Investigation of Carbon Black Ink on Fine Solid Line Printing in Flexography

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Abstract: - The flexographic printing process poses as an attractive candidate for printing electronics for its high speed printing capabilities where such volume and large active areas need to be printed. Therefore an investigation for its potential usage in printing electronics is highly in demand hence a research for suitable conductive ink related to this process is vital. This paper will focus on a novel development of carbon black ink in printing fine solid lines specifically developed for this type of printing method compared to commonly used silver metallic filled inks and polymeric inks readily available in printing technologies which will also be extensively reviewed and elaborated. A step by step approach by printing solid lines, measurements of printing plates and printed images and finite element analysis (FEA) has been carried out in advance to help comprehending this process that is influenced by many interacting parameters. Printing trials have also been carried out in comparison with water based Panipol ink to check the compatibility and the suitability of the ink developed for this printing technique.

Key-Words: - Flexography, printing solid line, waterborne carbon black ink, printing electronics

1 Introduction

Electronic devices manufactured by printing are likely to increase. The use of printing processes both as impact and non-impact (i.e. ink jet) variants for electronic products such as displays, back planes, memory, antennas, batteries and other devices is emerging because of the advances in material, fundamental research related to the printing processes and electronics design [1]. A significant amount of research has been carried out on both impact and non-impact printing to fulfill the emerging demand of printing electronics. However, impact printing processes are much faster and capable of printing over large areas compared with non-impact printing [2]. In impact printing, screen printing has the advantages over other type of printings and due to its capabilities to deposit thick layers of ink over large areas [3]. It is currently being used extensively and will continue playing a leading role in printing electronic products. However there are some disadvantages that include speed where a high resolution web based arrangement runs at only around 40m/min. And although a web fed rotary screen can run at up to 150m/min regrettably this system is only capable of lower resolution [4] and this limits the feature sizes that may be printed. The alternative processes comprise offset lithography, flexography and gravure. These are all high speed processes that are capable of high resolution printing achieving typically 50µm [5] features for lines in the gravure process compared with 20µm for flexography [6]. However, problems with electrical conductivity remain and where a continuous solid line is vital. The image shown in Figure 1 highlights such potential discontinuity and this needs to be addressed [7].

![Figure 1: Gravure printed images with jagged lines](image)

The flexographic printing process offers the possibility to print continuous fine solid lines [8]. While flexography is a simple process and the image carrier is cheaper compared with gravure, a vast
number of parameters affect this process which will ultimately affect the quality of the printed images. However, current research on printing plate technology [9] and investigation into critical parameters such as anilox rollers, ink rheology etc [10, 11] help to comprehend the impact and the affects of these and other parameters on the final printed images. Further research on the application of finite element analysis (FEA) including both linear and non-linear models provides complementary work to predict the printing plate deformation [12] and in understanding the ink spreading mechanism [13].

1.1 Conductive Inks
Printing a conducting track is a vital requirement for printing future electronic products. In printing technologies there are a number of conductive inks currently being considered. Commonly used are inks with metallic particles such as silver, gold, nickel and platinum. Also there are polymeric, organic and inorganic conductive inks. In high volume printing, there is a requirement for rapid drying and the ability of the ink to adhere to the substrate [14] or previously printed layer is essential. In flexography, silver particle inks have been explored [15-17], but these have served to highlight the problem of the particulate filling the engraving in the anilox.

One of the reasons for this occurrence is the size of the annilox cell opening which depend on the line ruling and engraving shape. Using white light interferometer measuring machine, a 1500 lines per inch (lpi) ruling anilox has a cell opening of only 14μm across as seen in Figure 2 whereas the silver flakes have a characteristic dimension in the range of 10-20μm as shown in Figure 3. The other concern is ink rheology. This is a delicate balance between the mixture of particulate and carrier fluid. A higher concentration of particulate is desired for better electrical properties i.e reducing resistance, but this can also lead to poor printability as the flow viscosity no longer falls within the process operating window. A few researchers have explored conducting polymer inks, such as Polyaniline [19-22]. The results from this point to the fact that the electrical performance is not as good as particle laden systems and that environmental factors such as temperature and humidity greatly affects the final results [23], placing strict demands on the processing requirements. Consequently alternative ink formulations need to be considered, one of which is based on a carbon system. Although carbon inks are already available, little is known about the ink formulation that is often subject to commercial confidentiality. In this work a carbon ink was formulated that used water as the main carrier fluid. The formulation comprised of carbon beads and water, solvent for quick drying, additives or surfactant as bubble deformer and acrylic styrenated self-crosslinking copolymer dispersion to enhance the adhesion of the inks to the ink carrier and onto the substrates. This ink formulation was tested in this research to identify its printability in exploring the feasibility to be used as conductive inks. This will be described in the following sections.

2 Experimental and Results
In this study, carbon black beads were used and milled using a milling machine as shown in Figure 4. Also in this research, the experiments were carried out under normal room temperature and kept constant avoiding further variables.
Ink formulations were then carried out where the grained carbon beads were mixed with the formulation described earlier. The particle size within the ink was measured using a Hegman gauge from which it was determined that a particle size ranging between 2 and 4µm was achieved. Based on the previous experiments, the size of the particle inside the inks should be typically three or more times smaller than the anilox cell opening. The viscosity of the carbon black ink was compared to a UV graphic ink that is known to work well on a flexographic press. Substrate suitability needs to be established and this has been performed using deionised water as this is a dominant component within the ink. This was established using a dynamic contact angle measurement device and a number of candidate substrates were tested as shown in Figure 5.

Figure 5: Water contact angle on various substrates

The data shown demonstrates that a BOPP (Biaxially Oriented PolyPropylene) with corona treatment is a suitable substrate as it is impermeable and has favourable wetting characteristics, denoted by the lowest value of contact angle.

The formulated carbon black ink was then compared to a non-engineered waterborne Polyaniline ink which has been specifically designed for offset and flexographic printing obtained commercially. The surface tension of both inks and its printing compatibility on the BOPP substrate was tested and the results are shown in Figure 6.

Figure 6: Surface Tension of carbon black and PANI

Observations show that the carbon black ink has a lower surface tension than the polyaniline counterpart, indicating that it spreads better on the substrate. Further analyses on the contact angle as shown in Figure 7 points to the fact that the carbon black is likely to be better than the polyaniline counterpart when printed on this substrate. It demonstrates that it will be more successful in wetting the substrate and consequently adhering to it when it is dry.

Figure 7: Contact angle of conductive inks on BOPP

A series of experiments on a bench press printer were also carried out to test these conductive inks more rigorously in terms of their printability. A successful printed images using carbon black ink can be seen in Figure 8. This was achieved under the 10N impression pressure and the multiple line shows a successful print of 50µm line width with a 100µm line gap. However an attempt to print waterborne PANI is unsuccessful due to high surface tension with this type of substrate.

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4 Conclusion

It is clear that the newly formulated waterborne carbon black ink is suitable for printing carbon tracks that exhibit a continuous structure, eliminating process failure through drying in the anilox. From the data obtained on the printed images, it shows that a homogeneous layer of carbon black ink could be deposited on thin film flexible substrate of BOPP. It also clearly shows excellent stability where there is no sign of pigment settling, pigment kick-out, surface colour floatation, liquid phase separation or any gellation after the ink has dried under ambient temperature. However the downside of this printing method is the ink film thickness were only between 5µm - 7µm could be deposited which may lead to a very high resistance if used as conductive tracks. Consequently, further research on this waterborne carbon black ink is required with a view to improving its electrical performance while not compromising its printing performance. A comparison of the two ink results reveals that engineered inks are needed and works better compared to a non engineered inks depending on the circumstances as commented by Commerford. Nonetheless, it shows that it could be utilized as passive RFID antennae in close range of few meters proximity are feasible with the advantage of flexographic printing process of fast reproduction and at a very low cost.

References:


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