Printing and Curing Silver Conductive ink Tracks from Modified on-shelf Inkjet Printer on Fabric

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***Abstract*— Inkjet printing has been seen promising in printing conductive inks on variety of substrates other than fabrics and it should be expanded to fabrics since fabrics with integrated electrical features able to form intelligent articles. This study presents the investigation on printing and curing of silver conductive inks track from modified on-shelf inkjet printer on fabric. Epson printer is selected for modification which conventional paper feeding concept is replaced with platform stage. The viscosity of the conductive ink is adjusted accordingly to prevent clogging. Variation of processing parameters including printing speed, deposition height, curing temperature and time were investigated and measurement of the dimensional accuracy of the printed pattern as well as mechanical and electrical test are performed and analyzed. The results obtained were as expected which the thickness of the ink tracks were very thin in the sub-micron range and multiple printing selection with suitable curing time and temperature are desired to generate ink tracks with compatible adhesion to the substrates and conductivity. Sample with low speed parameter and 0.15 mm deposition height resulted in dimension which is close enough to the targeted dimension. The used of modified on-shelf inkjet printer and DLP projector with hot plate are proven feasible to print and cure conductive ink tracks on fabrics.**

***Index Term*— Inkjet printing, conductive ink, curing, printing speed, deposition height, viscosity, temperature, time**

I. Introduction

Printing is a class of technique used to transfer conductive ink onto fabrics to create pattern structure. Among all printing methods, inkjet printing technology has shown great potential in printing with speed and quality. Inkjet printing is an emerging technology for printed electronics and due to the digital control of the printing process, the adaptation to different circuit board layouts is easy and fast. The possibilities of this technology holds seem limitless [1]. In the mean time, fabric materials with integrated electrical features capable to create intelligent articles with wide range of applications such as sports, work wear, health care, safety and others. These advances in technology may open new perspective for such areas of application in fabrics printing as sampling, mass production and customization [2].

II. Background

Inkjet printing is defined as a non-impact printing technology which projects inks onto the substrate in a controlled series of drops. The images quality depends on such factor as the resolution and speed defined in dots per inch (dpi), the shape and its drying time and the nature of the substrate's surface including matte, gloss, polished, coated and others. Ink jet printing is one of the fastest growing technologies in digital printing market. There are different types of ink jet printing including thermal, bubble, piezoelectric, hybrids of these and others. All involve the basic idea of making a droplet of ink and forcing this droplet to a substrate that is intended to be printed on. The manner that this is to be accomplished is dependent upon the technology used such as piezoelectric uses an electric pulse to mechanically displace the liquid. By applying voltage into some material that expands nearly instantaneously with the voltage, this material within the nozzle expands or changes shape in a manner that displaces ink in the nozzle causing it to fire a droplet. Originally designed for printing on papers, inkjet printing technology is now utilized in fabric printing market more and more often as it meets the demands of the new textile market [3].

III. Objective

Since the advances in inkjet printing technology may open new perspective for fabrics printing, this study is done to investigate the feasibility of printing the conductive ink using the on-shelf modified ink jet printer and curing the ink using DLP projector and hot plate on fabric. In addition, the right materials and techniques used are still not being established yet especially on fabrics.

IV. Methodology

A. *Modification of the Printer*

An EPSON printer (Model TX100) shown in Fig. 1 is used to be modified since it offers four separate empty ink cartridges for ink refilling and changing purposes as well as the print head has the capability to print different type of inks including pigment, direct to garment (DTG) and conductive inks. Furthermore, the printing resolution is also higher (700 x 700 dpi) than the other printers' type. A conventional paper feeding concept is replaced with a platform stage to accommodate fabrics.

Fig. 1. EPSON printer (Model TX100).

Depending on the printer modification characteristic, some parts of the printer need adjustment before it is being used. Each of the platform rails were aligned by adjusting its screw at different sides using a helix screwdriver. Following this, the nuts at the platform must be controlled properly since one of the factors that are contributing to the quality of the pattern printed is the deposition height between the nozzle tip and substrate.

B. Pattern Design

The electronics structure printed is a strain gauge sensor and it was modeled first using suitable drafting tool (AutoCAD) and its detail dimensions are shown in Fig. 2. The total length of the strain gauge is 221.42 mm long with a 2 mm width of track.

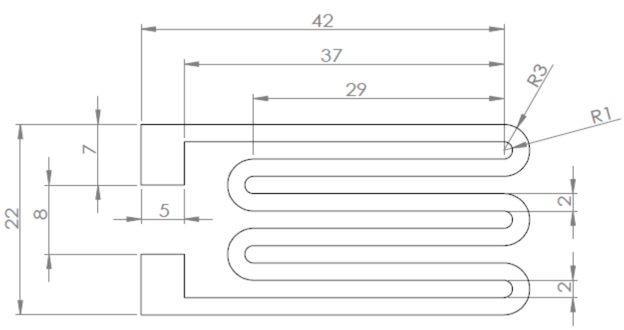


Fig. 2. Dimension of the strain gauge sensor (units in mm).

C. Conductive Ink

The conductive inks must contain an appropriate highly conductive metal such as copper, gold and silver. The type of conductive inks can be separated into two different types; particle and nano-particle. The nano-particle inks can also be classified as an organic and non-organic because of the different solvent used in the inks. Most of the organic type of conductive inks used water as the solvent to control the viscosity of the inks and water is the main ink component and it must be as pure as possible [4]. A conservative inkjet printer requires low viscosity of inks to allow it pass through the multiple micro nozzles in the print head. The silver conductive ink via on-the-shelf JET600C as depicted in Fig. 3 is used due to it is free from oxidation, easily available and based on homogeneous transparent solution and hardly causes any clogging in the print head. Its particle size is only range between 3-10 nm and suitable to be used on inkjet printer. Besides, it could also generate high conductivity when cured with curing temperature between 100°C to 150°C for less than 30 minutes. It has superior balance, long shelf life and the adhesion to substrates is better than others.

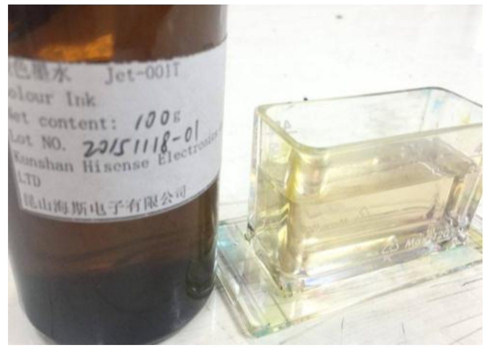


Fig. 3. JET-600C nano-particle silver conductive ink

D. Substrate

The fabric material used in this study is made of lycra. Lycra is a type of compression wear where under compression it clings strict to the skin and quite literally squeezing the muscles below, but without irritation. Since the aim is to embed sensor on cloth which is close to the skin in order to increase the sensor sensing capabilities especially on its monitoring application, lycra material is much suitable to be used for this sort of application.

E. Rubber Dye Ink Coating

Rubber dye ink coating is applied on lycra substrate using silkscreen printing technique prior to printing process as shown in Fig. 4. The purpose is to cover any voids in fabric and it also act as insulation layer to avoid the conductive ink from passing through the fabric hence it helps to ensure the continuity of the conductive ink track as well as to realize higher conductivity could be obtained after cured.

(a) (b)

Fig. 4. (a) Cross section view of the rubber dye coating (b) Surface texture of the rubber dye coating

F. Curing

The curing process is performed using a combination of direct light projector (DLP) and hot plate. The curing method used is one of a kind where the projector is placed on top of the frame as shown in Fig. 5 and the optical lens stand is placed on the left side of the frame purposely to converge the lights from the projector. The distance from the projector to the lens is set to be 85 mm and the distance from the lens to the sample is set to be 165 mm. In the mean time, hot plate is next placed at the bottom of the frame. An oven is used as a comparison purposes.

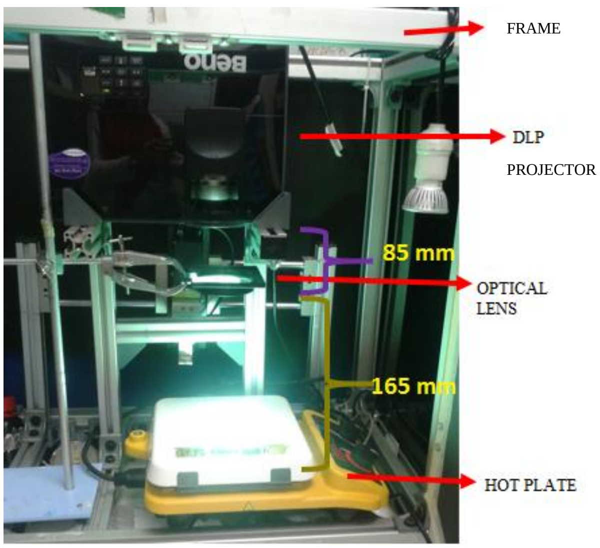


Fig. 5. Equipment setup of the curing process using DLP projector and hot plate

G. Experimental Parameter

The preferable parameters were set according to the arrangement of the overall printing operation. Printer driver properties have the ability to synchronize the speed of the print head with the motor track speed. By defining the suitable printing option, the printing speed could be determined thus the size of the ink drop could be controlled and the quality of the printing imaged could be analyzed [5]. The printing speed set is tabulated in Table I.

TABLE I
PRINTING SPEED PARAMETERS

Printing option	Printing speed	Quality
High quality	Low	Photo
High speed	Medium	Normal
Default	High	Normal

The deposition height between the nozzle tip and substrate is also determined and varied. Modification of the inkjet printer is focused on building a platform stage and it is closely to be in the right position because it is important to control the height between print head and printing surface (platform). The printing surface must locate closer enough to keep perfectly in right dimension for the printing pattern [6]. In general, the piezoelectric delivers very small spot that desire to specific deposition height with sufficient to expel the droplet toward the substrate or contact medium [7]. The deposition height set is tabulated in the following Table II.

TABLE II
VARIATION OF HEIGHTS

No.	Deposition height between nozzle and substrate (mm)
1	0.10
2	0.15
3	0.20

For the curing process, the curing parameters were first identified and the experimental parameters were characterized accordingly using Taguchi formula. The curing parameters investigated are curing temperature and time and both of them were varied accordingly. The curing temperature is first set to five different temperatures ranging from 10°C to 50°C with an interval of 10°C each. Curing time as well is set to five different curing times ranging from 3 to 15 minutes with an interval of 3 minutes each. Such arrangement is purposely done for curing using DLP projector with hot plate but not for oven which the temperatures were varied with ten different temperatures variation starting from 20°C to 150°C with an interval of 10°C each. The curing time for oven is varied at five different curing times starting at 5 to 25 minutes with 5 minutes interval.

H. Measurement

Printing resolution remains the key method to assess the printing quality. It is assessed by measuring the ink track dimensional accuracy of the printed pattern to the targeted dimensions. Several physical attributes of the ink track is measured including the line width, line to line distance, radius of circle and the curve edge dimension. An optical microscope is utilized to measure the dimension of the ink track physical characteristics and the error of dimensional accuracy is calculated using the following equation (1);

$$error\% = \frac{Measured\ ink\ track\ properties - targeted\ dimension}{targeted\ dimension} x100\% \quad (1)$$

A few mechanical tests were also performed including manual scratch test, hardness and adhesion test. These tests are intentionally done to measure the cure, hardness and adhesion level of the ink track on substrates after curing. Electrical test as well is performed via resistance measurement using two point probes (IV test) as depicted in Fig. 6. This is done to measure the current flow of the conductive ink track. Morphology of the ink track is also analyzed using optical microscope to establish its surface topography after it was cured.

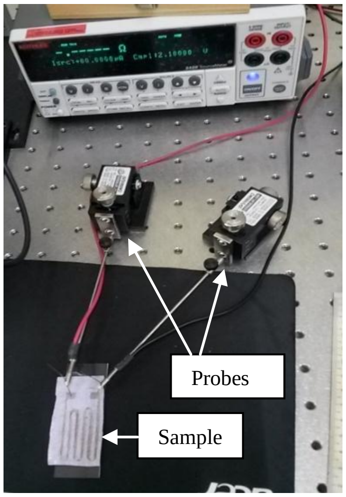


Fig. 6. Two point probes equipment (IV test)

V. RESULT AND DISCUSSION

A. Preparation of Conductive Ink

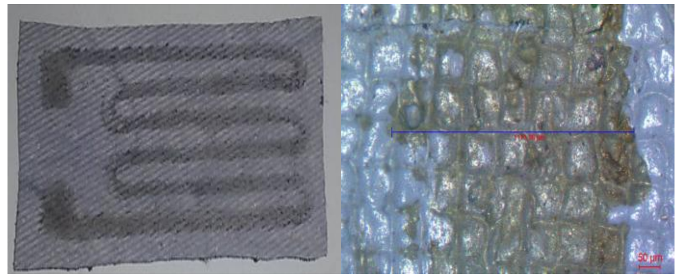
To ensure the silver particles can flows through the nozzle head, the viscosity of currently used conductive ink must be adjusted according to the viscosity of the standard pigment ink used by the paper printer. The viscosity of the standard pigment ink is much lower (2.5 mPa.s) than the viscosity of the silver conductive ink (8.99 mPa.s) and it required ten times of mixing with 2 ml of suitable solvent in this case butyl acetate to reduce its concentration and the full result of this process is shown in Table III.

TABLE III
THE RESULT OF LOWERING THE VISCOSITY OF THE CONDUCTIVE INK

No. of trial	Viscosity (mPa.s)
1	8.99
2	7.20
3	5.75
4	4.52
5	3.83
6	3.05
7	2.94
8	2.62
9	2.60
10	2.51

B. Printing of Strain Gauge

Inkjet printing is known as a drop of ink on a medium and it forms some area at drying stage. At first, the challenge is to achieve a connected spot due to a clog nozzle head. In other words, the spots are not connected on the surface efficiently in which it could not form a required continuous ink track. Furthermore, the thickness of the ink tracks is not thick enough and at some stage the tracks were not conductive at all. Printing conductive inks is differed from graphical printing due to the high requirement for layer thickness. To overcome this problem, multiple printing processes are needed on a single track and a printed strain gauge track is successfully printed as shown in Fig. 7.



(a) (b)

Fig. 7. (a) A printed strain gauge track on lycra substrate (b) Close up view on the silver ink track on lycra substrate

C. Dimensional Accuracy

The experiments were done using three different variations of printing speed and deposition height as tabulated earlier in Table I and II. Fig. 8 below shows the dimensional accuracy results for all three variations of deposition height parameter with a constant low printing speed since the other two printing speeds variation were failed to produce a continuous printed ink track. It was found that the result for 0.10 mm of deposition height is far from the targeted dimension which mostly 50% of error were produced from the targeted dimension. The line to line distance attribute is the worst error obtained. This is due to the deposition height set was too close to the platform and since the substrate is fabric, it is not flat and part of the fabric covered the nozzle head hence clogged the nozzle tip.

In the mean time, the results also show that using 0.20 mm of deposition height between nozzle head and substrates, resulting a far worst results than the results when using 0.10 mm of deposition height. All attributes resulted in more than 50% of error except the curve edge dimension attribute. This is might due to the fact that 0.20 mm is quite distance for the ink droplet to stay continuous. There is a huge gap between the spots and the track is not connected at all.

Meanwhile, the results when using 0.15 mm of deposition height are far better than the previous two sets of deposition height since it produced less error. Most errors of the ink track properties are in the average of less than 30% of error. It could be concluded that a medium range of 0.15 mm deposition height is most suitable in order to get a quality pattern image since the ink track produced were continuous and close enough to the targeted dimension set.

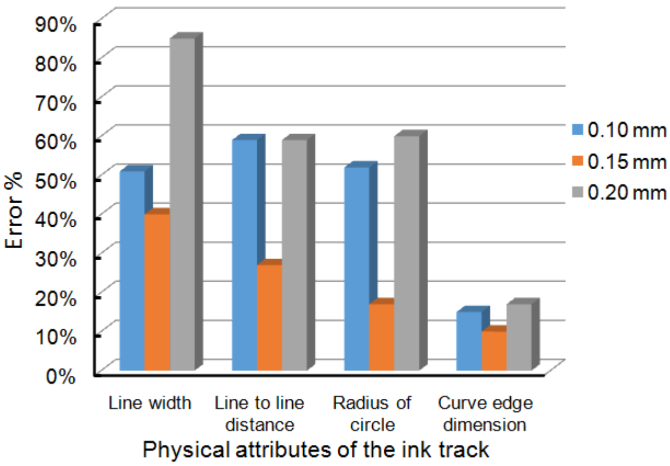


Fig. 8. Dimensional accuracy result for three variations of deposition height parameter

D. *Resistance*

The used of two point probes tools (IV test) is to measure accurately the current flows in the ink track. Only four samples of the ink tracks were measured from the curing process using DLP projector and hot plate and the contents of silver metal were assumed same for all. The results are shown in Table IV and a graph of resistance against curing temperature is also plotted and illustrated in Fig. 9. The trend shows that at first the resistance obtained is slightly decreased when the temperature is higher and then slowly increased to a certain value and maintain on that value until the end. This is much due to the over cure phenomenon where the resistance increase even though the temperature becomes higher.

TABLE IV
RESISTANCE RESULT FOR CURING USING DLP PROJECTOR AND HOT PLATE

Sample	Temperature (^{o}C)	Time (minutes)	Resistance (Ω)
5	15	15	1.207
10	20	15	0.934
20	40	15	1.085
25	50	15	1.064

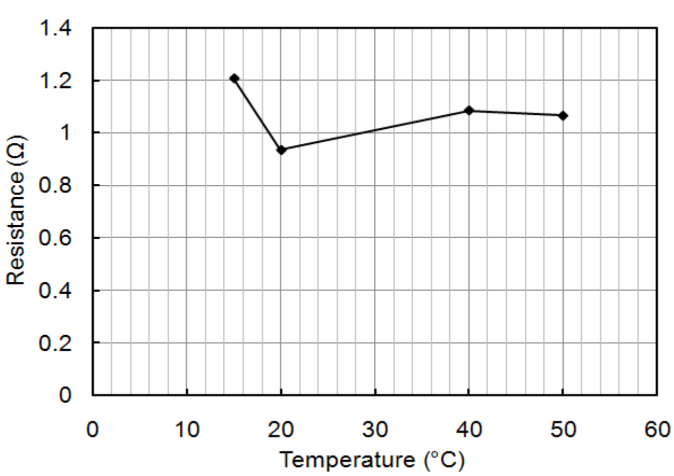


Fig. 9. Graph of resistance against curing temperature using DLP projector and hot plate

This is not the case when curing with oven as tabulated in Table V and illustrated in Fig. 10. The resistance measured is decerased when the temperature is increased following the theoretical concept which resistance will slowly decerase when temperature is constantly increase. This is due to the fact that the silver nanoparticle are impending to bulk silver [8] starting from 50°C to 100°C. At 100^{o}C, the resistance obtained started to increase back until 160^{o}C. This is mainly due to again the over cure phenomenon where the resistance is continuously increased even though the temperature becomes higher.

TABLE V
RESISTANCE RESULT FOR CURING USING OVEN

Sample	Temperature (^{o}C)	Time (minutes)	Resistance (Ω)
1	30	5	0.641
2	50	5	0.494
3	60	10	0.272
4	70	10	0.266
5	80	15	0.181
6	90	15	0.205
7	100	20	0.086
8	115	20	0.449
9	125	25	0.766
10	150	25	0.950

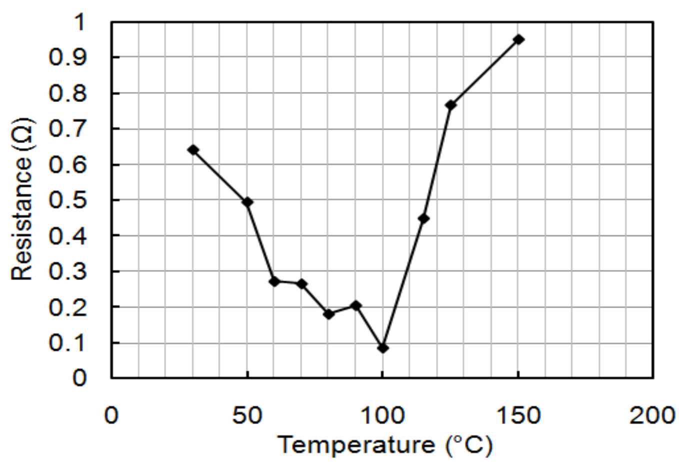


Fig. 10. Graph of resistance against curing temperature using oven

E. *Mechanical testing*

A manual scratch test is done on the sample and when the ink track had any smear, the sample is considered as not fully cured. It was found that all samples did not have any smear which could be concluded that the ink tracks were cured properly. The hardness test is then conducted to the cured sample to measure the hardness level of the ink track. A suitable test load is needed to be defined first prior to the test and it was found that the test load selected failed to measure the hardness level for all tracks. This error is caused by the layer of ink tracks were very thin in the sub-micron range and the surface texture of the ink tracks were not smooth as depicted in Fig. 11. The test load range selected were at minimum HV0.01 (98.07 m.N) and the maximum test load is at HV2 (19.614 N). Both test loads range did not have an effect on the ink track during testing.

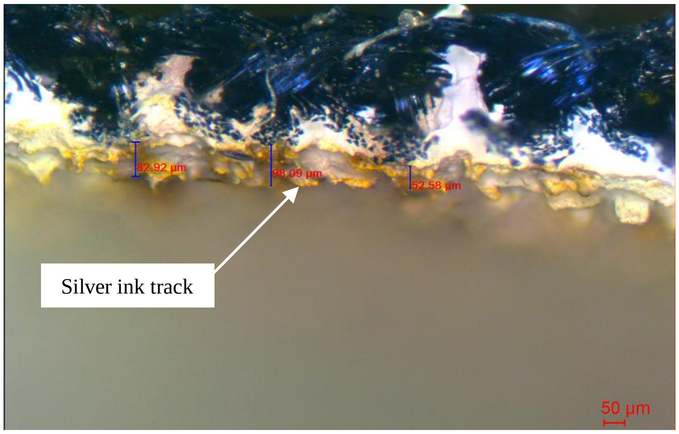


Fig. 11. Cross section view of the silver ink track thickness showing the layer is very thin in the sub-micron range

Besides, the adhesion test is also performed to measure the adhesion level of the ink track. The adhesion level is measured based on the percentage of the removed ink from the tape test method as shown in Fig. 12. The adhesion level was set according to a scale of 0B, 1B, 2B, 3B, 4B and 5B and the result of the adhesion level for both curing methods is illustrated in Fig. 13 respectively. It shows that the adhesion level of the ink track is increased linearly starting from the first sample until the last sample for both curing methods. This is fundamentally true since the cured sample is harder when the solvents inside the liquid ink are fully evaporated leaving behind only the metal contents in this case silver.

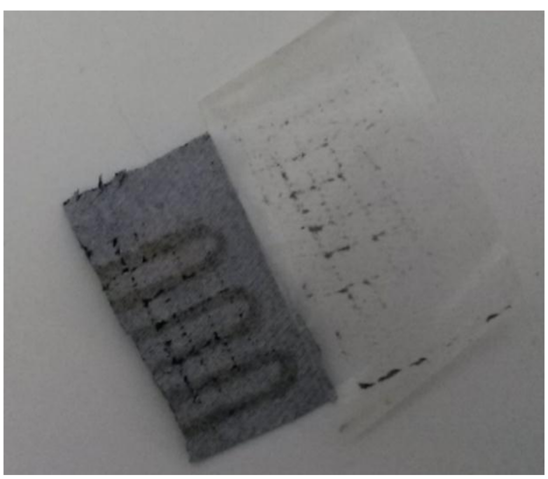


Fig. 12. Track image on the 3M sensitive-pressure tape (tape test)

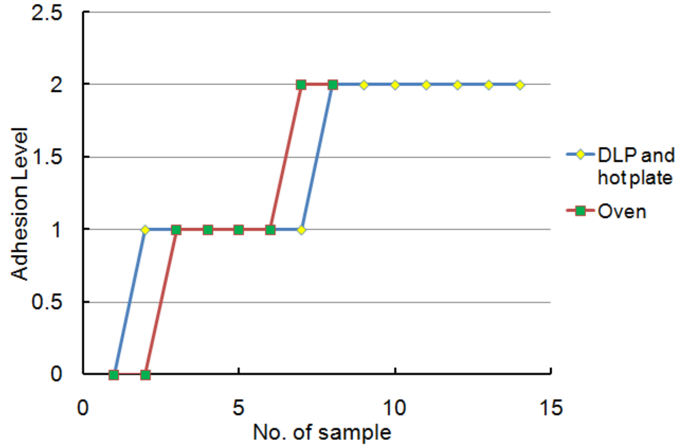


Fig. 13. Adhesion test result when curing using both DLP projector with hot plate and oven

VI. Conclusion

In conclusion, strains sensors on fabric structure were successfully printed and factors that affecting their dimensional accuracy were studied. The objective of the study which is to investigate the feasibility of printing silver conductive ink using the on-shelf modified ink jet printer and curing the ink track using DLP projector with hot plate on fabric is achieved. Besides, a variable printing speeds and deposition heights were tested and it found that both parameters did affect the quality of the ink tracks printed. On the other hand, the ink's viscosity is required to be adjusted to suit with the nozzle tip diameter so that a proper continuous ink tracks could be produced. Furthermore, from the series of experiment conducted, to achieve a quality printed continuous tracks on fabric is very difficult. Since fabric is understandably stretchable and the nozzle tip kept repeatedly clogged, some of the ink tracks could not be properly printed accordingly. Stability is needed in order to provide consistency during printing. In the mean time, a combination of DLP projector and hot plate was seen successfully cured the conductive ink. There are still many improvements that could be implemented in the future including the solvent used to mix with the silver ink. It could be changed from previously used butyl acetate to hydrazine hydrate since hydrazine hydrate capable of reducing silver nitrate and obtaining high concentration of nano-silver colloid. Enhancement of the currently used inkjet printer could also be done by making it more user friendly via providing a clip at each angle of the platform stage to avoid it from separated and clash with the nozzle head. Otherwise, a more suitable non-contact type of deposition method using the automatic fluid dispensing system is preferable especially in providing thicker filamentary bead of the ink tracks which is important to obtain the required conductivity. To achieve a good quality of the printed ink tracks, the nozzle head needs to be regularly cleaned after it is being used in order to maintain its stability of jetting out the ink.

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