Institution: Swansea University		
Unit of Assessment: 12		
Title of case study: Advancements in flexographic printing technology for graphic image printing and functional device fabrication.		
Period when the underpinning research was undertaken: 2004 – 2015		
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:**
D T Gethin D Deganello T C Claypole C O Phillips	Professor Professor Professor Lecturer	1985 to present 2005 to present 1986 to present 2000 to present
Period when the claimed impact occurred: 2014 – 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Swansea University (SU) has worked extensively with the entire supply chain in the flexographic printing industry with the strategic aim of improving print quality and achieving waste reduction. This has been achieved by translating fundamental research into delivery processes and technologies to enhance the sector. Based on SU research, new metrological tools by Troika Systems were developed, leading to demonstrable production cost savings of GBP428,000,000 per year and a 15% decrease in material waste that resulted in a cost saving of GBP90,000,000 per year. Ink transfer mechanism studies supported new photopolymer plate products for Asahi Photoproducts resulting in a 30% decrease in run time and a 20% increase in their global plate sales. SU research also informed a strategic R&D investment of EUR20,000,000 by leading press makers UTECO. SU produced a best practice guide for the sector, which was endorsed by the Flexographic Technical Association Europe (FTA Europe). By delivering Continual Professional Development (CPD), process quality and competitiveness has increased making flexography the dominant process for printing packaging which in 2017 had a total output value of EUR77,000,000,000 of which flexography captured a 54% market share representing EUR40,200,000,000.

2. Underpinning research

The flexographic printing supply chain comprises, in addition to substrate and ink, business sectors that include anilox rolls that have engraved surfaces to meter ink, photopolymer plates to transfer the printed image and presses. The underpinning research conducted at SU's Welsh Centre for Printing and Coating (WCPC) has been directed to address the challenges of equipment design and/or process application faced by each of these business sectors. Furthermore, it has been documented and translated by the FTA Europe to provide training and upskilling. Overall, this has made the quality of flexographic printed material equivalent to that of offset lithography as its nearest competitor printing process.

Photopolymer image carriers either comprise a pattern of conical frustum where the top diameter has dimensions measured in μm or remain without a pattern where solid coverage is required and where ink release from either surface type determines image quality. Our work, **[R1]** and **[R2][G1]**, has addressed the underpinning knowledge that is needed in the processing of photopolymer image carriers to improve image quality. The early work described in **[R1]** explores the deformation of the frustum during printing engagement and provided, for the first time, a detailed understanding of how this contributes to 'dot gain', where the printed dot diameter is different from that on the image carrier. The work in **[R2]** provides the first detailed exploration of how both the profile on the frustum top and plate surface chemistry (water- or solvent-washable) impacts print quality. Through complementary exposure and laser machining technologies, the frustum top can be profiled to be flat, convex or concave. Micropatterning can be added to the frustum top as well as

solid coverage areas with the aim of increasing the volume of ink transfer and improving print quality through uniformity. Our research in **[R2]** has shown that, contrary to vendor claims, dot profiling has very marginal benefit on print colour quality. Additionally, for solid coverage, our work showed that for low viscosity water-based inks, the frequency of Saffman-Taylor instability can be influenced by surface chemistry with higher frequency improving the uniformity of solid coverage areas.

Our underpinning work, **[R3][G2]** and **[R4][G2]** has focused on developing the precise volume measurement of engraved cells and ink release from these cells. This is critical to the determination of the ink supply within the flexographic printing process and impacts directly on print quality. Engraved cells are typically 10 µm deep and surrounded by a surface that is rough. Precise volume measurement must account for the surrounding surface roughness, and our work in **[R3]** develops a novel waterfall algorithm to determine the cell brim location and hence the cell volume in a fully automated manner. Ink release from the engraved cell requires consideration of filamentation and how the filament foot interacts with the cell. Our work published in **[R4]** proposes a model for ink extensional flow coupled with filament tracking that, for the first time, accounts for dynamic response of the contact point at its foot. The proposed method was developed within a level-set framework by modelling forced capillary flows, and the approach relaxed constraints imposed by previous attempts by allowing the system to define its own dynamic contact angle and its own contact line dynamics.

Flexography has been identified as a leading candidate process for the high-volume printing of functional devices. Our work on printing of conducting tracks and fine features initially exemplified in **[R5][G3]**, focuses on image transfer in the printing of conducting tracks that is a fundamental feature in a wide range of functional devices such as sensors and solar cells. Our work showed in detail how image design and process setting influenced feature dimension and functional performance. To address challenges in commercialisation, we have explored rapid ink curing using near infrared (NIR), as shown in **[R6]**, where we were the first to have demonstrated a 100-fold reduction in cure time and hence a commensurate reduction in dryer length. This work has been developed further recently through application in printed antennas **[G4]**. We were able to demonstrate the ability to print antennas that were sufficiently accurate that they would function 'as printed' without the need for further tuning and associated processing steps.

3. References to the research

The outputs below include four peer-reviewed journals, one PhD Thesis, and one peer-reviewed conference paper at a well-established international conference. Most of the journal articles are supported by funders including: EPSRC, WDA, ERDF, Tata, FP7 European Commission, and other industrial partners. Four grants (majority of which are competitively won) support the body of work totalling GBP1,758,262. This research has made important contributions to the discipline internationally and contributes important knowledge to the field likely to have a lasting influence.

[R1] Bould, D.C., **Claypole, T.C**., & Bohan, M.F.J. (2004). An investigation into plate deformation in flexographic printing. *Proceedings of the Institution of Mechanical Engineers*, Part B, 218 (11), 1499-1511. doi.org/10.1243/0954405042418428

[R2] Hamblyn, A. (2015). Effect of Plate Characteristics on Ink Transfer in Flexographic Printing. PhD Thesis, Supervised by **Gethin, D.T. and Claypole, T.C**. Swansea University. https://cronfa.swan.ac.uk/Record/cronfa42827

[R3] Deganello, D., Claypole, T.C., & Gethin, D.T. (2007). Analysis of interferometric data to obtain accurate geometric characterisation of engraved cells. *IARIGAI 2007 Proceedings: Advances in Printing and Media Technology*, 34, 77-84. http://jpmtr.org/Advances-Vol-34(2007)_online.pdf

[R4] Deganello, D., Williams, A.J., Croft, T.N., Lubansky, A.S., **Gethin, D.T., & Claypole, T.C**. (2010). Numerical simulation of dynamic contact angle embodied through a force based formulation. *Journal of Non-Newtonian Fluid Mechanics*, 166 (16), 900-907. doi.org/10.1016/j.jnnfm.2011.04.008

[R5] Deganello, D., Cherry, J.A., **Gethin, D.T., & Claypole, T.C.** (2010). Patterning of micro-scale conductive networks using reel-to-reel flexographic printing. *Thin Solid Films*, 518 (21), 6113-6116. doi.org/10.1016/j.tsf.2010.05.125

[R6] Cherrington, M., **Claypole, T.C., Deganello, D**., Mabbett, I., Watson, T., & Worsley, D. (2011). Ultrafast near-infrared sintering of a slot-die coated nano-silver conducting ink. *Journal of Materials Chemistry*, 21, 7562-7564. doi.org/10.1039/C1JM10630A

Grants

[G1] Claypole, T.C. [Principal Investigator]. (2010-2014). Image Transfer Mechanism in Printing. KESS PhD. [ESF 2007-20134/CASE ID: 80300]. European Social Fund. Welsh Government. GBP59,970.

[G2] Claypole, T.C. [Principal Investigator]. (2004-2008). DIPLE Digital, Industrial, Packaging, Lean & Environmental. [55051]. ERDF. Welsh European Funding Office. GBP1,104,492.

[G3] Gethin, D.T. [Principal Investigator]. (2008-2011). FAST2LIGHT: High-Throughput, Large Area and Cost- Effective OLED Production Technologies. [216641]. FP7 Programme, European Commission. GBP480,749.

[G4] Deganello, D. [Principal Investigator]. (2015-2016). HarFEst. [102154]. Innovate UK. GBP113,051.

4. Details of the impact

In 2017, the European packaging and label printing industry had a value of EUR77,000,000,000 and a compound annual growth rate of 2%, with flexographic printers capturing 54% (EUR40,200,000,000 per year) of this business. Similar values apply in America and Asia. Our research has underpinned process technology that is central to image transfer in flexography. The results of our research have been used by printing businesses to develop their technology, provide an independent benchmark, and provide the underpinning knowledge that has been used to promote and market their products. Our research has impacted Troika Systems, Asahi Photoproducts and UTECO, each of which are suppliers to flexographic printers on a global scale. We have engaged more broadly with the sector through the Flexographic Technical Association through the writing of good practice guides that are being used globally.

Troika Systems

Troika Systems are world leaders in the design and development of the state-of-the-art AniCAM™ 3D analysis system, which is a key tool in quality control in the printing industry. The development of this system's accuracy has been informed by our research on cell metrology **[R4]** that included analysis protocols and the development of a reference measurement set that has been used to validate the AniCAM™ system, covering the full range of engraving specifications. Following a global competitor benchmarking study, it was established that the Troika Systems, AniCAM™ was the best in class showing operator independence and superior accuracy when compared with a competitor product based on white light interferometer principles **[C1]**.

"Using the SU research we were able to evolve our AniCAM™ system to give accurate measurement of cell volume. Furthermore SU were able to ratify the 'accurate' volumetric measurement of engraved cells using both the WCPC protocols and the Troika Systems method, and knowing they correlate, has allowed us to emphasise the accuracy of our systems to the flexographic printing sector." Sales Director, Troika **[C1]**.

Within the printing industry and following the release of their validated AniCAM™ system in late 2013, Troika Systems are now recognised as world leaders in measurement and analysis of engraved anilox rolls and have extended their technology to include relief profiles on the image carrier plates in flexographic printing and the engraving of cylinders for gravure printing. The impact for Troika and the flexographic printing industry is significant.

"The result is that since 2014, Troika's client base has grown from 600 to 1500 installations, increasing our workforce from 8 to 16 and growing our business turnover from £900k to £2,000,000". Sales Director, Troika **[C1]**.

In addition, wider, significant, direct commercial and environmental benefits have been enjoyed by Troika's customers (secondary beneficiaries) by implementing Swansea University's research backed improvements **[R3]**. Based on the 1,500 flexographic printer installations Troika has found that most printers are recovering at least one hour of production time per press per day. This is attributed to changeover between different print jobs where there is a need to match the image with the ink supply that is controlled by the anilox. Through implementation of lean manufacturing, the AniCAM^{TM} system allows a match to be achieved efficiently resulting in time saving and reduced material waste. These process improvements are especially important considering market trends see print runs of typically 2 to 3 hours. Many of their customers operate at least 3 presses and for just 3 presses the benefit from a time recovery of one hour per press, per day leads to annual savings in excess of GBP225,000 per year. The hour saved leads to a productivity increase of 4%, and material waste at the start of a press run is reduced by 15%. The overall benefits are highlighted by Troika's Sales Director:

"*On application across the 1,500 installations, the production time savings corresponds to £428m per annum and the material waste a value of £90m per annum*" Sales Director, Troika **[C1]**.

Asahi Photoproducts

Asahi Photoproducts are a world-leading supplier of photopolymer plates to the flexographic printing industry where the global area of imaged plates is 8,000,000m^2, presenting a value of USD1,370,000,000 per year in 2020. Our underpinning research **[R1, R2]** on the effect of frustum deformation, patterning and surface chemistry on image transfer and hence print quality has contributed to the development of Asahi's ground-breaking innovation on image carrier technology.

"*The underpinning research conducted at Swansea University has established our fundamental understanding of image transfer in a new water washable plate technology (AWP) branded CleanPrint, and has provided both commercial and environmental benefits to Asahi and our customers*" Technical Marketing Manager, Asahi Photoproducts **[C2]**.

Most recently, our work **[R2]** has supported the development of Asahi's AWP 'CleanPrint' plate by providing underpinning knowledge and validation of its enhanced performance, eliminating the need for washout solvents and reducing management and disposal of chemicals that are toxic to workers and harmful to the environment. Within the REF period (between 2014 and 2020), adopting the CleanPrint plate resulted in a decrease in print run duration of 30%, accompanied by a similar reduction in energy consumption and improved productivity gains in excess of 30% **[C2]**. Indirectly, the quality improvement offered by the AWP plate has enabled the capture of new business from competitor high volume printing processes. The direct benefit is seen in Asahi's sales, where following its launch in late 2013, CleanPrint now represents 20% of Asahi's annual sales volume where they have been successful in capturing a *"….10% share of the flexo plate global market 2020*" **[C2]**.

UTECO

UTECO is a worldwide leading manufacturer and supplier of flexible packaging equipment, particularly flexographic presses. Our original work on printing fine conducting lines using flexography **[R5]** and innovative application of rapid curing **[R6]** has been critical in influencing UTECO's company strategy and has led to collaboration for the development of flexographic based RFID antennas, with demonstrators showcased by UTECO at the world-premiere industry trade fair, DRUPA 2016.

"Fundamental research conducted by Swansea University (SU) on the advancement of flexography, has had a pivotal role in the sector development over the last decade and in the strategic planning and operations of UTECO within this REF period the holistic and scientific approach to printing and associated technological improvement developed and promoted by Swansea has been critical in enhancing our position over the competition resulting in UTECO's

company growth from a turnover of approximately EUR95,000,000 in 2013 to EUR118,000,000 in 2018." CEO, UTECO **[C3]**.

"SU's research has informed our strategic decisions to investigate roll-to-roll printing for advanced functional and printed electronic applications and supported an overall R&D investment in new technologies within the company valued at approximately EUR20,000,000." CEO, UTECO **[C3]**.

Flexographic Technical Association Europe (FTA Europe)

FTA Europe was established to represent the common interests of the European flexographic printing industry and currently has 7 members. These are the national trade associations of Spain, Italy, France, Benelux, Sweden, Denmark and the UK, of which over 424 flexographic companies are members. Beyond this, FTA partners span the globe, including the Americas, Middle East and Asia.

Our pioneering research completed between 2000 and 2020 has led printing to be a manufacturing process that is now guided by scientific principles:

"Education and up-skilling form a key part of FTA Europe's activity and, in 2017, we embarked on the development of best practice guides as a CPD provision for our members and the wider flexo community. The project brought together flexo experts from across Europe –including Swansea University [Prof Tim Claypole as a co-author] *who contributed their pioneering research to the development of flexo printing best practices.*

The resulting product was published as an eBook on sale on Apple Books and iTunes: the 'FTA Europe Flexo Best Practice Toolbox'." President, FTA Europe **[C4]**.

The Toolbox was published in 2019, using state of the art knowledge, providing a unique product for the flexo printing industry. It is designed for trained users to refresh their knowledge and ensure predictable results on the flexo press each time. Not only does the Toolbox bring together the latest expert advice, but the combination of videos, images and multi-language versions means it is truly accessible and easy to use. After the recent publication of an Italian translation, further translations will be made to include French, Spanish, Dutch and Portuguese. To date, 103 businesses have downloaded the best practice guide and it has been used in training new and upskilling existing employees. The sector benefit is set out in the endorsement letter from the FTA where they state:

"FTA Europe recognises the research conducted by the Welsh Centre for Printing and Coating at Swansea University to be world leading and having contributed to the development of the European flexo industry, which in 2019 had an output valued at €40.2 billion. The University continues to have significant impact on the growth of the flexographic printing sector and is a highly valued partner of FTA Europe." President, FTA Europe **[C4]**.

5. Sources to corroborate the impact

Where organisations provide testimonials below, in what capacity they are involved with the impact follows in brackets:

[C1] Letter of Support: Sales Director, Troika Systems (Reporter)
[C2] Letter of Support: Technical Marketing Manager, Asahi Photosystems (Reporter)
[C3] Letter of Support: Group President & CEO Shareholder, UTECO (Reporter)
[C4] Letter of Support: President FTA Europe, Flexographic Technical Association (Reporter)