A study of the functionality of conventional pigmented inks in furnishing electrical conductivity to textiles

DOI: 10.35530/IT.073.06.202159

MUHAMMAD ALI
MUHAMMAD OWAIS RAZA SIDDIQUI
MUHAMMAD ZUBAIR
LONG LIN

ABSTRACT – REZUMAT

A study of the functionality of conventional pigmented inks in furnishing electrical conductivity to textiles

Electronic textiles technologies are finding widespread use in numerous sectors of our daily lives. One of the main enabling technologies for e-textiles is the additive deposition of functional material. The functional coatings that are used for such applications are based on a variety of materials such as conductive polymers, carbon-based materials, metals etc. There are several limitations associated generally with the commercially available conductive inks for non-textile substrates. The major limitations include (but are not limited to) high cost, inferior performance in terms of washing and creasing and difficulty in application, etc. In this study, we have evaluated two commercially available conductive inks and compared their washing and creasing performance with a conventional pigment printing system.

Keywords: *conductive textiles, carbon black, surface resistivity, pigment printing, e-textiles*

Un studiu al funcționalității cernelurilor pe bază de pigment convenționale în asigurarea conductivității electrice a materialelor textile

Tehnologiile textilelor electronice sunt utilizate pe scară largă în numeroase sectoare ale vieții noastre de zi cu zi. Una dintre principalele tehnologii de realizare a e-textilelor este depunerea aditivului pe materialul funcțional. Acoperirile funcționale, care sunt utilizate pentru astfel de aplicații, se bazează pe o varietate de materiale, cum ar fi polimeri conductivi, materiale pe bază de carbon, metale etc. Există câteva limitări asociate în general cu cernelurile conductive disponibile în comerț pentru substraturi netextile. Limitările majore includ (dar nu se limitează la) costuri ridicate, performanțe inferioare în ceea ce privește spălarea și șifonarea și dificultatea de aplicare etc. În acest studiu, am evaluat două cerneluri conductive disponibile în comerț și am comparat performanța lor de spălare și șifonare cu un sistem convențional de imprimare cu pigment.

Cuvinte-cheie*: materiale textile conductive, negru de fum, rezistivitate la suprafață, imprimare cu pigment, e-textile*

INTRODUCTION

Owing to its several applications, the electronic textiles (e-textiles) sector is attracting significant interest from the research community in academia and industry. As a result, the associated technologies are rapidly developing [1–3]. To fabricate various components of an electronic system on a textile fabric, one of the frequently employed methods is the printing of functional material to impart the desired functionality to the textile substrate [4]. For such printing, printing inks possessing a broad range of electrical characteristics are used [5]. The technology of conductive inks is not new. Instead, the printing of conductive inks on non-textile substrates is a well-developed technology [6, 7]. However, in the case of printing onto a textile fabric, such inks are generally not able to meet the performance requirements in terms of washing and creasing etc. [8]. Work is being done to produce inks that are suitable for imparting conductivity [9], magnetism, or other functionalities to the textile substrate. For this purpose, a broad range of materials is used, such as conductive polymers [10–17], gold [18], silver [19–21] or copper-nanoparticles [22], carbon-based conductive materials such as graphite [23], graphene [24, 25] and carbon nanotubes [26] etc. Some of these materials have considerably higher costs while some suffer from a lack of performance and functionality. For instance, carbon black pigments are generally considered to be lower in cost compared to other conductive materials such as silver nanoparticles. However, such materials are known to possess inferior electrical conductivity compared to metal nanoparticles. In this work, we have tested commercially available, carbon-based electrically conductive inks and compared their performance with that of a conventional pigment printing system for textiles. The results showed that even a conventional pigment printing ink system can be used to produce ink films possessing a broad range of electrical conductivity and therefore, it is promising for several e-textiles application areas.

MATERIALS AND METHODS

Commercial inks

The surface resistivity and the durability (resistance to washing and creasing) of the conventional pigment printing inks were compared against two commercially available highly conductive carbon-based inks, listed in table 1. The surface resistivity values that are shown in table 1 relate to a 25 microns thick ink layer deposited on a polyimide film.

Table 1

COMMERCIAL CONDUCTIVE INKS USED IN THE STUDY

Product	Supplier	Description	Surface resistivity (Ω/☐)
C2030519P4 Carbon/ Graphite ink	Gwent Electronic Materials Ltd	Carbon sensor paste	13–20
SD 2843 HAL	Peters GmbH	Carbon conductive ink	10

Pigment printing ink

The Printofix pigment printing system from Clariant (Archroma), details of which are provided in table 2, was used in this work.

Table 2

CLARIANT'S PRINTOFIX PIGMENT SYSTEM

Product name	Description
Printofix Thickener CSN liq	Thickener
Printofix Binder 83 liq	Binder for pigment print system
Printofix Black H-RT	Carbon black pigment dispersion

Substrate

Textile substrates such as 100% Cotton, 100% Polyester and PC blends do not possess electrical conductivity on their own and thus are good insulators [27]. The substrates used in this study are plain woven100% cotton fabric and 100% Polyester fabric. The specifications are provided in table 3. Due to low GSM, the 100% polyester fabric was coated with Printofix Binder 83 in its as-supplied form. Printofix Binder 83 is a typical binder for pigment printing and it was used as a primer layer on the 100% polyester fabric. The GSM of fabric is known to affect its properties such as conductivity after the application of a conductive ink/coating. However, the objective of the present study was to compare cotton and polyester for their suitability as substrates for functional printing. Thus, the effects of GSM variation were not studied.

Table 3

SPECIFICATIONS (PROVIDED BY SUPPLIER) OF TEXTILE SUBSTRATES USED IN THE STUDY

Substrate	Weave	GSM (g/m^2)
100% cotton	1 × 1 plain	80
100% polyester	1 × 1 plain	55

Testing and characterisation

The inks were drawn on the substrates using a hand coater apparatus. K-bar no 6 was used for this purpose. Washing tests were performed according to BS EN ISO 105:CO6 (Test A1M). For the creasing test, the ASTM F 2749-09 test method was adopted. The surface resistivity of the samples was measured using an electrode designed to cover the 9 cm^2 area of the sample. The electrode was pressed onto the substrate using a 500 g weight.

RESULTS AND DISCUSSION

After printing, the samples were cured according to the curing conditions specified by the ink manufacturer. The results of these washing tests are summarised in table 4.

Table 4

WASHING TESTS RESULTS OF COMMERCIAL INKS

Ink name	Substrate	Surface resistivity (Ω/☐)		
		Before wash	After wash	% Increase
Gwent C2030519P4	Uncoated Cotton	20.83	81.9	293.18
Gwent C2030519P4	Coated Polyester	19.14	77.4	304.39
Peters SD 2843 HAL	Uncoated Cotton	59.96	NR	-
Peters SD 2843 HAL	Coated Polyester	42.5	307	622.35
Printofix ink	Uncoated Cotton	716	838	17.04
Printofix ink	Coated Polyester	688	721	4.79

Note: NR refers to 'no reading', i.e., the surface resistivity was higher than 100 MΩ.

Before washing, the surface resistivity of ink layers produced from the commercial inks was considerably lower than the surface resistivity of the films produced from the Printofix pigment ink. However, the films produced from the commercial inks were less durable, as indicated by a significantly greater increase in surface resistivity after washing.

Furthermore, as shown in figure 1, commercial inks were removed from large areas of the fabrics during washing. This showed that the commercial inks tested were not suitable for printing fine lines, a quality that is often required of prints when printing electrical interconnects or resistive patterns.

Furthermore, the increase in the surface resistivity, when an ink film was deposited on Printofix Binder 83 coated polyester fabric, was less than that in the surface resistivity of the film of the same ink deposited onto uncoated cotton fabric. Thus, the creasing resistance of only the ink films produced on Printofix Binder 83 coated polyester fabric was tested. The durability of the ink films to withstand up to five creasing cycles was tested and the surface resistivity was

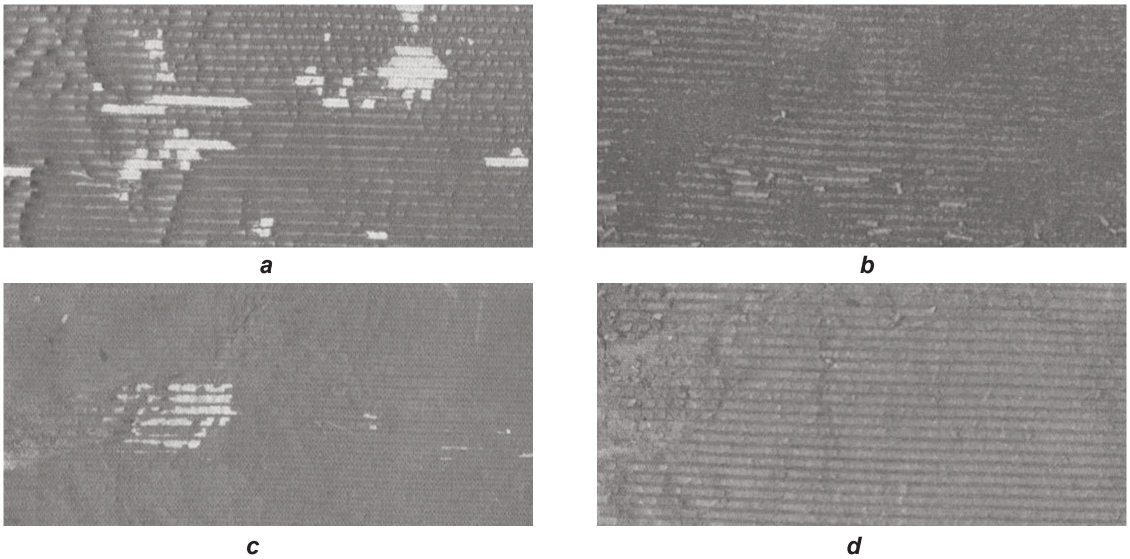

Fig. 1. Image recorded after washing of: *a* – Peters carbon ink on coated polyester; *b* – Peters carbon ink on uncoated cotton; *c* – Gwent carbon ink on coated polyester; *d* – Gwent carbon ink on uncoated cotton

recorded after each cycle. The results are tabulated in table 5. The results of creasing tests indicate that the overall increase in the surface resistivity of the films produced from the Printofix pigment ink was considerably lower compared to the increase in surface resistivity of films produced from the commercial inks.

Due to the promising results obtained for the Printofix pigment system, print pastes containing different amounts of the Printofix Black H-RT pigment were prepared. The formulations (table 6) were prepared in the same manner as normal printing inks are prepared for the textile printing. The only exception is that a binder was not added. This is because the primary objective here was to estimate the decrease that occurs in electrical resistivity upon increasing the pigment loading in the ink formulation. The resistance of the printed samples was recorded using an interdigitated electrode (provided by Peratech Holdco Limited, UK) which provided the advantage of being able to measure the electrical resistance of multiple parallel resistor elements as shown in figure 2. The resistance values obtained are tabulated in table 7.

Table 5

SURFACE RESISTIVITY OF INKS RECORDED DURING CREASE TESTING OF INK FILMS

Ink composition	Surface resistivity (Ω/☐)						
	Number of crease cycles						% Increase
	0	1	2	3	4	5	
Peters SD 2843 HAL carbon ink	28	63	98	157	196	411	311.00
Gwent C2030519P4 carbon ink	20	71	170	302	432	550	450.00
Printofix Ink	660	667	667	672	680	699	7.42

Table 6

COMPOSITION OF PRINT PASTES CONTAINING PRINTOFIX BLACK H-RT PIGMENT

Pigment (Printofix Black T-M)			Thickener			Water	
w/w% of total	Calculated amount (g)	Actual amount (g)	w/w% of total	Calculated amount (g)	Actual amount (g)	Calculated amount (g)	Actual amount (g)
4	0.8	0.800	1.8	0.360	0.360	18.84	18.98
6	1.2	1.214	1.8	0.360	0.363	18.44	18.451
8	1.6	1.604	1.8	0.360	0.361	18.04	18.042
10	2.0	2.004	1.8	0.360	0.360	17.64	17.660
12	2.4	2.401	1.8	0.360	0.363	17.24	17.241
14	2.8	2.800	1.8	0.360	0.362	16.84	16.844
16	3.2	3.196	1.8	0.360	0.362	16.44	16.442

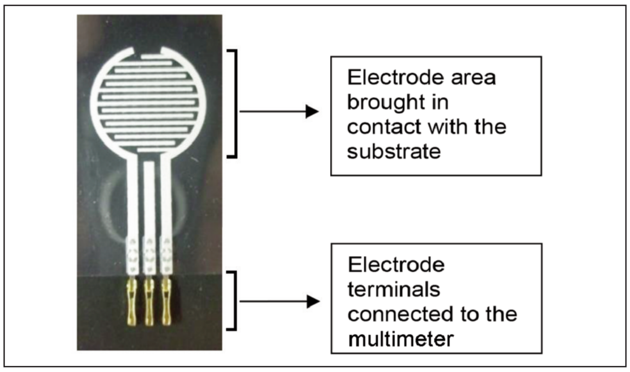

Fig. 2. Interdigitated electrode used for resistance measurement

Table 7

DC ELECTRICAL RESISTANCE MEASURED USING INTERDIGITATED ELECTRODE	
Amount of pigment Printofix Black TM (wt %)	**Resistance (Ω)**
4	45
6	24
8	17
10	15
12	12.5
14	11.5
16	11.5

CONCLUSION

In this work, we have tested commercially available, carbon-based conductive inks and compared their washing and creasing performance with that of a conventional pigment printing system for textile substrates. We found, as expected, that the surface resistivity of ink layers produced using commercial inks was considerably lower compared to the surface resistivity of ink films produced from a conventional pigment print system. However, the washing and creasing performance of the conventional pigment print system was considerably superior compared to that of the commercial conductive inks. This can be attributed to the fact that conventional pigmented carbon black systems contain pigment grades that have the low surface area and thus they can be added to the formulation in relatively large quantities. Furthermore, the polymeric binders preferably used in conventional pigment printing produce films that are soft and flexible and thus they are better able to withstand washing and creasing actions to which textiles are subjected during the end use. This clearly shows that such a conventional pigment print system can be fine-tuned with relative ease for a range of functional applications. The amount of pigment can be easily increased for further improvement in electrical conductivity as demonstrated in this study.

ACKNOWLEDGEMENTS

The authors would like to acknowledge NED University of Engineering & Technology, Karachi, for the moral support provided during the study.

REFERENCES

[1] Gemperle, F., et al., *Design for wearability,* In: Second International Symposium on Wearable Computers, 1998

[2] Marculescu, D., *E-textiles: toward computational clothing,* In: Pervasive Computing, IEEE, 2003, 2, 1, 89–95

[3] Troster, G., Kirstein, T., Lukowicz, P., *Wearble computing: Packaging in textiles and clothes*, In: 14th European Microelectronics and Packaging Conference & Exhibition, Wearble Computing Lab, ETH Zurich: Friedrichshafen, Germany, 2003

[4] Kannaian, T., Janarthanan, M., Thilagvathi, G., *An overview of electronic textiles,* In: The Institute of Engineers (India) Journal – Textiles, 2010, 90

[5] Child, A.D., DeAngelis, A.R., *Static dissipative textile and method for producing the same*, U.P.a.T. Office, Editor., USA, 2004, 18

[6] Savage, J., *Screen Printing Materials and Procedures*, In: Handbook of Thick Film Technology, P.J. Holmes and R.G. Loasby, Editors., Electrochemical Publications Ltd: Ayr., 1976

[7] Kosloff, A., *Screen Printing Electronic Circuits*, In: Screen Printing Techniques., The Signs of the Times Publishing Co: Cincinnati, 1981

[8] Karaguzel, B., et al., *Flexible, durable printed electrical circuits,* In: Journal of the Textile Institute, 2009, 100, 1, 1–9

[9] Jackie, E., Denise, M., *Superconducting screen printing ink and process for producing a thick superconducting film using this ink*, USPTO, Editor., USA, 1991

[10] Adams, L.W., Gilpatrick, M.W., Gregory, R.V., *Method for generating a conductive fabric and associated product*, U.P.a.T. Office, Editor., Milliken Researh Corporation: USA, 1994, 27

[11] Bhadra, S., et al., *Progress in preparation, processing and applications of polyaniline,* In: Progress in Polymer Science, 2009, 34, 8, 783–810

[12] Blanchet, G.B., Fincher, C.R., Gao, F., *Polyaniline nanotube composites: A high-resolution printable conductor,* In: Applied Physics Letters, 2003, 82, 8, 1290–1292

[13] Chen, M.X., *Printed electrochemical devices using conducting polymers as active materials on flexible substrates,* In: Proceedings of the IEEE, 2005, 93, 7, 1339–1347

[14] DeAngelis, A.R., Child, A.D., Green, D.E., *Patterned conductive textiles*, U.P.a.T. Office, Editor, Milliken Research Corporation: USA, 1997, 7
[15] Foitzik, R.C., et al., *Soluble poly-3-alkylpyrrole polymers on films and fabrics,* In: Synthetic Metals, 2005, 155, 1, 185–190
[16] Foitzik, R.C., Kaynak, A., Pfeffer, F.M., *Application of soluble poly(3-alkylpyrrole) polymers on textiles,* In: Synthetic Metals, 2006, 156, 7–8, 637–642
[17] Hwang, Y.S., Son, Y., Lee, Y., *Printed Circuit Patterns of Conducting Polymer,* In: Molecular Crystals and Liquid Crystals, 2007, 472, 113–122
[18] Nur, H.M., et al., *Ink-jet printing of gold conductive tracks,* In: Journal of Materials Science: Materials in Electronics, 2002, 13, 4, 213–219
[19] Locher, I., Troster, G., *Enabling Technologies for Electrical Circuits on a Woven Monofilament Hybrid Fabric,* In: Textile Research Journal, 2008, 78, 7, 583–594
[20] Merilampi, S., Laine-Ma, T., Ruuskanen, P., *The characterization of electrically conductive silver ink patterns on flexible substrates,* In: Microelectronics Reliability, 2009, 49, 7, 782–790
[21] Bao, L.R., Wei, B., Xiao, A.Y., *Conductive Coating Formulations with Low Silver Content,* In: 2007 Proceedings 57th Electronic Components and Technology Conference, 2007
[22] Park, B.K., et al., *Direct writing of copper conductive patterns by ink-jet printing,* In: Thin Solid Films, 2007, 515, 19, 7706–7711
[23] Azim, S.S., et al., *Studies on graphite based conductive paint coatings,* In: Progress in Organic Coatings, 2006, 55, 1, 1–4
[24] Jang, B.Z., Zhamu, A., *Nano graphene platelet-based conductive inks*, USPTO, Editor, USA, 2008
[25] Wang, S., et al., *High Mobility, Printable, and Solution-Processed Graphene Electronics,* In: Nano Letters, 2009, 10, 1, 92–98
[26] Baughman, R.H., Zakhidov, A.A., de Heer, W.A., *Carbon Nanotubes-the Route Toward Applications,* In: Science, 2002, 297, 5582, 787–792
[27] Bhat, N., Benjamin, Y., *Surface resistivity behavior of plasma treated and plasma grafted cotton and polyester fabrics,* In: Textile Research Journal, 1999, 69, 1, 38–42

Authors:

MUHAMMAD ALI[1], MUHAMMAD OWAIS RAZA SIDDIQUI[1],
MUHAMMAD ZUBAIR[2], LONG LIN[3]

[1]NED University of Engineering & Technology, Department of Textile Engineering,
University Road, 75270, Karachi, Pakistan

[2]North Carolina State University, College of Textiles, Raleigh NC 27695, USA

[3]School of Materials and Chemical Engineering, Ningbo University of Technology,
201 Fenghua Road, Ningbo, China

Corresponding author:

MUHAMMAD ALI
e-mail: alimughal@neduet.edu.pk