Ink Transfer in Image and Non-Image Areas in the Rotogravure Process

By

Andrew M. Clist
BEng (Wales), MSc (Wales)

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School of Engineering
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Andrew M. Clist

Flat 3/3, 294 Kilmarnock Road
Glasgow,
G22 5HZ, UK

Tel: (+44) 07782 162323
Email : amclist@hotmail.com

Profile

Skilled research engineer with PhD in Rotogravure ink release. Strong background in manufacturing process development and in product improvement programs. Experienced in all major print processes and color measurement technology. Experienced in managing multiple projects from conception to completion.

Education

PhD, University of Wales Swansea (2004)
"Ink Transfer in Image and Non-Image Areas in the Rotogravure Process"
This was the first published work investigating the causes of scumming in the Rotogravure printing process, and the first work performed on commercial presses to measure the volume of ink released from engraved cells. The work developed interferometric techniques for accurately examining engraved cells, printed dot volumes. Various color measurement techniques and protocols were also developed.

MSc, University of Wales Swansea (2000)
"The Effects of Thermal Transients on Waterless Offset Can Decoration".
Other projects included interferometric determination of ink film thicknesses and color measurement techniques, along with long term on-press trials and investigations

PGCE, University of Wales Swansea (1997)
Secondary Science (Physics)

BEng (Hons), University of Wales Swansea (1995)
Chemical Engineering

Publications

"The Influence of the Cylinder on Scumming" 2004 TAGA Conference
"Measurement of Engraving Diamonds" 2002 Institute of Physics
"Characterisation of Gravure Cylinders" 2001 TAGA Conference

Experience

Scientific Research Manager, Gavin Watson Ltd (2003 – Current)
Managed and carried out a variety of projects developing a printable environmentally sensitive ink and developing anti-counterfeiting products for both brand owners and the UK government, using both Lithographic and Flexographic printing processes

- Successfully completed courses in Project and Financial management
- Developed new security products, as well as liaising with existing manufacturers
- Managing projects from conception through development, planning, scheduling, supervision of technicians/pressmen, carrying out trials, analysis of data, presentation of program highlights to senior management and government liaison groups

Research Engineer, University of Wales Swansea (2000-2003)
Managed and carried out projects for several externally sponsored research and development projects.

- Used many measurement and analysis procedures, both traditional and novel, laboratory and site based
- Devised a methodology for interferometric analysis of gravure/anilox cells in great detail, including accurate measurement of volume, depth, area etc.
- Managed projects, including supervision of technicians/pressmen, carrying out trials, analysis of data, presentation of program highlights at technology group meetings
- Supervised undergraduate, MSc and Foreign exchange students projects
- Carrying out groundbreaking research into ink release and the problem of scumming

Physics Teacher, Pontllanfraith Comprehensive, Wales (1997-1998)
Classroom teacher for the 11-16 age group

- Taught Science to years seven and eight, physics to years nine to eleven
- Taught electronics to year 11
- Managed projects, including writing schemes of work and planning, performing and marking coursework

Positions of Responsibility

Rotogravure Printing Technology Group, 2000-2003
Member of Steering committee

Additional Information

- IMechE – Associate Member
- Languages – German and French to GCSE standard
- Driving License – Full and Clean (UK)
- Interests – Music, Classic cars, Mountain biking

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Summary

Rotogravure printing is one of the oldest printing processes, yet little is understood about the fundamentals, which drive the ink transfer in the process. This is largely due to the difficulties in analysing the process. The quantities of ink being transferred are very small, necessitating novel means to analyse them, and the practicalities of carrying out an investigation like this are significant. As a result, this is the first study to investigate the effects of compression ratio and stylus angle.

It has been shown that traditional methods of volume calculation are extremely inaccurate, never getting within 20% of the actual cell volume. A new method has been suggested which is accurate for the calculation of cell volume at 80% coverage. It has been demonstrated that measurement and calculation of ink release are possible, and the techniques required to analyse the release are detailed, including interferometric analysis to examine the cells and printed dots in detail and TDGCMS analysis to quantify the retained solvents in the ink. It has been identified that 18.3% ±2.5% of the total cell volume is released. This shows considerable agreement with previous work once calculation has been corrected for actual cell volume.

Additionally, the project has analysed the effects of several variables of the process on ink release. It is shown that by increasing the screen ruling, compression ratio or stylus angle, a higher percentage of the ink contained within the cell is released to the substrate, with the most significant effects observed with screen ruling and stylus angle, where variation within common ranges cause a 2% variation in ink release.

The effects of several variables on the levels of scumming (ink release from non-image regions) observed were also calculated, demonstrating that several variables will affect scumming. Changing substrates not only changes the levels of scumming observed, but also changes the form observed. Varying blade load has been shown to affect scumming levels, but may increase or decrease the scumming level depending on the hydrodynamic conditions affecting the blade. Surface finish has a small effect on the scumming, but provided normal levels of roughness are maintained this effect is minimal. Varying the ink however, caused significant changes in the levels of scumming observed. Interactions were observed between blade load, surface finish, ink type/viscosity and substrate type. Additionally it was shown that although surface finish is a primary factor affecting scumming levels, the roughness values do not critically affect the scumming within normal ranges. The surface form and structure were examined and found to be critical factors in controlling the levels, with cylinders polished with emery paper causing the highest levels of scumming. Significant correlations were drawn to blade coating with similar results obtained when compared with the blade coating film thickness / blade load characteristic curve.

Declaration

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed ______ *(Candidate)*

Date 1/6/04

Statement 1

This thesis is a result of my own investigations, except where otherwise stated. Other sources are acknowledged, giving explicit references. A bibliography is appended at the end of the thesis

Signed ______ *(Candidate)*

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Signed ______ *(Candidate)*

Date 1/6/04

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I would also like to thank my family and friends for their ongoing support, in particular Simon Hamblyn and Ian Fox for helping beat Microsoft Word into submission. In addition, I would like to thank Stuart Whittaker for carrying out my TDGCMS measurements. Finally, I would like to thank Tom Axon – my headmaster of many years ago for telling me I'd never achieve anything, and thus forcing me to, in order to prove him wrong.

Table of Contents

Table of Figures

Table of graphs

Chapter 1

Introduction

Despite the age of the process little is really understood scientifically regarding the process of rotogravure printing. As a result, the release of ink from both the image and non-image parts of a gravure cylinder were investigated. In addition, the effects of varying engraving characteristics were explored, in terms of both the volume of ink released, and the colour that this release prints onto the substrate. Investigation of the three primary engraving characteristics (screen ruling, stylus angle, compression ratio[1]) was performed, providing information regarding the size and shape of the cells, along with examination of the transferred ink dot sizes, contents and colour.

1.1 The Printing Industry

1.1.1 Introduction

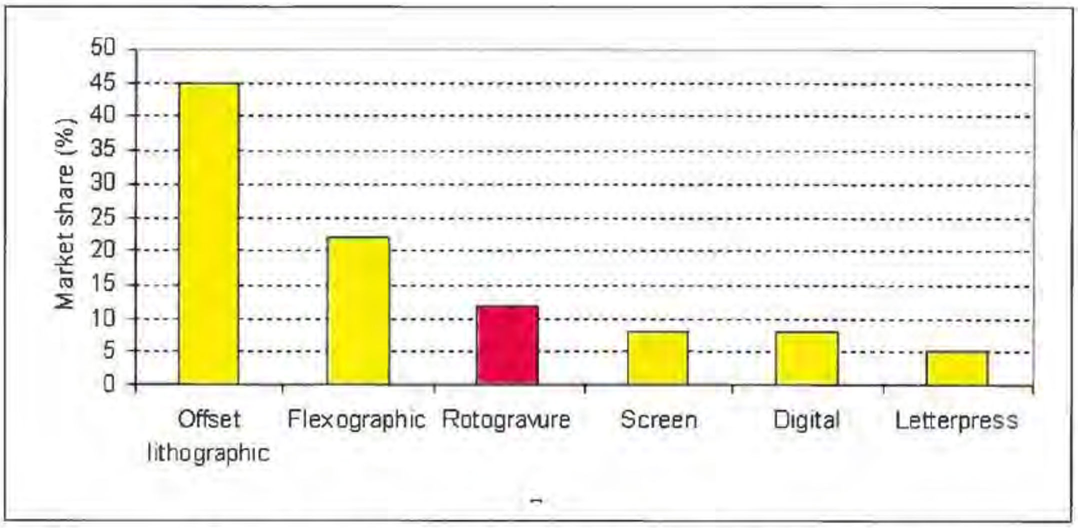
This section is in three parts. In the first section, the place of rotogravure printing in the modern printing industry is discussed, in relation to the other processes. In the second part, the development of the modern rotogravure process is examined. The third part covers the components of the modern rotogravure process, examining the cylinders, inks, doctor blades and impression rollers.

1.1.2 The Printing Industry

In 1998 a study was published [1], estimating that over 10,000 printing companies were operating within the UK, with a total turnover well in excess of £8 billion. A further report, published in 2000, indicated that the market had grown to

[1] For a definition of these and other terms, please see the Glossary – Appendix 5

approximately £13 billion [2]. The primary market is divided into six different, high volume printing processes. Offset lithography, flexography, rotogravure, screen printing, digital printing and letterpress. Graph 1.1 [1] (below) shows the relative market share of each process.



Graph 1.1 – Market share value (UK) of various printing processes

As indicated, rotogravure only makes up a small proportion of the UK market in terms of share value, despite the process being one of the earliest, as discussed later. Primarily this is due to the 'high cost' image of the process. Because the printing forme must be engraved individually for each job, the set-up costs per job are relatively high, unlike, for example, offset lithography or flexography, where a relatively cheap 'plate' is required. Traditionally therefore, rotogravure printing has been used for long run jobs, where the set-up costs become a minimal part of the total cost of a job, or where the highest quality available has been critical. 'National Geographic' for example, has always been gravure printed, due to the much higher quality available for photographic reproduction, and most mail order type catalogues are gravure printed. In this case the extremely long print runs and high speeds available to the gravure printer lower the total costs over the print run – along with the highest possible standards of reproduction, in order to accurately reproduce the items for order.

Unfortunately the process is little understood, and the industry has long been noted for its complacent attitude. Recently, in the face of shrinking market share it has been necessary for the industry to begin to examine itself, and to develop a more technical approach to market and process understanding. The purpose of this research therefore, is to understand the driving forces causing ink to be released from the cells on the gravure cylinder, and transferred to the substrate and hence affecting print quality.

1.1.3 The printing processes

The various printing processes can largely be defined in terms of whether the ink transfer process is rotational or linear. The three high volume processes are all rotational, which allows much faster, continuous printing. Each has its own advantages and disadvantages, strengths and weaknesses. Rotogravure printing is significantly the fastest of the printing processes, with presses operating at up to 1500m/min. Offset lithography is significantly slower (maximum speeds of approximately 600m/min), flexography slower still (approximately 200m/min) and letterpress running at similar speeds.

Lithographic (often referred to as 'offset printing') printing is a high speed, relatively high quality process. It is normally used for printing onto flexible substrates for the production of a wide variety of materials, from packaging to books, magazines to posters. An aluminium plate is drawn around a cylinder, and water and ink are applied. The water is applied first, coating the hydrophilic parts of the plate (non-image areas) and the ink applied afterwards to the hydrophobic regions to make up the image. The ink on the plate is then offset to a rubber printing blanket and from there to the substrate. The plate itself is planographic, unlike the plates used in both flexography and letterpress, and the cylinder used in rotogravure printing.

The plates in letterpress and flexography use raised sections to carry the ink. An inked roller (engraved uniformly over its surface) is pressed against the plate, and ink is transferred to the elevated surface, which is then transferred directly to the substrate. The primary difference between letterpress and flexography is the hardness of the plate. Flexographic plates are relatively soft, requiring a relatively low pressure printing nip. This makes it very suitable for printing halftones, unlike letterpress, which uses a much harder plate (originally, it used metal letters, screwed together to make up the image / text) and is therefore not good at printing halftoned images. Letterpress is only used for a few specific purposes, for example, book printing.

'Digital' covers a large number of possible printing techniques, from relatively high volume rotary systems, similar to photocopiers, with laser imaged drums and powdered ink, through to low speed, wide carriage inkjet printers. Each has specific applications, and is used in specific situations, from inkjet print heads being used to print 'use-by' dates onto food packaging, or to produce personalised letters. Other applications include many that have traditionally been the preserve of screen printed products – large posters and advertisements, point of sale material and very short run products.

Screen printing is another very old process, being essentially unchanged in principle from the traditional process of silk-screen printing. A screen (usually made of tensioned polyester mesh, fastened with a stencil) is placed above the printed substrate. A squeegee is pulled over the surface to force the ink through the screen and onto the substrate. It should be noted that in certain circumstances rotary presses are used, for example, printing carpets and wallpaper.

1.2 History of the rotogravure process

The gravure process is one of the oldest volume printing processes. Rotogravure printing is an intaglio process, i.e. one where the ink to be transferred is carried in areas recessed into the image carrier, Figure 1-1. Prints are made by covering, or immersing the surface in ink, wiping the excess away, "doctoring", and bringing the substrate firmly into contact with the image carrier. The first known metallic intaglio plates date from 1446AD where playing card manufacturers used engraved copper plates to print their product. The illustrations on the cards were produced by engravers, making illustrations consisting of line drawings, with close diagonal lines to indicate shadow. Originally these plates were produced by hand, with artists directly engraving the plates. This continued until the early 16th century, when chemical etching began to be introduced.

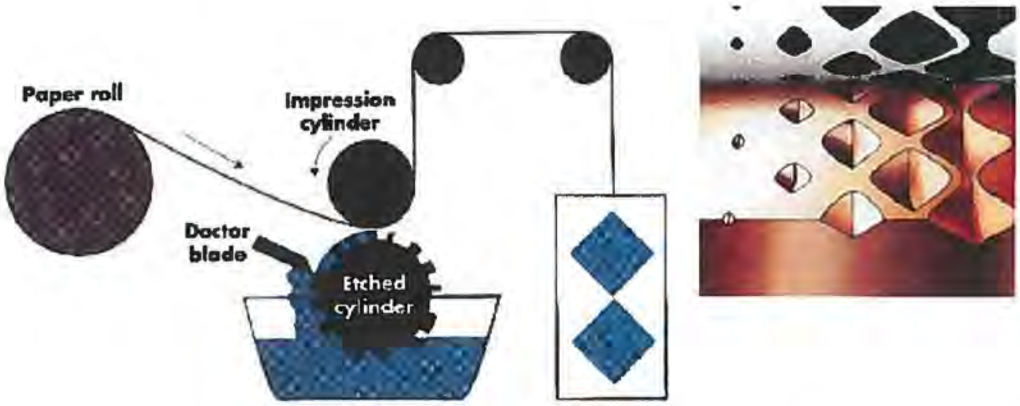


Figure 1-1 –The gravure process

Chemical etching is a technique, which involves using a chemical (usually an acid) to engrave the image. The surface to be engraved was covered with a soft 'resist'. The artist removed the resist layer in the areas he wished printed, allowing the chemical to come into contact with the exposed copper. Chemical etching also allowed the use of harder, longer lasting materials, such as zinc, iron or steel. These flat metal plates were not compatible with Gutenberg's letterpress, and so the processes could not be combined. This made it necessary for gravure pages to be added separately to books, or to be supplied as additional volumes in the case of encyclopaedias or other reference books.

The other primary applications of gravure printing included maps, stamps, music and currency; i.e. those applications requiring artwork other than text. Engraving remained the dominant form of image reproduction until the latter part of the 19th century.

Modern gravure printing uses the rotogravure process, as the name suggests, using a rotary intaglio system. This system was first used as far back as 1680, when the textile industry used intaglio cylinders to print continuous patterns onto material. Thomas Bell received a patent in 1784 for a rotary intaglio-printing machine. The patent details the inking unit, printing cylinder, doctor blade and impression roll - Figure 1-1.

The system changed little until the introduction of photography and the invention of carbon tissue, which provided a technique by which an image could be placed onto a cylinder and etched, simplifying the engraving process dramatically. Following the invention of the halftone screen in 1860, Karel Klic developed an engraving process by which he exposed the carbon tissue to a screen, and then exposed the now-screened tissue to a contone positive image. This caused the cells between the grid lines to harden relative to the density of the image. This process was used until halftone gravure was developed in the 1960s.

In the 1960s, electromechanical engraving was introduced. The first machines were developed by the Hell Corporation. The machine used either an electronic scanner, or a direct digital input, driving a diamond cutting tool, engraving mechanically, rather than by etching the material on the cylinder. Three diamonds are used. The first is simply dragged over the surface of the cylinder to give a reference position for the surface. The second diamond engraves the cells, and the third, the 'burr cutter' removes the burrs from the surface, following engraving. In the 1980s Crosfield introduced direct laser engraving, using a high-powered laser to engrave cells on a roller coated with epoxy. The project was abandoned due to problems with the roller materials. At a similar time, the Hell corporation introduced electron beam engraving, although this was also abandoned due to a need for a high investment in data processing and vacuum technology. Daetwyler AG produced a laser engraving system in 1995 using direct laser engraving onto a zinc coating on top of the normal copper surface of the gravure cylinder. This process allows much faster engraving (70,000 cells per second per head, compared with 8,000 cells per second per head for electromechanical engraving) albeit at a higher capital cost [3] [4] [5] [6] [7] [8]

1.3 Components

1.3.1 Cylinder

The printing cylinder consists of a critically balanced steel base with a layer of copper electroplated onto it. The exact thickness of the copper layer can be varied to allow variation of the circumference and thus the 'repeat length' of the print, and to allow 'progression' between the cylinders in a print job (where successive cylinders in a job increase gradually in size to compensate for the stretching of the substrate) [9] [10]. The top surface of the copper is 'polished' using two machines in series. The first precisely mills the top surface of the copper to provide an extremely smooth surface. The second 'roughs up' the surface using either emery paper or grinding stones in order to provide necessary surface roughness for lubrication to take place between the doctor blade and the cylinder using the ink retained by the cylinder surface. The cylinder may then be engraved, either by etching, electromechanical engraving or laser engraving. This engraved surface is then further electroplated, this time with a chrome surface to provide a harder face which is less likely to be damaged, particularly by the doctoring process, giving a much longer lasting cylinder than one without a chrome finish. Once chromed, the cylinder is polished once more, again with either paper or stone. It is conventionally believed that the surface is roughened up by this polishing, but as is shown later, this actually smoothes the surface further.

1.3.1.1 Gamma Curves

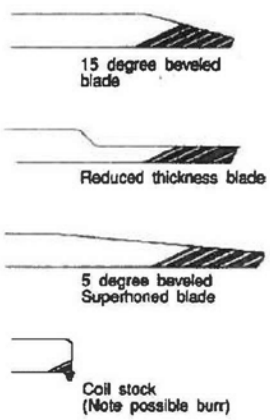
Gamma curves are applied in the engraving process to achieve two aims. Firstly they compensate for the tone gain, and secondly they compensate for the non-linear increase in cell volume with depth. Gamma curves are generally derived empirically by the engraver, calculating backwards from the density of a print made from a cylinder without a gamma curve applied to it. This is an iterative process. If the gamma curve is applied correctly, a smooth vignette will not appear to have any discrete 'jumps' in density, and will evenly go from 0% to 100% coverage. If the gamma curve is applied incorrectly, a smooth vignette will either have bands in it, or it will not increase in density smoothly. It will either appear to gain in density very quickly in the highlight regions, and slowly in the shadows, or vice versa.

1.3.2 Ink

Gravure inks are approximately Newtonian fluids, and are made of four primary components – 'Base', 'Medium', 'Additive' and solvent. The base contains pigment, plasticiser and other trace components (including up to 70% solvent), medium is essentially base without the pigment, while the additive contains many different components, including anti-foaming compounds, wax, resin, further plasticisers and a 'keying additive' or 'adhesion promoter'. The last, and biggest part of the ink is solvent, which makes up to approximately 70% of the press ready ink (not counting that already within the ink) depending on the final viscosity required. This fraction is often added at the press to avoid the need to ship large quantities of ink. This solvent may be Methanol, Ethanol, Propanol or several other compounds or mixtures thereof. Total solvent content in gravure inks may be as high as 90% by volume [3] [7] [11] [12]

1.3.3 Doctor Blade

The doctor blade is a thin strip of metal clamped in the press and placed in contact with the rotating cylinder between the ink bath and the printing nip. Several types are available, with different thicknesses, widths and tip configurations. It is widely regarded that 'lamella' tips provide the best wear characteristics but at the cost of price. As a result, most blades in use are conventional, that is, a strip of metal with a honed edge, Figure 1-2. This blade is brought into contact with the cylinder, and used to remove the excess from the cylinder surface as it rotates in the bath. Transverse oscillation is applied to the blade in order to prevent localised wear (to the blade or cylinder) being caused by the image patterns on the cylinder, and to prevent draglines caused by particulate matter in the ink being caught under the blade. In theory the blade pressure should be maintained at the minimum level required to remove the excess ink, but in practice both the load and angle of the blade are varied by the operator to control the colour of the final print. [7] [13] [14]. Figures 1.3 and 1.4 indicate how the blade is mounted on the press, and the forces on the blade tip.



Traditional blade

'Lamella' blade

Superhoned blade

Coil blade

Figure 1-2 – Types of doctor blade

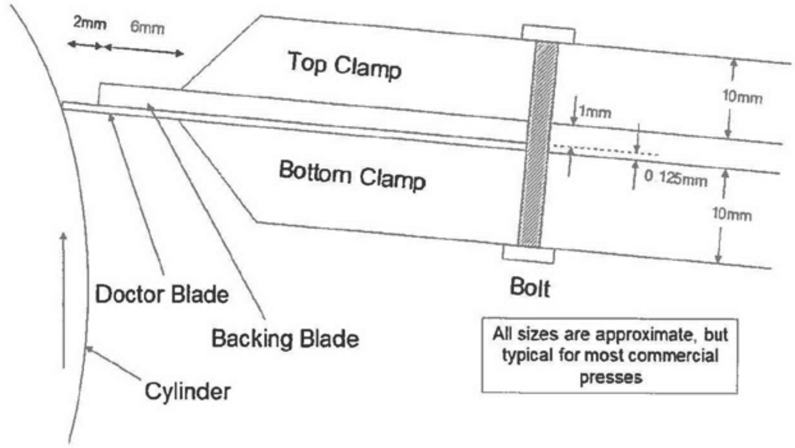


Figure 1-3 – Doctor Blade Mounting

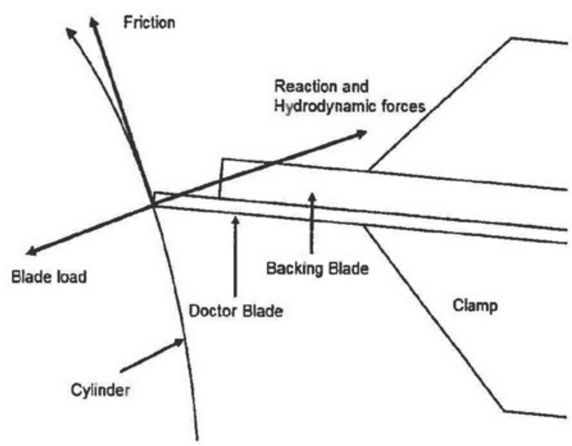


Figure 1-4 – Doctor Blade nip, indicating forces

1.3.4 Impression Roller

The impression roller is an important part of the process. It consists of a rubber coated roller which is used to force the substrate into contact with the inked cylinder, thus facilitating ink transfer. The load which the cylinder applies to the substrate is controlled by either hydraulic or pneumatic pistons. The load is varied further by the use of either hard or soft rubber coatings. Soft rubber coatings will distort more than harder coatings for the same impression loads, thus spreading the force over a larger area and giving a lower overall pressure, but giving a longer dwell time in the printing nip, whereas harder rubbers force the substrate further into the cells, thus forcing the substrate into contact with the ink in the cells, Figure 1-5. Impression rollers may be solid or use sleeves, which allow quick cylinder changes between jobs.

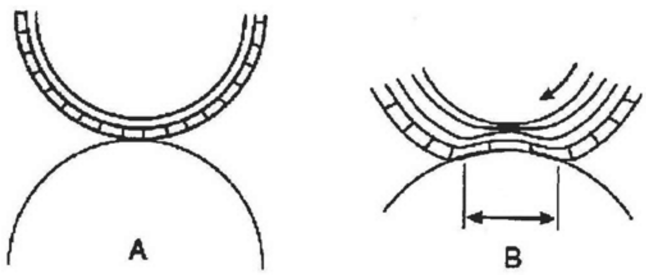


Figure 1-5a – Hard impression roller   Figure 1-5b – Soft impression roller

Figure 1-5 – Impression roller application

1.4 Motivation

The objectives of this thesis are to analyse and quantify the ink release from both the image and non-image areas of gravure cylinders under production conditions, and using production equipment and materials. Primarily this will focus on measurement of the precise volume of gravure cells, together with the quantity of ink released from a gravure cell, and on the factors that affect / cause ink transfer in non-image areas. The latter is referred to as 'scumming'.

As previously stated, little is understood regarding the effects of process parameters in the rotogravure process. Specifically, very little is known regarding the effects of varying engraving parameters (outside of screen ruling) and about ink transfer, when performed under production conditions (largely due to the prohibitively large costs involved), and virtually nothing is known regarding the volume of the engraved cells, due to a lack of available measurement equipment and methodology. As a result, this work will investigate thoroughly the effects of stylus angle and compression ratio on cell volume and geometry, and will also examine screen ruling, as little work beyond the analysis of density change with screen ruling has hitherto been performed. This will be performed in terms of density and in terms of the cell volume and geometries.

Furthermore, the problem of scumming is a significant one in the industry, yet there is no published literature exploring the causes of scumming. Here, the first stages of an investigation are performed, investigating the effects of several of the variables believed to be the primary causes of scumming, detailing their effects, and suggesting avenues for further research into the problem.

This work is intended to further process understanding, by understanding the method by which engraving variables will affect the ink release within the process, and by evaluating the effects of several variables on scumming levels. Only by understanding the effects of process variables can further improvement in the process be achieved.

1.5 Closure

To achieve the understanding highlighted above, the thesis is set out in the following format;

- Chapter 1 – The history and components of the rotogravure process. This chapter also includes an overview of the other volume printing processes and the reasons for the work.
- Chapter 2 – A review of the literature regarding previous work that has been performed in this area of research.
- Chapter 3 – A review of the experimental and analytical methodologies, detailing the new techniques which have been developed to allow quantification of the ink release.

- Chapter 4 – Experimental results and discussion regarding the release of ink from gravure cells. The procedures, results and techniques are all discussed.
- Chapter 5 – Experimental results and discussion regarding the transfer of ink to substrate in the non-image areas ('scumming').
- Chapter 6 – Conclusions and recommendations.

Chapter 2

Review of Literature

The purpose of the programme was to examine the factors affecting ink release from gravure cylinders. This includes the roles of the cylinder, the ink, the substrate, the doctor blade and the impression roller. The purpose of this chapter is to review the previous work, which has been carried out on rotogravure printing. Searches of the current literature has shown that there are few studies which have been carried out on the gravure process specifically, and fewer still which have been performed on production presses, under production conditions. However, in performing the literature review related fields were included and the most relevant papers have been commented on, thus the chapter is divided into three sections. The first section reviews the use of different measurement techniques to analyse ink transfer mechanisms as covered in this work. The second details the results from experimental research completed to date on the rotogravure process, and the final section will examine the use of numerical models in the printing process, with specific reference to ink release from cells.

2.1 Introduction

2.2 Experimental Measurement Techniques

To examine the mechanisms of ink release, the review of experimental measurement techniques is split into two subsections. The first examines the use of colour measurement whilst the second examines different techniques of volume measurement at the relevant scale.

2.2.1 Colour Measurement

When attempting to define 'print quality', "Colour" is the key requirement, and this has motivated research to measure it. The standard technique for analysing prints is to measure either the colour or the density of the ink [15] [16] [17]. As the colour of the ink will be determined by the thickness of the ink film, this measurement has traditionally been used to quantify the transfer of ink and provide data that may be used to infer the thickness of the film.

Print 'colour' is traditionally measured in terms of either its printed density or its colour. Spectrophotometers are used to measure colour, and give an accurate descriptor as numerical values. In a reflectance system, a beam of light is shone onto the surface. The light reflected at a specific angle (usually 45° from the illuminant) is passed through a lens or prism, to split the light by wavelength. This is passed onto a CCD array, and the intensity of light reflected at different wavelengths is measured. A diagram of a spectrophotometer is given below, Figure 2-1.

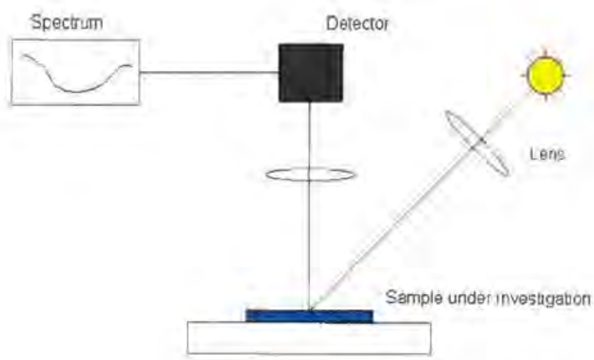


Figure 2-1 - Spectrophotometer

This data is then used to calculate a variety of parameters, including CIELAB colour space data. CIELAB (or CIE 1976 ($L^*a^*b^*$) colour space) defines a colour in terms of its lightness 'L^*' value, how red/green (+a / -a) a colour is, and how blue/yellow (+b, -b) it is. It is designed to be uniform perceptually, with equal distances in colour space giving equal perceptual differences in colour [17]. Two representations of the CIELAB colour space are given below, Figure 2-2.

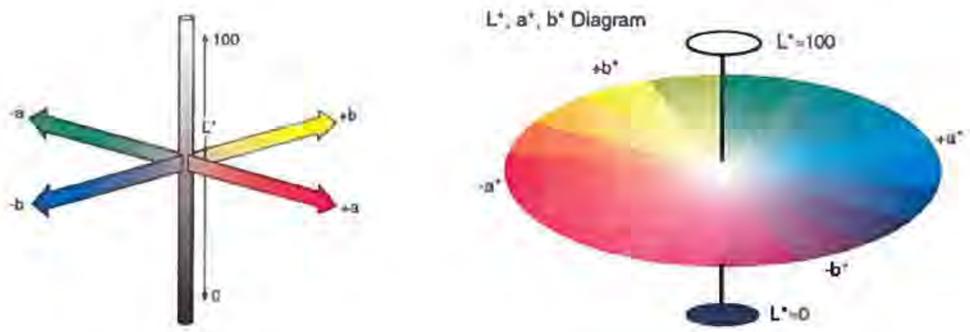


Figure 2-2 – CIELAB colour space [18]

Although CIELAB is designed to be uniform, it is not perfectly so, and as such the CIE94 formula was defined. This weights the parameters defining the colour according to their saturation, thus improving uniformity [17]. This adaptation is little used in industry, and as such has not been used for this investigation.

CIELAB values must have several parameters specified to be comparable. For the purposes of this experiment, all parameters will be specified to be D50 illuminant, 2° observer angle, ANSI T standards. For further details, see Field, [16].

Density is a more common concept for printers and engravers, not least because it only requires the use of a single variable to define a colour (assuming the use of process colours for printing). A densitometer (or spectrodensitometer – also capable of measuring colour) is the tool required to analyse density. Because of their inflexibility, a densitometer is significantly cheaper than a spectrophotometer. However, because the filters applied to the reflected light are applied electronically rather than physically, spectrophotometers can measure density as well as colour. A diagram of a densitometer is given below, Figure 2-3. In this case, the detector and the illuminant have been swapped compared to the diagram of a spectrophotometer. In practice the positions of these are interchangeable, and have merely been swapped for clarity.