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## *Title*

Optimisation of screen printing process for functional printing

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## Abstract

In this study, the effects of screen printing parameters on the quantity of ink deposited and as well as the print quality in the context of printing of functional inks were studied. Both these aspects of printing are crucial in the case of conventional as well as functional printing. This is because in the case of conventional printing, the quantity of ink deposit affects the color strength while in the case of functional printing, it directly affects the resulting functionality of the ink layer. In this work, an automatic lab-scale screen printer was used to print functional inks on a paper board substrate. The printing parameters, i.e., printing pressure and squeegee angle were altered and the resulting effects on the quantity of ink that was deposited were recorded. The quantity of ink deposit was related to its surface resistivity. In addition, the quality of print was also assessed by examining the design registration quality. We found that the altering the squeegee angle has a significant effect on the properties of the resulting ink deposit. More importantly, we found that the deflection in the rubber blade squeegee was greatly dependent on the initial angle of the squeegee at the start of the printing stroke. For each set value of squeegee angle that was considered, the actual angle during printing was recorded and used in the analysis. A

printing pressure of 3 bars and squeegee angle of 20° resulted in maximum weight of ink deposit with a correspondingly lowest surface resistivity.


## Keywords

Coatings, screen printing, functional printing, printing parameters, electrical resistivity.


## 1. Introduction

In comparison to several alternative manufacturing methods, the major advantages of roll-to-roll printing include high through put rate, low cost and simplicity of the process (Mathews et al., 2010) (Rogers et al., 1999). Owing to this, printing is increasingly becoming a preferred method for localised deposition of a desired material on a substrate. Due to the intrinsic versatility of the process and its several variations, almost any type of substrate can be printed these days. On the basis of the intended purpose of the product manufactured, all printing processes can be categorised into two categories – conventional printing and functional printing. Conventional printing of a substrate generally refers to colouration of a substrate for aesthetic purposes. On the other hand, functional printing refers to a printing process that is desired to impart certain functionality to the substrate, for instance, electrical conductivity. Various aspects pertaining to the formulation of electrically conductive inks have been studied by the authors separately (Ali and Lin, 2018) (Ali et al., 2019).

Due to advantages highlighted in the aforementioned text, printing is increasingly being used to produce a broad range of functional devices such as flexible sensors (Chen, 2005) (Cochrane et al., 2007) (Qi et al., 2008) (Sokolov et al., 2009), large-area electronics (Parashkov et al., 2005), organic light emitting devices (Pardo et al., 2000) (Lee et al., 2009) and polymer solar cells (Krebs et al., 2009) etc. The use of printing techniques is even more prevalent in fabrication of basic components of an electrical system such as conductors (Locher and Tröster, 2007) (Karaguzel et al., 2009), resistors, capacitors (Jost et al., 2013) and transistors (Garnier et al., 1994) (Gray et al., 2001) on flexible substrates.

For functional printing on flexible substrates, some of the more widely practiced types of printing processes include offset printing (Pudas et al., 2004), flexographic printing, gravure printing (Pudas et al., 2005), screen printing (Jost et al., 2013) (Hyun et al., 2015) and inkjet printing (Sirringhaus et al., 2000) (Yoshioka and Jabbour, 2006) (Kim et al., 2009). Screen printing offers several crucial advantages over other printing techniques (Savage, 1976) (Krebs, 2009) (Secor et al., 2014) and it is the subject of this work. However, regardless of the type of printing process, its objective (conventional or functional) and the substrate, determination of the optimum process parameters is imperative to achieve the desired print quality. In all screen printing processes, a hydrodynamic pressure is developed in the wedge of print paste that lies between the squeegee and the screen (Dubey, 1975). The quantity of paste that is forced out of the screen depends on this hydrodynamic pressure which in turn depends on the squeegee angle, base length of the pressure zone, speed of movement of squeegee, paste viscosity and screen pore radius (Yen et al., 2011) (Lin et al., 2008) (Thompson, 1995). In addition, other factors that influence ink transfer in screen printing include the ingredients of the ink system and the screen specifications (Piao et al., 2008) (Hawkyard and Miah, 1987). Detailed accounts on the effects of printing parameters on print paste consumption have been reported for flat screen printing (Dowds, 1970) as well as for rotary screen printing machines (Lomas and Short, 1999). Due to the aforementioned factors, the ink film thickness can be varied considerably in screen printing (Huebler et al., 2002). This is particularly beneficial in case of functional printing due to the following reasons. In case of printing of electrically conductive inks or of inks possessing any other type of functionality, it is imperative to achieve the desired print quality in terms of appearance of the print as well as in terms of functionality of the print. In such cases, besides the total amount of ink transferred onto the substrate, the integrity of the deposited ink layer is also of prime importance. For instance, if a given amount of ink is smeared over a larger area of the substrate then the resulting ink film thickness will be less compared to the same amount of ink printed over a smaller area of the same substrate. It is to be noted that the thickness of ink layer is often regarded as the prime characteristic to control in case of functional printing (Pudas et al., 2004).

In the present study, the effects of changing printing parameters on the amount of print paste delivered and quality of registration were studied for a lab scale screen printing machine. The amount of print paste delivered as a result of changing printing parameters was calculated and related to the DC electrical resistance of samples.

## 2. Materials and Methods

### *2.1 Substrate selection and preparation*

All samples were printed on Incada Exel standard packaging paperboard. 175 mm x 100 mm samples were cut from A4 size sheets of the substrate and multiple samples for each set of printing parameters were prepared.

### *2.2 Preparation of print pastes*

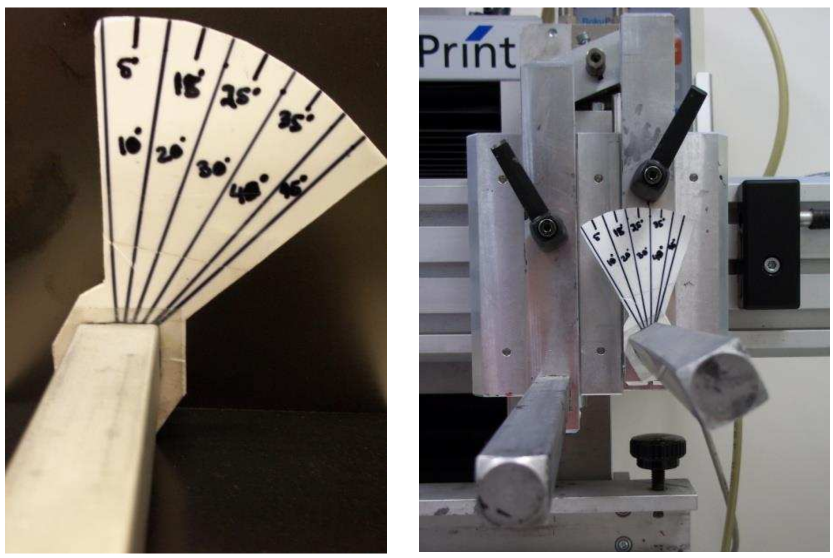
Print pastes containing 4 w/w%, 8 w/w% and 12 w/w% Clariant's Printofix Black T-M were prepared using Clariant's Printofix Thickener CSN liquid. Other printing auxiliaries such as binder, etc were not added in the print paste. This is because the primary objective of this study was to analyse the printed ink layer and the amount of print paste deposited.

Figure 1 depicts the sequence of steps in preparation of the print pastes. Required amount of thickener was measured in a beaker and D.I. water was added followed by stirring at 2000 rpm for 5 minutes using an IKA high speed overhead stirrer. Printofix Black T-M carbon pigment was then added in the required amount and the mixture was stirred again at 2000 rpm for 10 minutes. The print paste is left for 4 hours for de-aeration. Thus, 20 g print paste of each formulation was prepared.


Figure 1: Steps of print paste preparation

### *2.3 Printing*

Rokuprint flat screen printer SD-05 was used to print the samples. The equipment is not provided with a means of measuring the squeegee angle. To overcome this problem, a reference scale was made and fitted coaxially with the squeegee holder. This arrangement, as shown in Figure 2, provided a means of adjusting the squeegee angle quickly and accurately during the preparation of samples.



(a) (b)

Figure 2: Squeegee angle measurement arrangement. (a) Reference scale fitted coaxially with the squeegee holder. (b) Squeegee holder with scale mounted on the machine

Minitab 15 was used to design a full factorial experiment to test various combinations of printing parameters. The factor levels are provided in Table 1. The rationale for selecting the factor levels is based primarily on the equipment design limitations. In trial runs, it was observed that squeegee pressure below 3 bars was insufficient to move the squeegee holder down to the print position. On the other hand, the pressurised air supply connected to the machine provided a maximum of 5.5 bars. Thus, the high and low levels for squeegee pressure were set at 5 and 3 bars respectively. The machine manufacturer's recommendation for squeegee angle is 30° (from the vertical) which led to selection of 20° and 40° as low and high levels of squeegee attack angle. The full factorial DOE is provided in Table 2.

Table 1: Factor and levels for printing parameters

| Factor | Levels | |
|---|---|---|
| | High | Low |
| Squeegee pressure | 5 bar | 3 bar |
| Squeegee angle | 20° | 40° |

Table 2: DOE to test combinations of printing parameters

| Standard Order | Run Order | Squeegee pressure in bars (SP) | Squeegee angle from vertical axis (SA) |
|---|---|---|---|
| 2 | 1 | 5 | 20° |
| 3 | 2 | 3 | 40° |
| 5 | 3 | 4 | 30° |
| 1 | 4 | 3 | 20° |
| 4 | 5 | 5 | 40° |

80 shore hardness square edge squeegee was used in all experimental runs. Rectangular area measuring 30 mm x 120 mm was printed using a 52 mesh stainless steel screen with an emulsion thickness of 20 microns. The snap-off height was set at 2 mm. For printing, the substrate was secured on the vacuum plate of the printer.

### *2.4 Testing and characterisation*

The weight of each substrate was recorded just before and immediately after printing. For this purpose a typical electronic weighing scale was used. The other important test in the context of present study is the DC electrical resistance of printed conductive inks. Prior to measuring the DC electrical resistance, the printed samples were dried in ambient conditions for 24 hours. The resistance measurement setup consisted of an interdigitated electrode as shown in Figure 3. The electrode terminals were connected to Keithley 2100 high precision digital multimeter as shown in Figure 4. The registration quality of the printed samples was analysed by scanning the dried samples at 300 dpi using a typical flat-bed scanner.

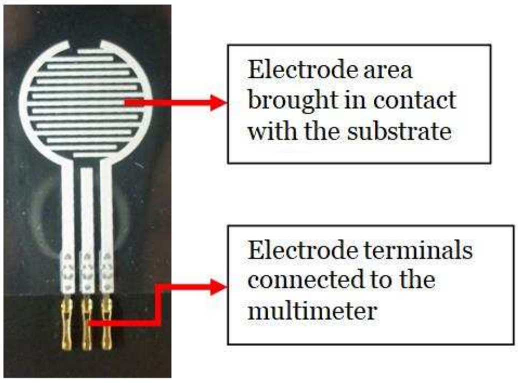



Figure 3: Inter-digitated electrode used for resistance measurement

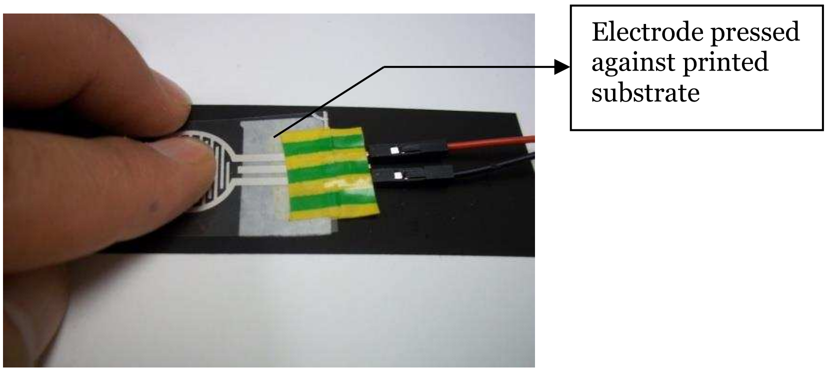



Figure 4: Resistance measurement setup

## 3. Results & Discussion

In order to determine the amount of print paste transferred onto the substrate at each set of printing parameters, the weights of printed and unprinted substrates were recorded. The difference of weights gives the amount of deposited print paste.

The weight of each sample had to be measured just before and after printing the ink. In this way, it was assured that little or no variation occurred due to evaporation of water from the ink layer. In addition, oven drying was not carried out to avoid any un-recordable variations in the moisture content of the paperboard substrate also. As this technique did not involve cutting the samples for weight measurement, any variations due to inaccurate cutting dimensions were also eliminated. For all sets of printing parameters, the difference between weight of printed and unprinted samples was recorded using this approach. The DC electrical resistance was then measured after drying the samples for 24 hours in ambient conditions. Relevant results are given in Table 3.

Table 3: Ink deposit and DC electrical resistance of samples

| Run Order | SP | SA | 12 w/w% pigment | | 8 w/w% pigment | | 4 w/w% pigment | |
|---|---|---|---|---|---|---|---|---|
| | | | Ink deposit (g) | R (Ω) | Ink deposit (g) | R (Ω) | Ink deposit (g) | R (Ω) |
| 1 | 5 | 20° | 0.0183 | 12.71 | 0.0052 | 17.283 | 0.0895 | 13.733 |
| 2 | 3 | 40° | 0.018 | 12.143 | 0.0192 | 14.57 | 0.0996 | 15.467 |
| 3 | 4 | 30° | 0.0077 | 12.54 | 0.0004 | 16.443 | 0.0918 | 13.403 |
| 4 | 3 | 20° | 0.0223 | 11.923 | 0.0216 | 14.5 | 0.1078 | 13.24 |
| 5 | 5 | 40° | 0.0198 | 12.793 | 0.0210 | 16.423 | 0.0967 | 16.513 |

It was observed that the actual squeegee attack angle during printing stroke was directly dependent on the squeegee pressure and the initial squeegee angle (when no pressure is applied on the squeegee). Thus, for each set of printing parameters, the effective squeegee angle was measured during printing stroke by marking the position of squeegee blade on a board attached to the rear end of squeegee as shown in Figure 5. An example of the angle calculation method is shown in Figure 6 and the effective squeegee angles, calculated using this technique, are provided in Table 4. The data presented in Table 4 shows that increasing the squeegee pressure for a given initial squeegee angle (from vertical) resulted in decrement in the effective squeegee attack angle. The significance of this in relation to the effects on print characteristics are discussed in the following text.

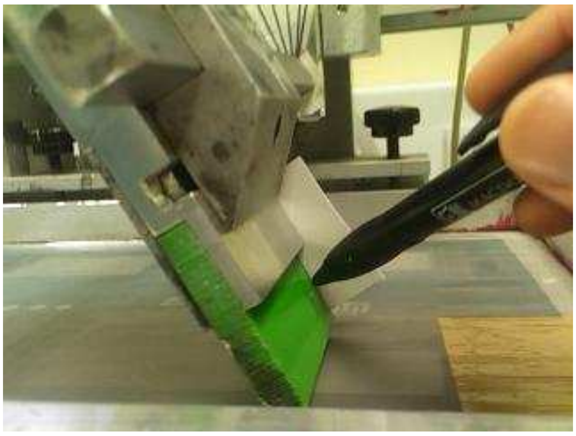


Figure 5: Measurement of the deflection of squeegee during printing stroke

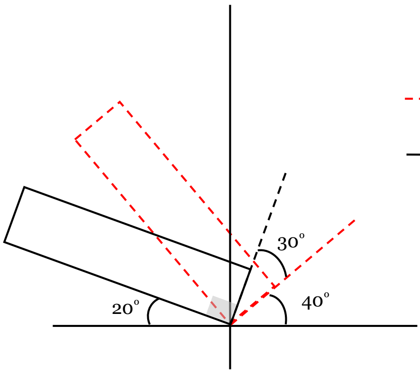



Figure 6: Effective squeegee attack angle calculation

Table 4: Effective squeegee attack angles

| Printing parameters | Effective Angle (from the surface of screen) |
|---|---|
| 5 bar, 40º | 20º |
| 4 bar, 30º | 40º |
| 3 bar, 40º | 35º |
| 3 bar, 20º | 60º |
| 5 bar, 20º | 45º |

Figure 7 to Figure 9 show the surface plots of the weight of ink layer deposited and the resistance of each sample that were obtained for various combinations of printing pressure and squeegee angle. In these surface plots, a rather clear correlation can be observed between the amount of ink deposit and the DC electrical resistance of the printed area. In all cases, i.e., 4 w/w%, 8 w/w% and 12 w/w% pigment-containing inks, the DC electrical resistance decreased as the amount of deposited ink increased. This result is in-line with the expected characteristics of a layer of a functional ink. For the experimental conditions (machine settings, substrate and ink properties), a particular trend was observed in the amount of ink deposited. It was found that the combination of 4 bar squeegee pressure and 30° squeegee angle (from vertical) resulted in a minimum deposit of ink onto the substrate. It was also found that for all of the inks used, the combination of 3 bar squeegee pressure and initial squeegee angle of 20° (60° from the surface of screen during printing stroke) delivered a higher amount of print paste and these samples had the lowest DC electrical resistance as well. Reference will now be made to the data presented in Table 4 from which it is evident that increasing the squeegee pressure for a given initial squeegee angle resulted in a considerable decrease in the effective squeegee angle, i.e., the angle of squeegee from the surface of the screen. Such a decrease should result in an increased hydrodynamic pressure in the print paste and subsequently a larger amount of ink should be forced out of the perforations in the screen (Hawkyard, 2003). Our results (Figure 7c - Figure 9c) show that a smaller angle between the surface of the screen and the squeegee does not necessarily result in an increased ink deposition. Besides the direct effects of printing process parameters, this finding can be attributed to other factors as well: the absorbency of the substrate arguably being the most important one. Nevertheless, this result suggests that it is crucially important to optimise the printing process parameters according to the purpose of printing and the required characteristics in the end product.

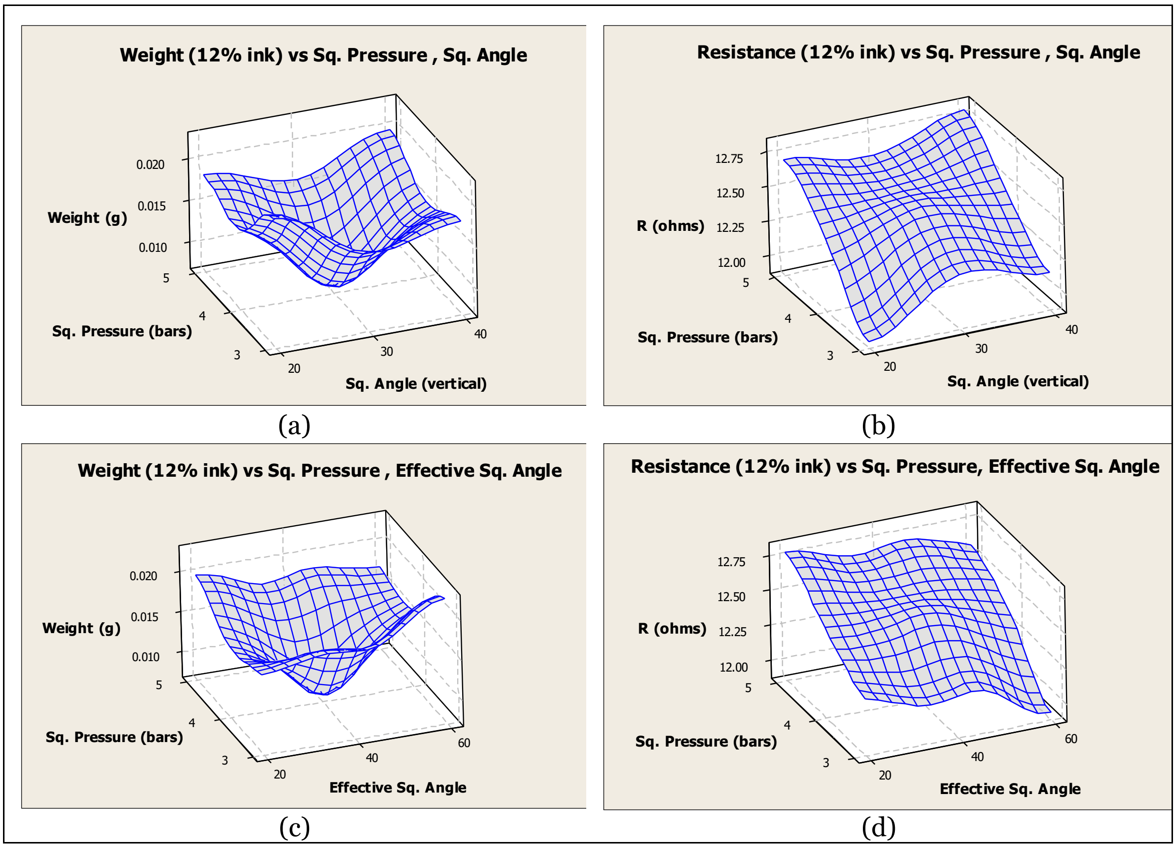


Figure 7: Weight of ink deposit and resistance of 12w/w% pigment ink

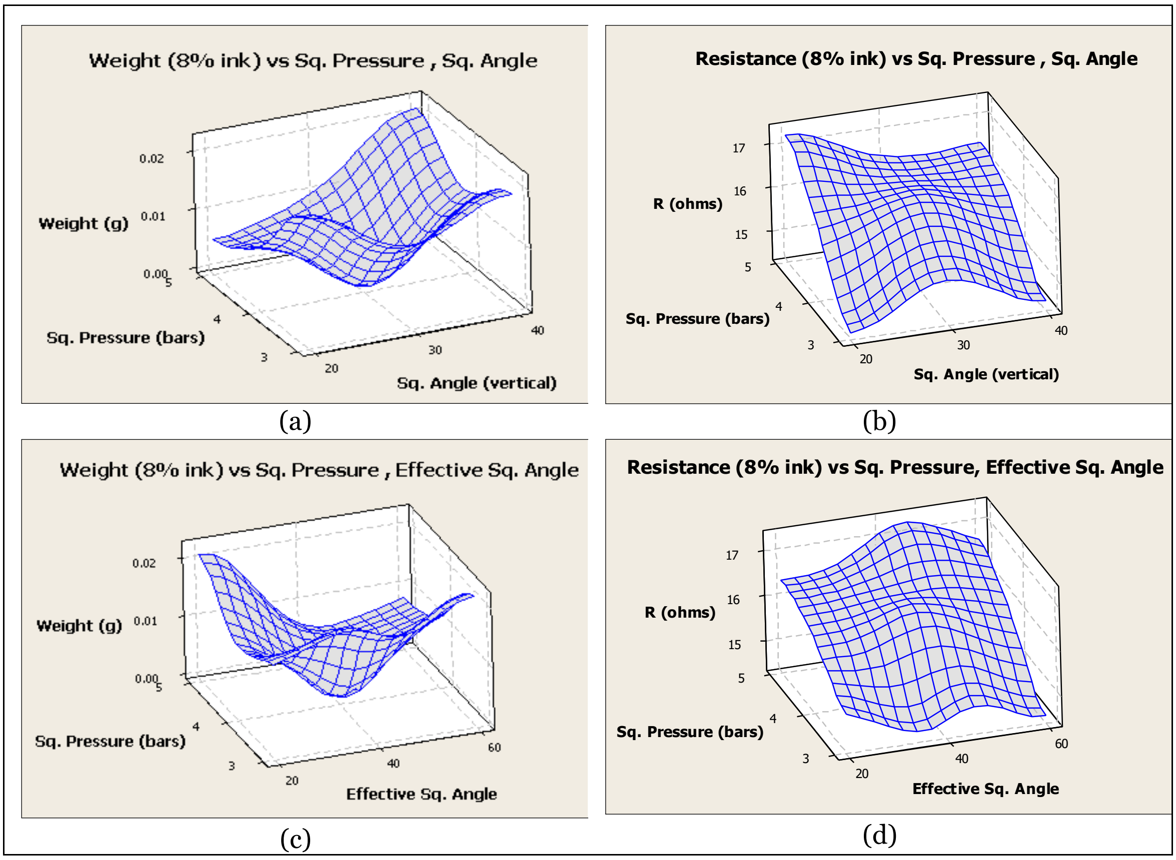
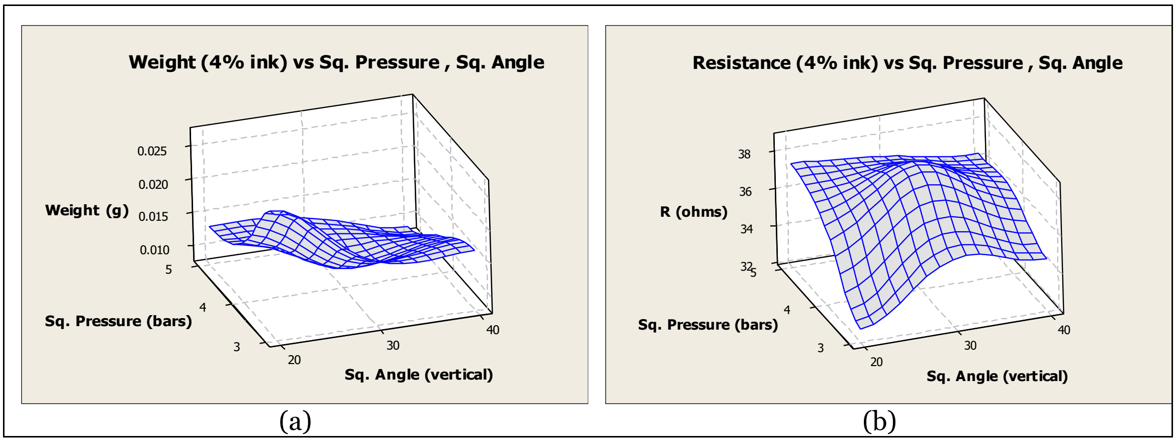
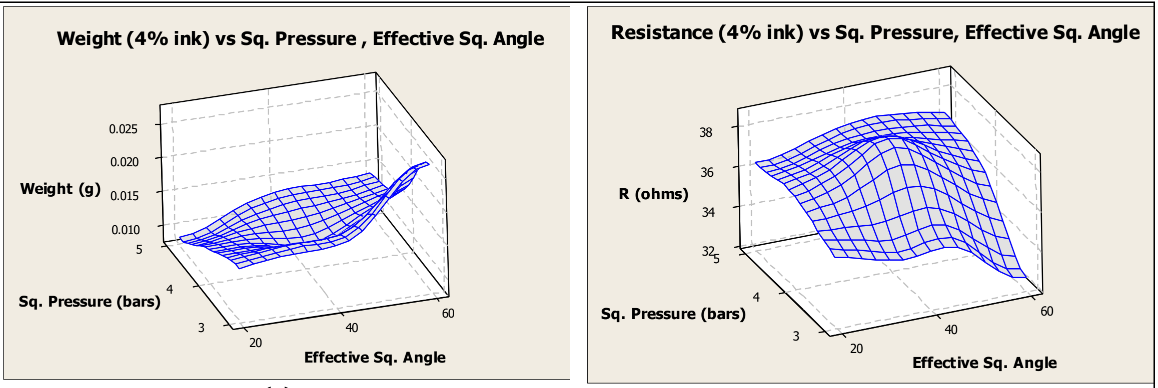



Figure 8: Weight of ink deposit and resistance of 8 w/w% pigment ink



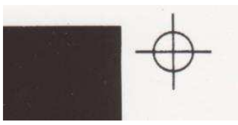
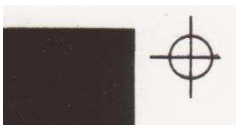
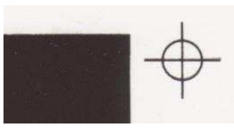
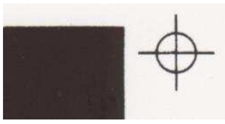
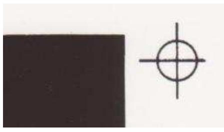
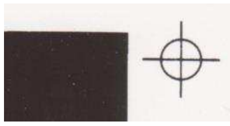


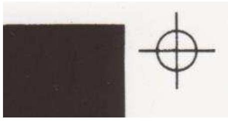
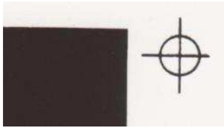
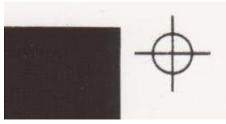
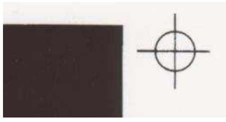
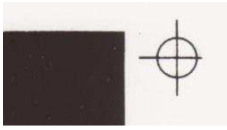
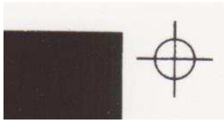
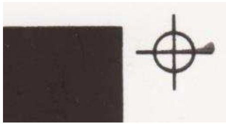
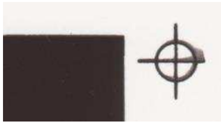
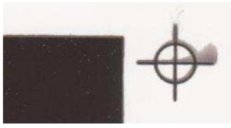

(c) (d)

Figure 9: Weight of ink deposit and resistance of 4w/w% pigment ink

Although the primary objective was to determine the optimum printing parameters which result in maximum deposit of print paste, registration of design could not be ignored as it is an important factor to consider in the context of this study. This is because a thick ink deposit with poor registration is of limited used in printed electronics applications (Dubey, 1975). Thus, the quality of print was analysed by scanning the samples at 300 dpi using a typical flat bed scanner.  The scanned images of all the samples are tabulated in Table 5. It was found that high squeegee pressure and larger initial squeegee angle (from vertical) deposited a thick ink layer in many cases but the registration quality was considerably poor (e.g. for SA = 5 bar, SP = 40°). In contrast, the combination of 3 bar squeegee pressure and 20° attack angle produced a very fine registration mark without smearing as shown in Table 5. This result is also in-line with the observations made regarding the weight of ink deposit and DC electrical resistance and it can be concluded that with this particular set of printing parameters, i.e., squeegee pressure of 3 bar and initial squeegee angle of 20°, the integrity of the ink film that was deposited onto the substrate was maintained.

Table 5: Registration quality in printed samples

| Printing parameters | 12 w/w% pigment ink | 8 w/w% pigment ink | 4 w/w% pigment ink |
|---|---|---|---|
| SP = 5 bar<br>SA = 20° |  |  |  |
| SP = 3 bar<br>SA = 40° |  |  |  |

| | | | |
|---|---|---|---|
| SP = 4 bar<br>SA = 30º |  |  |  |
| SP = 3 bar<br>SA = 20º |  |  |  |
| SP = 5 bar<br>SA = 40º |  |  |  |

## 4. Conclusion

The effect of printing process parameters namely printing pressure and squeegee angle have been studied in the context of printing of electrically conductive inks. Some minor modifications have also been made in the lab-scale automatic flat screen printing machine to improve control over machine parameters. The approach that is presented to improve control over machine parameters is expected to be useful for the concerned in this field of work. In this study, we found that the combination of 3 bar squeegee pressure and 20º squeegee attack angle deposited a greater amount of ink and correspondingly lower DC electrical resistance was obtained on the paperboard substrate that was considered in this work. The amount of pigment in print paste was found to have no effect on the ink deposit. More importantly, the results clearly indicate that a smaller squeegee angle form the surface of the screen, which is known to increase the hydrodynamic pressure in the print paste wedge between the screen and the squeegee, does not necessarily yield the best results and a careful optimisation of the printing parameters, as proposed in this study, is critically important.

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## 6. References

ALI, M. & LIN, L. 2018. Optimisation and analysis of bead milling process for preparation of highly viscous, binder-free dispersions of carbon black pigment. Progress in Organic Coatings, 119, 1-7.

ALI, M., LIN, L. & CARTRIDGE, D. 2019. High electrical conductivity waterborne dispersions of carbon black pigment. Progress in Organic Coatings, 129, 199-208.

CHEN, M. X. 2005. Printed electrochemical devices using conducting polymers as active materials on flexible substrates. Proceedings of the Ieee, 93, 1339-1347.

COCHRANE, C., KONCAR, V., LEWANDOWSKI, M. & DUFOUR, C. 2007. Design and Development of a Flexible Strain Sensor for Textile Structures Based on a Conductive Polymer Composite. Sensors, 7, 473-492.

DOWDS, B. F. 1970. Variables in Textile Screen Printing. Journal of the Society of Dyers and Colourists, 86, 512-519.

DUBEY, G. C. 1975. The squeegee in printing of electronic circuits. Microelectronics Reliability, 14, 427-429.

GARNIER, F., HAJLAOUI, R., YASSAR, A. & SRIVASTAVA, P. 1994. All-Polymer Field-Effect Transistor Realized by Printing Techniques. Science, 265, 1684-1686.

GRAY, C., WANG, J., DUTHALER, G., RITENOUR, A. & DRZAIC, P. S. Screen printed organic thin film transistors (OTFTs) on a flexible substrate. Organic Field Effect Transistors, 2001 San Diego, CA, USA. SPIE, 89-94.

HAWKYARD, C. J. 2003. Screen printing. In: MILES, L. W. C. (ed.) Textile Printing. SDC.

HAWKYARD, C. J. & MIAH, A. S. 1987. The parameters of rotary-screen printing. Journal of the Society of Dyers and Colourists, 103, 27-31.

HUEBLER, A., HAHN, U., BEIER, W., LASCH, N. & FISCHER, T. High volume printing technologies for the production of polymer electronic structures. 2nd International IEEE Conference on Polymers and Adhesives in Microelectronics and Photonics, 2002. 172-176.

HYUN, W. J., SECOR, E. B., HERSAM, M. C., FRISBIE, C. D. & FRANCIS, L. F. 2015. High-Resolution Patterning of Graphene by Screen Printing with a Silicon Stencil for Highly Flexible Printed Electronics. Advanced Materials, 27, 109-115.

JOST, K., STENGER, D., PEREZ, C. R., MCDONOUGH, J. K., LIAN, K., GOGOTSI, Y. & DION, G. 2013. Knitted and screen printed carbon-fiber supercapacitors for applications in wearable electronics. Energy & Environmental Science, 6, 2698-2705.

KARAGUZEL, B., MERRITT, C. R., KANG, T., WILSON, J. M., NAGLE, H. T., GRANT, E. & POURDEYHIMI, B. 2009. Flexible, durable printed electrical circuits. Journal of the Textile Institute, 100, 1 - 9.

KIM, D., JEONG, S., LEE, S. H., MOON, J. & SONG, J. K. 2009. Ink-jet printing of organic semiconductor for fabricating organic thin-film transistors: Film uniformity control by ink composition. Synthetic Metals, 159, 1381-1385.

KREBS, F. C. 2009. Fabrication and processing of polymer solar cells: A review of printing and coating techniques. Solar Energy Materials and Solar Cells, 93, 394-412.

KREBS, F. C., JØRGENSEN, M., NORRMAN, K., HAGEMANN, O., ALSTRUP, J., NIELSEN, T. D., FYENBO, J., LARSEN, K. & KRISTENSEN, J. 2009. A complete process for production of flexible large area polymer solar cells entirely using screen printing—First public demonstration. Solar Energy Materials and Solar Cells, 93, 422-441.

LEE, D. H., CHOI, J. S., CHAE, H., CHUNG, C. H. & CHO, S. M. 2009. Screen-printed white OLED based on polystyrene as a host polymer. Current Applied Physics, 9, 161-164.

LIN, H.-W., CHANG, C.-P., HWU, W.-H. & GER, M.-D. 2008. The rheological behaviors of screen-printing pastes. Journal of Materials Processing Technology, 197, 284-291.

LOCHER, I. & TRÖSTER, G. 2007. Screen-printed Textile Transmission Lines. Textile Research Journal, 77, 837-842.

LOMAS, M. & SHORT, I. G. 1999. Screen printing variables and their effect on print paste consumption. Coloration Technology, 115, 262-269.

MATHEWS, N., LAM, Y. M., MHAISALKAR, S. G. & GRIMSDALE, A. C. 2010. Printing materials for electronic devices. International Journal of Materials Research, 1, 236-250.

PARASHKOV, R., BECKER, E., RIEDL, T., JOHANNES, H. H. & KOWALSKY, W. 2005. Large Area Electronics Using Printing Methods. Proceedings of the IEEE, 93, 1321-1329.

PARDO, D. A., JABBOUR, G. E. & PEYGHAMBARIAN, N. 2000. Application of Screen Printing in the Fabrication of Organic Light-Emitting Devices. Advanced Materials, 12**,** 1249-1252.

PIAO, J., SUN, K., ZHANG, N. & XU, S. 2008. A study of process parameters of LSM and LSM–YSZ composite cathode films prepared by screen-printing. Journal of Power Sources, 175**,** 288-295.

PUDAS, M., HAGBERG, J. & LEPPÄVUORI, S. 2004. Printing parameters and ink components affecting ultra-fine-line gravure-offset printing for electronics applications. Journal of the European Ceramic Society, 24**,** 2943-2950.

PUDAS, M., HALONEN, N., GRANAT, P. & VÄHÄKANGAS, J. 2005. Gravure printing of conductive particulate polymer inks on flexible substrates. Progress in Organic Coatings, 54**,** 310-316.

QI, Q., ZHANG, T., YU, Q., WANG, R., ZENG, Y., LIU, L. & YANG, H. 2008. Properties of humidity sensing ZnO nanorods-base sensor fabricated by screen-printing. Sensors and Actuators B: Chemical, 133**,** 638-643.

ROGERS, J. A., BAO, Z., MAKHIJA, A. & BRAUN, P. 1999. Printing Process Suitable for Reel-to-Reel Production of High-Performance Organic Transistors and Circuits. Advanced Materials, 11**,** 5.

SAVAGE, J. 1976. Screen Printing Materials and Procedures. In: HOLMES, P. J. & LOASBY, R. G. (eds.) Handbook of Thick Film Technology. Ayr: Electrochemical Publications Ltd.

SECOR, E. B., LIM, S., ZHANG, H., FRISBIE, C. D., FRANCIS, L. F. & HERSAM, M. C. 2014. Gravure Printing of Graphene for Large-area Flexible Electronics. Advanced Materials, 26**,** 4533-4538.

SIRRINGHAUS, H., KAWASE, T., FRIEND, R. H., SHIMODA, T., INBASEKARAN, M., WU, W. & WOO, E. P. 2000. High-Resolution Inkjet Printing of All-Polymer Transistor Circuits. Science, 290**,** 2123-2126.

SOKOLOV, A. N., ROBERTS, M. E. & BAO, Z. 2009. Fabrication of low-cost electronic biosensors. Materials Today, 12**,** 12-20.

THOMPSON, D. 1995. Screen Printing with Pigments. In: AATCC COMMITTEE RA80 (ed.) Handbook of Pigment Printing. North Carolina: American Association of Textile Chemists and Colorists.

YEN, Y.-T., FANG, T.-H. & LIN, Y.-C. 2011. Optimization of screen-printing parameters of SN9000 ink for pinholes using Taguchi method in chip on film packaging. Robotics and Computer-Integrated Manufacturing, 27**,** 531-537.

YOSHIOKA, Y. & JABBOUR, G. E. 2006. Desktop inkjet printer as a tool to print conducting polymers. Synthetic Metals, 156**,** 779-783.