Institution: Queen's University, Belfast

Unit of Assessment: 12

Title of case study: QUB plays Pivotal Role in Rotomoulding Global Success Stories

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

Researchers in QUB developed the first commercial process control system (***Rotolog***) and simulation software (***RotoSim***) for the Rotomoulding Plastics Industry. There has also been recent commercialisation of a new energy-saving system, the ***Rotocooler*.**

The fundamental understanding of the process that was developed also enabled the moulding of new materials for new application areas, notably motorcycle fuel tanks (now used by BMW, Ducati, Harley Davidson and Honda) and the **world's first concept car made from sustainable polymers.**

Global economic and environmental impact arises from a significantly more efficient process, better product quality, a greater selection of processable materials and thus increased sales.

2. Underpinning research (indicative maximum 500 words)

QUB is internationally renowned for its innovative research into the rotational moulding of plastics, initially under the direction of Roy Crawford FREng in the mid 1990s and has continued with significant contributions from Wright, Harkin-Jones, Kearns and Hornsby. QUB is regarded by the academic community and the rotomoulding industry as ***the world leader in this field*** with specialist staff and equipment housed within the Polymer Processing Research Centre (PPRC)

Rotolog: A process control system allowing measurement of mould internal temperature and pressure transmitting measurements via radio to a receiver and associated analysis and control software. Initial research (Crawford) in 1995 [1] allowed the operator to **determine *for the first time* when to remove the part from the oven** to avoid oxidative degradation yet ensure good sintering. It also led the way for the development of **multi-layer moulding** and facilitated a fundamental understanding of the influence of process and material parameters on warpage.

RotoSim: This software which was developed over the period 1994-1996 (Crawford, Wright) allows the user to input a CAD model of the part to be manufactured and it **predicts the build-up of polymer on the mould, the wall thickness distribution, final part dimensions and cycle times.** This enables the moulder to optimise the rotation ratio, speed and oven temperature to achieve a desired material distribution and cycle time. The underlying science involves modelling of granular material flows in a biaxially rotating mould, heat transfer including melting and crystallization and shrinkage [2, 3].

Rotocooler: An EU project (Micromelt, 2006-09) led to prototype internal mould water spray device. Further collaboration with the German company Maus GmbH (2010-2013) resulted in the development of the commercial Rotocooler device.

New materials: A combined experimental and theoretical study between 1993 and 2001 (Harkin-Jones) provided the information necessary to enable the industry to **start moulding reactive liquid engineering polymers** [4, 5]. Production of a part with uniform wall thickness requires an

understanding of the very complex interactions between mould speed, shape and dimension, the rheology of the material as it reacts and heat transfer in the process.

Research into multilayer constructions [6] includes collaboration with **Total Petrochemicals** [7], **one of the world's largest petrochemicals companies**, led to the development of the **first rotomoulded multi-layer polyethylene/polyamide fuel tanks** and the development of a **rotomoulded concept car** using a **novel bio-based polymer system** (Kearns). Key research challenges included development of materials to achieve a good bond between the two layers and significant process optimisation to ensure that the material layers were neither poorly sintered nor degraded.

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

Journal publications

1. Crawford, RJ, *Recent advances in the manufacture of plastic products by rotomoulding*, Journal of Materials Processing Technology, (1996), 56, 263-271. doi.org/10.1016/0924-0136(95)01840-9
2. Xu L, Crawford RJ, *Computer simulation of the rotational molding process*. Plastics, Rubber and Composites Processing and applications, (1994), 21, 257-273.
3. Attaran MT; Wright EJ; Crawford RJ, *Computer modelling of the rotational moulding process,* Journal of Reinforced Plastics and Composites (1998), 17, 1307-1318. DOI: 10.1177/073168449801701405
4. *Harkin-Jones, E. and Crawford, R.J*. Advances in Reactive Rotational Moulding.* Advances in Polymer Technology, (1996), 15, 71-100
5. *Fomin S., Watterson J.K., Raghunathan S., Harkin-Jones E. *The Run-Off Condition for Rimming Flow of a Power-Law Fluid*, Theoretical Computational Fluid Dynamics, (2001), 15, 83-94. DOI: 10.1007/s001620100044
6. *Kearns M, et al. Patent: 'Method for making a part with clearance volume by rotational moulding and resulting part'. Patent Numbers: United States Patent 7247268, WO 0218117, FR 2813232, EP 1313602, CA 2419433 (granted 2007)

*Best 3 Outputs

Grants/Industrial Funding

7. Industrial funding from Total Petrochemicals, £839,309
8. **EPSRC grants:** GR/M95219/01, Enhanced polymer processing (*Development of the reactive rotational moulding process)*, May 2000-Jan 2004, **£547,494**. GR/M10045/01 Reduction of cycle times for the rotational moulding of plastics, May 1998-April2001, **£201,139**. GR/K86534/01 Development of process technology for moulding multi-layer products from powdered plastics, Jan 1997-April 1999, **£133,208**. GR/K03579/01, Computer simulation for rotational moulding of plastics, March 1995-May 1998, **£135,231**. GR/J24898/01, Improved Dimensional Control of Rotationally Moulded Plastic Products, Jan 1994-December 1996, **£181,197**.
9. **EU Grants**: Rotoflex-217727, Jan 2009-2011, **£479,222**. Rotofast-243607, Aug 2010-July 2013, **£463,046**. Micromelt-030434-2, Sept 2006-Aug 2009, **£206,286**. Badana-232287, July 2009-June 2011, **£102,688**. Alamo-512833, Nov 2004-Oct 2006, **£65,480**

Prizes/Awards

10. Association of Rotational Molders International 2004 Organisational Service Award, October 2004

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

Since 2008 the rotomoulding research group at QUB has continued to make a major contribution to the understanding of the process, the development of improved rotomoulding grade polymers, advances in the application of high performance polymers for more demanding product applications and novel developments in rotomoulding technology aimed at improving the efficiency and versatility of the process [1,2].

Global Industrial Training Seminars

Since 2008 QUB staff have trained over 400 personnel from companies throughout the world in the latest processing technologies arising from QUB rotational moulding research. These training seminars have been located in rotomoulding hotspots throughout the world. Establishment if this industry in developing countries, such as Thailand, would not have been possible without knowledge transferred from QUB [3]. Furthermore developed countries, such as Australia and New Zealand have significantly benefited. Leisa Donlan, Chief Executive Officer, Association of Rotational Moulders Australasia has stated "*Your contribution allows our members to quantify and strive toward global industry best practice and the independent nature of your position means that we can confidently provide our members access to your workshops without any concerns about competitive issues. We believe there will be substantial benefits to the industry through the training*" [4]

Rotolog

First marketed via a university spin out company, Rotosystems, which was sold to Ferry Industries, USA one of the largest rotational moulding suppliers in the world in 2003. ***It has since become the standard method for rotational moulding process control, used around the world***. Beyond 2008 Ferry Industries continue to successfully market this product [5], with its proven use significantly reducing new product development times with consequent savings in raw materials, energy and labour. It furthermore ensures consistency of part properties which again companies to assure part quality and reduce process scrap.

RotoSim

This software has been licensed for commercial use via Rotomart [6]. The total number of licences for RotoSim for the period 2008-2013 stands at 74 to 27 counties at a cost of $1560 per licence (sales total $115,440). The majority of licences have been bought and used by rotomoulding companies, mould manufacturers and polymer manufacturers. ***It continues to be the only process simulation software available to the rotomoulding industry*** [7]***.***

Rotocooler

This device reduces cooling times for the rotomoulding process by up to 40% with production rate increase by up to 15%. In 2013 QUB set up an exclusive licence deal with German company Maus [8]. The Rotocooler product was launched in June 2013 and to date 5 units have been sold within Europe and USA at approximate cost of €10,000 per unit. The market is global and Maus expect to sell 200 units per year by 2018.

Materials

The work on *multi-layered products* conducted in collaboration with Total Petrochemicals (one of the top 5 petrochemical companies in the world) has led to a number of new product developments since 2010, including skin/foam/skin constructions and **multi-layered fuel tank** (both using *TP-Seal* technology). Total Petrochemicals exclusively used QUB facilities for product development

and pilot trials. Process setup is performed on location by QUB staff at rotomoulding companies using TP-Seal in Japan, Germany, Italy and USA; supplying companies such as **BMW, Ducati, Harley Davidson and Honda.**

The environmental impact is highly significant since cross-linked polyethylene was used in fuel tank manufacture prior to 2010. This material was permeable to fuel, permitting hydrocarbons and toxins to be release to the atmosphere. **The new TP Seal multilayer technology is resistant to permeation of fuel and meets all US Environmental Protection Agency fuel permeation regulations introduced in 2010.**

Total Petrochemicals have also collaborated with QUB to develop a new rotomouldable bio-based sustainable material (Bio-TP Seal) recently showcased in a concept car at both the Frankfurt Motor Show in 2011 [9] and Paris Motor Show in 2012. This is the **world's first car to be produced using sustainable polymer materials in place of metal parts.** This has a light-weight skin-foam-skin material produced from sustainable poly lactic acid (derived from Maize and Sugarbeet). Demonstration car components were produced by QUB staff on secondment at Total.

Reactive liquid polymers in which the polymerisation process occurs inside the mould present an exciting opportunity for the rotational moulding industry in terms of engineering material properties and significantly reduced cycle times (from 40 mins. to 5 mins. for a 5mm thick moulding). The work done on *reactive materials* at QUB has led to a number of companies introducing these materials into production including one of the largest rotomoulders in the US, Centro Inc (suppliers to companies such as Caterpillar, John Deere etc.) [10]. Caprolactam usage over a 12 month period in 2011 was roughly [text removed for publication] with product sales just under [text removed for publication]. In 2012 Centro's sales volume in this area has increased by nearly [text removed for publication].

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

1. Titan Excel Rotational Moulding acknowledgment of QUB: http://www.rotomould.co.uk/rotational-moulding.aspx
2. Managing Director, Clarehill Plastics Limited
3. Product Development Manager, Rotomoulding, SCG Chemicals, Thailand
4. Chief Executive Officer, Association of Rotational Moulders Australasia
5. Ferry Industries Rotolog system: http://www.ferryindustries.com/support.html
6. Rotosim: http://www.rotomart.com/product_print.php?item_id=273
7. CEO, Rotosim
8. Rotocooler press release: http://www.europeanplasticsnews.com/subscriber/headlines2.html?id=2399
9. Innovative Total Concept Car, http://www.rotoworldmag.com/innovative-total-concept-car/
10. VP Advanced Technology & Engineering, CENTRO Inc.,