EFFECT OF STRETCHABLE CONDUCTIVE INK ON ELECTRICAL CONDUCTIVITY UNDER TENSILE STRESS

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DECLARATION

I declare that this project entitled "Adhesion Characterization of Electrically Conductive Polymer" is the result of my own work except as cited in the references.

Signature : ……………………………………..

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Hons).

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DEDICATION

This project work is dedicated to my beloved family and friends for always been there to support and inspire me throughout my life.

ABSTRACT

Conductive ink is widely used in industry especially in the electronic printed industry. Conductive ink is more flexible, smaller and multi-purpose compare with the traditional wire and electronic devices. There are several types of conductive ink such as copper nanoparticle conductive ink, conductive polymer, carbon complex ink and others. Each type of conductive ink has different mechanical properties and function. The conductive ink can be printed on the substrates by different method such as laser printing, screen printing and so on. The aim of this research is to investigate the conductivity of the conductive ink under tensile stress. The carbon conductive ink needs to print on the thermoplastic polyurethane (TPU) and cure in the oven by using 120°C and 30 minutes. The conductive ink is clamp on the stretching equipment and stretch in different elongation. The resistivity is measure by multi-meter and the sheet resistance is measured by four-point probe. Surface structure of the conductive ink is observed by using microscope and recorded down in computer. The result shows that the resistance increased when the elongation increased. For 40mm length of conductive ink, the initial resistance is 0.562 kΩ and its become 1.217 kΩ when stretch until18% of its initial length. The sheet resistance of the conductive ink also increased due to the defection on the surface of conductive ink when under tensile stress. For 40mm length of conductive ink, the sheet resistance is 793.17 R/sq at initial state and become 3059.37 R/sq when stretch until 18% of its initial length. By comparing the different length of the conductive ink, the cracking point for 40mm length of conductive ink when stretching with 5.6mm of elongation while the strain level is 0.14. Besides, the cracking point of 60mm length of conductive ink is 9.6mm of elongation with 0.16 of the strain level. The strain level of the cracking point between different length are very closed. As conclusion, when under tensile stress, the sheet resistance and resistivity will increase which mean the drop of conductivity. The conductive ink will start to crack when the strain level is reach around 0.15.

ABSTRAK

Dakwat konduktif digunakan secara meluas dalam industri terutamanya dalam industri bercetak elektronik. Dakwat konduktif lebih fleksibel, lebih kecil dan pelbagai guna berbanding dengan wayar tradisional dan peranti elektronik. Terdapat beberapa jenis dakwat konduktif seperti tembaga dakwat konduktif nanopartikel, polimer konduktif, dakwat kompleks karbon dan lain-lain. Setiap jenis dakwat konduktif mempunyai sifat dan fungsi mekanikal yang berlainan. Dakwat konduktif boleh dicetak pada substrat dengan cara yang berbeza seperti percetakan laser, percetakan skrin dan sebagainya. Tujuan penyelidikan ini adalah untuk mengkaji kekonduksian dakwat konduktif di bawah tegangan tegangan. Tinta konduktif karbon perlu mencetak pada poliuretana termoplastik (TPU) dan menyembuhkan dalam ketuhar dengan menggunakan 120 ° C dan 30 minit. Dakwat konduktif adalah pengapit pada peralatan regangan dan regangan dalam pemanjangan yang berbeza. Resistivity adalah ukuran oleh pelbagai meter dan rintangan lembaran diukur oleh kuar empat titik. Struktur permukaan dakwat konduktif diperhatikan dengan menggunakan mikroskop dan direkodkan dalam komputer. Hasilnya menunjukkan bahawa rintangan bertambah apabila pemanjangan meningkat. Untuk panjang 40mm dakwat konduktif, rintangan awal ialah 0.562 kΩ dan menjadi 1.217 kΩ apabila regangan hingga18% daripada panjang permulaannya. Rintangan lembaran dakwat konduktif juga meningkat disebabkan oleh pembelotan pada permukaan dakwat konduktif ketika berada di bawah tegangan tegangan. Untuk panjang 40mm dakwat konduktif, rintangan helaian ialah 793.17 R-persegi pada keadaan awal dan menjadi 3059.37 R-persegi apabila regangan sehingga 18% daripada panjang awalnya. Dengan membandingkan panjang dakwat konduktif yang berlainan, titik retak untuk panjang 40mm dakwat konduktif apabila meregangkan dengan pemanjangan 5.6mm manakala tahap ketegangan adalah 0.14. Selain itu, titik retak 60mm panjang dakwat konduktif ialah 9.6mm pemanjangan dengan 0.16 paras terikan. Tahap ketegangan titik retak antara panjang yang berbeza sangat tertutup. Sebagai kesimpulan, apabila tegangan tegangan, rintangan lembaran dan resistiviti akan meningkat yang bermakna penurunan kekonduksian. Dakwat konduktif akan mula retak apabila paras ketegangan mencapai sekitar 0.15.

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Ag	silver
C.I	conductive ink
CIJ	continuous ink-jet printing
DOD	drop-on-demand
EB	electron beam
PEN	polyethylene napthalate
PET	polyethylene terephthalate
TPU	thermoplastic polyurethane
UV	ultraviolet

LIST OF SYMBOL

°C	Degree Celsius
I	Current
mm	Millimeter
R	resistance
R/sq	resistance per square
V	voltage

CHAPTER 1

INTRODUCTION

1.1 Background

Technology nowadays want to improve the performance of the device and reduce the size of the electronic device so that it will become more flexible, smaller and multi-purpose. Intend for reduce the size and increase the flexibility of the device, the traditional solid-state technology poses such as copper wire need to be eliminate and new technology should be developed which is conductive ink. Several types of conductive have been developed for using in flexible circuit device such as metal-based inks, conductive polymers and carbon complex (Tran, Dutta and Choudhury, 2018). In metal-based ink, that are few types of metal are using for the filler for conductive ink such as copper and silver. These types of ink have high conductivity and they are commonly used in traditional solid-state electronic. However, metal-based ink are high-cost and will be oxidize under ambient condition (Woo *et al.*, 2009) .

The carbon complex which called graphene, it consists of a two-dimensional layer of carbon lattice. Graphene have a very good electrical conductivity by using high charge mobility to conduct electricity (Grande *et al.*, 2012). Conductive polymers are the creation of the mobility to charge on the polymers backbone so that it can conduct electricity. The example of conductive polymers is polyacetylene. It compress pellets are arrange as conjugated structure to exhibit the electronic conductivity (Ramakrishnan, 2011).

These several types of conductive ink need to print on the surface so that it can connect the electronic product together. Few kinds of printing techniques have been developed to achieve the fabrication process which are ink-jet printing, screen printing, and gravure printing (Tran, Dutta and Choudhury, 2018). Among these 3 types of printing, screen printing is the most common printing technique in the industries process due to its compatibility. Screen printing is the low-cost, scalable and able to produce both fixed and flexible thin-film compare with the others printing technique (Cao *et al.*, 2014). Although ink-jet printing is high cost but it has high registration accuracy so that it can produce a fine product (Sirringhaus *et al.*, 2009). During ink-jet printing, the liquid jets had been break up and then governed by using the theory of fluid dynamics to form the conductive ink on the surface of the material (Cummins and Desmulliez, 2012). However, the gravure printing are high scalability and flexographic printing which mean it have high printing resolution and it can print uniformly. The conductive ink is printed by the rotary-screen printing to form the conductive line on the surface of the paper or plastics film (Pudas *et al.*, 2005).

Based on the project title “Effect of Stretchable Conductive Ink on Electrical Conductivity Under Tensile Stress”, I need to figure the material of the conductive ink that used in this project and I also need to print the conductive ink on the polymer so that it can stretch and test its conductivity. Lastly, I should record the result and make a report for this tittle.

1.2 Problem Statement

The development of conductive had growth rapidly at the electronic industry to replace the traditional solid-state wire to produce the smaller and flexible electronic components. However, the current technology and design of conductive ink is not fully replacing the conventional soldering method because that have many unknown variables of the conductive ink that we haven’t find out and it also have many limitations such as limited electrical conductivity, low life-cycle, and low stretchability. Researcher had been continuously researching about conductive ink under stretching condition and improve the stretching ability without affect the electrical conductivity.

The main parameter that will affect the conductivity of the conductive ink under tensile stress is the elongation of the conductive ink during stretching. Based on the previous study using four-point probe analyser to measure the resistivity of the stretchable conductive ink under stretching condition, we can know that the resistance is increasing when the strain is increase due the cracking on the surface of the conductive ink (Park *et al.*, 2018).

Beside that, the stretching cycle also will affect the resistance of the stretchable conductive ink. Based on the result of the study, the resistance had change 3% after 10,000 cycles of stretching with the strain rate of zero to twenty percent. That means the resistance will increase after many stretching cycles due to the deformation of the stretchable conductive ink (Pii, Su and Materials, 2016). Hence, this aim of study is to figure out the conductivity of the stretchable conductive ink under tensile stress and improve the stretchability without changing the resistivity of the conductive ink.

1.3 Objective

The specific objective of this project are as follows:

1) To fabricate the tool that can stretch the conductive ink during experiment.
2) To investigate the conductivity of the stretchable conductive ink under tensile stress.
3) To observe the surface structure of the stretchable conductive ink under stretching condition.

1.4 Scope

The scopes of this project are shown as bellow:

1) Fabricate the stretching equipment to claim and stretch the conductive ink.
2) Print the stretchable conductive ink and measure its conductivity in different elongation by using the four-point probe and multi-meter.
3) Observe and record the surface structure of the stretchable conductive ink in different elongation by using Microscope

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, there are reviews of the related topics to the tittle of the project based on the previous study which include the stretchable conductive ink, types of materials used in the conductive ink, method used to measure the conductivity of the conductive ink, and the result based on the previous study. The sim of this chapter is help us to understanding the problem that we are facing during research and locate my research within the existing research.

2.2 Stretchable Conductive Ink

The stretchable conductive ink is the component that are more flexible, stretchable and lightweight that can replace the traditional solid-state component in this modern society. This kind of ink used the technology of metal nanoparticles so that it has many tiny spheres of metal inside the conductive ink. The metal tiny spheres allow the electron travel from one nanoparticle to another inside the conductive ink and hence the conductive ink can conduct the electricity. The main components that exist in the conductive ink are metal nanoparticles and the liquid used to carry the nanoparticles. When we use the conductive ink on the paper, the random network of nanoparticles will connect with each other when then conductive is dried so that the electron can pass through and conduct electricity.

2.3 Type of Stretchable Conductive Ink

Based on the previous study, it has three types of conductive ink which are metal-based ink, conductive polymers and carbon complexes. These 3 types of conductive ink have their own advantage and disadvantage.

2.3.1 Metal-Based ink

Metal-based ink normally contain metal nanoparticle inside the conductive ink such as copper and silver. Copper and silver metal-based ink is widely used because of their good conductivity and it also familiar due to commonly used when traditional solid-state component (Woo *et al.*, 2009). Moreover, silver and copper have excellent electrical properties that make them widely used in electronic industry (Mazhuga and Vecherskaya, 2013). However, silver and copper metal-based ink also have their limitation on the aspect of conductive ink. Silver cannot function properly when migrated into device layer and the cost of this conductive is high. Meanwhile, copper metal-based conductive ink will be oxidize when expose to surrounding. This will affect the performance of the conductive ink to transfer the current. Beside that, metal-based ink also need the high sintering temperature when printing and cause the damage on the surface of the component such as paper and plastic substrates (Tran, Dutta and Choudhury, 2018). The sheet resistance of metal based ink is 0.1 ohm per square which mean the metal based ink have very good conductivity due to its low resistivity (Farraj, Grouchko and Magdassi, 2014). The price of the metal based ink is very high, 20 g of silver nanoparticle ink with 50 wt.% of concentration is sell with RM 767.70 on internet.

2.3.2 Conductive Polymers

Conductive polymers that contain of organic polymers that are metallic conductivity and become similar characteristics with semiconductor. The conductive polymers have high electrical conductivity but it do not have the same mechanical properties with other polymers due to organic materials inside the conductive polymers. That are few types of conductive polymers which is polyacetylene, polypyrrole, polyindole, athnd polyaniline. The conductive polymers are prepared by many process such as dehydrogenation. Conductive polymers are not commonly used because of their poor processability. (Kraft, 2007) The surface resistance of conductive polymer is around 100 ohm per square while the transmission rate is retain at 70% (Gustafsson, G., Cao, Y., Treacy, G. M., Klavetter, F., Colaneri, N., & Heeger, 1992). The conductive polymer coating sell on internet is RM 25.80 per gram.

2.3.3 Carbon Complex Ink

Carbon complex ink which mean the conductive ink that contain the carbon nanoparticles to carry the electron to conduct the electricity. Graphene is the most common product of carbon complex ink which have low-cost and easily apply on the flexible substrates. Carbon complex ink had been used more commonly than the other conductive ink due to its high performance of electrical conductivity and low-cost. Furthermore, carbon complex ink also can be print by using screen printing, ink-jet printing and gravure printing. Hence, the carbon complex ink had emerge quickly in nowadays (Zhu *et al.*, 2010). The sheet resistance of carbon complex ink is between 5 to 15 ohm per square when the thickness of the carbon complex ink is 0.5 to 2 μm (Ren and Cheng, 2014). The cost of carbon black ink is lower than other types of conductive ink. It only sell RM145 per bottle of carbon based ink with 50 ml of its volume.

Table 2.1: Comparison between different type of conductive ink

Specification / Type	Resistivity	Oxidation	Cost	Processability
Metal-Based ink	Very low (0.1 ohm)	Yes	High (RM 38.39/g)	Good
Conductive Polymers	Medium (100 ohm)	No	Medium (RM 25.80/g)	Poor
Carbon Complex Ink	Low (10 ohm)	No	Low (RM 2.90/ml)	Good

2.4 Printing Method of Conductive Ink

To apply the conductive ink on the surface of material, we need to use the printing technique like ink-jet printing, screen printing, and gravure printing so that the ink can stick on the surface of material and manufacture the electronic device.

2.4.1 Ink-jet Printing

Ink-jet printing is widely used in industry because it is flexible to print different kind of printing pattern. Ink-jet printing also as a plateless printing which is non-contact with the substrates. This printing technique is suitable for the frequent design change but not suitable for mass production (Nie, Wang and Zou, 2012). That are two types of Ink-jet printing which is continuous ink-jet printing (CIJ) and drop-on-demand (DOD) ink-jet printing. Continuous ink-jet printing will spray the tiny ink droplets continuously and the droplets is controlled by electric field to change it direction so that it can form printing image (Lizasoain *et al.*, 2015).