

Impact case study (REF3b)

Institution: Swansea University
Unit of Assessment: 15 - General Engineering
Title of case study: The benefits to business and practitioners of advanced manufacturing by printing of complex inks
1. Summary of the impact

Research in the Welsh Centre for Printing and Coating (WCPC) at Swansea University has produced a sophisticated understanding of the physics of the fluids and interfaces in the printing process, and has pioneered the development of printing with complex, multi-phase inks. The application in volume manufacture made possible by the research has generated significant, **multi-million pound, economic impact** in the printable electronics and packaging industries, directly leading to the creation of **new high technology printed products**, including next generation lighting. It has also led to the development of the supply chain for complex functional inks, whilst a comprehensive revision of the ISO standard on ink colorimetric characterisation in 2013 has demonstrable **impact on practitioners**.

2. Underpinning research

With the development of digital printing in the 1980s the craft of printing needed to be transformed into a science. Today, it is a high volume, precision manufacturing process capable of accurately selectively covering and curing as many as 15 materials up to speeds able to cover a football pitch in around a minute. This transformation has only been possible through the development of a sophisticated understanding of the physics of the fluids and interfaces in the printing process.

To adapt to the emerging digital printing technology, a group of researchers was assembled at Swansea University in 1990 to address the urgent need to turn the craft of printing into an advanced manufacturing process. The underpinning research has been produced by a team led by **Prof TC Claypole** (1990-date) and **Prof DT Gethin** (1990-date), and comprising **Dr D Deganello** (research staff, 2003-12, academic staff since 2012), **Dr MFJ Bohan** (research staff 1990-00, director Graphic Arts Technical Foundation, USA since 2000), **Dr E Jewell** (research staff since 1993), **Dr TV Korachina** (research staff since 1996) and research students **IJ Fox** (1997-2001), **P Townsend** (2000-03), **Dr SM Hamblyn** (1999-04, research staff since 2004) **Dr D Beynon** (2003-06, research staff since 2006), and **Dr J Cherry** (2003-06, research staff since 2006).

The research has delivered a sophisticated understanding of the fundamental processes of fluid mechanics and image transfer [R1, R2, R5] and predictions of the ink transfer process [R6]. The findings of R4 represent a major improvement in the characterisation of printing inks, whilst R3 is an application-driven paper for printed electronics. Supported by two £1m projects with the *DTI Design of High Speed Machinery* program [G1 and G2] this work uncovered the lack of basic underpinning process science, which became the focus for the Welsh Centre for Printing and Coating at Swansea University over the last twenty years.

Until the work described in R1, R2 and R3, flexible electronics had been reliant on highly engineered and coated polymers. Many companies producing flexible electronics relied on slow processes such as ink jet technology or variants on traditional silicon fabrication technology. Some of the coatings, though flexible, were brittle, particularly if subjected to extensional strain. An international collaboration with Group Info Tech directly led to inks that could be successfully applied to paper leading to a whole new class of functional, flexible electronic products [R3, G3].

During this period there has also been a drive to take advantage of the large area capability of traditional print processes to provide scale-up of laboratory concepts based on micro, nano and bio materials. One of the most successful volume products in this period has been self-illuminated electro luminescent posters. The work at WCPC on printing of conducting inks on paper [R3], an International Collaboration with Group Info Tech performed as part of the EPSRC Platform Grant [G3] **showed for the first time the potential for the printing of conductive inks on paper**. These developments have led to significant FP7 collaborative funding for OLED (organic light-emitting diode) lighting development [G6] and more recently the EPSRC Centre for Innovative

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Manufacture (CIM) in large area electronics with Cambridge, Manchester and Imperial College. In this latter activity it is the scaling science and equipment developed over the last ten years that has led to these high impact collaborative programmes.

The research at Swansea developed the knowledge that underpins the major volume printing processes [R1-R6, G3 and G5]. The printing ink itself is at the heart of the printing process and is a complex multi phase liquid which comprises carrier fluids, binders, active materials that depend on the application. These include pigments, long chain polymer electronics, nano silver, graphene, enzymes, antibodies etc, and solvents [G6 and G7]. The rheology of the ink changes with both shear and extension, which can be related to the forces applied to the ink during printing. Deformable rollers and image carriers, normally made of polymers, are used to transfer the ink in a selective manner to the substrate [G4]. To understand this required the development of numerical models of thixotropic materials subjected to large strains, which could be combined with the fluid flow of the ink. In the final stage of the printing process, the ink that was applied as a liquid is then cured for its final application. The need to apply multiple layers to manufacture a product required the understanding of interlayer interactions, both of surface chemistry and topography.

3. References to the research

Papers R1, R2 and R5 best represent the quality of the underpinning research. R1, R2, R5 and R6 were included in the RAE2008 submission to the General Engineering panel. These papers derived from research under the EPSRC Platform grant with which Swansea made significant inroads into the underpinning science [G3]. This grant was peer reviewed by EPSRC on completion and was rated "Internationally leading" for scientific achievement and impact. The Oil and Colour Chemists Association Stern prize for the best paper published in 2002 was awarded to R5. At the time of publication of papers R3 and R4, the Annual Technical Conference of the Technical Association of the Graphic Arts (TAGA) was the premier route for publication of research related to printing to reach both academic and industrial researchers.

Publications

- R1.** IJ Fox; TC Claypole, and DT Gethin; *An Experimental Investigation Into Ink Transfer Using a Roller Squeegee in High Speed Screen Printing*, Proc. Instn. Mech. Engrs. Vol.217, Part E: J. Process Mechanical Engineering, 2003
- R2.** DC Bould, TC Claypole, and MFJ Bohan; *An Investigation into plate deformation in flexographic printing*, IMechE part B, Vol 218, pp 1499 - 1511, 2004
- R3.** TC Claypole, EH Jewell, WJ Ray and Y Berri; *Printing of conducting inks on paper*, Proc. 56th TAGA Annual Technical Conference, 2004 pp. 541-550
- R4.** TC Claypole and P Townsend; *An Improved Method for the Routine Measurement of Ink Colorimetrics*, Proc. 54th TAGA Annual Technical Conference, 2002, pp 302-323
- R5.** SM Hamblyn, EH Jewell, TC Claypole, DT Gethin; *An Investigation into Screen Printing Using UV Process Colour Inks*, Surface Coatings International, Part B: Coatings Transactions, 85, 2002
- R6.** DT Gethin, MFJ Bohan, TC Claypole, I.J. Fox; *Ink Film Thickness Prediction in Half Tone Screen Printing*, Proceedings of the Institution of Mechanical Engineers, October 2003, pp. 345-359(15) Volume: 217(4) ISSN: 0954-4089 DOI: 10.1243/095440803322611705

Major Relevant Research Grants

- G1.** T.C. Claypole, D.T. Gethin and B.J. Roynance; *Improving the productivity of high quality screen printing*, EPSRC/DTI LINK, 1993-96, £350k Ref: GR/F26287/01
- G2.** T.C. Claypole and D.T. Gethin; *A demonstration of the feasibility of a high speed high quality belt screen press*, EPSRC, 1998-01, £327k, Ref: GR/M09353/01

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- G3.** T.C. Claypole and D.T. Gethin; *Effect of the printing process on image transfer*, EPSRC Platform Grant, 2000-04, £360k, Ref: GR/N63567/01
- G4.** T.C. Claypole and D.T. Gethin; *TSB “Accuflex”*, 2008-11, £279k, DTI Project No: TP Q0507C
- G5.** P.R. Williams, D.T. Gethin, T.C. Claypole et al; *Complex Fluids and Complex Flows*, EPSRC Portfolio Grant, 2004-08, £2.8m, Ref: EP/G061882/1
- G6.** D.T. Gethin and T.C. Claypole; EU Theme 3 – FP7 ICT Large-scale integrating project “*Fast2light*”, 2008-11, £383k, Grant agreement no: 216641
- G7.** D.T. Gethin and T.C. Claypole; *TSB “Niche”*, 2008-11, £480k, TP ref AG192B

4. Details of the impact

The underpinning research has delivered clear, economic impacts and has led to a comprehensive revision of the ISO standard on ink colorimetric characterisation, which has significant impact on practitioners and has changed printing industry practice. **Economic impact** is evidenced in the following three examples:

1) The underpinning research [R1, R2, and (in particular) R3] has led to the development of a new class of functional products at the core of the range produced by Nth Degree Technology, a spin out company from Group Info Tech. The capabilities of this approach to printed electronics has enabled the production of an addressable Electroluminescent (EL) paper television display, and the launch of a self-illuminated point of sale poster based on EL technology (posters that make use of printed lighting). As a consequence of the studies undertaken with Swansea University as part of its research program into image transfer, a new business has been established.

*“These two developments were the basis for the creation of the new company, Nth degree technology [...] So, from that early start, we now have a company valued at **\$50 million with an enormous IP portfolio that feeds into market spaces worth several hundreds of billions of dollars.**”*

Chief Technologist of Nth Degree Technology

2) Many of the companies in the printing sector are small-to-medium sized enterprises with little or no resource for research and development. The expertise generated as a result of the research led by the WCPC initiated by the publications outlined was recognised by the European Regional Development Fund, which provided technology transfer funding for a number of industry facing projects. One such project, the Digital, Industrial, Packaging, Lean and Environmental (DIPLE) printing project won the 2009 EU Regiostar award. Based at Swansea University, DIPLE led projects with partner companies to support their long-term viability and to transfer knowledge, particularly in relation to the printing and coating of novel inks at high speed. Whilst many companies were supported in their economic growth, an excellent example is the development of conductive inks for printed electronics and health with Gwent Electronic Materials (GEM).

*“Through the DIPLE project, we were able to secure access to expertise on ink transfer and volume printing at the University for the development of our Carbon and silver conductive inks. The extensive facilities and experience of running high volume printing presses are beyond the resources of even a high technology company such as GEM. The net benefit can be seen in the sales of these inks during the period 2007 – 2012, which was well **in excess of £3m**”.*

Chief Executive Officer, Gwent Electronic Materials

3) The Welsh Government has provided funds through its Academia 4 Business programme, which enables Welsh SMEs to become involved with advanced printing and coating activity at Swansea.

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The Printing of Functional Materials (Print FM) project has been targeted at the development of processable functional coatings. A key function is conductivity since this is required in all printed electronics and is often applied via vapour deposition. New materials (carbon nanotubes and functionalised exfoliated graphene) created by Haydale Ltd (a Swansea University spin out) have been formulated into electronic inks (C3).

*“The direct benefit has been to assist in obtaining a **£1,500,000 investment**, the establishment of new premises, development of a range of new products”.*

Business Development Director, Haydale Ltd

In 2011/2012 alone, the products generated revenue for the company of £140,855, led to three new patent applications and the employment of two new staff.

Impact on practitioners across the printing industry is evidenced through the revision of an ISO standard as a direct result of the underpinning research. Most packaging is printed using flexographic printing. In 2012 this had an estimated value of \$263m. Prof Claypole served as a UK expert on ISO standards through the TC130 graphic arts committee to enable the research [R4, R5, R6] at Swansea to be integrated into new standards. An experimental program at Swansea to evaluate the standards for ink colorimetric characterisation for flexographic printing identified deficiencies in the method of test print preparation which resulted in there being no control on the ink film thickness. ISO 2846-5 “Graphic technology - Colour and transparency of printing ink sets for four colour printing - Part 5: Flexographic printing” **has been modified to address these issues**. To quote from the introduction to the 2013 revision of ISO 2846-5, “*After the debut of this part of the ISO 2846 series, a paper (R4) was published that challenged the technology used here, indicating that there were inadequate controls on the film thickness*”. The new standard has included film thickness measurement.

5. Sources to corroborate the impact

- C1.** EPSRC – Individual Grant Review – GR/N6356701 “Image Mechanisms in Printing processes”
- C2.** Letter from Chief Technologist, Nth Degree Technology, Phoenix, USA
- C3.** Letter from Technical Director, Gwent Electronic Materials
- C4.** Letter from Business Development Director, Haydale Ltd
- C5.** ISO 2846- 5, revised 2013
- C6.** Full records of the output of “DIPLE” project audited by Welsh European Funding Office are archived in Swansea University
- C7.** Full records of the output of “Print FM” A4B project audited by Welsh Government Department of Business, Enterprise, Technology and Science are archived in Swansea University