Institution: University of Bradford

Unit of Assessment: B12 Engineering

Title of case study: MicroForm® - a new process for manufacturing ultra-precision components with high value rubber materials.

Period when the underpinning research was undertaken: 2001-2016

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof Ben Whiteside	Professor of Precision Engineering	2001- present
Prof Phil Coates	Professor of Polymer Engineering	1978 - present
Prof Tim Gough	Head of Mechanical and Systems Eng.	2000 - present
Prof Adrian Kelly	Professor of Process Engineering	1997- present

Period when the claimed impact occurred: 2015-2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Pioneering research in the field of Thermoplastic Microinjection Moulding was applied to develop a new understanding of manufacturing processes for high value synthetic rubber components. This has resulted in a single process that replaces a multi-stage manufacturing process chain, which has been implemented in a successful business unit at a leading international component supplier. The new knowledge brings significant benefits in terms of new design tools, improved component quality, increased process reliability and higher volume outputs. This has resulted in new market opportunities, including silicon wafer lithography process equipment and high-performance chemical analysis systems.

2. Underpinning research (indicative maximum 500 words)

The academic team members who contributed to this case study are Profs Coates (1978 – present), Whiteside (2001 – present), Kelly (1997 – present) and Gough (2000 – present). Prof Coates is the Research Leader of the Polymer Interdisciplinary Research Centre at The University of Bradford and started the first active research in the area of microinjection moulding with an EPSRC grant 'Micromoulding' in 2001 (RG1). Prof Whiteside was employed as a PDRA to deliver the work, has seen a number of promotions since and now leads the Polymer Micro and Nano Technology Research and Knowledge Transfer Centre. Prof Kelly provides expertise in material optimisation for processing and rheology. Prof Gough is an expert in advanced characterisation methods for polymers in manufacturing processes.

Since 2001 the team has performed extensive research work in the emerging area of ultra-precision polymer manufacturing processes to produce high value components with microscale tolerances and micro and nano scale surface patterns. The processes offer a route for high volume outputs of critical components for applications in key industries including telecommunications, medical devices and optics.

Such manufacturing methods have unique processing environments with very high flow rates and thermal gradients (spatial and temporal) that far exceed those encountered in conventional moulding processes. These can result in unexpected material flow behaviour and molecular configuration during cooling, which can significantly affect the physical properties of the resulting components (1). The team saw this as a significant opportunity for fundamental research to

develop a clearer understanding of material behaviour during the process which would lead to the development of improved manufacturing systems for industrial supply chains.
The team developed advanced process characterisation tools to perform a more accurate assessment of the process environment, and to provide opportunities for process monitoring and control. The small scale and complexity of the mould tools posed significant challenges for in-process measurements (as the entire cavity filling process could happen in just a few milliseconds). To overcome the limitations of existing industrial process monitoring systems, the team developed bespoke high speed data acquisition systems (2,3). Material flow characteristics within the process were not well understood, so the team developed a new high shear rheometry technique that was able to collect data at shear rates representative of micro injection moulding which were typically three orders of magnitude higher that the industry standard. The resulting data showed unexpected polymer behaviour related to the extreme stresses and high pressures encountered in the process (5). To investigate the flow behaviour within the mould cavity itself, high speed process imaging systems were developed that could record the cavity filling directly. The team pioneered the technology for microinjection moulding applications and developed systems capable of 50,000 frames per second with high resolution (4).

The quality of the data generated became attractive for mould-filling flow simulation software providers and the team has worked closely with the industry leader, Autodesk Simulation Moldflow Insight, to validate results and provide models to improve simulation accuracy. The models generated have been presented to the Moldflow User community at dissemination events (6). Further work with Moldflow created knowledge about the heat flux behaviour in micromoulding processes (RG5) and how thermal characteristics influenced the processing environment and the resulting final product properties.

These fundamental research activities were subsequently broadened to include national (RG2, RG3) and international partners to explore further grant-funded research activities, for applying the technology for real world production of precision components. The Bradford team was a key partner in the EU FP7 project 'COTECH' (RG4), a multi-partner programme that saw the development of new processes for a range of industrial applications and enabled the release of the Wittmann-Battenfeld Micropower 15 injection moulding machine. The University had the first example of this machine in the UK and this technology was adopted for the KTP project (RG6) that resulted in this case study.

In 2013, Precision Polymer Engineering Ltd and the team were awarded a KTP with the aim of developing new micromoulding processes, product quality assurance methods and new simulation strategies for producing virtual models of the manufacturing system. The work built on the extensive expertise in thermoplastic materials to develop new understanding of the behaviour of the high-performance elastomers in the PPE material portfolio. Key research breakthroughs were made for tooling design (optimised for high temperatures and low viscosity flow behaviour), process optimisation (determining ideal process windows for material families and applications), process simulation (development of new material models and modelling strategies) and part characterisation (developing in-process machine vision methods and CT scanning protocols) which demonstrated the viability of a full production platform that produced the impact in this case study.

3. References to the research (indicative maximum of six references)

1) Whiteside, B.R., Martyn, M.T., Coates, P.D, Greenway, G., Allan, P.S., Hornsby, P.R. (2003), Micromoulding: process characteristics and product properties. *Plastics, Rubber and Composites: Macromolecular Engineering.* 32 (6) pp 231-239. https://doi.org/10.1179/146580103225002650

2) Whiteside, B.R., Martyn, M.T., Coates, P.D. (2005) In-process monitoring of micromoulding - assessment of process variation. *International Polymer Processing* 20 (2), pp 162-169 https://doi.org/10.3139/217.1876

3) Whiteside, B.R,, Martyn, M.T., Coates, P.D. (2006) Introduction to Micromoulding, in: Greener, J. and Wimberger-Friedl (eds) *Precision Injection Moulding*, pp 239-264, Hanser Munich ISBN 13:978-1-56990-400-8

4) Whiteside B.R., Spares, R., K Norris, K., Ono, Y., Brown, E.C., Kobayashi, M., Cheng, C.-C., Jen, C.-K., Coates, P.D. (2008) Optical imaging metrology for micromoulding cavity flows and products. *Plastics, Rubber and Composites: Macromolecular Engineering*. 37 pp 57-66 https://doi.org/10.1179/174328908X283384

5) Kelly, A.L., Gough, T., Whiteside B.R., Coates, P.D. (2009) High shear strain rate rheometry of polymer melts. *Journal of Applied Polymer Science* 114 pp 864-873. https://doi.org/10.1002/app.30552

6) Whiteside B.R., Caton-Rose P. (2013). Simulation Moldflow Analyses at the University of Bradford. Autodesk University 2013. https://www.autodesk.com/autodesk-university/class/Simulation-Moldflow-Analyses-University-Bradford-2013#presentation

Grants

RG1 P Coates Micromoulding GR/R15573/01 EPSRC GBP228,000 04-2001 – 03-2003

RG2 P Coates MNT Network Capital Facilities CHBS/007/00050 TSB GBP330,000 04-2006-03-2009

RG3 P Coates Micro & Nano-Moulding 901117 Yorkshire Forward GBP792,000 2001-06-12-2008

RG4 Ben Whiteside COTECH - COnverging TECHnologies EU FP7 No214491 GBP440,000 (of GBP6,000,000) 10-2008-10-2012

RG5 Ben Whiteside Thermal contact resistance modelling for polymer processing EP/I014551/1 EPSRC GBP536,000 04-2011-03-2014

RG6 Ben Whiteside PPE Ltd KTP KTP008982 InnovateUK GBP118,000 01-2013 – 01-2015

4. Details of the impact (indicative maximum 750 words)

Precision Polymer Engineering (PPE) Ltd (prepol.com) supplies high value performance sealing components to key markets from its main facilities in Blackburn, UK (materials and technical development) and Brenham, Texas, US (manufacturing and local support for oil and gas/semiconductor industries). PPE historically specialises in compression moulding manufacturing lines to produce a range of standard and custom components, but before the link with Bradford, it had some rudimentary injection moulding capabilities which operated with limited success. The process had multiple stages that contained many potential failure mechanisms, which caused significant issues with product quality and yield with an associated impact on the process productivity.

As the relationship with Bradford developed (through the KTP) it soon became clear from the results of the early work packages that the new process developments provided significant opportunities for new product lines at PPE. The KTP was completed with very significant outcomes that demonstrated the feasibility of a single automated process, capable of producing high quality components that are defect free, fully cured and quality assured with a 100% inspection system in just a few seconds. When compared with the existing 5 step process at PPE, the new process had significantly improved yields with very few defective components compared to the previous defect rates of 40% or more. The final report for the KTP captured the significance of the Bradford contribution which embedded “Knowledge and principles of micro moulding technologies, mould flow simulation software, access and knowledge gained through Bradford University on use of high magnification and measurement techniques and robotics." This created "new business opportunities in areas such as micro fluidics, bio medical, lab on a chip etc". (A)

These results provided the confidence to try and implement more challenging processes and a follow-on project with the University saw the development of complex insert/overmoulding processes to provide hybrid devices consisting of rigid and compliant properties in a single component.

The improved functionality, quality and productivity of the new process led to the commissioning of a new business unit within the company – MicroForm®. This unit specialises in microscale component production, using high value synthetic rubbers. The production facility is fully operational, providing components for silicon wafer handling systems, high value fluid management systems and customised sealing applications. Specifically, the capability to make wafer handling pads from the right perfluoro elastomer material, meeting tight tolerances and strict quality requirements, has allowed PPE to engage and maintain a very strong relationship with one of the biggest semiconductor OEM groups. The impact of this research has also directly benefitted PPE in other key areas as follows:

1) **New product lines:** 14 new component lines have been manufactured and qualified by customers (B)
2) **Improved products:** Components produced using the new process show significant improvements over those manufactured using existing processes, as demonstrated by the following customer testimonial:
   "The quality of MicroForm® part looks superior with tighter tolerances. The lip radius of the MicroForm® parts is significantly smaller and visually looking a lot sharper. This will allow the lip to be readily energised and provide better sealing performance" – Semiconductor process equipment manufacturing Engineer (C, D, E).
3) **Process reliability:** The knowledge gained from the Bradford team has allowed the creation of 12 new material grades optimised for the MicroForm® process. These bespoke materials, combined with the reduced number of stages in the process and the integrated camera-based quality assurance, has ensured that the occurrence of defective components returned by customers has been almost completely eradicated (B).
4) **Improved process yields:** for highly complex components. A sealing component for a challenging electronics application saw a fall in reject rate from over 50% to under 5% when the process moved to MicroForm®. A second flow control valve application saw a fall from 95% to under 25% reject rate (B).
5) **Better design capabilities:** The new precision moulding expertise embedded within the Company allows the creation of new solutions for customers with the confidence that they are going to be successful without requiring extensive development work (D).
6) **Refined development processes:** The work with the Bradford team provided the expertise for adoption of flow simulation software within the company, which dramatically accelerated the manufacturing and tooling design processes by replacing a resource-intensive trial and error method with a virtual engineering approach. This accelerates development times and reduces the requirement for tooling modification to repair process deficiencies (C,D).
7) **Enhanced perception by key industrial stakeholders:** PPE Ltd has always positioned itself as a technology-driven manufacturer and provides a range of training resources, design guidelines and technical guides, in addition to the supply of components. The implementation of MicroForm® as a high value, ultra-precision manufacturing capability has provided new marketing opportunities to promote PPE Ltd. as a dynamic, science and technology-driven manufacturer within a competitive marketplace (C,D,E).

The Company continues to work closely with the University, using funded R&D projects to develop new products, inspection methods and manufacturing techniques to further broaden the capability of MicroForm®.

5. Sources to corroborate the impact (indicative maximum of 10 references)

A. KTP Final Report. Provides feedback from all parties involved describing the project success, outcomes and details of the initial investment by PPE.
   Pages 4-9 for PPE Ltd project results
B. Testimonial Letter from Head of materials, PPE
   "*This was the first big collaboration between PPE Ltd and an academic partner. The success of this venture made quickly evident the benefits and possibilities available through Industry-Academic partnerships. A number of short projects and visits to Bradford University established further this relationship and made Bradford the first point of contact for investigating new future opportunities*".
C. MicroForm® Brochure. Professional brochure produced by the company to showcase the benefits of the new manufacturing process.
   Page 3 for Simulation – Manufacture – Inspection workflow resulting from KTP
   Page 5 for customer testimonials and evidence of improved products
D. Promotional video: https://www.prepol.com/video-webinar-library/microform-micro-molded-components-in-high-performance-elastomers
   Timestamp 0.50 – Simulation software demonstration
   Timestamp 1.18 – Evidence of improved components
E. PPE: Micro Seals and Components
   MicroForm® website landing page on main company website.