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Investigation of Curing Process of Silver Conductive ink on Polymer Substrates using Halogen Lamp and Oven

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Abstract: The use of conductive silver ink has lately become popular in a variety of electrical applications. They are often sold in liquid form and need curing by heating to reveal their metallic components, with solvent residues remaining after curing for a few hours before thoroughly vaporizing. Halogen light and an oven were used to cure silver conductive ink on a polymer substrate, and the results of this research were presented in this article. The curing parameters were determined, and the impact of these factors on the conductivity, adhesion, and hardness level of the ink track was assessed. The connection between curing time and temperature to resistance has also been effectively established, demonstrating that the resistance of conductive ink track is proportionate to the length of curing time and temperature. In this study, it was discovered that the Oven is capable of generating a good curing process. When the temperature is raised, the amount of time it takes to cure the ink is lowered significantly. With less damaged polymer substrate, the optimal temperature and duration for curing silver conductive ink were 110°C for 90 minutes, and the lowest resistance achieved was 0.9Ω with the least amount of damage. According to the mechanical test, all of the results obtained in the Oven are entirely cured. It demonstrates that the Oven may be utilized as a preferred curing method in this study to adequately cure silver conductive ink on polymer substrates, as shown in the results.

Keywords: Curing Process, Halogen Lamp, Oven, Silver Conductive Ink, Polymer Substrates

1. Introduction

Advanced printing technology is exceptionally competent and perfect with polymeric materials, substrates, and links that enable flexible electronics applications to brand-new technology. According to [1], different printing ink drying mechanisms are used useable, depending on the following factors: printing process, type of printing ink (liquid, paste, water or organic solvent-based, radiation curing ink, etc.), speed of printing machines, substrates of printing materials, type of printing product and

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characteristics of drying systems (hot air, curing systems, IR). The extent of conductive inks lies in implementing the next phase of technological promotion, such as versatile and printable electronics, to which the use of conductive inks is mainly due [2]. Creation of inks for conduction due to printed electronics' successful production, ink central conductive elements are metals such as silver, copper, nickel, and aluminum [3]. Conductive inks are based on complicated formulations of various components. Various methods have been used involved curing processes such as using the Oven, hot plate, and laser. The study's objective is to compare the performance of cured ink track between Oven and halogen lamp utilizing curing time, temperature, electrical and mechanical properties. The conventional oven cure is one of the most suitable and cost-effective sintering methods for silver conductive inks between these curing process methods. Unfortunately, this method takes a very long time to cure the ink [1].

On the other hand, using a laser to cure the conductive ink is more reliable than other conventional methods [4]. Laser curing of conductive ink is advantageous for speed and the protection of nearby heat-sensitive components. This process uses electric heating elements to convert electrical energy into heat by running through the heating coil with a relatively high electrical resistance level for the usage of a hot plate. In this study, the Halogen lamp is the best option to cure silver conductive ink in various parameters and substrates [5]. The expected outcome for this study is to compare the halogen lamp, and the Oven was curing silver conductive ink process, a correlation between the variation of curing time and temperature to resistivity and the capability of the halogen lamp compared to the Oven in reducing curing time without damaging the substrate. The halogen lamp comparison result shows a big difference in the percentage between previous of this study.

2. Materials and Methods

2.1 Material and Substrate

A straight line ink track having a length of 30 mm and a width of 0.8 mm is developed, as shown in Figure 1. Numerous studies have been conducted on metal nanoparticle inks such as silver (Ag) and copper (Cu) nanocomposites, with silver nanoparticles being preferred as the most devoted conductive ink for printed electronics circuits due to their superior conductivity, anti-oxidation, and low acid and alkaline resistivity [6]. As shown in Figure 2, the ink utilized throughout the research is a silver epoxy-based ink substance (Model: AG806). Due to the ink's high solid fraction, it cannot be used directly; therefore, it must be adjusted to the proper viscosity (refer to table 1) for a smooth deposition process via dilution with toluene's solvent. A polymer sheet through a polyethylene terephthalate (PET) transparency sheet was utilized as a substrate shown in Figure 3.

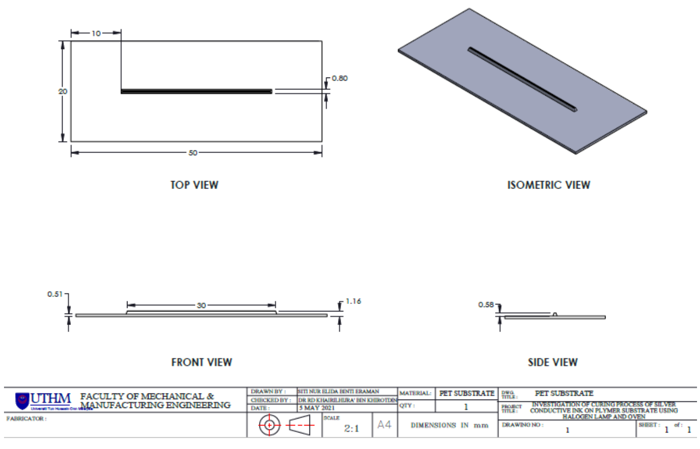

Figure 1: A straight line ink track (Length: 30 mm and width: 0.8 mm)

Figure 2: Silver conductive ink (Model: AG 806)

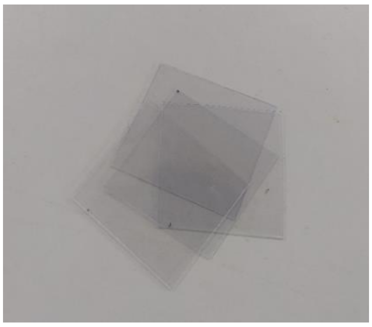

Figure 3: PolyEthylene Terephthalate (PET) polymer sheet

2.2 Printing and Curing Process

As shown in Figure 4, a printing procedure using automated syringe-based deposition equipment (Model: F4200N.1) is utilized to print the ink with the optimal printing parameters listed in Table 1. The technique is precise and fast, and it is capable of working with a broad range of materials, including conductive ink. Meanwhile, the curing procedure was critical in ensuring the ink track had low resistance, mainly when dealing with conductive ink [7]. The curing procedure removes unnecessary solvents from the ink, allowing the metal content to be visible while also promoting adhesion to the polymer materials. The curing parameters are shown in Table 1, with the temperature range being 110°C to 190°C and the time range being 10 to 90 minutes. The process of curing with a halogen light was started by adjusting the distance between the lamp and the work area to get an optimal space for the curing process. The temperature was measured using a Fluke thermal imager, and it was discovered that the temperature acquired was directly related to the distance specified. Throughout the research, a sufficient length of 10 mm was maintained.

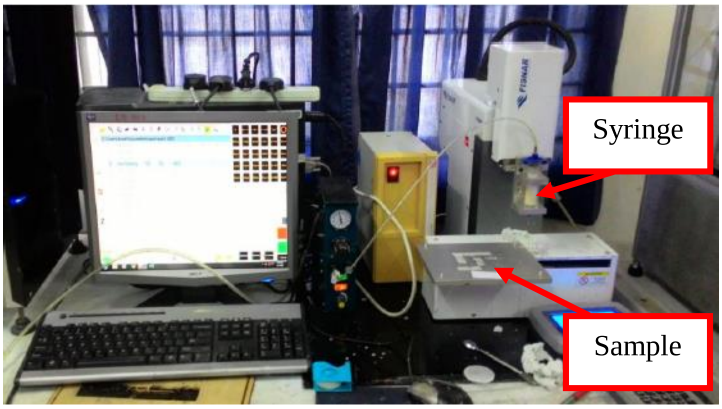

Figure 4: Automated syringe-based deposition system

Table 1: Printing and curing parameters

Printing Parameters				
Pressure (kPa)	Speed (mm/s)	Deposition Height (mm)	Nozzle Diameter (mm)	Viscosity (Pa.s)
100	17	1.00	0.51	2.40
Curing Parameters				
Temperature (°C)			Time (minute)	

110 - 190	10 - 90

2.3 Measurement and Testing

In order to improve the comparison of the past result, a thermal imager (Model: Fluke Ti25), as shown in Figure 5, was used to compare the temperature set correctly. For halogen lamps, the heat from the temperature set by using the dimmer will be captured with a thermal imager to justify the designated temperature. Also, the same way for Oven to explain the selected temperature by using a thermal imager.

Figure 5: Thermal imager (Model: Fluke Ti25)

The electrical test was done to determine the amount of resistance inside the ink track of silver conductive by using an LCR meter (Model: GW Instek LCR 819), and it can be used to measure inductance (L), capacitance (C), and resistance (R). The resistance obtained can be used to calculate the resistivity and conductivity of the sample. The value of resistivity of the model can be obtained by using the equation (1) below:

$$\rho = R\frac{A}{l} \tag{1}$$

where ρ is the volume resistivity in Ω.mm, R is resistance, A is the area of ink track in mm^2 and l is the length of the ink track. For the value of the size of ink track, it can be obtained by using the equation of semi-ellipse in equation (2) below:

$$Area\ of\ Ellipse = a \times b \times \pi \tag{2}$$

where a is the radius of the width of the ink track and b is the thickness of the ink track.

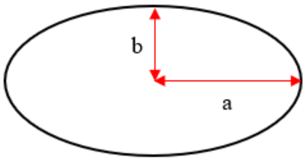

Figure 6: Area of an ellipse

3. Results and Discussion

3.1 Electrical Properties

Table 2 shows an average total of 20 samples were produced and cured according to the parameters listed in Table 1. In contrast, Figure 7 and Figure 8 represent the resistance transition between inks cured with a halogen lamp and an oven as a function of curing time and temperature variation. Additionally, it was shown that ovens had a lower resistance value than halogen lamps. The resistance value for the halogen lamp was somewhat more significant, indicating that the silver ink was not fully cured owing to the low temperature and the ink manufacturer's specifications. Because the silver conductive ink was initially combined with a tiny quantity of toluene solution, it affected the minimum curing temperature. As a result, it was determined that the oven temperature was somewhat higher than it should have been due to the oven system being regarded as a closed system and the heat produced being supposedly twice.

Table 2: Average Resistance (Ω) between Halogen lamp and Oven

Experiment	Temperature (°C)	Time (minutes)	Average resistance (Ω)	
			Halogen lamp	Oven
1	110	90	2.3	1.2
2	130	70	2.6	0.9
3	150	50	3.4	1.4
4	170	30	2.9	2.1
5	190	10	1.8	2.3

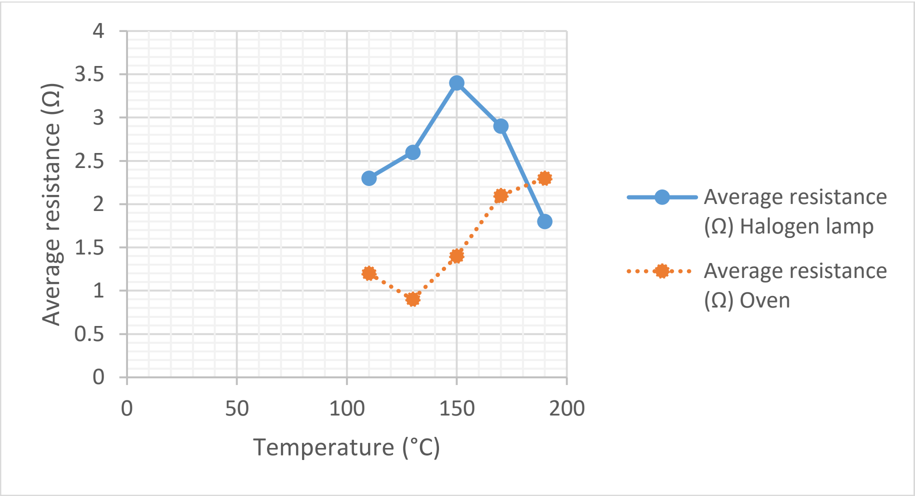

Figure 7: Graph of an average resistance (Ω) versus temperature (°C) between Halogen lamp and Oven

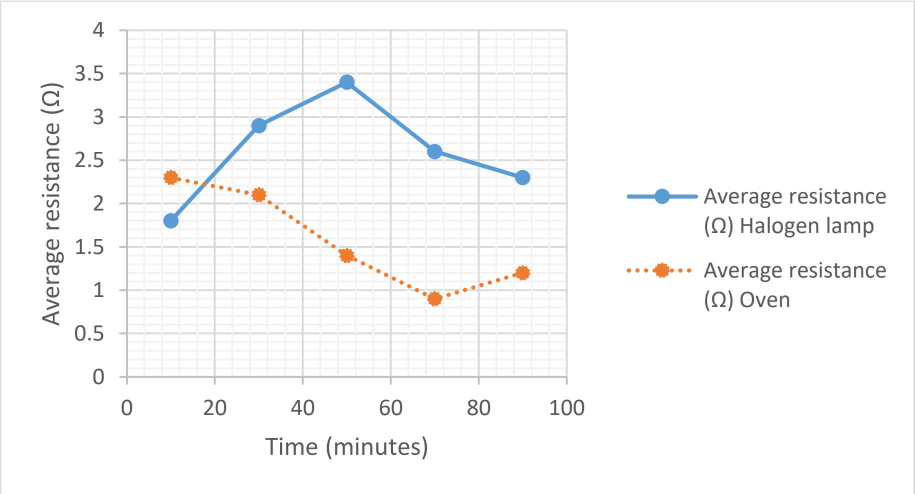

Figure 8: Graph of an average resistance (Ω) versus time (minute) between Halogen lamp and Oven

3.2 Mechanical Properties

There are three tests involved in mechanical tests: manual scratch test, adhesion test, and hardness test. The hardness test and adhesion test cannot be performed due to Movement Control Order (MCO). A manual scratch test is using by the needle and applying a minimum force to check whether the smear appeared or not. Based on the result in Table 3, the sample has a higher resistance value for the halogen lamp, which is not fully cured. Thus, a smear appeared on the ink track during the test for halogen lamp curing. It may be concluded from the experiment's results in Table 4 that oven curing produces the best curing results. The temperature in the Oven may be somewhat higher owing to the closed system, as opposed to the open system of a halogen bulb. The experiment discovered that the temperature in the Oven was not the same as the temperature set at the display by employing a thermal imager during the inquiry for this cure. It is most likely because the Oven's heating element is not functioning correctly. According to the findings of this investigation, the temperature of the bulb was not the same as the temperature set by the dimmer in the case of halogen lamps. Because the halogen lamp is an open system, the temperature of the halogen lamp will dissipate the heat during the curing process at a particular point. It's also probably because the dimmer is not working correctly, and the bulb has not been used in a long time. To cure thoroughly, air curing (at room temperature) shall be avoided, and only a Halogen lamp will be used. The mechanical test findings for both cures are the same since there is a minor variance in the Oven and the curing in the closed system. The prior result showed that the sample was not fully cured at the same temperature as the halogen lamp and that it was cured in an open system.

Table 4: (Halogen Lamp) Manual scratch test result

Run	Temperature dimmer (°c)	Temperature thermal imager (°c)	Time (minutes)	Manual scratch	Hardness
1	110	115	90	Smear	N/A
2	110	119	90	Smear	N/A
3	130	137	70	Smear	N/A
4	130	139	70	Smear	N/A
5	150	152	50	Smear	N/A
6	130	154	50	Smear	N/A
7	170	174	30	Smear	N/A
8	170	174	30	Smear	N/A
9	190	196	10	Smear	N/A
10	190	197	10	Smear	N/A

Table 5: (Oven) Manual scratch test result

Run	**Temperature Dimmer (°C)**	**Temperature thermal imager (°C)**	**Time (minutes)**	**Manual scratch**	**Hardness**
1	110	98	90	Not smear	N/A
2	110	98	90	Not smear	N/A
3	130	125	70	Not smear	N/A
4	130	125	70	Not smear	N/A
5	150	148	50	Not smear	N/A
6	150	148	50	Not smear	N/A
7	170	162	30	Not smear	N/A

8	170	162	30	Not smear	N/A
9	190	188	10	Not smear	N/A
10	190	188	10	Not smear	N/A

4. Conclusion

Printed electronics was a group of printing techniques that were used to build electrical devices on a variety of surfaces. In most cases, printing is done using standard printing equipment capable of defining patterns on a variety of materials. This study aims to evaluate the performance of cured ink tracks treated in an oven and against a halogen light in terms of healing time, temperature, electrical, and mechanical characteristics. The experiment will begin by comparing the temperature set appropriately using a thermal imager to achieve the goal. Another purpose for this experiment is to demonstrate that the halogen lamp can speed up the curing process and can also be used as a substitute for Oven and laser curing. The result of the electrical test and the result of the mechanical test for the previous study and this current study showed that the same result. It is proven that on adhesion test, oven results show that silver inks are fully cured compared to halogen lamps that are not fully cured.

Acknowledgement

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