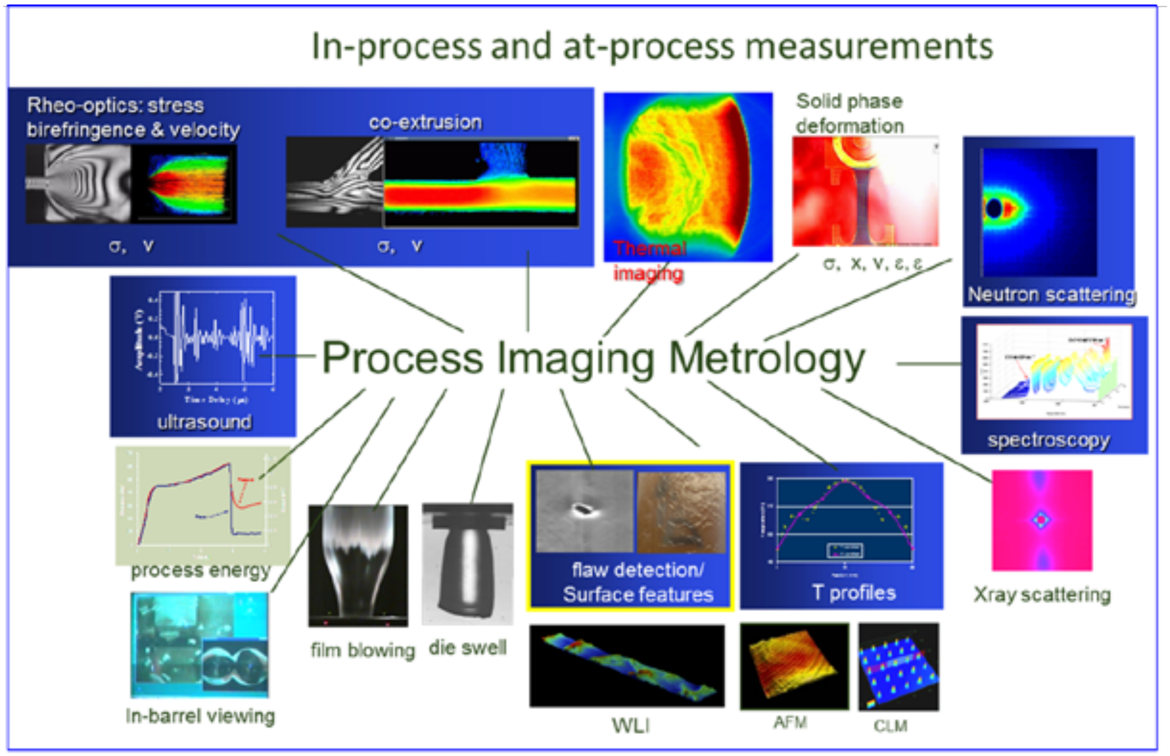
We structure polymers in a controlled way via the manufacturing process, to control and enhance final product properites or functionalities ('process structuring' - see below). The Polymer IRC laboratories at Bradford have been built on pioneering in-process measurements, which are vital for developing understanding of the way in which polymers behave during processing in relation to their molecular structure and the associated kinetics of long chain molecules as they reptate in the melt, then change on cooling to the solid state to particular crystalline or amorphous morphologies in extruded or moulded products - but having been subjected to *imposed* process variables such as stresses, strains, heat fluxes, with their own dynamics. The interaction of material kinetics and process dynamics produces the final product properties.

Process structuring:
'material kinetics' versus 'process dynamics'



The products may then may undergo further structural changes in subsequent processes e.g. under deformation in the solid phase to cause orientation and further enhanced properties.

In-process measurements are vital to our understanding and control of polymer processing operations. We have pioneered in-situ measurements including pressure, IR temperatre, thermocouple grids, ultrasonic velocity and transit time for bulk melt flows, visualisation of melt free surfaces, rheo-optical and thermal imaging of process flows, in-situ IR, MIR and UV-vis spectroscopy and in-situ SAXS and WAXS; imaging metrology for polymer deformation and solid phase processing and surface feature assessments.



Our research addresses significant global and local societal and commercial needs

- particularly in the areas of:

- medical technology
  - o materials and devices for tissue and joint repair,
  - o biomedical materials, including bioresorbable and shape memory materials,
  - o drug eluting implants and fixations,
  - o drug delivery technologies,
  - o minimally invasive surgery technologies
  - o prosthetics and gait;
- precision manufacturing (micromoulding and conventional moulding) for
  - o control of surface features and properties, including antimicrobial surfaces and drug delivery techniques such as micro needles,
  - o telecommunications, optics and anti-counterfeiting,
  - o automotive and structural parts in polymer composites;
- solid phase orientation polymer technologies for property enhancements for
  - o medical devices, such as tissue fixations and arterial stents,
  - o building products (see Eovations LLC) ranging from decking to hurricane-resistant building products;
- 3-d printing for novel manufacturing using multiple streams of polymers
- resource efficient materials including upcycling for food containers, thermal/acoustic barriers and enhanced properties for high added value;
- modelling of novel processing and product performance in all of the above sectors.

Our Laboratories

Processing

- Micro & Nano Technology processing WB11
  - ultraprecision injection moulding using electric and ultrasonic injection technologies, high speed in-process measurements
- Injection moulding - large scale WB9
  - electric and hydraulic injection moulding, 2K moulding
- Extrusion large scale WB10
  - medium scale twin screw extrusion, precision feeders; large scale single screw extrusion; precision fibre extrusion
- Precision solid phase processing WB17
  - small scale die drawing and supporting precision extrusion facilities
- 3-d printing WB17
  - fused deposition and liquid laser curing facilities
- Clean Room Suite WB13
  - o Reactive Extrusion, with 40:1 L/D twin screw reactive extrusion
  - o Nanomaterials Compounding - twin screw extruders and precision feeders
  - o Pharmaceuticals processing - stainless steel twin screw extrusion; microscale extrusion compounding
- Pharmaceutical Processing
  - o Spray drying
  - o freeze drying
  - o high shear granulation
- Polymer battery manufacture WB15
  double extruder system
- Films - Extrusion WLB1
  - cast film, blown film, film on substrate extrusion facilities;
- Biaxial stretching WLB1
  - 'Long' biaxial stretcher; vertical biaxial stretcher with windowed oven
- Solid phase processing large scale WLB3
  - large scale die drawing facilities - batch, and continuous die drawing
- Electrospinning WG37
  - twin stream with roller collector
- Cell culture WG37
  - two laminar flow units
- Coating WG17
  - a range of experimental coating facilties for fluid flow/ air entrapment/ rheology studies
- Compression moulding WLB1, WLB3
  - two temperature controlled (heating and cooling) presses
- Processing store WLB4

Materials Characterisation

- Surface properties WG21
  - 3 Atomic Force Microscopes, one with confocal laser microscope; 2nd confocal laser microscope; nanoindenter;
- Micromechanical properties WG21
  two high precision micromechanical testers - Biomomentum and Bose
- Rotational & Extensional Rheometry WG21
  - two high precision rotational rheometers, with add on extensional rheometry and shear cell, temperature controlled extension cell
- Thermal characterisation WG21
  - DSC, DMA, TGA
- Spectroscopy WG33
  - NIR, UV vis, Raman Surface Mapping
- TEM WG34
  - Technai FEI/Thermo Fisher TEM
- X-ray WG34
  - Anton Paar SAXSpace
- Micro CT WB16
  - Nikon micro CT, large data storage
- SEM WB11
  - Hitachi bench top SEM
- HPLC WG16
  - Waters HPLC

Clean Room suite

- Capillary Rheometry WG9
  - Rosand RH10 and Rosand RH7 twin bore capillary rheometers
- Norcroft Building: University Analytical Centre
  - SEM/nmr/Raman microscopy/ DMA/

Materials Preparation

- cryomicrotoming WG21
- microscopy sample preparation WLB1
- chemical preparation - Clean Room WG13
- fume cupboard - Clean Room WG13
- TEM sample preparation
- Materials stores - WG18 & Loading Bay

Computer modelling

- Computer Modelling Centre WG17
  - a range of commercial modelling software including Autodesk Moldflow, Abaqus and in-house codes

Experimental and Modelling Facilities

PROCESSING/ MANUFACTURING TECHNOLOGIES

Injection Moulding

- Ultraprecision micromoulding WB11 Wittman Battenfeld Micropower (2) & Microsystem (2)
- ultraprecision larger scale injection moulding WB9 Fanuc 30B
- high speed thin wall injection moulding WB11 Fanuc 100t
- with Fanuc 6-axis robot
- Ultrasonic microinjection moulding WB11 Ultrasion
- 2K injection moulding WB9 Battenfeld 120t
- large scale injection moulding WB9 Fanuc 50t, Battenfeld 75t
- small scale injection moulding WB11 Fanuc 5t

Extrusion

- micro extrusion WB13 Clean room Xplore
- micro extrusion WB13 Clean room Thermo Fisher
- miniature twin screw extrusion WB13 Clean room Thermo Fisher 11mm
- small scale twin screw extrusion WB13 Clean room Prism 16mm; APV 19mm;
- small scale twin screw extrusion WB9 Clean room Prism 16mm
- mid scale single screw extrusion Rondol 18mm
- small scale single screw extrusion Rondol 12mm
- mid-scale twin screw extrusion WB13 Clean room Thermo Fisher 16mm 40:1 L/D
- large scale twin screw extrusion WB10 Thermo Fisher 25mm 40:1 L/D
- with 3 KTron loss in weight feeders
- twin screw extrusion (gel electics) WG14 Rondol 19mm
- feeding single screw extruder Rondol 20mm
- small scale single screw extrusion WLB1 Randcastle
- medium scale single screw tube extrusion WB17 Dr Collin 16mm
- medium scale single screw film extrusion WB17 Dr Collin 20mm
- medium scale single screw extrusion WLB1 Betol 38mm
- large scale single screw extrusion WB9 Betol 63mm
- fibre extrusion line - dual fibre WB9 FET 25mm
- film blowing WLB1 Betol 38mm
- film blowing miniature WG17
- cast film - 3 roll stack WLB1 Betol 38mm
- extrusion cast film/ coating WLB1 Betol 38mm
- extrusion Killion 25mm
- extrusion single screw WLB3 Boston Matthews 25mm
- metering pump

latest processing facilities

5th micromoulding machine

Ultrasonic moulding

Mini extrusion compounding

Microwave reactor

+ extensive fibre/ drawing;
+ 2 component electrospinning

3-d printing

Solid phase orientation
- precision small scale die drawing WB17 Gillard precision hauloff
- precision small scale die drawing WB17 linear drive
- precision small scale drawing - Changchun Lab linear drive
- small scale die drawing - tensile draw frame WB17Messphysik
- small scale die drawing - tensile draw frame WB17
- (long travel) Messphysik
- Fibre drawing frame WB17 Rondol
- Tensile testers WB17Instron (x2)
- Biaxial stretcher (vertical) WLB1

latest characterisation facilities

AFM + confocal laser microscope

cryomicrotome

nanoindentation

surface energy

Raman surface mapping

Micromechanical testing

TEM

SAXS-WAXS

- Biaxial stretcher (horizontal) WLB1Long/ ICI

3-d printing
- fused deposition (x6) WB17
- laser curing (x2) WB17
- Microfabjetlab

Other
- Electrospinning (bi-component) WG37
- ultrasonic welding WB11
- plasma etching WB11
- wear testing WLB1

IN PROCESS METROLOGY

- optical imaging cameras, inc high speed
- thermal imaging cameras, inc high speed
- ultrasound
- thermocouple meshes
- pressure
- displacement
- National instruments interfaces
- Labview software
- Python/ Image J software

PRODUCT CHARACTERISATION

Surfaces
- AFM - Asylum WG21 Oxford Instruments with Leica Confocal Laser Microscope
- Nanoindentation WG21 Hysitron
- Confocal Laser Microscopy
- White Light Interferometer WLI Veeco
- Raman surface mapping Thermo Fisher

Physical properties
- AFM Asylum WG21Oxford Instruments with Leica Confocal Laser Microscope
- AFM Veeco WG21
- nanoindentation Hysitron WG21
- micromechanical WG21
- Biomomentum
- Bose Electroforce
- surface energy
- contact angle WF21
- wear WG37
- Micro CT Nikon WB17

MODELLING

software
- Autodesk Moldflow
- Abaqus FEA
- Compuplas
- CFX
- Materialise
- Labview - various in-house programs
- Python/ Image J - various in-house modules

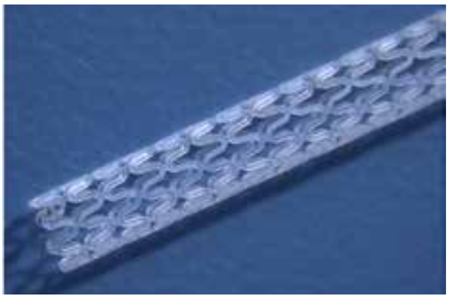
hardware
A range of high end PCs and Macs, plus various large data storage systems

The Polymer IRC hosts three University RKT Centres. Advanced Materials Engineering, Polymer Micro & Nano Technology and Pharmaceutical Engineering Science. These deliver into focussed areas, but have coherent research activities across discipline boundaries. All pursue the controlled structuring of polymers and polymer-related materials through processing, to achieve enhanced property products.

Advanced Materials Engineering
(director Prof Phil Coates)
Research focusses on structuring advanced polymeric and biomedical materials via processing, and modelling, for

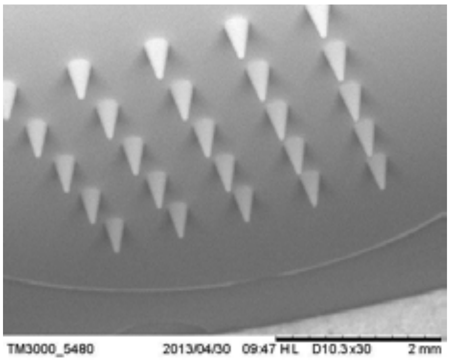
- high added-value products and methodologies and therapies aimed primarily at health and wellbeing; and
- resource efficient materials, enhancing the value of feedstocks.

The AME Centre builds on 'smart materials' expertise associated with the Polymer IRC and beyond, into the growth areas of medical and biomedical products and advanced materials for other high added value applications, and the developing area of sustainable materials. Unique, world-leading capabilities include precision solid phase orientation processing of polymers in a variety of profiles, from high precision oriented tubes for arterial stents to structural building products. Typical medical/ biomedical products include bioresorbable or non-resorbable shape memory polymer orthopaedic components for joint repair or replacement, stents for vascular repair,



spinal braces, structured films for wound dressing, precision tubing, medical devices and components, and medical packaging. These may also include active pharmaceutical ingredients, e.g. aimed at drug eluting implants.
Sustainable material products include novel acoustic materials made from recycled polymers, and smart incorporation of recyclates into conventional products for lower carbon footprint.
See *https://www.bradford.ac.uk/research/rkt-centres/advanced-materials-engineering/* for more details.

Polymer Micro & Nano Technology
(director Prof Ben Whiteside)
Polymer Micro & Nano Technology (MNT) is a world-class facility within the Polymer IRC laboratories at the University of Bradford, with research in ultraprecision polymer processing, especially micro injection moulding (micromoulding). simulation, in-situ characterisation and measurement techniques. Micromoulding has developed rapidly for micro-component manufacture or surface feature moulding, offering high production capacity at low marginal cost, with wide applications in healthcare, telecommunications, energy and consumer goods. Extensive in-process measurement techniques include high speed thermal and optical imaging in-situ in micromoulds, optical and mechanical product metrology, including bespoke product characterisation.
Key areas of expertise are in: moulding of microscale features; nano-structured surfaces; nano fillers compounding and processing; metal/ceramic powders; materials characterisation, product measurement; and inspection systems.
Applications include: Medical devices, including dental obturation points, eye



surgery devices, implants, microneedles; micro-optics; and integrated micro devices.
Polymer MNT helps develop new and improved micro and nano-components in a range of materials via process optimisation, tool design, proof of concept and low volume manufacture.
The Polymer MNT collaborative network is an interdisciplinary partnership with colleagues from academia and industry.
See *https://www.bradford.ac.uk/research/rkt-centres/polymer-mnt/* for more details.

Pharmaceutical Engineering Science
(director Prof AnantParadkar). The Centre for Pharmaceutical Engineering Science (CPES) is an interdisciplinary research and industrial collaboration centre, with expertise across the pharmaceutical sciences, chemistry and polymer engineering disciplines.
The Centre has core capabilities in the areas of preformulation analysis including solid state screening, pharmaceutical and healthcare formulation development, drug delivery systems, enabling process technologies including melt processing, proprietary innovative technologies and Process Analytical Technology (PAT) and Quality by Design (QbD) approaches to pharmaceutical and healthcare product development.
Research activity is focused on design of novel formulation technologies for the development of enhanced pharmaceutical and related products, together with process optimisation in the niche areas related to advanced pharmaceutical materials. We offer

expertise and access to a range of proprietary and enabling technologies focused on solubility enhancement of poorly soluble actives and offer pharmaceutical development services covering a range of drug delivery mechanisms including transdermal, inhaled and more conventional solid dosage oral formulations.
The centre has expertise in process understanding and product development to a range of industrial sectors including nutraceuticals, health and personal care, foodstuffs and medical devices. The centre also has a focus on developing innovative green technologies specialising in waste and solvent reduction, energy efficiency and optimisation of processes.
The CPES has established links with research laboratories within the UK, Europe, USA and Canada as well as China and India.
See *https://www.bradford.ac.uk/research/rkt-centres/pharmaceutical-engineering/* for more details.

Materials Chemistry, led by *Professor Stephen Rimmer*, became a fourth research centre in the Polymer Interdisciplinary Research Centre at Bradford, in 2015. Prof Rimmer (previously at Sheffield University) is a long-standing collaborator, having been involved in all of our Science

Bridges China/ UK-China AMRI Research Workshops. He is a Board member of the UK China AMRI. Aspects of Steve's work and that of his team can be found at *http://www.brad.ac.uk/life-sciences/chemistry-and-forensic-sciences/research/*.

The Polymer Science activity is focused on the synthesis and properties of functional polymers. Research in Chemistry includes:

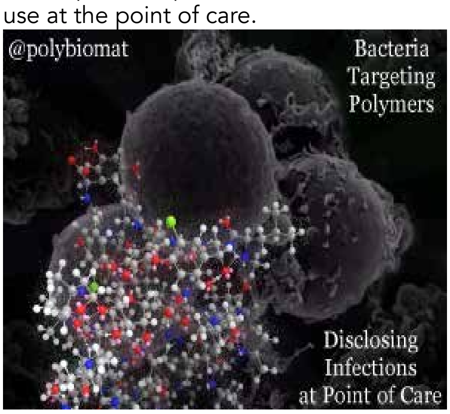
• Nanoscience • Medicinal Chemistry (our Institute of Cancer Therapeutics, is heavily involved in the Science Bridges China/ AMRI platforms) • Polymer Science • Functional Materials • Crystal Engineering and • Analytical Chemistry.

Functional polymers are produced using a variety of methods including radical, cationic and ring-opening polymerisations as well as step-growth techniques such as polyurethane synthesis. We also make extensive use of polymerisations in disperse media; such as emulsion polymerisations.

Recently, one of our focuses has been on producing functional hydrogels to support cells for applications in tissue engineering.

Here our aim is to control cells as they develop and grow and to examine how the structure of the materials affects performance and cell compatibility.

Another strong theme is to use functional polymers to detect pathogens in infective diseases and here we are developing unique medical devices for use at the point of care.



The Polymer IRC world class facilities were further enhanced by a major EPSRC Capital award which has seen extensive processing and characterisation facilities installed in our laboratory which promote the interdisciplinary working across Engineeirng and Life Sciences. Also, industrial donations including extensive biomedical materials extrusion and drawing facilities from Smith & Nephew Ltd (FET fibre line and Rondol fibre drawing frame, Prism extruder) and an Xplore PM5 stainless steel conical twin screw extruder and film line, aimed primarily at pharmaceuticals processing.

International

A key feature of the Polymer IRC at Bradford is our extensive international presence, collaborating with many leading overseas partners in Europe, India, the USA and especially China. The Science Bridges China platform led to the formation of the UK-China Advanced Materials Research Institute, and we have over 300 leading UK and Chinese academics actively involved in joint research projects, research exchanges, and Joint Laboratories.

Science Bridges China
www.sciencebridgeschina.com
中英科技桥
GLOBAL ENGAGEMENTS

UK-CHINA amri
Advanced Materials Research Institute

Joint International Laboratories

The Polymer IRC at Bradford has three Joint International Research Laboratories in China.

The first of these was formed with Sichuan SKLPME for **Polymer Micro Processing** in 2010, and was formally approved by MOST in 2014. It is directed by Prof Coates and Prof Qi Wang, with Prof Xia and Prof Whiteside), and we have achieved a range of joint research grants, high level publications, patents, awards and many researcher exchanges, including Chinese Scholarship Council awards. Prof Coates is an Honorary Professor of Sichuan and Prof Wang is an Honorary Professor of Bradford.

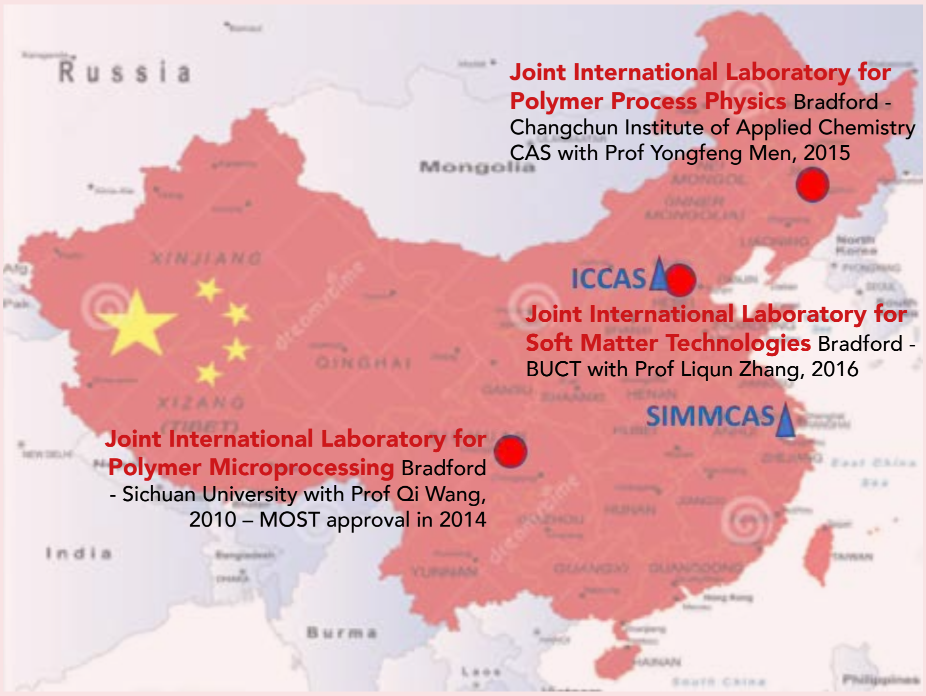
The second Joint Laboratory was formed with Changchun CIACCAS for **Polymer Process Physics** in September 2015, directed by Prof Coates and Prof Xianiu Yang and Prof Yongfeng Men, with Dr Caton-Rose and Prof Whiteside. We have excellent joint programmes, especially Royal Society Advanced Fellowship funding, and high level publications.

These were complemented in December 2016 by the new Joint International Laboratory for **Soft Matter Technologies** with BUCT – directed by Prof Liqun Zhang and Prof Phil Coates. We already have research exchanges, and excellent joint publications with Prof Zhang's team and Prof Coates is an Honorary Professor of BUCT. We look forward to joint programmes!

These laboratories are promoting our research collaborations and joint publications of leading research. They continue to provide a major platform for collaborative ventures and joint funding, and promote our international visibility.

Web sites

- **www.polyeng.com** - our main site, with full information and links
- **www.polymerirc.org** - includes the original Polymer IRC web site
- **www.ukchina-amri.com** - our UK China Advanced Materials Institute
- www.sciencebridgeschina.com



Some Industry projects

We collaborate with over100 companies, local to international, small to global.

These include:

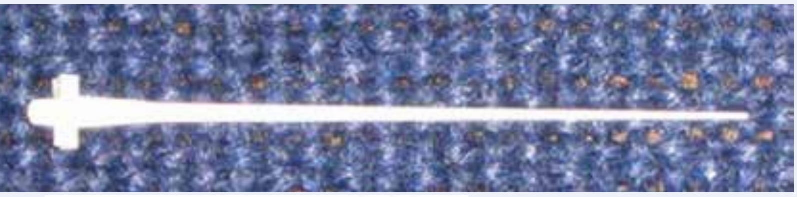
- Aedstem *cell assay testing device*
- Anton Paar *XRD*
- Arterius *oriented polymer stents*
- Astra Zeneca *pharmaceutical processing*
- Autodesk Moldflow *long fibre orientation, process models*
- BASF *materials processing*
- BNL *precision bearing moulding*
- Bristol Myers Squibb *pharmaceutical processing*
- Cella Energy *novel hydrogen fuel manufacture*
- Coronet Medical *surgical device moulding*
- Delstar *graphene filter products*
- Dow Building Products *structural products*
- DRFP *dental root canal filling precision cores*
- Dyson *surface feature moulding*
- Ebeam *polymer treatment*
- Floreon *PLA materials*
- GTS *medical devices*
- Invibio Ltd *development of PEEK medical devices*
- JRI Orthopaedics *medical devices*
- Kimberley Clark *support*
- Lacerta *characterisation technology*
- Low Carbon Futures *light collecting devices*
- Microsystems *precision tooling and processing*
- Natures Laboratory *nutraceuticals*
- Nylacast *cast nylon large scale*
- Orthoplastics *medical moulding*
- Innovate Orthopaedics *medical fixations*
- PolymerMedics *precision moulding*
- Precision Polymer Engineering *elastomers*
- Purac *PLA for shape memory fixations*
- Sabic *oriented polymer products*
- Sabic micromoulding *microneedles*
- Sofmat *anti-counterfeiting technologies*
- Sinopec BRICI Beijing *oriented polymers*
- Sinopec Yanshan *oriented polymers*
- Smith & Nephew *bioresorbable shape memory soft tissue fixations*
- Surgical Innovations *minimally invasive surgery tools*
- Thermo Fisher *polymer & pharmaceuticals*
- Thomas Swann *graphene products*
- TrakRap *packaging solutions*
- Ultrasion *ultrasonic injection moulding technology*
- Victrex *PAEK processing*
- Wittman Battenfeld *micromoulding technology*
- Xiros *medical fixations*
- Xplore *pharmaceutical processing*

In addition, we hold Bradford Industry Group meetings, open to all of our existing and prospective industrial collaborators annually, and run the biennial Polymer Process Engineering international conferences, which have strong industrial involvement.

Eovations LLC spin out in the USA, using our oriented polymer technology;

DRFP ProPoint - ultraprecision moulded dental obturation points;

Arterius clean room manufacturing for bioresorbalbe polymer stents, based on our process technology and solid phase orientation



Awards in the Polymer IRC

The internationally leading nature of the Polymer IRC is reflected in a range of prestigious international and national awards.

International Awards (Prof Coates)

2015 Tian Fu Friendship Award, of the People’s Government of Sichuan Province (first ever awarded)

2016 Sichuan Science and Technology Progress Award: International Scientific Co-operation (2016) –first time awarded.

2017 James L White Innovation Award of the International Polymer Processing Society, the top award of the PPS for leading achievement in polymer innovation

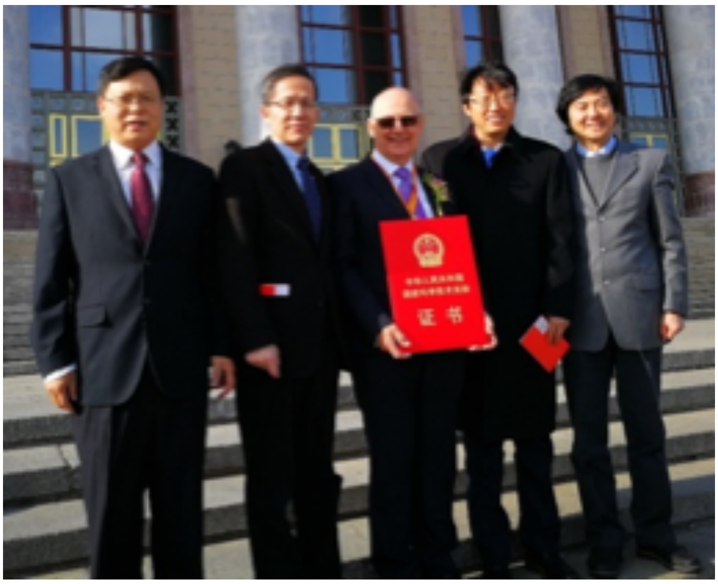
2018 Society of Plastics Engineers International Award, the top award of the Society, for lifetime achievement in polymer engineering

2018 International Science & Technology Cooperation Award of the People's Republic of China, presented by President Xi Jinping

The award; pre-meeting of awardees with President Xi Jinping and the full leadership team of the PR China

Award Ceremony in the Great Hall of the People

Medal presentation by Vice President, Madam Liu



Outside the Great Hall - with great support from Chinese colleagues, Prof Hesheng Xia, Prof Guangxian Li, Prof Liqun Zhang and Prof Yongfeng Men

Personal Awards

Prof Phil Coates:

- 1986 Elected Fellow of the PRI (later Institute of Materials)
- 1990 Elected Fellow of the Institution of Mechanical Engineers
- 1995 Elected Fellow of the Royal Academy of Engineering
- 1999 Netlon Award (Gold Medal) for Innovation in Processing, Institute of Materials
- 2006 Plastics Industry - Award for Personal Contribution to the Sector
- 2008 IoM3 Swinburne Award & Gold Medal – personal
- 2008 Honorary Professor (2008) Sichuan University
- 2008 Molecular Sciences Forum Professor, Chinese Academy of Sciences, Institute of Chemistry, Beijing
- 2009 Honorary Professor (2009) Beijing University of Chemical Technology
- 2010 Famous Overseas Scholar, Ministry of Education, China / Sichuan University
- 2010 High End Foreign Professor, Sichuan University
- 2011 Top Foreign Expert of the State Foreign Experts Bureau
- 2012 Changchun Institute of Applied Chemistry, Chinese Academy of Sciences honorary lecturer

Science Bridges China team awards

- 2008 RCUK Bradford Science Bridgs China top ranked bid
- 2008 UKTI/Y&H China Business Award – Best Education
- 2011 Interdisciplinary Working Award, Bradford University
- 2014 Vice Chancellor's Award for Outstanding Achievement, University of Bradford

Industry-related Awards

2007 Yorkshire Forward Innovation Award
2007 Best Knowledge Transfer Partnership Award, NE England
2008 EU Regio-Stars Award - Centres of Industrial Collaboration
2011 Medical Design Excellence Gold Award - Supplier
2014 Horners Award (Propoint)

Funding awards

We have over £10m current portfolio of research funding (over £30m in the past decade) from UK research councils, companies and international programmes.

Some key awards include:

- 1988-90 Wolfson Foundation: Wolfson personal Research Awards Scheme (£0.2m)
- 1989-2000 IRC in Polymer Science & Technology original award (£23m)
- 1998-2000 Enhamced Polymer Processing EPSRC award (Bradford, Queens Belfast, Brunel) (£2m)
- 1998 - 2003 MUPP EPSRC awards (Leeds, Bradford, Cambridge, Durham, Oxford, Sheffield) (£2.2m)
- 2007-9 EPSRC Virtual Institute - Polymer Process Structuring, with China (£0.23m)
- 2008 -12 RCUK Science Bridges China - top ranked award (£1.25m)
- 2012 EPSRC Global Engagments: China (£0.5m)
- RCUK-MOST 2013-15 (Bradford, Sheffield, Durham, Sichuan, ICCAS) (£0.2m)
- 2013-2017 111 programme (Sichuan/ Bradford, + international team (USA, Europe, led by Bradford; (9m RMB)
- 2013-18 EPSRC Soft tissue fixations (£0.9m)
- 2013- 2018 EPSRC MeDe: UK Centre of Innovative Manufacturing in Medical Devices (Leeds, Bradford, Newcastle, Nottingham, Sheffield Universities; (£5.7m)
- 2013 - 2021 Sinopec BRICI polymer orientation (£0.68m)
- 2014-2024 EPSRC Capital Grant: Advanced Materials for Healthcare (£5.42m including £2m UoB)
- 2015-18 Royal Society Newton Advanced Fellowship with Prof Men, Changchun; (£0.11m)
- 2015-2019 EU H2020 Marie Curie Microman network (£3.57m)
- 2017- 2020 EU H2020 HIMALAIA injection mouding platform (£3.9m)
- 2018-21 EPSRC Healthcare Innovation Partnership (£1.1m)

Publications

We publish extensively in leading journals, often with international co-authors.

Recent examples of our publications:

2018

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M Babenko, J Sweeney, P Petkov, F Lacan, S Bigot, B Whiteside Evaluation of heat transfer at the cavity-polymer interface in microinjection moulding based on experimental and simulation study Appl. Therm. Eng. 130, 865-876 2018

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C Kulkarni, AL Kelly, T Gough, V Jadhav, KK Singh, A Paradkar Application of hot melt extrusion for improving bioavailability of artemisinin a thermolabile drug Drug Dev. & Indust. Pharm 44 (2), 206-214 2018

Y Meng, L Ye, P Coates, P Twigg, In Situ Crosslinking of Poly(Vinyl Alcohol)/Graphene Oxide-Polyethylene Glycol Nano-Composite Hydrogels as Artificial Cartilage Replacement: Intercalation Structure, Unconfined Compressive Behavior and Bio-Tribological Behaviors, J Phys Chem C 122(5) DOI: 10.1021/acs.jpcc.7b12465 January 2018

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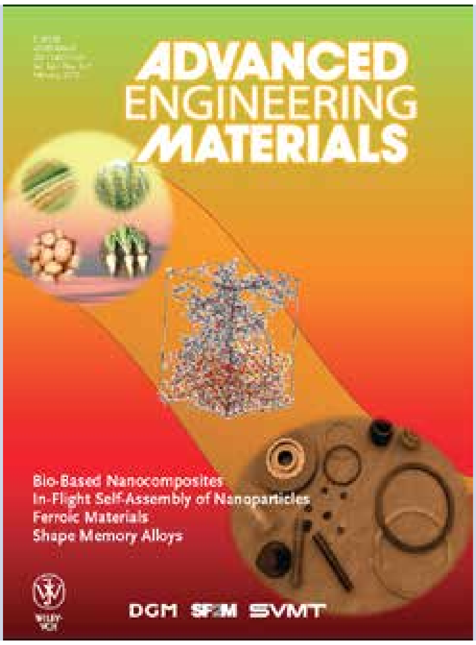
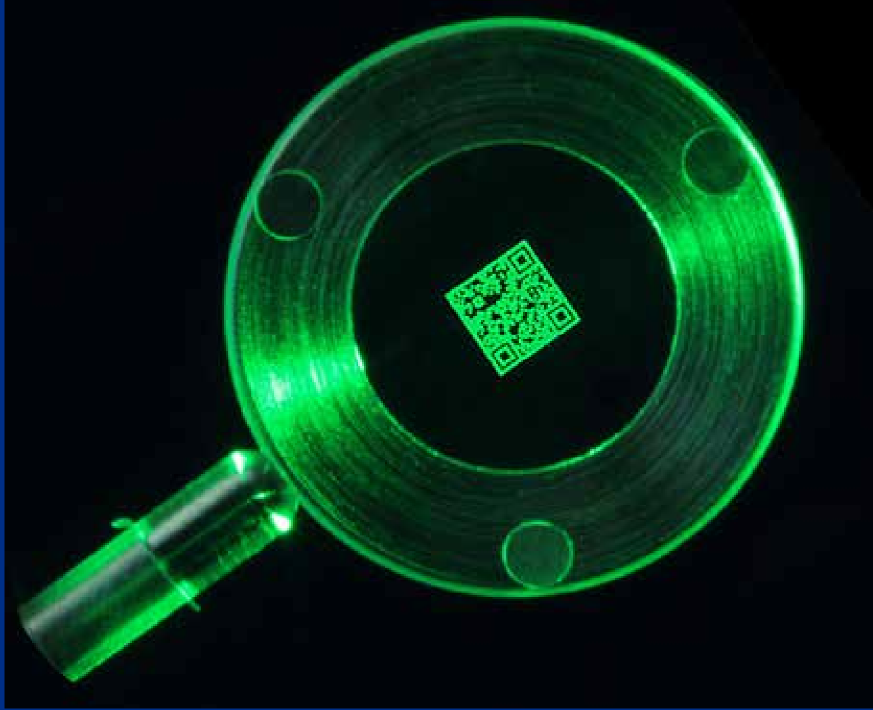
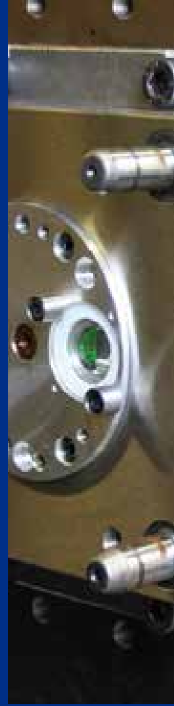
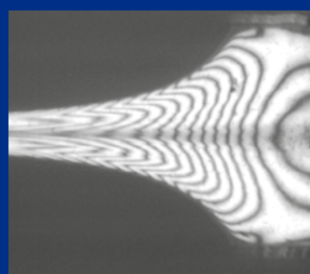



FLIR







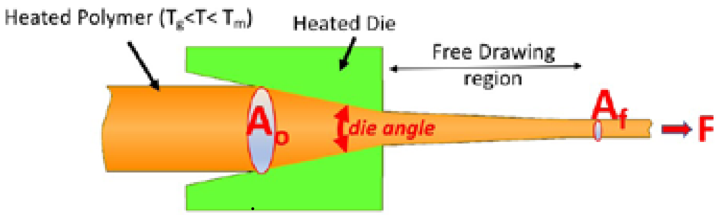

State Key Laboratory of Polymer Materials Engineering

Polymer IRC: Examples of Solid Phase Orientation products

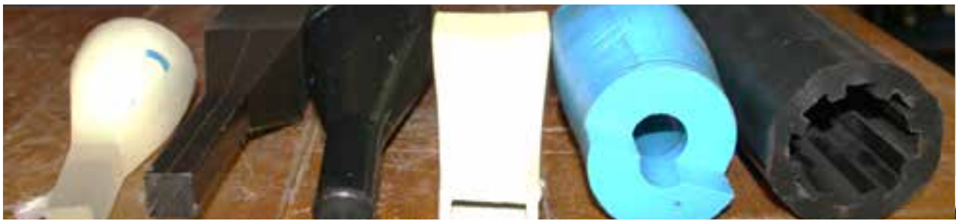
Polymer IRC:
Examples of Solid Phase Orientation products

A wide range of precision products, and novel processing technologies from our unique solid phase processing:

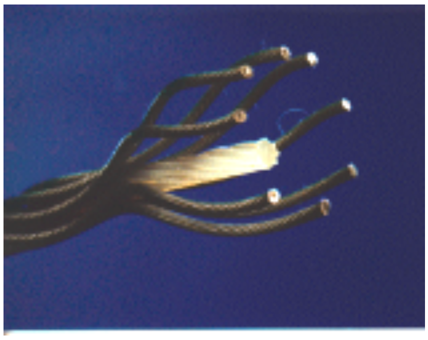
1. Historic - Die drawn rods and profiles (medium to large scale)



Draw Ratio λ = area reduction = A_0/A_f

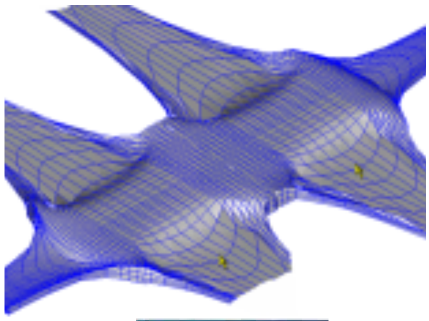


a. various sections for BP Chemicals (original licensees of patents) obtained by die drawing - tensile drawing of polymers through a convergent die, to form an oriented polymer product



b. Die drawn PP - Bridon International 'Trulift' elevator rope core
The die-drawn polypropylene rod formed an 'engineered core', exploiting a moderate draw ratio (axial strain), for winding steel ropes used for elevators. A continuous die-drawing process was developed with the company.

c. Die drawn POM - Bridon International rope material
Die drawn polyoxymethylene cable was produced in large lengths (>20km) aimed at long, high strength to weight ratio marine cables e.g. for stabilising oil platforms, where steel ropes would creep under their own weight.

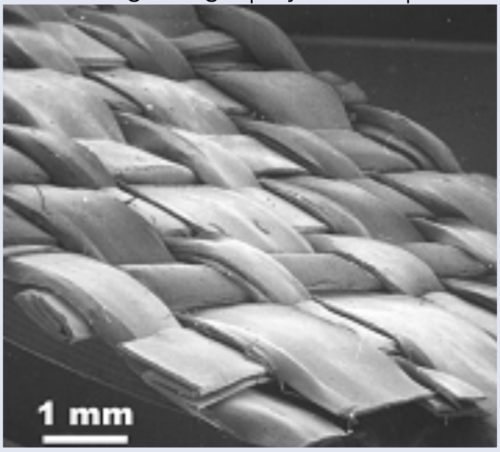


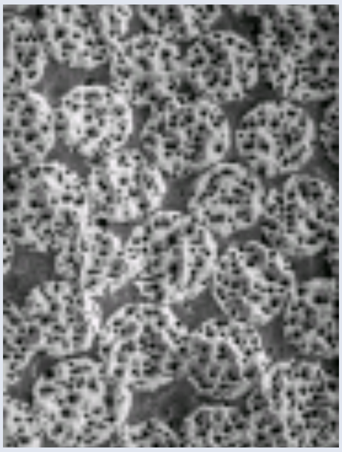
d. Netlon Tensar PP land stabilisation/ geogrids
Polypropylene sheet, with specific geometry punched holes is stretched biaxially in a sequential process to form a mesh with a distribution of strains (various degrees of molecular orientation) which gives a high strength mesh for land reinforcement applications (e.g. gabions, roads, airport runways).

e. Metal Box - PET transparent food containers
The enhancement of barrier properties, stiffness and clarity in die drawn PET tube aimed at see-through food cans.

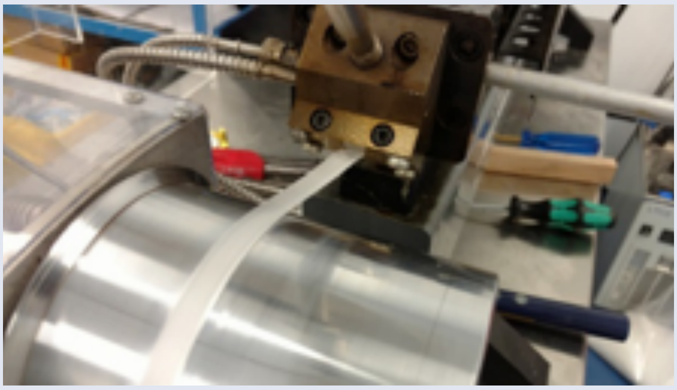
2. Hot compaction products

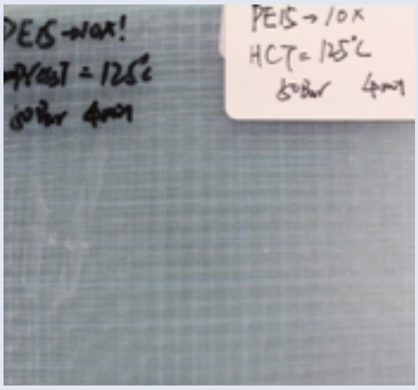
a. Historic items in PP – leading to Samsonite luggage, and other products (personal protection, speakers, automotive). Original IRC patents are via Leeds University. Hot compaction involves compression of oriented polymer tapes or fibres under controlled temperature and pressure to form transcrystalline bridges between the oriented fibres, making a single polymer composite. This can then be thermoformed.





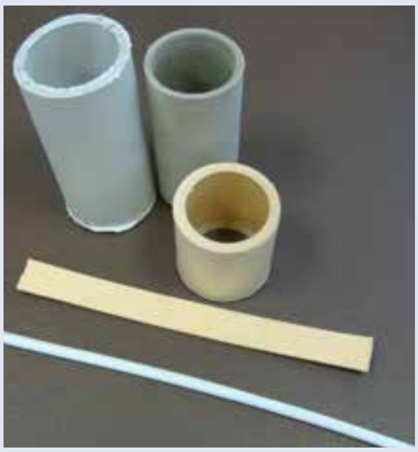
b. From die-drawn tape (Sinopec)





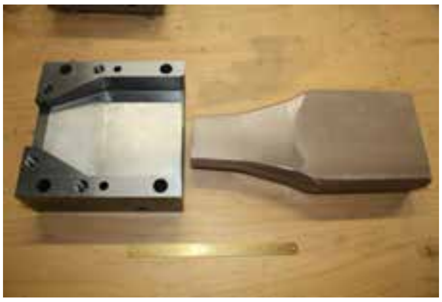
3. Wood filled polymer products

Various fillers have been used in die drawn products, including natural wood powder, which gives strong, stiff and lightweight products.



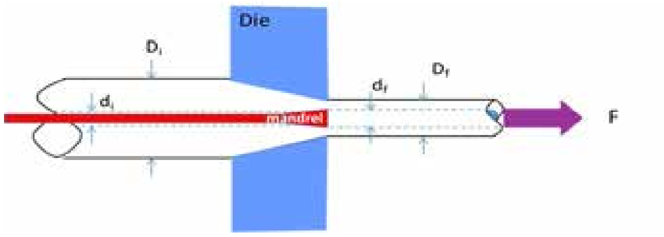
4. Dow programme – die drawn talc filled PP structural products

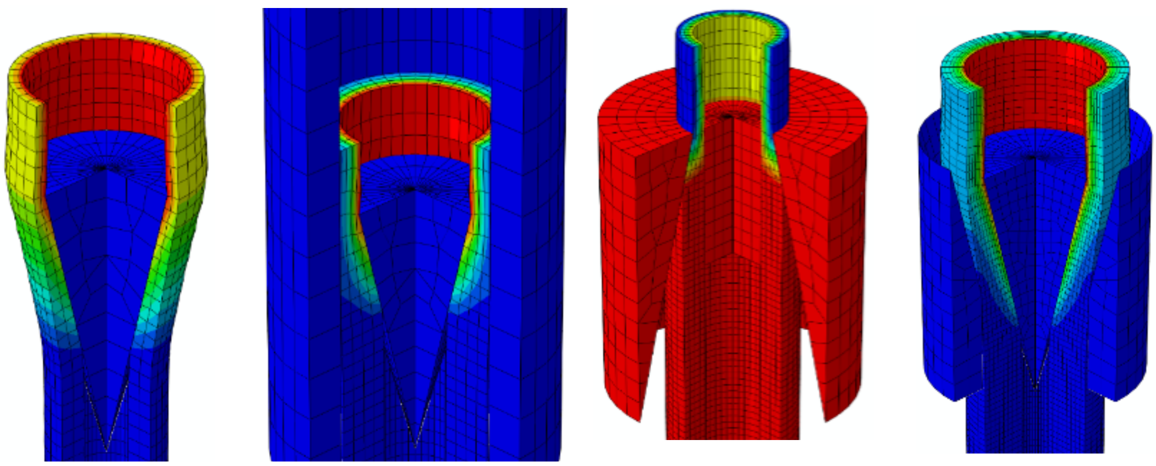
When PP filled with talc (43% in commercial products) is die drawn, cavitation occurs at the talc particles in parallel with molecular orientation of the PP matrix. This leads to controlled, unique high stiffness and strength but low density products, exploited via the spin-out company, Eovations LLC - a joint venture of Dow Building Products and United Forest Products in the USA; production is now near Atlanta and R&D in Michigan. We hold a portfolio of patents with Dow.



5. Tube die drawing

Drawing hollow polymer sections over a mandrel (a central shaped rod) leads to controlled biaxial orientation, with a balance of axial and hoop orientations. There are currently various confidential product interests - but see also sections 6 & 7.





mandrel only
lowest axial strain

constrained

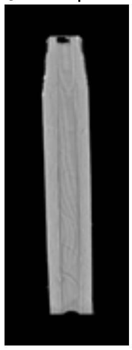
converging die, parallel mandrel

diverging die and mandrel
highest inner bore hoop strain

6. Smith & Nephew shape memory bioresorbable fixations

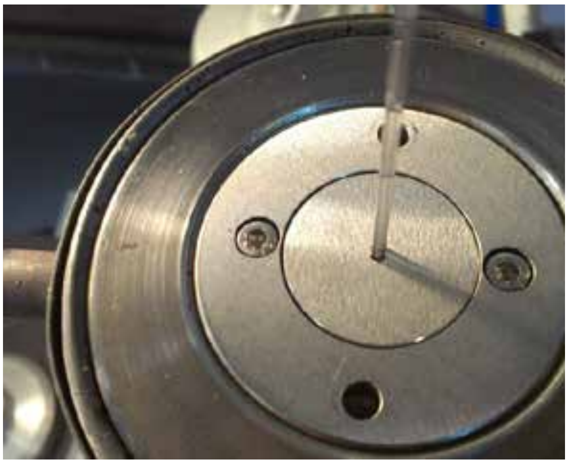
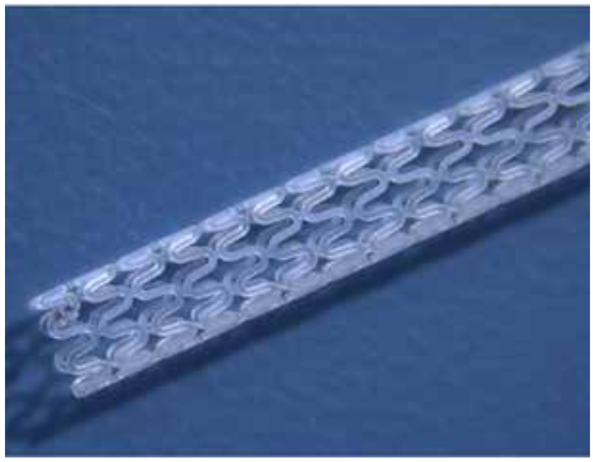
Die drawn rods including PLA materials can exhibit Shape Memory behaviour when a stimulus (e.g. temperature) is applied, allowing relaxation of molecular orientation. This can be exploited in cementless fixations e.g. of soft tissue to bone or bone to bone (see 10). The soft tissue devices are aimed at minimally invasive surgery. We have a portfolio of joint patents with Smith & Nephew.





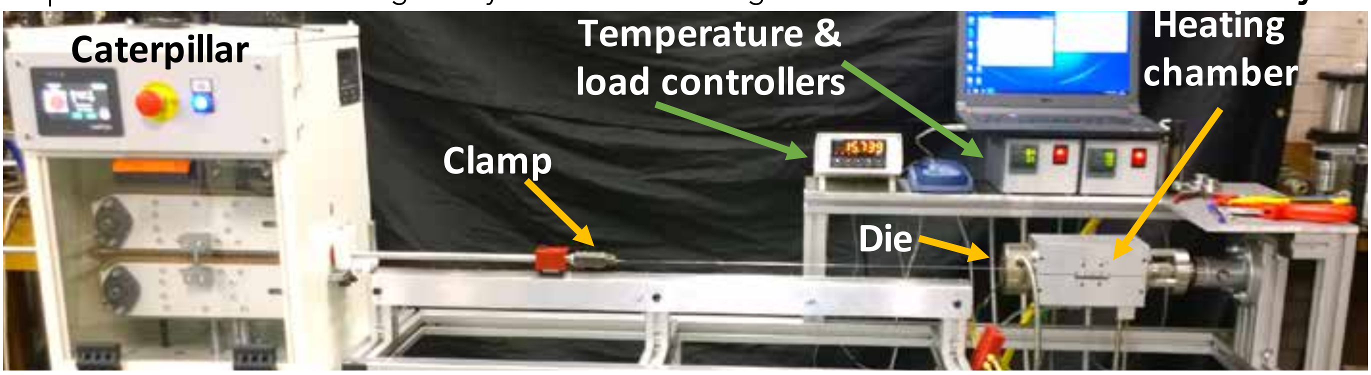

7. Arterius 'Arteriosorb' arterial stents

Precision die drawn micro tubes, laser cut, form **bioresorbable oriented polymer stents** which outperform the current 'best in class' stents for arterial repair. We have a joint patent with Arterius.

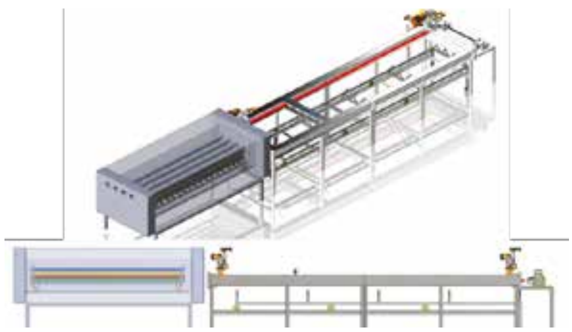
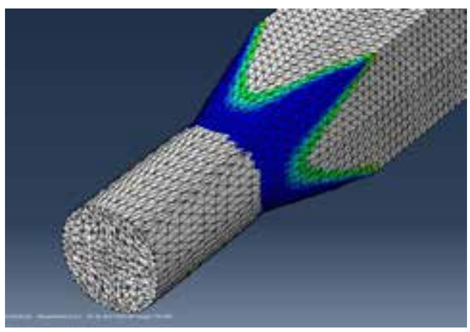



8. Precision small scale die drawing equipment

This precision micro die drawing facility is the basis of design for the **Arterius Ltd clean room facility**

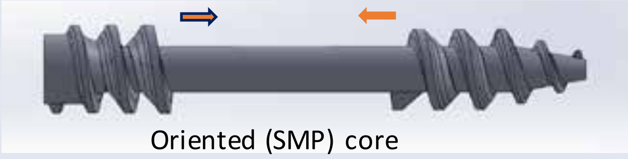


9. Nylacast – cast nylon die drawn products and technology for machine bearings

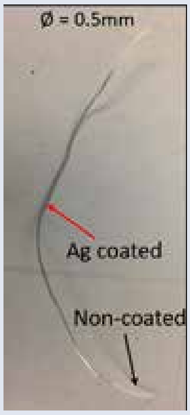
10. Shape memory oriented polymer (SMP) bone to bone fixations

Shape memory polymers with suitable additives can achieve body temperature reversion in clinically relevant timescales. The product shown has property distribution - the central element alone reverts.



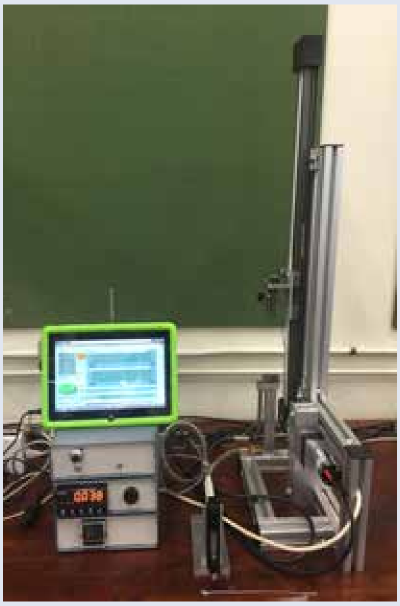
11. Shape memory sutures

Shape memory die drawn fibres or tapes can have a novel plasma coating (e.g. of antimicrobial agent, Ag - collaboration with Nottingham University).



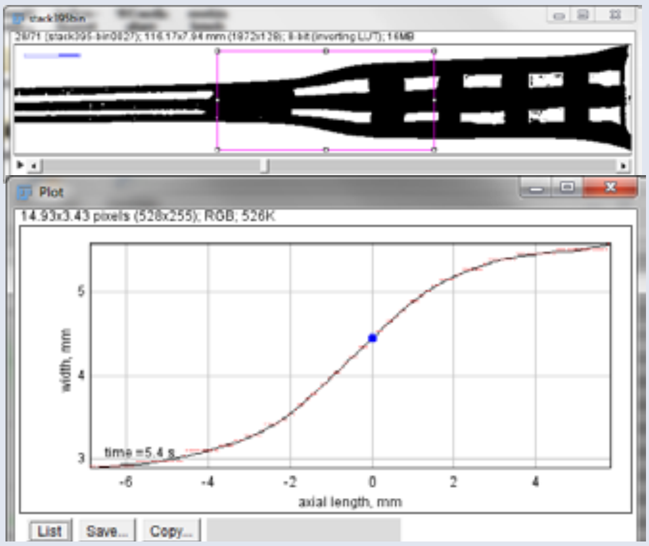
12. In-situ X-ray beam line small scale die drawing

A facility designed and installed for the Xray beamline at Changchun CIACCAS



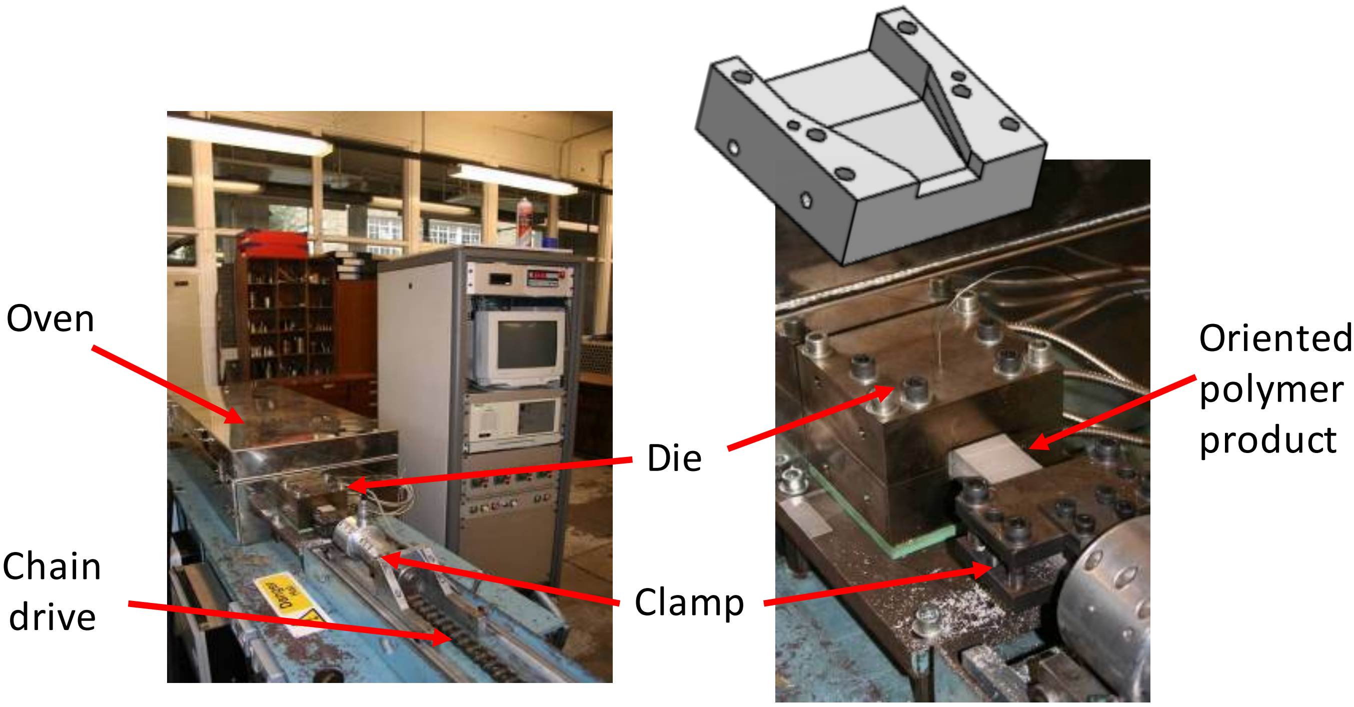
13. Automated imaging systems (hardware & software)

We capture, analyse and better understand the fundamental deformation behaviour of polymers, which is key to optimal die-drawing die designs.

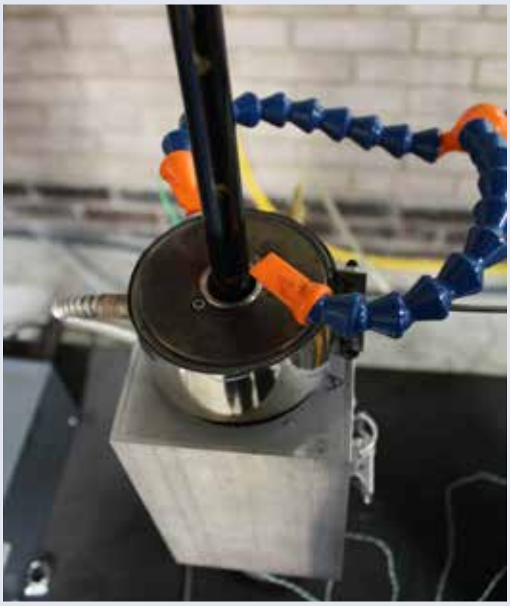


Solid Phase Orientation Processing of polymers:
a unique range of facilities at the Polymer IRC Laboratories

Large scale batch and continuous die drawing processes, draw speeds > 1m/minute:



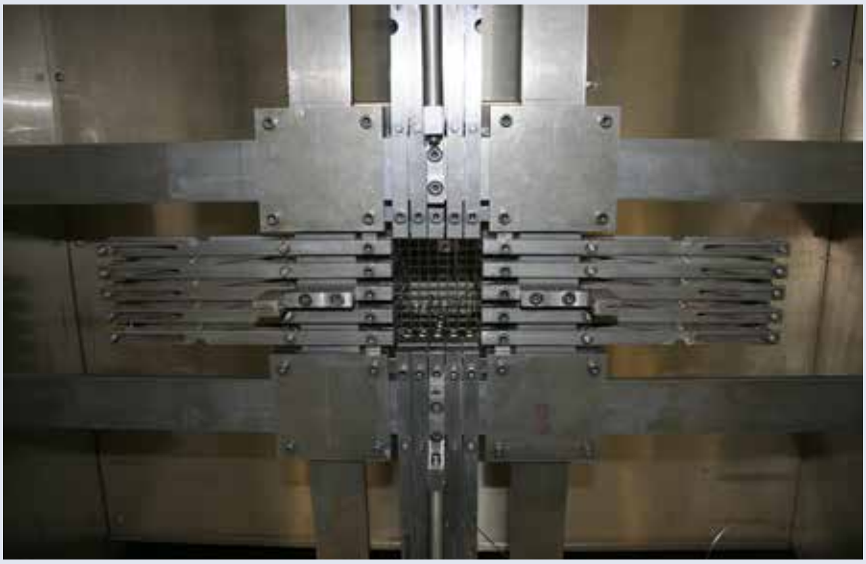
Medium to small scale die drawing:



Precision small scale extrusion and die drawing facilities:

Die Drawing Production in clean room installation at Arterius Ltd, Leeds, UK

Biaxial and constant width sheet stretching:



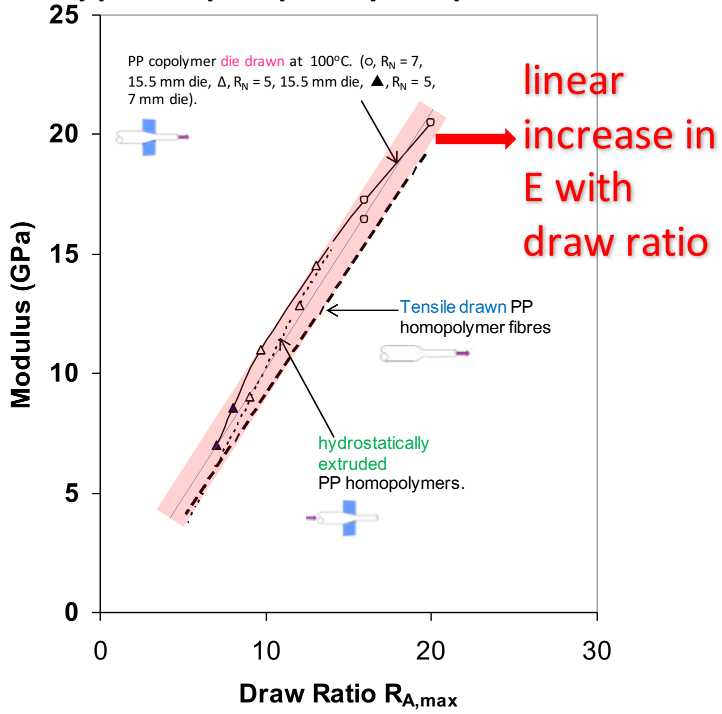
Advantages of solid phase orientation of polymers:

Solid phase orientation of polymers (at Tg < T < Tmelt) unlocks the potential of molecular orientation - a prime example of structuring polymers via processing - to dramatically enhance properties:

Solid phase deformation – typical property improvement

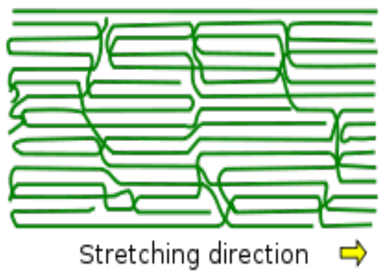
Material	Uniaxial Draw Ratio	Axial Young's Modulus (GPa) Isotropic	Axial Young's Modulus (GPa) Drawn
HDPE	20	1.0	20
Polypropylene	20	1.5	20
Polyoxymethylene	16	3.0	25
PET	4	3.0	10
PEEK	4	3.7	11
PVC	3	2.5	6
PVDF	6	2.0	4

i.e. typically 200 to over 2000% increase
(HDPE can reach 80GPa)

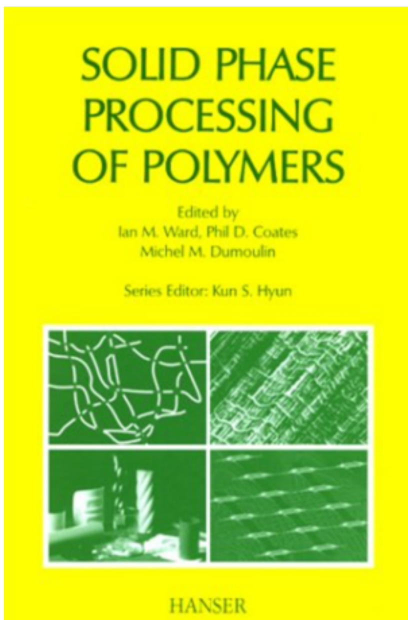


Molecular orientation-induced property changes can include:

- Very high strength and stiffness (via orientation + load bearing crystal continuity) – giving ultra high specific strength & stiffness
  - Specific stiffness, E/r to ~100 (steel ~2.5)
- Low creep;
- low axial coefficient of thermal expansion but high axial thermal conductivity;
- Low permeability of gases and fluids;
- Improved resistance to chemical attack
- potential shape memory materials (via recovery of orientation)
  - particularly for amorphous polymers
- anisotropic release of drugs in drug-eluting products



schematic of highly oriented polymer chains



Research text, edited by Ward & Coates
(ISBN 1-56990-307-7,
Hanser Gardner
ISBN 3-446-19622-6
Carl Hanser Verlag, 2000)

Solid Phase Orientation: background

Ian Ward promoted the fundamentals and practise of solid phase orientation of polymers in an eminent career at Leeds University after Bristol University and ICI Ltd; he was joined at Leeds by Phil Coates in 1974. Phil moved to Bradford University in 1978. They are both founder members of the Polymer IRC, of which Phil is now Director, and they developed extensive research programmes particularly involving Drs Peter Hine and Paul Unwin (Leeds), Dr Fin Caton-Rose (Bradford) who is currently Manager for the Solid Phase Orientation area, Prof John Sweeney, Keith Norris and Glen Thompson all initially of Leeds University, then Bradford University.

Interdisciplinary Research Centre in Polymer Science and Technology founder members:
Back row:
Robin Harris (Durham), Geoff Davis (Leeds), Bill Colwell (business manager);
Middle row:
Phil Coates (Bradford), Eric McIntyre (Leeds), David Bower (Leeds), Alan Duckett (Leeds);
Front Row:
Jim Feast FRS (Durham), **Ian Ward FRS (Leeds, first Director)**, Tony Johnson (Bradford).

The IRC was initially formed in 1989 by an EPSRC grant which extended to £23m over 11 years;
a forerunner at Bradford was the Polymer Research Unit, founded in 1985 by Mike Edwards (Chem Eng), Tony Johnson (Chemistry) and Phil Coates (Mech Eng).

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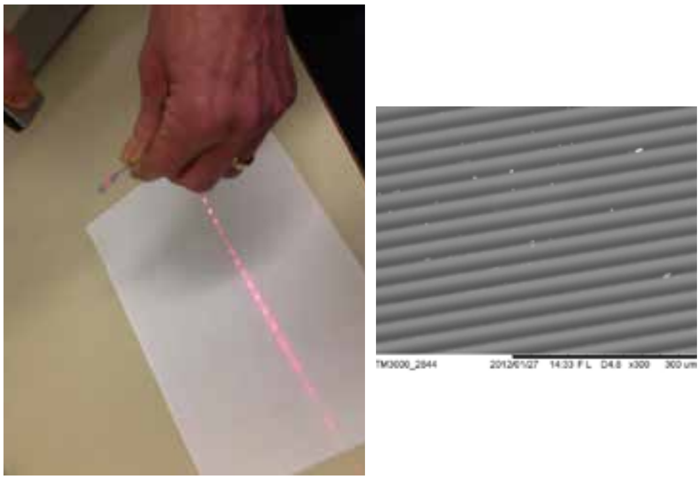
Dr Fin Caton-Rose p.caton-rose@bradford.ac.uk; Prof John Sweeney j.sweeney@bradford.ac.uk
See www.polyeng.com; www.polymerirc.org; www.sciencebridgeschina.com; www.ukchina-amri.com

Polymer IRC: Examples of Ultraprecision moulding products

Diffraction Gratings

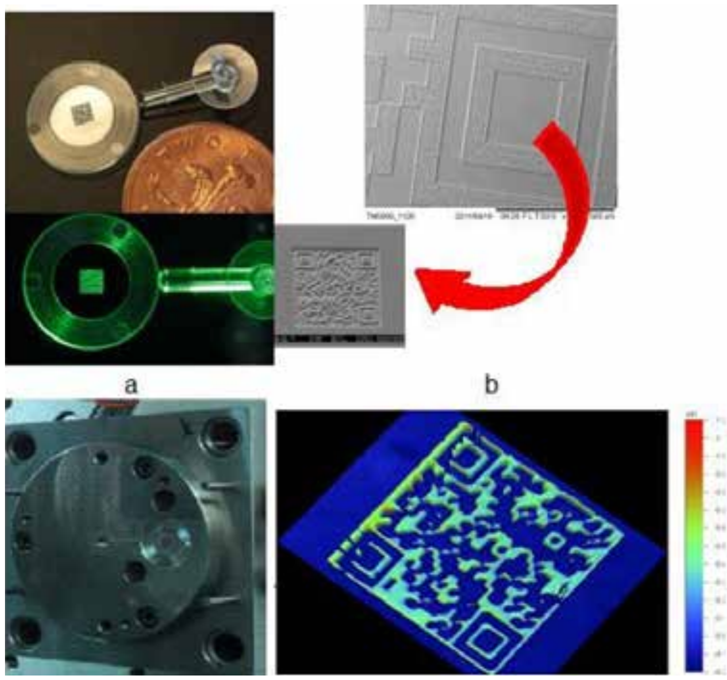
Diffractive optics structures are used when there is a need to separate light of different wavelengths with high resolution. A large number of parallel, closely spaced slits constitutes a diffraction grating. The condition for maximum intensity is the same as that for the double slit or multiple slits, but with a large number of slits the intensity maximum is very sharp and narrow, providing the high resolution for spectroscopic applications. The peak intensities are also much higher for the grating than for the double slit. These kind of devices can be used for: diagnostics, anti-counterfeiting, etc. The components were moulded in LED 2045 PC on the Battenfeld Microsystem 50 with high replication of the diamond machined insert. Three different line spacings are available on the same insert.



Example diffraction pattern obtained through the component; SEM image of the grating

Anticounterfeit QR code

A QR code (Quick Response code) is a type of matrix barcode (or two-dimensional code) and due to its fast readability and comparatively large storage capacity became very popular for marking high quality products. The code consists of black modules arranged in a square pattern on a white background. In our case a high quality laser machined QR pattern was created in order to mark injection moulded products. For even higher precision in a pixel of the laser machined coded is reproduced with high precision via FIB (Focused Ion Beam) technique the same QR code in miniature (~50µm).
The parts were fabricated on a Battenfeld Microsystem 50 using various polymers and injection parameters. Positive results were obtained on 5 polymers with high replication of the original metal QR code.



QR codes: a – Image of the QR code injected moulded component; b – SEM image of the laser and FIB patterns; c – the QR code mould, d – White light interferometry measurement of the polymer QR code

DRFP - SmartPoint

The traditional natural rubber fillers, shaped like a tooth pick, used to fill root canal cavities doesn't always fill the area completely. The DRFP 'SmartSeal' system uses a bespoke polymer core, to which a hydrophilic coating is applied. This would expand on contact with the moist tissue until all of the cavity is filled.
Because the polymer had to show up on x-ray, it needed to contain a ceramic powder, but this then made it difficult to produce to the small sizes required by dental practitioners and hard to ensure consistency in the production. Whit the appropriate tool design and process parameters the final product was achieved with high quality standard.
The product is fabricated via injection moulding on an Battenfeld Microsystem 50 using a three plate mould.

Image of the injected moulded SmartPoint, the commercial product and Medical Design Excellence Award

Heat Exchange Device

A heat exchanger is a device which can achieve efficient heat transfer from one medium to another. The device produced in our labs was fabricated via injection moulding Fanuc Roboshot S2000i100A machine for cooling electronic circuitry. The poor thermal performance of the polymer was improved by compounding with carbon nanotubes (CNTs).

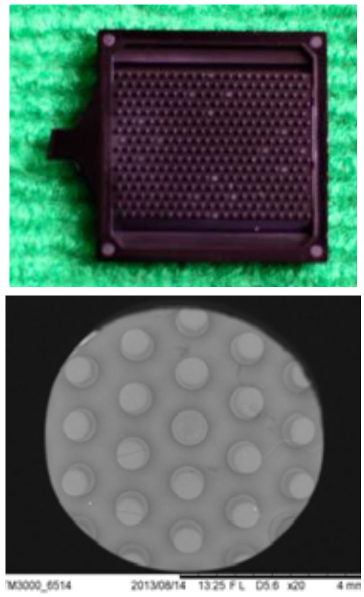
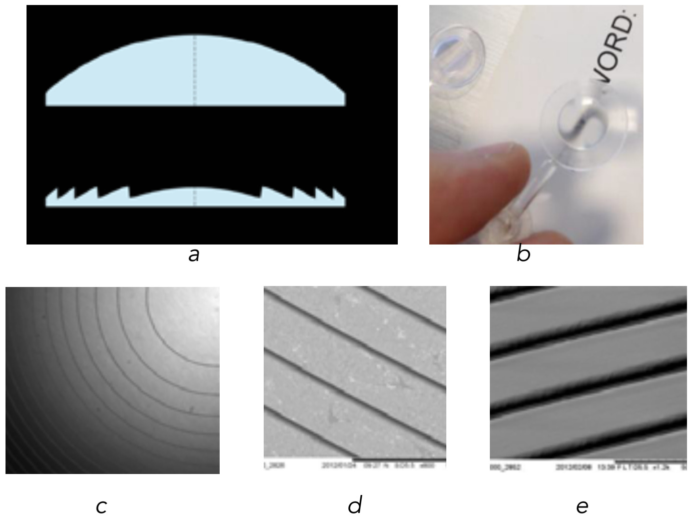


Image of the injected moulded components; SEM image of the component in polymer

Fresnel Lenses

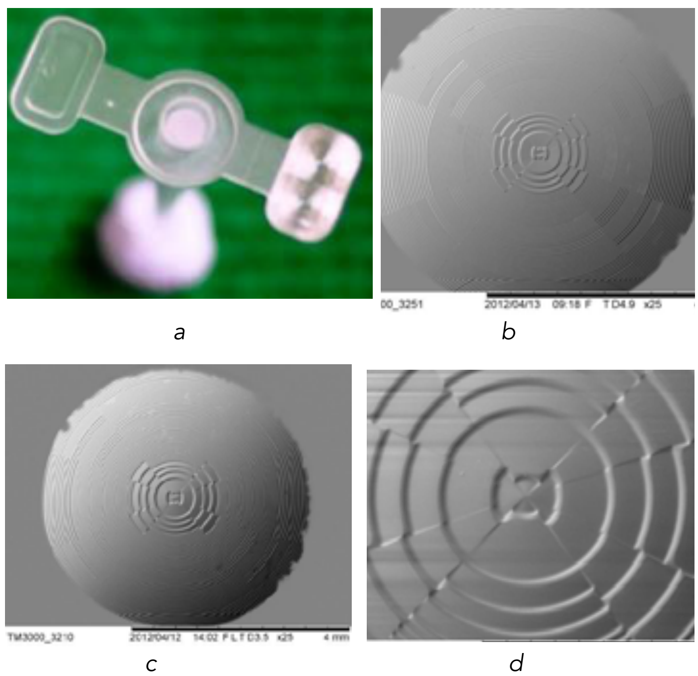
The contour of the refracting surface of a conventional lens defines its focusing properties. The bulk of material between the refracting surfaces has no effect (other than increasing absorption losses) on the optical properties of the lens. In a Fresnel (point focus) lens the bulk of material has been reduced by the extraction of a set of coaxial annular cylinders of material. The polycarbonate lenses are produced via injection moulding on a diamond machined mould insert using a Battenfeld Microsystem 50. Low height compact lenses have applications in: camera phone flashes, collimating lenses etc.



a -Construction of a Fresnel lens from its corresponding asphere. Each groove of the Fresnel lens is a small piece of the aspheric surface, translated toward the plano side of the lens. b - Fresnel lenses acting as magnifier, – SEM image of the diamond machined mould insert, c,d,e,– SEM images of the Fresnel lenses reproduced in PC in different groove regions

LED diffuser

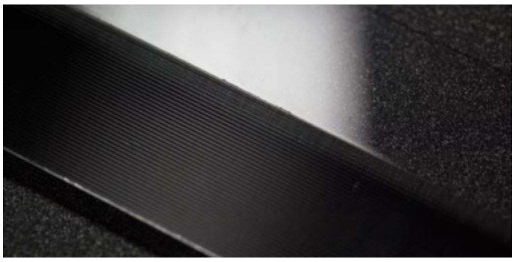
In optics, a diffuser is any device that provides uniform, diffuse lighting from a point source. This micro-structured lens consists of a mixture of refractive and total-internal reflection structures arranged in a sectored way in order to perform the beam shaping of light emitted by an LED.
The combination of both types of structures allows to have superior performances in terms of efficiency and uniformity of the resulting distribution pattern.
A range of materials have been used, including PC, PMMA, COC and COP.
The samples were produced on Fanuc Roboshot S2000i100A injection moulding machine using a high precision injection/ compression moulding technique.

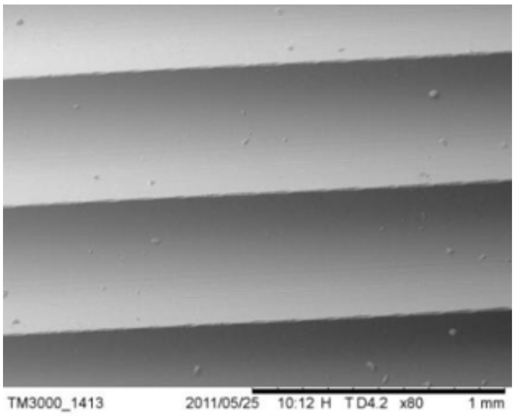


a – injection moulded LED diffuser; b - SEM image of the LED diffuser insert, c, d – SEM image of the polymer component

Energy harvesting devices

The light collecting devices are used to concentrate light on a photovoltaic (PV). They are optical devices and in our case the aim is to capture more sunlight then a normal PV. The device is used to channel light to photovoltaics by applying a sensitive dye on the injected moulded component. The components are moulded on the Fanuc Roboshot S2000i100A on a diamond flycut insert produced in amorphous aluminium (Durham). The polymers used were: Polycarbonate, polystyrene and COC. The project was in collaboration with the University of Sheffield

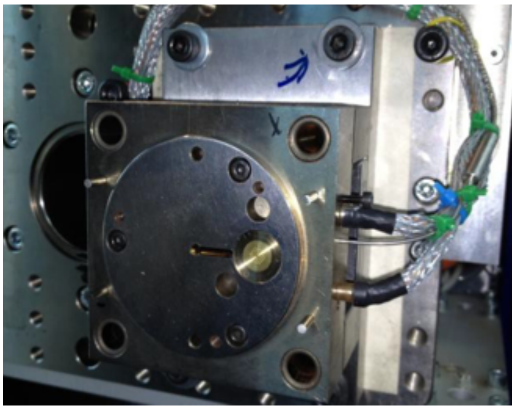




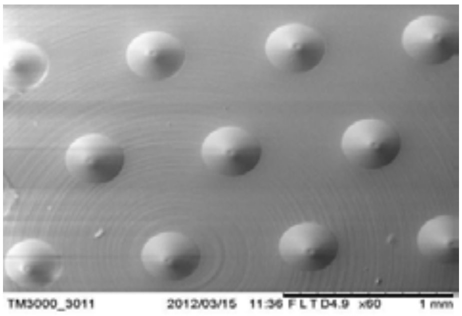
a light collecting device,
SEM image of the light collecting device

Transdermal microneedles

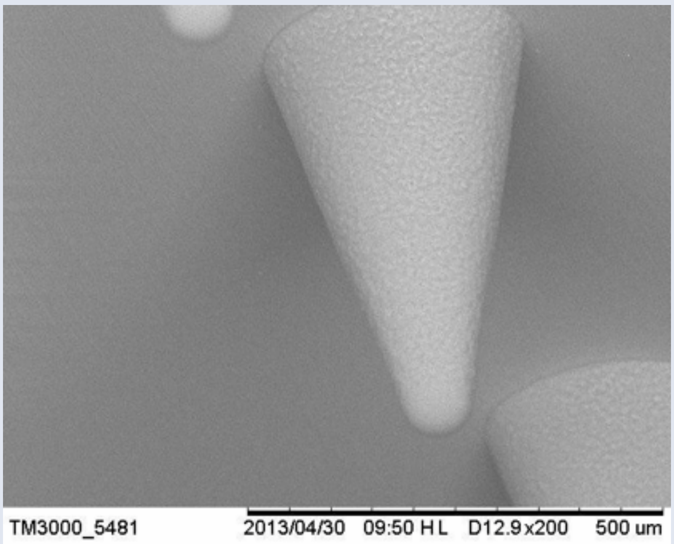
Transdermal drug delivery is a simple and painless injection method. Micro-needles (MN) allow a drug to be injected into the epidermis through the stratum corneum. The advantage of the method is that the micro- needles are thin enough to avoid touching the nerves. Micro-injection moulding of micro-needles can lower costs, with reduced moulding cycle time. This is considered to be the most promising route for mass production of MNs. Microneedles produced in our labs were moulded on a Battenfeld Micropower 15, exploring various materials.

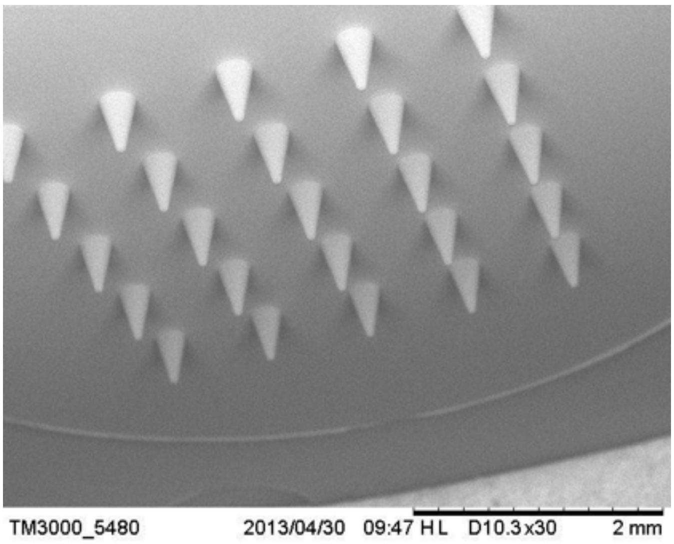


The mould used for replication of MNs,



SEM image of initial MNs
manufactured by microinjection moulding,





SEM images of microinjection moulded higher aspect ratio MNs


IRC
polymer

The UK Polymer Interdisciplinary Research Centre

A simple philosophy:

Aim to be the best at what we do

Build bridges – science, technology and people

Cross the bridges!

Delivering 21st century polymer-rleated research and knowlege transfer aligned with UKRI strategic aims, we provide researchers with an environment in which ideas and innovations can flourish. We build locally, nationally and globally (with 3 Joint laboratories in China), to help develop fundamental understanding, meet societal needs and benefit our industry sector. We work with over 100 companies, and have an excellent track record of delivery.

Early career 'rising star' researchers are particularly important to us – we have in the past few years run over 60 Researcher Exchanges with overseas partners, including our collaborators in other UK universities, to help develop longer term research strengths and international relationships.

Our 'process structuring' research addresses a wide range of sectors, including advanced healthcare, precision engineering devices, electronics, transport, construction products and consumer goods. We are at the leading edge of advanced manufacturing technologies, including process instrumenation, process modelling and control. We uniquely reach across polymer synthesis, polymer physics and engineering and pharmaceuticals processing. Polymers are vital materials - too good to waste – they are chemically rich, made from the amazingly rich oil (only a small fraction of which is turned into polymers, which contain the same calorific value as the oil they are derived from); it makes no sense to scrap polymers having invested in making these important and highly useful materials. We are consequently much involved in 'green processing' and in promoting the Circular Economy approach which aims to promote recycling, re-use, and to move away and from the traditional make-use-dispose economic model.

We strongly welcome interdisciplinary collaborations in the UK and worldwide.

Professor Phil Coates FREng
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