ANNALS OF THE UNIVERSITY OF ORADEA
FASCICLE OF TEXTILES, LEATHERWORK

COLOUR FASTNESS ANALYSIS OF PRINTED ELECTRONICS THROUGH THE FLEXOGRAPHY TECHNIQUE ON TEXTILE SUBSTRATES

RODES-CARBONELL Ana M[1], FERRI Josué[1], GARCIA-BREIJO Eduardo[2], BOU-BELDA Eva[3]

[1] Textile Research Institute (AITEX), Alcoy 03801, Spain

[2] Universitat Politècnica de València, Instituto Interuniversitario de Investigación de Reconocimiento Molecular y Desarrollo Tecnológico (IDM), Valencia 46022, Spain

[3] Universitat Politècnica de València, Department of Textile and Paper Engineering, Plaza Ferrándiz y Carbonell s/n. 03801, Alcoy. Spain.

Corresponding author: Rodes, Ana María, E-mail: arodes@aitex.es

Abstract: *The work is framed within Printed Electronics, an emerging technology for the manufacture of flexible electronic products such as electronic textiles. Among the different printing methods, interest on roll-to-roll flexography technique has increased because it allows continuous manufacturing and high productivity at low cost. Nevertheless, the incorporation of the flexography printing technique in the textile field is still very recent due to technical barriers such as of durability and withstanding bending, stretching, abrasion and washing. Specifically, the study is focused on investigating the colour fastness to wash and rubbing of electronic inks printed on textiles through the flexography process. By a comparison of the same ink printed on different flexible substrates it has been concluded that woven and nonwoven fabrics are a suitable option regarding colour fastness to wash instead of thin polymeric and paper substrates that tear at the wash machine. The ink volume transferred to the substrate should be optimized when conductivity and colour fastness to washing are the objectives, still, several coatings could also be applied after the printing. Concerning colour fastness to rubbing where poor results were obtained, a solution for an optimal electronic printing on textiles would be the surface substrates pre-treatment by applying different chemical compounds that increase the adhesion of the ink avoiding its absorption.*

Key words: *e-textiles, wearables, printed-electronics, fastness, flexography.*

1. INTRODUCTION

Printed electronics (PE) refers to the technology that allows the fabrication of electronic devices through a printing process. PE is one of the fastest growing technologies in the world as it provides different printing techniques for fabricating low-cost and large-area flexible electronic devices [1]. In recent years, Flexible electronics has attracted considerable attention as a new technology applicable to wearable devices including flexible displays, flexible batteries and flexible sensors [2] in different areas such as aerospace and automotive, biomedical, robotics, and health applications [3]. Among them, wearable electronic textiles (e-textiles) are of great significance, as they provide better comfortability, durability and lighter weight as well as maintaining the desirable electrical property [4].

The PE printing technique selection shall be according to the type of electronic application (e.g., small, thin, lightweight, flexible and disposable, etc.) to be fabricated, the production cost and volume. Also, the materials (inks/pastes and substrates) must meet certain requirements, depending on the type of printing technology being used and the final application.

PE technologies are divided in contact techniques (e.g., flexography, gravure printing and soft lithography techniques), in which the printing plate is in direct contact with the substrate and, non-contact techniques (e.g., screen printing, aerosol printing, inkjet printing, laser direct writing), where only the inks get in contact with the substrate [5]. Those techniques suitable for roll-to-roll (R2R) processing, such as flexography, are especially attractive as they offer continuous production and high productivity [6].

Flexographic printing is known for depositing a wide range of thicknesses with the same resolution. Impression cylinder, plate cylinder, anilox roller, doctor blade and inking unit are the main parts of the flexographic printing [1]. Variables associated with the flexographic printing process include print speed, print force/engagement, anilox cell volume, anilox force/engagement as well as the ink and substrate properties. [7] Those variables have a direct impact on the prints' morphological and electrical behaviour, as well as the print uniformity has a considerable influence on the final functionality of the device [8]. It must be highlighted in the context of printed electronics on fabrics, the challenge of durability and withstanding bending, stretching, abrasion and washing [9].

Numerous reviews and books have been already published considering printed electronics on substrates that are usually used on electronic devices such as glass, metal, paper or polymers [3,6]. However, the incorporation of the flexography printing technique for printed electronics in the textile field is still very recent and there are not enough studies for its application. As a result, the authors have proposed to analyze this printing methodology for conductive inks on textiles not regarding electronic performance but evaluating the color fastness properties.

2. MATERIALS AND METHODS

2.1 Materials

In addition to polymeric and siliconized paper substrates, which are typical used in printed electronics [3,6], two substrates were also chosen for the study: woven and nonwoven fabric. The four flexible substrates are characterized in Table 1.

Table 1: *Substrates characterization*

Code	Substrate	Material	Structure	Mass per unit area[1]	Color	Protector
SA	Woven fabric	100% Cotton	Plain	300 g/m^2	Greige	No
SB	Spunbonded Nonwoven fabric	100% Polypropylene	Nonwoven	50 g/m^2	White	No
SC	Paper	Siliconized paper	-	140 g/m^2	White	No
SD	Polymeric	100% Thermoplastic Polyurethane	-	94 gr/m^2	Transparent	Yes (white paper)

[1] *Mass per unit area determined according to the standard ISO 3801*

Same aqueous flexo-printable conductive ink, PFI-600 – Silver ink from Novacentrix, has been used in all prints to ensure comparable results. The ink contains silver nanoparticles and has been formulated for high conductivity, fast curing, and improved levelling at lower printing speeds.

2.2 Method

Flexography is a roll-to-roll direct printing technology, where an anilox roller, covered with micro-cavities on its surface, allows the collection of ink, and then is transferred to the printing plate cylinder. At the study, the one-layer flexography printing process has been performed using flexography experimental plants (Flexo VCML Lab from RK and Lambda from Edale) for printing the samples. Different test drawings for the pattern of the printing plate cylinder were designed specifically for the study. The printing process was carried out using 12 cm^3/m^2 of Anilox at 6-22 m/min in all samples except SD fabric, which was performed using 11 cm^3/m^2 at 5 m/min.

Printed layers were dried using an in-line air flow convection dryer with temperatures within 80-150º C.

Once dried, the samples were analyzed regarding color fastness to wash and rubbing (dry and wet) and according to standards methods ISO 105-C10 and ISO 105-X12. After both tests, treated samples were compared with untreated samples visually using grey scale, according to ISO 105-A02 standard.

3. RESULTS AND DISCUSSSION

The grade of color fastness to wash and rubbing of the electronic flexo printed samples were evaluated and presented in the Table 2. Neither the siliconized paper (SC) nor the polymeric substrate (SD) could stand the washing test and were torn at the wash machine. Furthermore, the SD was not capable of withstanding the rubbing test, crashing with the pressure of the crockmeter.

Table 2: *Color fastness to was and rubbing results*

Code	Rubbing				Washing	
	Degradation		Discharge		Degradation	Discharge
	Dry	Wet	Dry	Wet		
SA	4-5	3-4	1	1	4	5
SB	4	1-2	3	2	4	5
SC	2	1	3	1	-	-
SD	-	-	-	-	-	-

The overall results of color fastness to rubbing of samples showed poor fastness properties in terms of discharge, which was harmonious with previous studies of other printing techniques [10]. SA and SB showed an improved grade in the rubbing degradation possibly due to the large amount of ink deposited on the surface although wet rubbing properties are lower than dry. In order to address these challenges, surface pre-treatment onto rough and porous substrates should be done in order to improve the ink adhesion and therefore the electrical behavior [4].

On the other hand, the overall results of color fastness to wash of woven (SA) and nonwoven (SB) fabrics samples were very good to excellent. According to a previous review [11], an increment of ink volume improves the ink coverage, upgrading in this case the conductivity, nevertheless it enhances the ink wash-out effect. For this reason, the ink volume transferred to the substrate should be optimized when conductivity and color fastness to washing are the objectives. In addition, coating and lamination processes could be done in order to ensure the continuous conductive pathway on textiles [9].

4. CONCLUSIONS

By a comparison of the same ink printed on different flexible substrates it has been concluded that woven and nonwoven fabrics are a suitable early option regarding colour fastness to wash instead of thin polymeric and paper substrates that tear at the wash machine. The ink volume transferred to the substrate should be optimized when conductivity and colour fastness to washing are the objectives. Future work will explore several coatings that could also be applied after the printing to protect the circuits and then improve the electronic behaviour after washing.

Concerning colour fastness to rubbing, even better than for thin polymeric and paper substrates, poor results were obtained for woven and nonwoven fabrics. For this reason, future work will be focused on surface pre-treatment onto rough and porous substrates in order to improve the ink adhesion and therefore the electrical behavior.

ACKNOWLEDGMENT

This research is part of HYBRID project that is funded by the Conselleria d'Economia Sostenible, Sectors Productius i Treball, through IVACE. Application No.: IMAMCI/2020/1.

REFERENCES

[1] Avuthu, S.G., Gill, M., Ghalib, N., Sussman, M.R., Wable, G., Richstein, J., Ph., D., & Jabil (2016). "*An introduction to the process of printed electronics*".

[2] Kim, C., Jeon, S.W. & Kim, C.H. "*Reduction of Linearly Varying Term of Register Errors Using a Dancer System in Roll-to-Roll Printing Equipment for Printed Electronics*". Int. J. Precis. Eng. Manuf. 20, 1485–1493 (2019).

[3] Cruz, Sílvia & Rocha, Luis & Viana, Julio. (2018). "*Printing Technologies on Flexible Substrates for Printed Electronics*". 10.5772/intechopen.76161.

[4] Karim, N., Afroj, S., Tan, S. et al. "*All Inkjet-Printed Graphene-Silver Composite Ink on Textiles for Highly Conductive Wearable Electronics Applications*". Sci Rep 9, 8035 (2019).

[5] Cano-Raya, Clara & Denchev, Zlatan & Cruz, Sílvia & Viana, Julio. (2019). "*Chemistry of solid metal-based inks and pastes for printed electronics – A review*". Applied Materials Today. 15. 416-430. 10.1016j.apmt.2019.02.012.

[6] Søndergaard, Roar & Hosel, M. & Krebs, Frederik. (2012). "*Roll to roll fabrication of large area functional organic materials*". Journal of Polymer Science. 51. 16-34.

[7] Mogg, Benjamin & Claypole, Tim & Deganello, Davide & Phillips, C.O.. (2016). "*Flexographic printing of ultra-thin semiconductor polymer layers*". Translational Materials Research. 3. 015001. 10.1088/2053-1613/3/1/015001.

[8] Davide, D. (2019). "*Control of morphological and electrical properties of flexographic printed electronics through tailored ink rheology. Organic Electronics*", 73, pp. 212-218.

[9] Yang, K., Torah, R., Wei, Y., Beeby, S., & Tudor, J. (2013). Waterproof and durable screen printed silver conductive tracks on textiles. Textile Research Journal, 83(19), 2023–2031.

[10] Vasić, Jelena & Kasikovic, Nemanja & Delic, Gordana & Đurđević, Milana. (2018). "*Impact of type of ink and substrate on colorimetric values of inkjet prints*". 365-372. 10.24867/GRID-2018-p44.

[11] Kasikovic, Nemanja & Vladić, Gojko & Milic, Neda & Novaković, Dragoljub & Milošević, Rastko & Dedijer, Sandra. (2018). "*Colour fastness to washing of multi-layered digital prints on textile materials*". Journal of the National Science Foundation of Sri Lanka. 46. 381. 10.4038/jnsfsr.v46i3.8489.