Printing Fine Solid Lines in Flexographic Printing Process

MOHD SALLEHUDDIN YUSOF

Adv. Dip. (Nagasaki)

Swansea University
Prifysgol Abertawe

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SUMMARY

Solid lines are essential to enable printing of conducting tracks for various electronic applications. In the flexographic printing process, the behaviour of the printing plate plays a vital role in how ink is printed onto the substrate as it deforms when passing through the printing nip. This deformation is dependent on the material properties of the plate, the geometry of the lines and the pressure within the printing nip. These will influence the printed track width and the ink film thickness, which will affect the electrical performance of the printed conductors. This thesis will focus on experiments on Flexographic printing capabilities in printing ultra fine solid lines. The development of a measurement technique which leads to successfully capturing the printing plate line geometry details through the application of interferometry techniques, will be demonstrated. This information is used in a Finite Element models to predict the deformation and consequent increase in line width using both a linear and non linear material models, the latter being based on a hyperelastic representation. A series of experiments on a bench top printer and a web press machine to determine the capabilities and the limitation of the Flexographic printing process in printing fine solid is also presented. Through the experiments conducted the link between the IGT-F1 printer and an industrial scale web press machine has been established where the success in study on certain printing parameters and its affects lead to a successful prints of 50μm line width with 50μm line gaps. The experiments also point the importance of light engagement pressures within the printing train and the requirements for using anilox cylinders having fine engraving. The work also shows than process parameters (e.g. contact pressures) that are important for

graphics printing have a similar effect when the processes is used to print fine line features.

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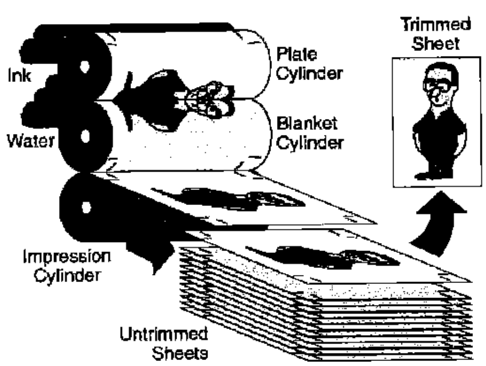
CHAPTER ONE

1 INTRODUCTION

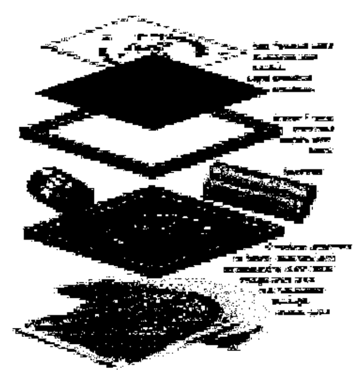
1.1 BACKGROUND

It is believed that printing started in 3000 BC in Mesopotamia where some of the earliest surviving examples were found. Later examples include those dated 220 BC from China and some from the 4th century in Egypt. In 1452 Gutenberg earned the credit for aggregating printing technologies known centuries before him. He conceived the idea of a moveable lead type which revolutionised book productions, previously accomplished by hand. In his workshops, he brought together the technologies of paper making, oil-based inks and a wine press to print books (Kippan, 2001).

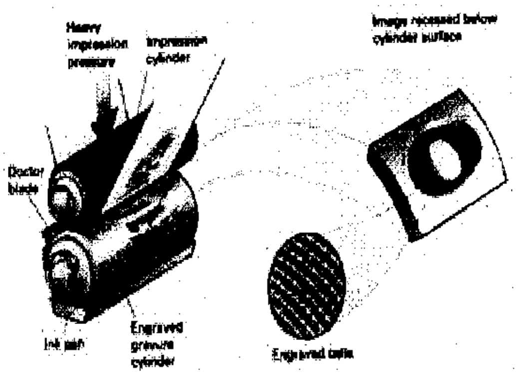
Clearly since the initial work of Gutenberg there have been major developments in printing technology especially in the context of volume printing where printing is commonly achieved by a contact method. Notably four main processes have emerged as shown in Figure 1-1.



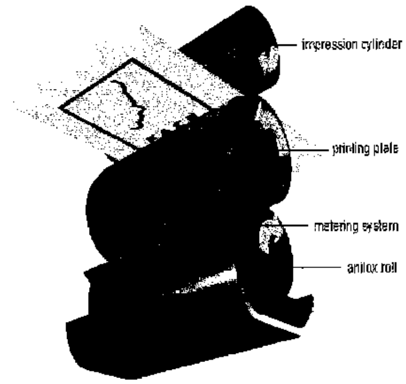
Offset Lithography



Screen Printing



Rotogravure Printing



Flexographic Printing

Figure 1-1 : Four contact printing processes

However fundamentally, printing is simply described as a process or technique of transferring ink onto a substrate. The principles of these processes are depending on the type of image carrier it uses as shown in Figure 1-2 (Kippan, 2001) where each process has their own characteristics of suiting itself to different applications and purposes.

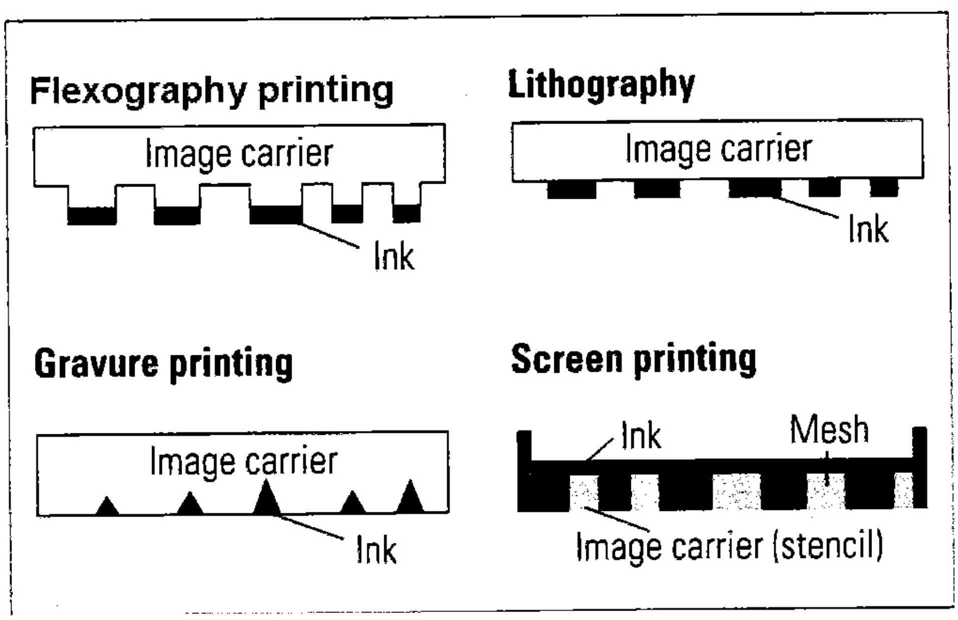


Figure 1-2: The four main conventional printing technologies (Kippan, 2001)

Until recently, printing has been used almost exclusively to print graphic images. It is one of the largest industries in the world , for example, it employs approximately 30000 people in 1000 companies in Wales and a proportionate amount in all other European companies (Hamblyn, 2005). Historically offset lithography and rotogravure have been used where high quality is required with gravure being advantageous when print runs are long (Michael L. Kleper et al., 2004). Screen printing is a process that is historically associated with high density coverage as it can deposit thick films coupled with the possibility to deposit a diversity of inks onto a diversity of substrates (Michael L. Kleper et al., 2004). Flexography formerly known as aniline printing has been viewed as a low resolution process due principally to the plate imaging technology based on a moulding process. However, the advent of the photopolymer plate has removed this restriction making it comparable with other high volume printing processes (Liu and J.T., 2003, Kippan, 2001).

The ability to print materials on a flexible substrate has been considered to be a core requirement for the economic manufacture of a diverse range of future products, such as lighting, signage photovoltaic devices and many more (IDTechEX, 2009). The use of printing for the fabrication of electronics components such as displays, back panels, memory, antennas and batteries etc has become possible due to the advances in materials and fundamental research related to the formation of electronic circuits on thin flexible plastic. Electronics fabrication is a process that involves the application of finely articulated patterns in precise repetition. It is an established technology that will enable a new and exciting future in which intelligence is incorporated into many products that we use daily (Michael L. Kleper et al., 2004).

It is also forecast that printed electronics will integrate the printing, chemicals and electronic companies to a new level in order to achieve the targeted value. As in printing electronics and producing thin film electronics there are some major factors that contribute to the successful printing of images with electrical functional capability. The key elements of device production are the manufacturing technique, substrate and material deposited. Changing one of these will affect the other two (IDTechEX, 2009).

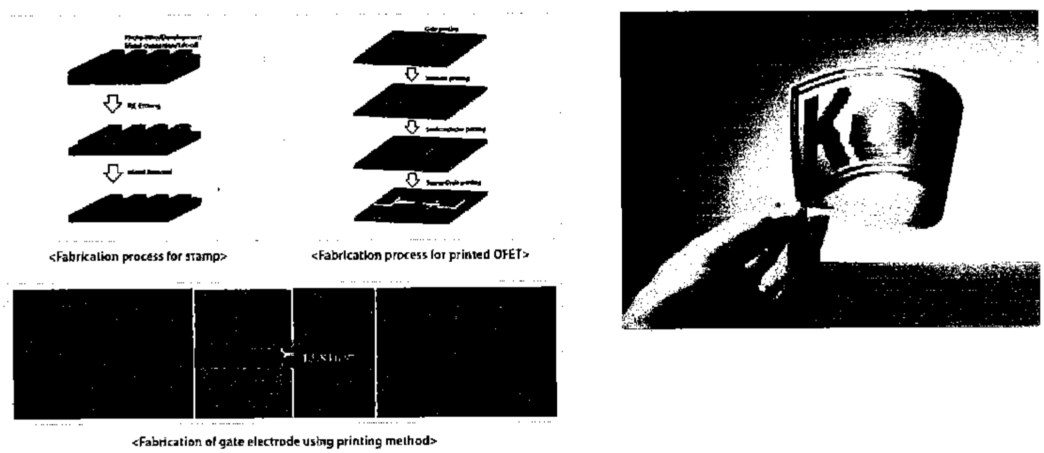


Figure 1-3: Electronic products made by printing (Kenry, 2009)

Figure 1-3 shows an example where printed electronics has been applied. The examples shown are an Organic Field Effect Transistors (OFET) printed using the screen printing technique and flexible panel displays printed on plastics (Blass, 2006). These exhibit the key features of printing electronics where consistency and homogeneous ink layers are crucial. It also reveals the importance of printing continuous solid lines where partial images will be a catastrophic failure.

Therefore a deep scientific understanding of the process chosen is crucial to meeting such stringent requirements routinely.

Hence this research will put a step forward looking into the fundamentals of printing a solid line which is vital prior to printing any functional materials on thin flexible plastics or other substrates layered with conductive ink either partly or entirely.

1.1.1 PRINTING OPPORTUNITY

In the context of graphic printing, the main thrust over the last twenty five years has been aimed at improving the quality of the printed product combined with reduction in processing cost and process ownership costs. There are three key elements for device production and these are 1) the manufacturing technique, 2) substrate and 3) material deposited. Changing one of these will affect the other two (IDTechEX, 2009) and this will be overviewed further in the following sections. However the advantages of having printing processes capable of meeting the demand for close registration and other aspects of close process control has opened a new era for printing industries into printing electronics where the demands for such are significant as seen in Figure 1-4 (IDTechEX, 2009) It is also forecast to have a $330 billion market by 2027 and the market territory where it is likely to be building in the world as seen in Figure 1-5.

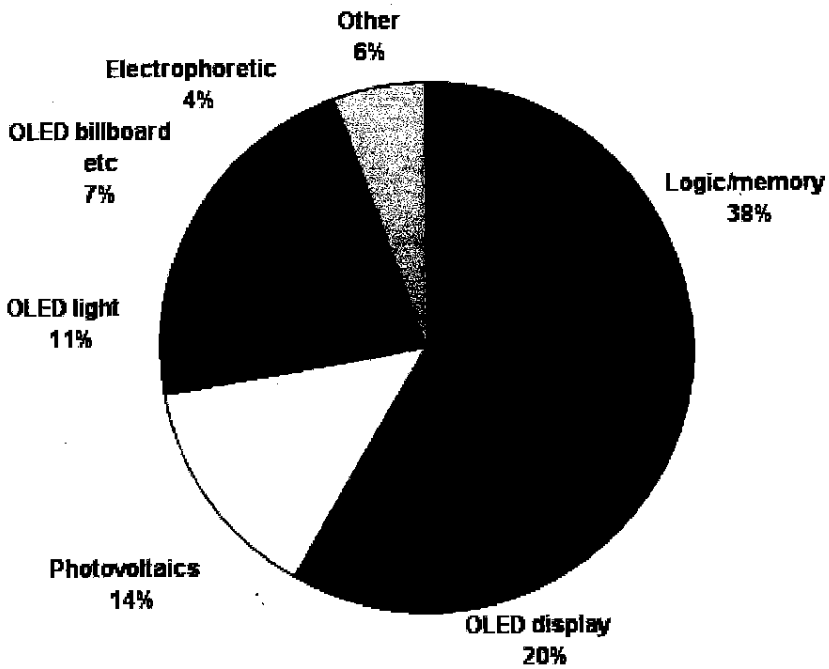


Figure 1-4: Market share of electronics by printing (IDTechEX, 2009)

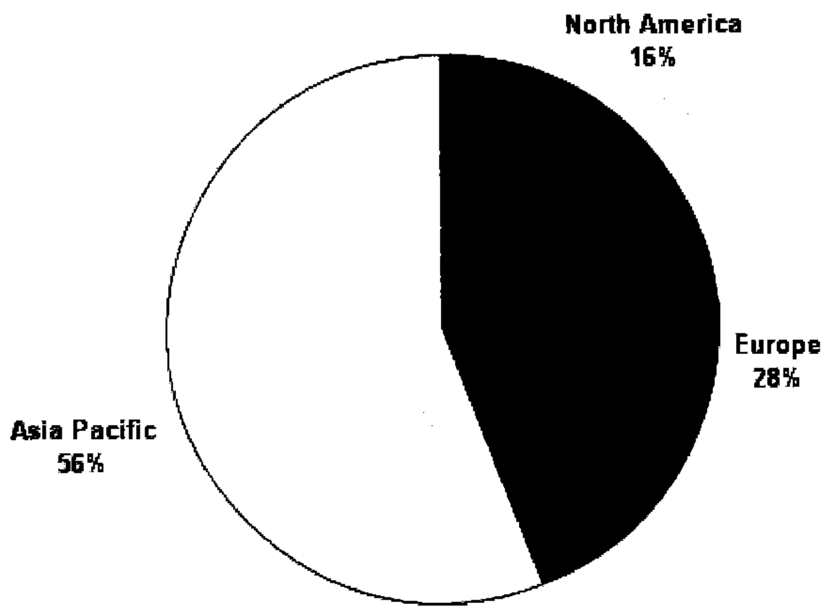


Figure 1-5: Market production by territory (IDTechEX, 2009)

1.1.2 PRINTING TECHNIQUES

Gravure printing is the fastest printing process in the market today. Several researchers have attempted to use it to print with functional materials such as Pudas (Pudas et al., 2004, Marko Pudas, 2004), Makela (Makela et al., 2002) and Leppavuori (M.Lathi; et al., 1995). These have been confined to low resolution devices and furthermore the imaging technology leads to stepped line features when their direction in neither circumferential nor transverse to the cylinder. This impact on electrical properties when printing fine features and the high cost of this printing technique coupled with rigid design is a major drawback.

Offset lithography is a planographic process that has also been explored. Kleeper et al (Michael L. Kleper et al., 2004) elaborated in his book that it uses high viscosity inks with long inking trains that is hard to stabilise. It has also been found to be poor at reproducing fine features due to suffering from lateral distortions.

Screen printing is currently the most widely used in printing with functional materials due to its capability in depositing thicker inks onto a diverse range of substrates. It is a slow reproducibility printing technique though having the advantage of very close print to print consistency. Prominently, it has been used in the manufacture of disposable blood sugar level sensors (Fang et al., 2007, Turner et al., 1999, Takahiko et al., 2006) and (Hu, 2009)

Beginning from the 20th century, flexography is the newest printing method evolving from the letterpress printing technique (Association, 2000). It is one of the simplest forms of printing as it transfers the image onto the substrate using a plate as an image carrier, see Figure 1-6. The plate is inked using an anilox roller that picks up the ink within its cells from the ink bath and it is metered using a doctor blade. It then inks the relief image on the printing plate where finally it transfers the inked image onto the substrates.

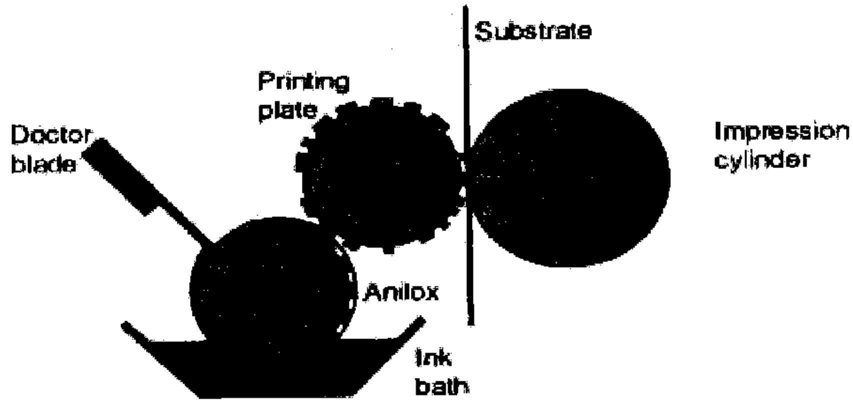


Figure 1-6 : Schematic of Flexography printing process

Flexography enjoys increasing application due to quality improvements attributed to photopolymer printing plate technology, (Michael L. Kleper et al., 2004).

Printing Process	Smallest Printable Feature	Application
Gravure Offset	50 μm	• Conductor lines on ceramic substrates • Pattern thin-film transistors for low-cost displays
Offset Lithography	25 μm	• Fabrication of capacitors using printed lines
Electrophotography	Not Available	• Pattern transistors and conductors on dielectric materials
Screen Printing	50–75 μm	• Commercial printed circuit boards
Inkjet	10–30 μm	• Presently the dominant experimental method

Figure 1-7: Application of traditional printing processes to the fabrication of electronics (Michael L.Kleper et al., 2004)

It is a simple process compared to other printing processes such as offset lithography, gravure or screen printing (Kippan, 2001). However its inherent and unique advantage is that it is capable of printing fine features at any orientation.

As a summary, Figure 1-7 itemises the currently known capabilities of the four contact printing processes, in terms of feature size and ink film thickness, including examples of application areas (Michael L. Kleper et al., 2004).

1.1.3 INKS

Historically inks can be traced back to 12^{th} century in China with the exploitation of dyes from plants, animals and minerals. Inks are either liquid or paste which contain pigments or dye for colorants. It is used to colour a surface to form an image, text or design. It can be a complex medium comprising solvents, pigments, dyes, resins lubricants, solubilizers, surfactant, particulate matter, and many other materials. The components of inks serve many purposes; the ink's carrier, colorants, and other additives control flow and thickness and its appearance when dry

The ink must dry or cure on the substrate, here the differentiation is basically made between physical (absorption, evaporation) and chemical drying (oxidation, radiation curing) procedures. In particular with flexographic printing processes, solvent inks or Ultra Violet (UV) cured inks are two commonly used types. Solvents such as toluene and resins are commonly used as an additive to the ink acting as a carrier substance for the colorants and also as a thinning agent especially in gravure printings (Napim, 2000). This type of ink normally uses a combined drying process (absorption and evaporation) to form an image. The inks must have a good adhesion to the substrates where it can be achieved by either mechanical or chemical mechanisms

1.1.4 SUBSTRATE

For many applications, substrates are likely to be either polymer films or coated papers. In 2600 BC papyrus was found as the forerunner of paper (Kippan, 2001). The strips were cut out of the inside of the plant following which it was pressed, beaten and smoothed out. However a courtier named Ts'ai-Lun, from Lei-yang in China, was the first recorded inventor of paper circa 105 A.D. He presented paper and a papermaking process to the Chinese Emperor which was noted in the imperial court records.

Currently, paper uses a pulp as a starting point, initially comprising 99% water and 1% cellulose fibres. The paper mat is then formed through a drying process and is classified as an uncoated paper. Subsequent coating treatments can be applied dependent on end application and surface requirements. This defines the paper surface roughness, permeability and wetting properties to hold the printed image.

1.2 RESEARCH CHALLENGES

The preceding comments highlight the potential for the flexographic process to print functional materials. However as a precursor, it is appropriate to explore the use of flexography to print fine line features using graphics inks, as these are of low cost by comparison. Although flexography is a simple printing process, a vast number of parameters affect it and these need to be fully understood, particularly when the precision requirements of printing functional materials is being addressed. A fishbone diagram depicting the range of parameters is shown in Figure 1-8 where each parameter has their own effect against the final printed results. Yet only some of these will be investigated in this research and they are marked in red.

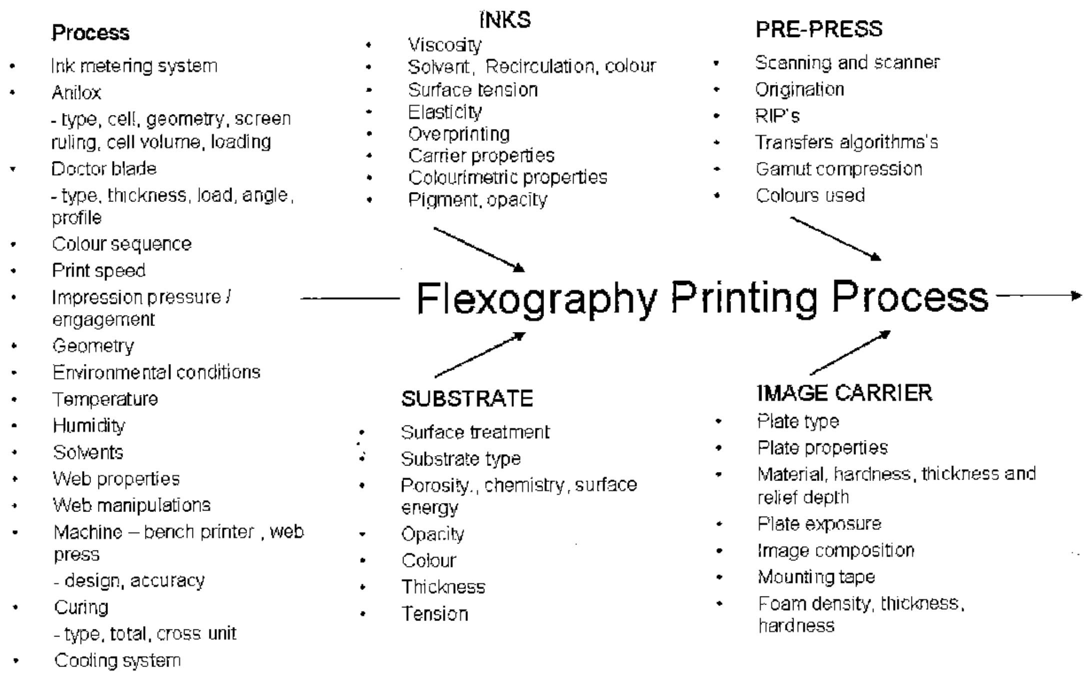


Figure 1-8: Flexographic parameters fishbone (Hamblyn, 2004)

1.3 AIMS AND OBJECTIVES

The purpose of this research is to examine the flexographic printing process and its capabilities as a means of printing fine solid lines which is vital to print conductive tracks, where this will hopefully lead to printing electronics devices or circuits. The thesis is therefore presented in three major parts:

Part I: In which to enable the scientific understanding of the flexographic printing processes, and establishment of measuring method.

Part II: In which the printing trials were carried out to investigate the effects of a few parameters in printing fine solid lines with graphic inks.

Part III: The development of Finite Element Analysis (FEA) in linear and non linear models to quantify the ink spreading mechanism.

The objectives of this research are to explore the parameters that are important for printing conductive tracks using the flexographic printing processes. The early experiments carried out are to determine the measuring method which is novel in this application and measuring equipment capabilities. In the second stage, experiments were conducted to determine the flexographic printing process capabilities of printing fine lines which are novel in this field as well. These were carried out both using the bench top printer (IGT-F1) and a reel-to-reel press.

1.4 THESIS OUTLINE

This thesis has been organised into seven chapters, the following six are as follows

Chapter 2 Literature Review: This chapter will cover the main literature review that is related to each chapter and the foundation and rationale of the research and experiments that have been carried out to achieve the objectives.

Chapter 3 Investigations of Printing Parameters: This chapter will provide a review and a short introduction of certain vital parameters that will be taken into consideration during the press trials in the later chapters. It will also cover the essential work on developing the method of measuring solid lines and the construction of geometry detail to be used in finite element modelling which is novel and needed to support the experimental work carried out in this thesis.

Chapter 4 Bench Press Printing Trial: This chapter focuses on the investigation of flexographic printing parameters and its effect using a bench printer (IGT F1 bench printer) on printing fine solid lines. Furthermore, the knowledge gained and tested on variables parameters and it affects in printing solid lines compared to printing dots were obtained from this chapter. These provide vital information on the selected parameters tested before the printing trials were brought to a web press machine.

Chapter 5 Web Press Printing Trial: A further printing trial investigation on Flexography printing parameters with an industrial size web press machine will be disclosed in this chapter. A few additional parameters such as aniloxes and engagements were used and also assorted printing plates. Here a novel achievement was made in printing technology where we successfully achieved a 50μm line width with 50μm line gap which progresses from the smallest line width and gap at 76μm previously achieved by the flexographic printing process while using conventional plate technology processed in standard form.

Chapter 6 Finite Elements: This chapter demonstrates the modelling work of the printing plate when passing through a printing nip. Initially, the first stage of the development of a linear model for a solid line will be elaborated in this chapter. Then the model was developed further to include a hyperelastic material, which is a novel achievement in this field of research.

Chapter 7 Conclusions and Future Work: This chapter will summarise the conclusion drawn previously in each chapter and will propose recommendations for potential future work.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 INTRODUCTION

Flexographic printing is mainly used for printing packaging materials cost effectively. This application has driven process innovation because there has been a demand to increase image quality to facilitate product promotion. Hence a considerable amount of literature has been published on graphic application that has led to a focus on halftone printing. However solid line and geometric feature printing is a requirement for manufacturing functional devices by printing where printing lines and features to construct devices has received substantially less scientific attention. The main objectives within this project are to provide a first step into volume production and high reproducibility of printing solid lines.

A short introduction on printing electronics will follow in this literature review. The demand to find a method to reduce the cost of printing electronics as a means of introducing innovation into a diverse range of products, such as printing onto flexible substrates, has led to research in both non-contact printing and conventional printing processes. However, in this research only a review on contact printing will be discussed due to its ability to deliver faster and cheaper printing options along with its capacity to print on a larger scale compared to non contact printing. These include offset lithography, rotogravure, flexography and screen printing techniques. Therefore the work in non contact printing will not be reviewed extensively and will only be commented on if related to a specific point. Parameters such as tone gain, hue, saturation and others relevant to the graphical side of the printing will be excluded from the aims of this research as they do not align with printing functional devices directly.

Consequently this literature review will be divided into 4 sections covering the contents of the thesis. The first section will review the process and the effect of some critical parameters on the printed image. The second section will review the work that has been done in exploring the usage of finite element analysis in simulating contact phenomena in printing. The third section is about printing processes with functional material and the fourth section will review the necessity of printing solid lines in comparison with printing dots with functional inks.

2.2 PROCESS PARAMETER EFFECT IN FLEXOGRAPHIC PRINTING

A search of the literature has shown that very few publications have addressed printing solid lines with flexography. Therefore this chapter will first provide a review of flexography to improve a scientific understanding of the physical processes that are present along with a structured review of the process shown in Figure 1-9. The figure itemises all currently known parameters, grouped under the headings of process, substrate, ink, image carrier and pre-press. Focus is placed on the parameters shown in red to maintain a manageable scope to this project. In addition, a short review of computer simulation work will be undertaken as this is used in this project to gain insight into the mechanisms that are present in the contact between the printing plate and substrate within the printing junction.

The quality characteristics that are relevant in this work (Figure 1-9) focus on a printed line and a range of features have been explored by Barden (Barden, 2005) in conjunction with screen printing. The author used image analysis for line width assessment and white light interferometry to estimate the line section profile. The author performed the measurements down to 100µm line width but did not perform measurements for finer lines. The measurement techniques faced fewer challenges owing to the relatively thick lines printed on the substrate, typically up to 80μm while images printed using flexography lies in the range of 3μm to 8μm ink thickness. Consequently a measurement technique suitable for finer lines needed to be developed and tested. Barden explored measures of line width consistency coupled with edge smoothness that he expressed as a roughness parameter due to undulating surface topology derived from the mesh threads and knuckles on the screen. He used white light interferometry for measuring the print surface while using statistical and Fourier transform techniques to calculate the period, magnitude and the effective increase in surface area. This technique is claimed by the author to be useable in gravure and flexography as well and this technique is also well used by Hamblyn and Cherry in their investigation.

Flexography is, in principle, a simple printing process but it is made complex by the nature of the flow that takes place within the final image transfer process and consequently several parameters affect the final result. Developing process understanding in which several parameters interact in a non-linear way is particularly challenging and for industrial relevance this needs to be done on a full scale press. This is explained by Bohan et al (M.F.J.Bohan; et al., 1996) who showed why statistical techniques must be applied to account for the variation of printing from copy to copy. This will be taken into consideration where the protocols of the experimental work that will be carried out need to be designed and developed to minimise the effects of any variability. Bohan has also presented methods for applying Design of Experiment (DoE) techniques in printing research, highlighting strategies such as combining array subsets to build a full array, e.g two L4's to make up a L8. This was motivated by process stoppages as the duration for a L8 could be long (a few hours) and any stoppage introduced unwanted disturbance into the results. The L4's could be completed in a short time scale and so were not so susceptible to failure due to process stoppage (Bohan et al., 2000).

2.2.1 PROCESS AND SETTINGS

In flexography, Bould (Bould, 2001) looked into a number of process parameters and conducted research into the improvement of quality for graphic application where he noted several critical parameters. He explored process settings that include engagements (anilox to plate and plate to substrate), effects of anilox line rulings and the effect of plate thickness and 3 variables of printing speed. The author commented that the engagements had the greatest effect on tone gain[1] as the quality characteristic. Line ruling[2] is the second most important parameter. The author noted that the total tone gain was significantly higher than the results gained from numerical investigation. This was attributed to ink spreading, however it could also be attributed to treating the photopolymer plate as an elastic material, rather than a more complex photopolymer system that can exhibit a

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[1] Tone gain: known as tonal value increase. Occurs in litho and flexo which causes printed material to look darker than intended (Johansson et al, 2006). The growth of halftone dot from the original size on the printing plate to the printed image.

[2] Line ruling: The number of lines of dots per inch, both vertically and horizontally, on a screen tint or halftone screens (PrintingTips.com 2011). Also the frequency of the halftone dots on the printing plate or cells on the anilox rolls

nonlinear response. The difference in tone gain was small for high engagements, becoming more significant at the lighter contacts. The author also suggested adopting a simple 2 dimensional model developed within his research to account for plate composition using different material properties which will permit, for example, the study of the effects of different front and back exposures on tone gain. The author also noted that plate thickness has less than significant impact on the results. However greater deformation occurs on thinner plates compared to thicker plates. The line ruling has shown to be a critical parameter for tone gain in flexography. As line ruling increases the dot areas decreases resulting in a greater dot perimeter. In this study the author claimed that printing speed has little effects on tone gain.

Hamblyn (Hamblyn, 2004) continued the work initiated by Bould and within his research investigated the role of the plate in ink transfer. He pointed out several important parameters which influenced the printed results and extended the work carried out by Bould. In his study, the author included printing speed as one of the most critical parameter where within his research on tonal graphics he clearly showed the importance of engagement effects and the printing speed where the dots became elongated at high printing speeds and high engagement. Other critical parameters which affected the printed results are the engagement effect between the printing plate and the aniloxes. The author also included other variables in his study such as multiple plate thickness and hardness and also extended the work with a 3 dimensional model FE analysis compared to 2 dimensional simulations developed by Bould. Studies by Bould and Hamblyn highlight the importance of process settings for dot reproduction, it remains important to establish if their observations hold for line printing where the plate relief formed as a line will respond differently from a dot relief profile. Therefore an investigation on engagements and speed needs to be carried out within this research and these will be explored using a laboratory bench printer and the web press machine.

The annilox is one of the most important components in flexography as it controls the supply of ink. The anilox can be constructed with options of material type (chromed or ceramic surface), cell depth, screen ruling and cell geometry (diamond stylus engraved or laser machined). Uniquely, laser machining has enabled the manufacture of a number of cell geometries, in which open area and volume can be controlled independently. Damroth (Damroth et al., 1996) investigated viscosity, anilox cell volumes and press speed for an UV curing ink[3] system where the author noted that the anilox line count had an influence on the print density. The tone gain for high coverage (i.e.75% dots) increased as the viscosity of the ink increased for the lower capacity anilox rollers but showed little change at the highest line rulings. However, for low coverage (i.e. 5% dots) and high anilox screen rulings tone gain decreased as viscosity increased. The inconsistencies of the results were unexplained and the press speeds were found to have little effect on tone gain. This exhibits the lack of understanding and the complexity of the flexographic process where Bould and Hamblyn have successfully resolved some of the conflicting results observed in publications on

[3] UV curing inks are attractive test inks as they contain no volatile components and so exhibit minimal volume reduction during curing.

graphics printing thus opening an opportunity to further the investigation to comprehend how the solid line behaves, if differently, from a dot.

Because ink release from the anilox is a central consideration for image quality, Cherry (Cherry, 2007) conducted a specific research looking at the ink release from a number of anilox designs that included line ruling and cell geometry effects achieved through engraving using both YAG and CO_2 lasers. The former yield V shape cells and the latter U shape cells. Generally he found that at comparable volumes and cell profiles the YAG engraved cells gave a better ink release. To quantify this, he successfully developed a method of using white light interferometry to quantify the ink within a cell at a pre and post printing stages resulting in the ability to calculate the percentages of ink released. The author also noted that as the cell volumes and depth to opening ratios increased, the percentage of ink released from both anilox rolls decreased. It was found that the optimum ink release takes place at a depth to opening ratio of 20%. It was also noted that as the plate coverage increased the percentage of ink released decreased. When the plate screen ruling increased the percentage of ink released from the anilox also increased. The study also suggests that increasing press speed results in a decrease in optical density due to reduction of ink transfer, and increasing anilox to plate engagement had variable effects as the physical dot volume increased at the lighter engagements but then decreased at the higher engagement. This comprehensive study on anilox choice shows a complex influence on dot gain. The effect of anilox when printing solid lines needs to be explored and thus it will be investigated briefly in this programme within Chapters 4 and 5.

Work has been carried out on bench top devices that approximate the conditions on a web press. There are potential advantages such as the ability to explore material interactions and to explore in an approximate way the influence of process parameters. Although a bench top printer is not as fast as a web press, it does have the advantage of easily allowing some printing parameters to be screened for their importance as elaborated by Toshimichi in his research of testing flexographic printing parameters (Toshimichi, 2005). It is also valuable for conducting short run experiments, evaluating test samples while saving on inks and materials. Many researchers have benefited from the use of a bench printer in their researches such as T.Uesaka et al (M.Holmvall; and T.Uesaka, 2007) and Johnson (Johnson, 2008). However none of these researchers extended their work onto a web press machine and so the industrial relevance may be viewed as limited. However Hamblyn (Hamblyn, 2004) and Bould (Bould, 2001) used a bench printer and a web press and their work showed trends which are present on both bench and web press printing machines. The bench printer has the benefit of allowing some parameters to be tested before further research is carried out on the web press hence the experimental results utilizing a bench top printer will be further investigated and elaborated in Chapter 4.

2.2.2 INKS

There are three types of inks which are commonly used in flexographic printing. The first are water based inks which usually dry through evaporation and absorption on the substrates or paper. The second are solvent based inks which contain blends of alcohol which have the advantages of quick drying through evaporation but have the side effects of volatile organic compounds some of which are hazardous. The third commonly used inks are UV curing inks in which the inks are cured by exposing them to the UV radiation. Within this research a UV curing ink is used as there is little volumetric loss due to evaporation. UV curing functional inks have yet to be developed at a commercial level, however they are being developed as experimental inks due to potential curing and environmental advantages.

As mentioned in Chapter 1 flexographic inks can be formulated for a range of application. These inks are usually non Newtonian in nature, therefore their viscosity changes under shear. To enable functional materials to be printed, the rheological performance of the ink itself needs to be engineered to suit the type of printing techniques chosen as elaborated by Kippan (Kippan, 2001). For functional inks, the rheology is influenced significantly by the particulate content, for example if a high loading is required to achieve a functional characteristic, such as good conductivity, this can lead to an ink of high viscosity that can only be printed by a screen process.

The flexographic printing process uses a low viscosity ink for which the range lies between 0.05 – 0.5 Pa.s. The surface tension is determined by the substrate specific surface energy as this finally determines the ability for the ink to wet the substrate. Hamblyn (Hamblyn, 2004) in his research conducted some experiments with different types of inks. In his conclusion, UV inks printed on a non porous substrate are the best combination to conduct a scientific understanding and accurate measurements of printed results due to the fact there are no losses of actual printed images where the inks were absorbed by the porous substrate or the solvent or carrier evaporates leaving the pigments only.

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