EFFECT OF STRETCHABLE CONDUCTIVE INK ON ELECTRICAL CONDUCTIVITY UNDER TENSILE STRESS

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B041510083

BMCG

A report submitted

In fulfilment of the requirements for the Degree of

Bachelor of Mechnical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MAY 2019

Faculty of Mechanical Engineering

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.

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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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LIST OF ABBREVISTION

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).

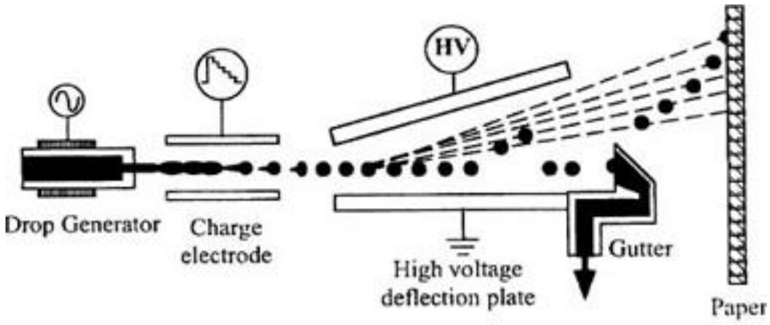

Figure 2.1: Continuous Ink-jet Printing Technology.

That are two group of printing in drop-on-demand printing which are piezoelectrically ink-jet and thermal ink-jet. Piezoelectrically ink-jet has a tiny reservoir to hold the conductive ink and there has a membrane to push the conductive out of the nozzle. However, thermal ink-jet has a special reservoir that can heat up the bubble inside the nozzle. The bubble is heated and will expand rapidly to push the conductive ink eject from the nozzle (Cummins and Desmulliez, 2012).

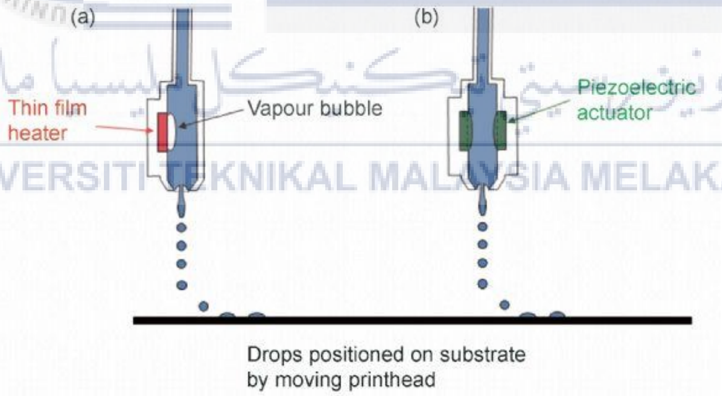

Figure 2.2: Thermal Ink-jet and Piezoelectrically Ink-jet technology.

2.4.2 Screen Printing

Screen printing is the process that using a stencil onto a substrate like paper or plastic and the conductive ink is apply on the stencil. Then, scrape the ink with the squeegee to force the ink form the printing picture same as the stencil (Lavigne and Marcq, 2014). This technique is low-cost, easy to use and fast process that suitable for mass production in industry. However, it can only print the image that follow the stencil and cannot keep changing the printing picture like ink-jet printing (Cao *et al.*, 2014).

Figure 2.3: Screen Printing Technique.

2.4.3 Gravure Printing

Gravure printing also known as rotary-screen-printing. It contains 4 components in the printing process which is engrave cylinder, ink fountain, doctor blade, and impression roller. The substrates is pass through the engrave cylinder and the impression roller. The conductive ink is printed on the substrates follow the printing pattern of the engrave cylinder and the excess ink will be wiped by the doctor blade (Hrehorova *et al.*, 2011). This printing process is a high-speed process and can produce a fine conductive line with 4-7 µm thick. However, the cost of the cylinder is high and it not suitable for shot runs (Pudas *et al.*, 2005).

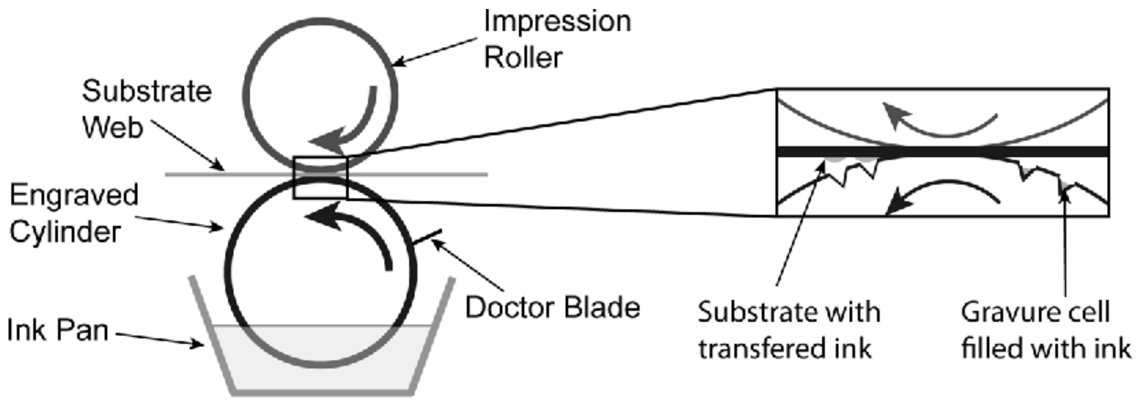

Figure 2.4: Gravure printing process.

Table 2.2: Comparison between different type of printing method.

Specification / Type	Accuracy	Ability to change the printing shape	Cost	Processability
Ink-jet Printing	High	Good	High	Good
Screen Printing	Medium	Good	Low	Good
Gravure Printing	High	Poor (fixed mold)	High	Poor

2.5 Curing Process of Conductive Ink

Curing process is an important process to toughening or hardening the conductive ink. During this process, the polymer chain will be cross-link and the unwanted water particle inside the conductive ink will be evaporated. Hence, the conductive ink will become dry and hard after curing process. Curing process will been done after the conductive ink was printed on the substrates. There are many types of curing process such as curing oven, laser, ultraviolet (UV) radiation, and electron beam (Khairilhijra *et al.*, 2017). There are few elements need to be monitored during curing process which is substrate temperature, curing temperature and curing time. These few elements must be managed properly so that the conductive ink can be cure perfectly (Whitford, 2017).

2.5.1 Type of Curing Process

The different type of curing process will bring different effect to the conductive ink. Below show the 4 type of curing process of conductive ink which are curing oven, laser, ultraviolet (UV) radiation and electron beam.

2.5.1.1 Oven

Curing oven is most commonly used to cure the conductive ink compared with other type of the curing machine. Curing is easy to control and used, it just needs to adjust the temperature, fan speed, and the timer. The curing temperature is depending on the suitable curing temperature of the conductive ink and the melting point of the substrates. This need to be control by the operator to prevent substrates from melting and perfect cure of the conductive ink. The curing time of the curing process is between 25 to 35 minutes to make sure the cross-link of the polymer chain. The fan speed can be adjusted by the operator to control the air flow inside the curing oven and the temperature can apply evenly on the conductive ink (Kenneth N. Kraft, 2018).

Figure 2.5: Curing oven.

2.5.1.2 Laser

Laser curing is the machine that used the laser beam that generate by the laser diode source to transfer the heat energy to the conductive ink so that the unnecessary solvent can be removed (Lopes *et al.*, 2014). Laser curing is suitable for some substrates with lower melting point. Other type of curing process may damage the substrate with high temperature, but laser curing can control the direction of the laser beam and heats the specific area so that it can cure the conductive ink without damage the substrate. Laser curing process can prevent the excess heat energy apply on the substrates and affect the properties of the substrates (Wei *et al.*, 2015).

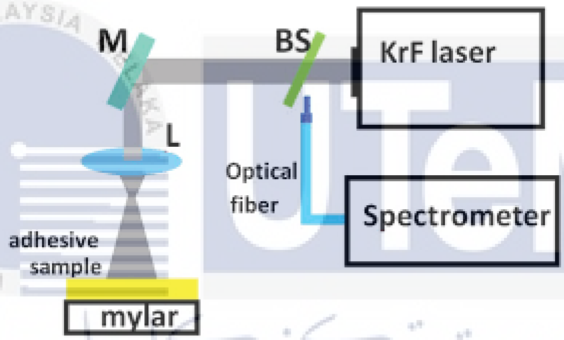

Figure 2.6: Laser curing process.

2.5.1.3 Ultraviolet (UV) radiation

Ultraviolet (UV) radiation curing process is usually used in industrial application due to its unique advantage (Decker, 2002). Ultraviolet radiation curing used shorter time compare with other type of curing process. Other type of curing process may used 30 minutes to cure the product but ultraviolet radiation curing just used few minutes to cure the product which mean this type of curing reduced the time cycle significantly (Endruweit, Johnson and Long, 2006). The ultraviolet radiation can by generate by different sources such as mercury arc lamps. Different type of radiation sources has different curing ability. So the radiation source should choose carefully to cure the product perfectly (Decker *et al.*, 2005).

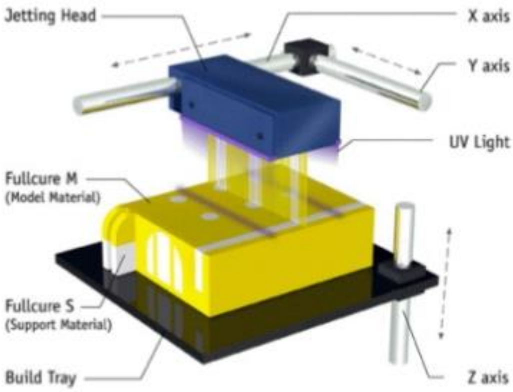

Figure 2.7: Ultraviolet (UV) radiation curing process.

2.5.1.4 Electron Beam

Electron beam (EB) curing process also called as X-ray curing process. The advantage of this process is there are no limit on composite thickness. Electron beam curing process can cure a composite that more than 40 mm. Compare with thermal curing process, this curing process is more effective when curing the thicker composite (Guasti and Rosi, 1997). Moreover, electron beam curing process does not cure with oxidation process. So, the conductive ink with metal based such as copper based conductive ink does not form an oxide layer on the surface and affect its conductivity (Epstein, 2018). Besides, electron beam can cure the composite with ambient temperature and reduce the time to cure the composite (Berejka and Eberle, 2009).

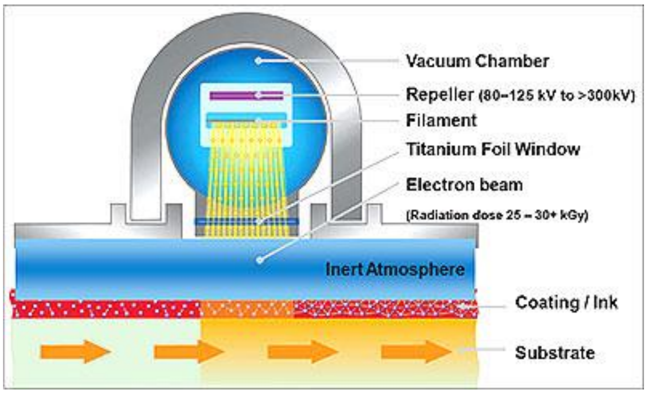

Figure 2.8: Electron beam curing process.

Table 2.3: Comparison between different type of curing process.

Specification / Type	Accuracy on curing conductive ink.	Curing speed	Cost	Penetrability	Substrate damageable
Oven	Poor	Slow	Low	Poor	Yes
Laser	High	Medium	High	Poor	No
Ultraviolet (UV) radiation	Medium	Fast	High	Medium	Yes
Electron Beam	Medium	Medium	High	Good	Yes

2.6 Substrate

Substrate is an important material for conductive ink. Conductive ink needs to be printed on the substrate so that it can connect the electric circuit. Therefore, substrate is act as a base for conductive ink. There are few types of substrates that are suitable to print the conductive ink which are thermoplastic polyurethane (TPU), polyethylene terephthalate (PET), polyethylene napthalate (PEN), and paper (Merilampi, Laine-Ma and Ruuskanen, 2009).

2.6.1 Thermoplastic Polyurethane (TPU)

Thermoplastic polyurethane (TPU) thin film is act as a substrate for printing conductive ink. Thermoplastic polyurethane (TPU) are one of the class of thermoplastic elastomers (Segal and Narkis, 2002). They are elastic, transparent and resist to abrasion. Thermoplastic polyurethane (TPU) are widely used in electronic application due to its flexibility and biostability. They does not have any reaction with the composites so that the properties of composites will not be affected (Feng and Ye, 2011). Besides, thermoplastic polyurethane (TPU) cannot withstand very high temperature. Its melting point are in the range of 190°C to 220°C and it start to deform between 140°C to 160°C. The maximum elongation of thermoplastic polyurethane (TPU) is 300% to 550% (Keywords *et al.*, 2018)

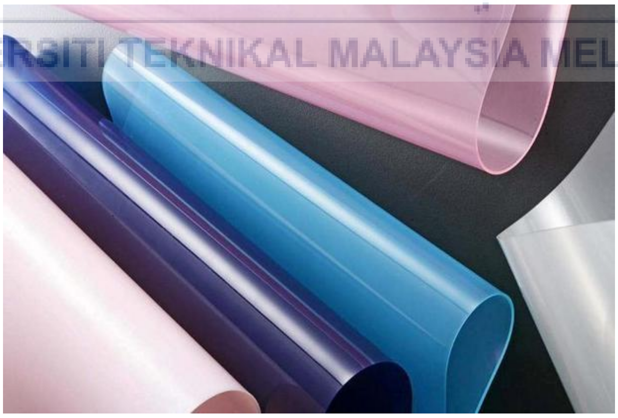

Figure 2.9: Example of thermoplastic polyurethane (TPU) thin film.

2.6.2 Polyethylene Terephthalate (PET)

Polyethylene terephthalate (PET) is a member of polyester and it is widely use for electronic application due to its special characteristics. Polyethylene terephthalate (PET) have high strength which can resist to impact and called as solid-state crystallization (Kim, Jeong and Moon, no date). Polyethylene terephthalate (PET) is a recyclable plastic and listed as type 1 plastic. Its melting point is above 250°C and its working temperature is in the range of 115°C to 170°C to prevent the deformation of polyethylene terephthalate (PET). The maximum elongation of polyethylene terephthalate (PET) is 40% of its original length (Rockwell, no date).

Figure 2.10: Example of polyethylene terephthalate (PET) thin film.

2.6.3 Polyethylene Napthalate (PEN)

Polyethylene napthalate (PEN) is grouped in polyester. Polyethylene napthalate (PEN) have good dimensional stability which will not react with other composites. Polyethylene napthalate (PEN) will start to deform at 190°C and its working temperature usually at the range of 100°C to 150°C. Its maximum elongation is 60% of its initial length (Macdonald *et al.*, 2004). Its has a melting point with 270°C and higher barrier property than other type of substrates (Bedia *et al.*, 2001).

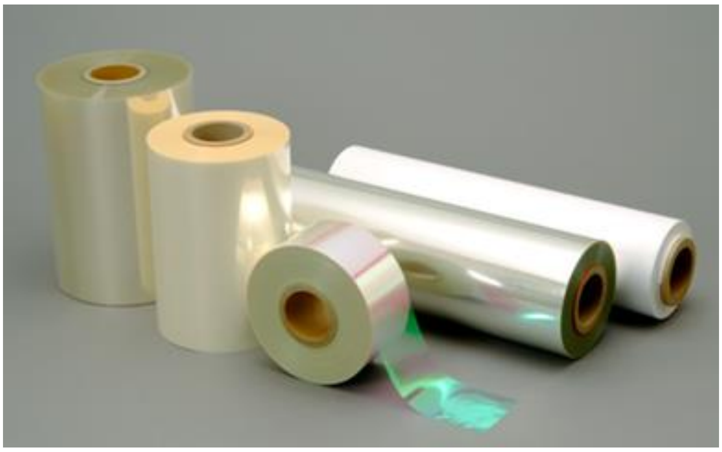

Figure 2.11: Example of polyethylene napthalate (PEN) thin film.

2.6.4 Paper

There are 3 type of paper used to print the conductive ink on the surface which are coated, uncoated and recycle paper. Paper substrate is the lowest cost for printing conductive ink compare with other type of substrates. Although paper have lower cost, but it cannot withstand with high temperature. It has maximum elongation less than 5% of it initial strength. Conductive ink which printed on paper have a shorter curing time because paper will absorb the unnecessary solvent in the conductive ink (Jerić, Bratić and Svilar, 2015).

Figure 2.12: Example of paper.

Table 2.4: Comparison between different type of substrate.

Specification / Type	Melting point (°C)	Working temperature (°C)	Maximum elongation (%)	Stretchability
Thermoplastic Polyurethane (TPU)	190-220	100-120	300-550	Good
Polyethylene Terephthalate (PET)	250	115-170	40	Poor
Polyethylene Napthalate (PEN)	270	100-150	60	Medium
Paper	-	-	5	Poor

2.7 Method to Measure the Electrical Conductivity

Electrical conductivity is the measurement of the total electricity that can pass through the material. There have numerous ways to measure the electrical conductivity but only few type of equipment are suitable to measure the electrical conductivity of conductive ink which are 4-point probe and multi-meter.

2.7.1 Four-point Probe

Four-point probe also called as four-terminal sensing used to measure the resistivity of the material especially for the bulk or thin film specimen. Four-point probe can get the accurate result on those specimens compare with other equipment. The design of four-point probe is used four tungsten metal tips and arrange in a row. The two outer tungsten metal tips is supply by current and two inner tungsten metal tips is supply by current. To reduce the damage on tips when probing, the spring is added on every tips so that the tips are extensible and reduce the impact of probing. (Correction, Measurements and Engineering, 2018) Four-point probe will touch the sample and the resistivity will be shown on the screen. After we get the resistivity of the sample, we can calculate the conductivity with the formula V=IR where V is the conductivity or the voltage of the sample, I is the current used in the four-point probe, and R is the resistivity that we get from four-point probe. (Smits, no date)

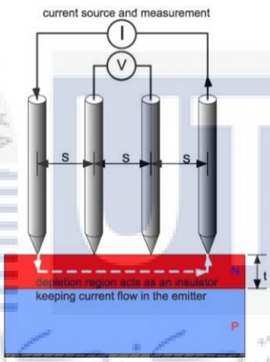

Figure 2.13: Concept of four-point probe.

Figure 2.14: Example of four-point probe.

2.7.2 Multi-meter

Multi-meter also known as volt-ohm meter. Its are widely used in many aspect due to its flexibility. Its can measure voltage, resistance, current and other values. Multi-meter bring lot of convenient to people to do testing at anytime and everywhere.(Is, 2018) Multi-meter contain 3 main part which are display, selection knob, and ports. Display will show the digits that represent the result of the measurement. The selection knob allow the user to change the mode of multi-meter to do different testing such as voltage, current and resistance testing. The ports are connected to two probes which have positive and negative sign. The probes will touch the components and do the testing. Hence, the result will shown on the display of multi-meter.(Learn and Support, 2018)

Figure 2.15: Example of multi-meter.

Table 2.5: Comparison between 2 types of electrical measurement tool.

Specification / Type	Unit	Range
4 point probe	Ohm/square	3 mΩ/sq to 10 MΩ/sq
Multi-meter	Ohm	1Ω to 20kΩ

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter is described about the methods and procedures involved in this project, which include the preparation of conductive ink and the type of testing. The methodology is summarized in Figure 3.1 which shows the flow chart of the experiment in this research project. The activity and procedures that carry out during this final year project are summarized as below:

i. Print the bare conductive ink on Thermoplastic polyurethane (TPU) by using hand printing or screen printing.
ii. Put the bare conductive ink into oven for curing process.
iii. Test the resistivity by using 4-point probe and calculate the conductivity by using formula.
iv. Test the resistivity by using different elongation of the bare conductive ink.
v. Observe the microstructure of different elongation and test it hardness.
vi. Data collection and analysis.

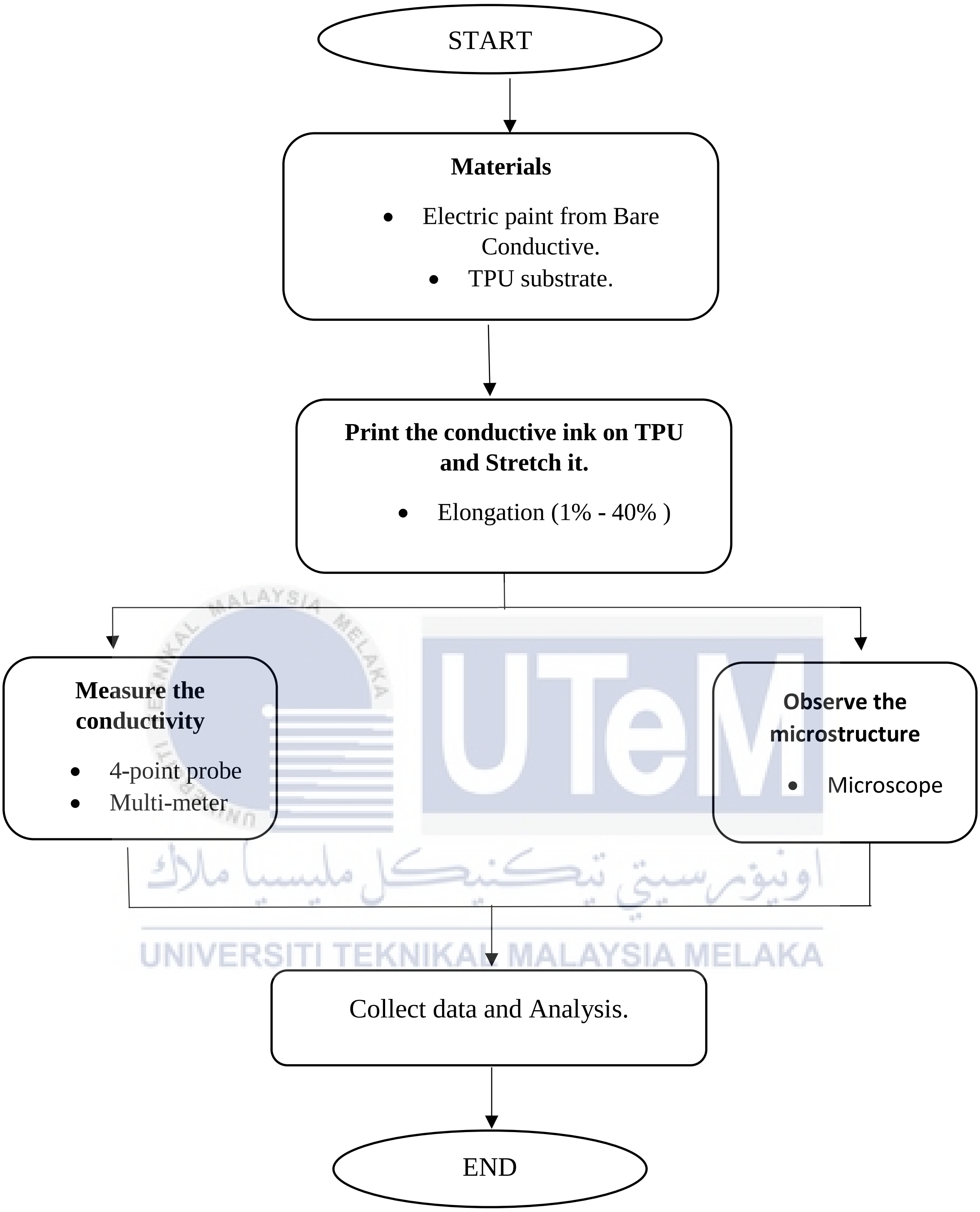

Figure 3.1: The Flow Chart of the Methodology.

3.2 Material Used in This Experiment

That are two main materials will be used in this experiment which is bare conductive ink and thermoplastic polyurethane (TPU). Bare conductive is the material we need to determine its conductivity under tensile stress. Meanwhile, Thermoplastic Polyurethane (TPU) is a substrate for the bare conductive ink to print on its surface.

3.2.1 Bare Conductive Ink

Bare conductive ink is the type of conductive ink that choose to use in this experiment. The material contain in this ink is water, natural resin, conductive carbon, humectant, and preservatives.(bareconductive, 2017) Among all the material, conductive carbon is the most important material that used to carry the electron to pass through the conductive ink. Carbon is very good in conduct electricity and it has a low resistance. When the conductive carbon is used in conductive ink, that are more suitable that using silver and copper as the material because it will not under oxidation when expose to surrounding and has a lower cost (Pantea *et al.*, 2003).

The maximum voltage apply on bare conductive ink is 12V in direct current. The curing process for this conductive ink is 15 minutes with room temperature, but it also cures by thermal curing process so that the unnecessary solvent can be removed thoroughly and make sure it has good conductivity after curing process. This conductive are self-adhesive and it can will adheres to metal, paper, plastic, and wood surface. The substrate that I choose is thermoplastic polyurethane (TPU) and the bare conductive ink are suitable to be printed on its surface.

Figure 3.2: Example of Bare Conductive Ink.

3.2.2 Thermoplastic Polyurethane (TPU)

The reason to choose thermoplastic polyurethane (TPU) as the substrate in this experiment is thermoplastic polyurethane (TPU) is strong and high stretchability. Based on previous study, the maximum elongation of the thermoplastic polyurethane (TPU) is 300% to 550% and its melting point is in the range of 190°C to 220°C. This suitable for this experiment and can be cure in the curing oven with printed bare conductive ink on its surface.

3.3 Experiment Setup

Before carry out my experiment, all the material are well prepare and book AMCHAL laboratory to conduct my experiment smoothly.

3.3.1 Screen printing

The printing technique that choose to print the bare conductive ink on the substrate is screen printing because screen printing is an easiest way for me to print the bare conductive ink on thermoplastic polyurethane (TPU). It does not need any machine and it only required the bare conductive ink, scraper and stencil. First, need to prepare a piece of thermoplastic polyurethane (TPU) and draw the dimension of the conductive ink that I need to print later.

Then, apply the scotch tape on the outside of the dimension to make sure the bare conductive ink can follow the dimension when printing. After that, use the razor blade as scraper to scrape the ink to force the ink print on the thermoplastic polyurethane (TPU) by following the dimension. Lastly, remove the scotch tape and it will get the conductive line on the thermoplastic polyurethane (TPU).

Figure 3.3: Razor blade that act as scraper.

Figure 3.4: Draw the dimension on thermoplastic polyurethane (TPU).

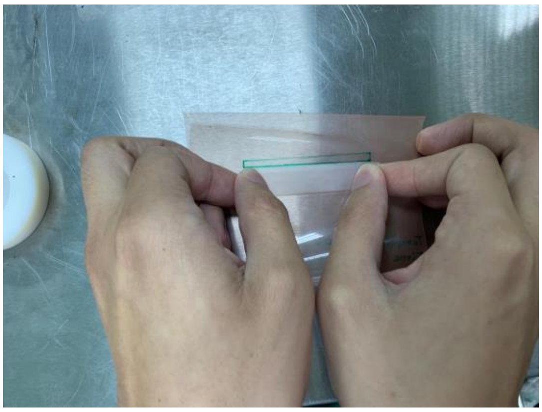

Figure 3.5: Apply scotch tape on thermoplastic polyurethane (TPU).

Figure 3.6: Print the bare conductive ink by using screen printing technique.

Figure 3.7: Remove the scotch tape after screen printing.

3.3.2 Curing process

Curing process is an important process to dry the conductive ink so that the bare conductive ink can adhere on the thermoplastic polyurethane (TPU). During the curing process, put the thermoplastic polyurethane (TPU) with conductive line into oven and set the temperature at 120°C to prevent thermoplastic polyurethane (TPU) from melting or deforming. After 30 minutes, I take out the product and conductive is well prepared.

Figure 3.8: Example of oven for curing process.

3.4 Process of Experiment

In this experiment, the bare conductive ink is stretch with certain elongation. Then, test the conductivity with four-point probe, check the hardness by using micro hardeners and observe the microstructure of the bare conductive ink with microscope. Lastly, record the result of the experiment.

3.4.1 Stretching Tool

It will need to fabricate a small stretching tool that are portable and easy to set up to stretch the bare conductive ink during the experiment. The bare conductive ink needs to be claim on this tool and stretch with certain elongation. The concept of the stretching tool is shown as below:

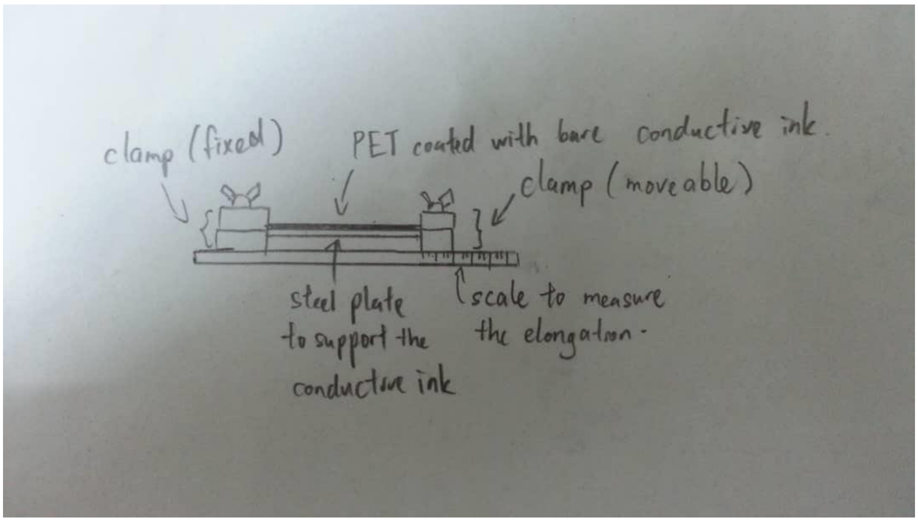

Figure 3.9: Concept of Stretching Tool.

Figure 3.9 is the basic idea of the stretching equipment and sketch by hand. The conductive are printed on the substrate and the substrate are claimed on the both claim so that it can be pull and stretching. One of the claim is fixed and another are moveable, adjust the moveable claim to stretch the conductive ink.

3.4.1.1 Design of stretching equipment

With the basic idea of stretching equipment, 2 type of stretching equipment is design in software ‘Solidwork’ with details such as dimension, mechanism and material used of the stretching equipment. There are 2 types of mechanism are used to design the stretching equipment. First is rolling mechanism, the conductive ink is printed on the substrate and the substrate are claim on the roller. By turning the roller to pull and stretch the substrate and conductive ink. Second mechanism are same as the basic idea which is pulling mechanism. The substrate are claimed on both claim and move the claim to stretch the conductive ink.

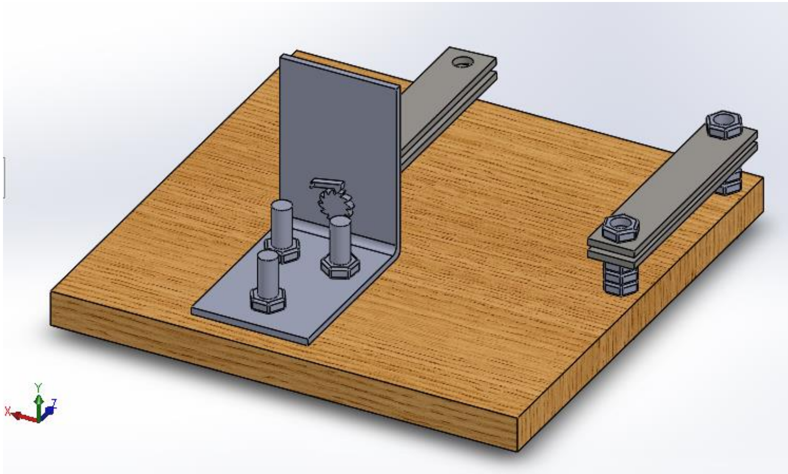

Figure 3.10: Roller type of stretching equipment.

Figure 3.10 shown the design of stretching tool, there have 2 claims at each side of the stretching tool. One of the claims is fixed and the other claim can be turn. When the thermoplastic polyurethane (TPU) with conductive ink is claimed on both claims. Turn the flexible claim to stretch the thermoplastic polyurethane (TPU). A mechanical lock is at the end of the shaft to prevent the flexible claim turning back. This stretching tool is small and portable.

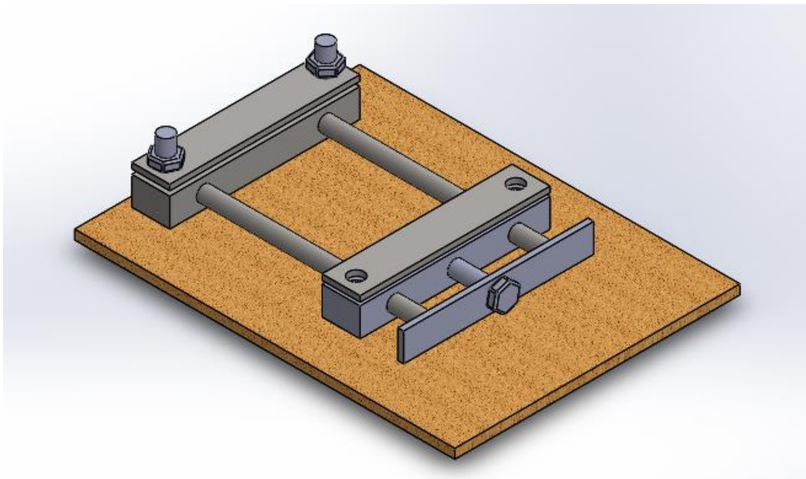

Figure 3.11: Pulling type of stretching equipment.

Figure 3.11 is the design that using pulling mechanism. There are 2 claim on this equipment, one is fixed and another is moveable. The moveable claim is connect with a turning shaft with spiral thread. When the shaft is turning the claim will move toward the side of the equipment hence the thermoplastic polyurethane (TPU) will be stretch. In this design, we can control the elongation more accurately due the spiral thread of the turning shaft. So, this design will be fabricate in future study.

3.4.2 Four-point probe

After stretching with certain elongation, take the bare conductive ink and measure its resistivity by using four-point probe. When get the resistivity (R), use the formula to calculate its conductivity (V). The formula that I use is shown as below:

V = IR

V is the conductivity of the element.

I is the current used in four-point probe.

R is the resistivity of the element.

Figure 3.12: Four-point Probe.

When using four-point probe to test the resistivity, make sure the sample are flat and print uniformly on thermoplastic polyurethane (TPU) so that four-point probe can have the contact with each point of the surface and more accurate result can be record. Besides, the current used in four-point probe can affect the reading shown on the display of four-point probe. The current source should be adjusted to maximum to test the very low resistivity material. The ideal current source is 10nA because the of the heating effects and excessive current density at the tips of four-point probe. On the other hand, use low current source when testing the high resistivity material to prevent the voltage is greater than 200mV. Moreover, unsmooth or unclean surface will affect the accuracy of four-point probe.

3.4.3 Microscope

Lastly, observe the microstructure of the bare conductive ink under stretching condition to find out there have any cracking or deformation inside the conductive line. The microscope can observe 10 micrometres of the surface structure. The microscope is connected with the computer. Hence, the result that observe from the microscope will be shown on the screen and save the data or picture of the microstructure of bare conductive ink.

Figure 3.13: Example of microscope.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, the preliminary result of the experiment such as the resistivity of the stretchable conductive ink, the microstructure of the conductive ink and the different curing time and temperature for conductive on substrates will be discussed. In this experiment, the different curing temperature have been used to determine the best curing temperature for the conductive ink. Besides, there are 2 different curing time are used in this experiment which are 15 minutes and 30 minutes to determine the suitable curing time for the conductive ink.

4.2 Stretching equipment

Stretching equipment is important in this experiment. Thermoplastic polyurethane (TPU) that printed with conductive ink need to be stretch with this stretching equipment. The conductive ink need to be test while stretching hence the stretching equipment need to be remain stationary after stretch with certain elongation.

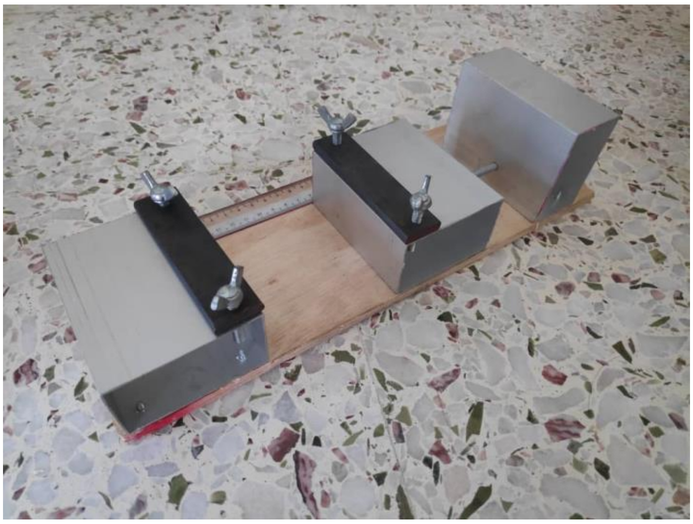

Figure 4.1: Stretching equipment.

Figure 4.2 show the stretching equipment that had been fabricated by follow the design in software 'solidwork'. There are 2 claim in this stretching equipment. The claim on left side are fixed and right side of the claim are connected with a thread screw which will moved when turning the screw. The black colour claims claimed the thermoplastic polyurethane (TPU) by tighting the screw on the claims to prevent slipping of thermoplastic polyurethane (TPU). A ruler is added at the side of stretching equipment to measure the elongation of the thermoplastic polyurethane (TPU) while stretching. This stretching equipment can stretch the substrate with a maximum 60 mm elongation and the dimension of this stretching equipment is 32 cm length and 12 cm width.

4.3 Preliminary result

4.3.1 Relationship Between Resistivity and Different Curing Temperature

To test the effect of different temperature to the conductive ink, I had used 4 different temperatures which are 100°C, 120°C, 140°C, and 160°C. The bare conductive ink are printed on the glass slide because the glass slide have higher melting point than thermoplastic polyurethane (TPU) which will not melt easily at high temperature. After printing process, conductive ink had cured by the different temperature by 30 minutes. Then, the resistivity had been measured by using four-point probe. Lastly, the result had been recorded and compare with each other. Table below show the resistivity of conductive ink under different curing temperature.

Table 4.1: Resistance of conductive ink under different curing temperature.

Temperature	Resistance (R/sq)				
	Point 1	Point 2	Point 3	Point 4	Average
100	407.92	498.56	407.92	453.25	441.91
120	362.59	362.59	317.27	362.59	351.26
140	362.59	317.27	362.59	362.59	351.26
160	226.62	226.62	271.94	226.62	237.59

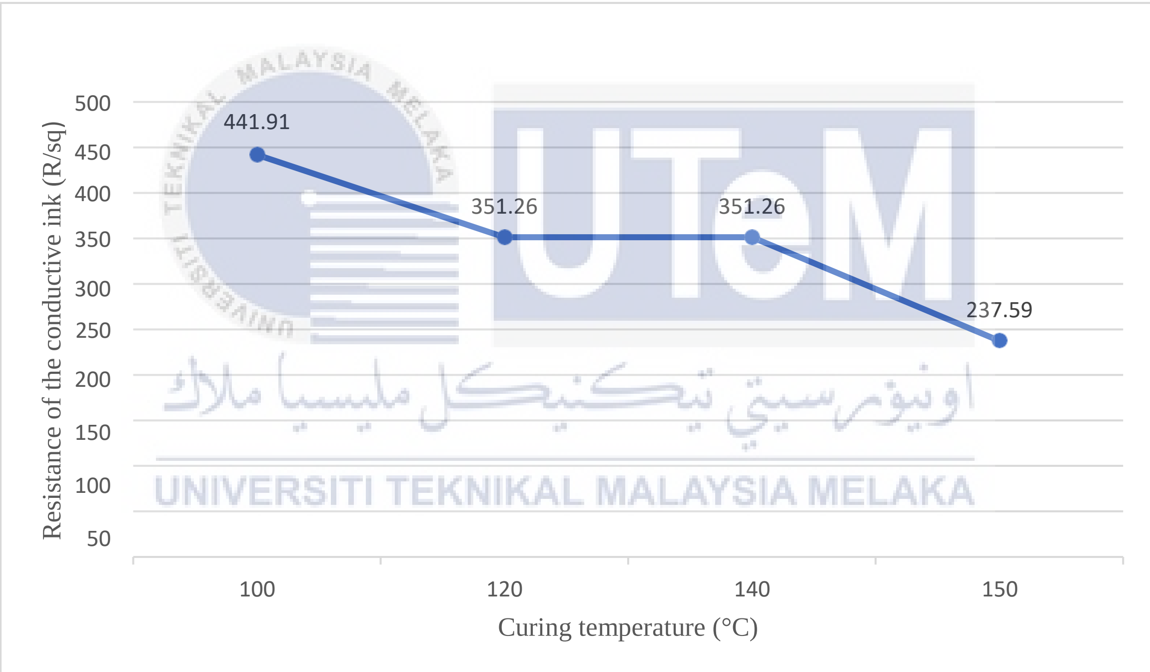

Figure 4.2: Graph of resistivity against curing temperature.

4.3.2 Discussion on Relationship of Resistivity of Conductive Ink and Curing Temperature

From table 4.1 and figure 4.1, the resistance of conductive will become lower when using higher curing temperature. This is because the unnecessary solvent inside conductive ink evaporate more at higher curing temperature and the cross-linking of the polymer strain was increased. Hence, the resistance will be decreased and the conductivity will be increased. Form the result above, conductive ink should be cure in 160°C so that it has better conductivity but thermoplastic polyurethane (TPU) will deform at 160°C.To avoid the deformation of thermoplastic polyurethane (TPU) and change it properties and elasticity, the future experiment will use 120°C for curing temperature of stretchable conductive ink.

4.4 Conductive ink with different length

To test the relationship between the conductivity and length of the conductive ink while stretching, I had printed different length of conductive ink on thermoplastic polyurethane (TPU) which are 40 mm, 60 mm and 80 mm. The width and thickness of the conductive ink are the same which are 5 mm and 0.2 mm. The conductive that already printed on on thermoplastic polyurethane (TPU) and cured with 120°C and 30 minutes inside the oven. Then, stretch the conductive ink with the stretching equipment and measure its resistivity by using 4 point probe and multi-meter. The data were collected and compared at below.

4.4.1 Conductive ink with 40mm length, 5mm width and 0.2mm thickness

4.4.1.1 Resistance of the Conductive Ink that measured with Multi-meter and Four-Point Probe

Table 4.2: Resistivity of conductive ink with 40mm length measure by multi-meter.

L=40mm, w=5mm, t=0.2mm						
Elongation		R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	R4 (kΩ)	Average (kΩ)
0%	0mm	0.573	0.536	0.550	0.589	0.562
2%	0.8mm	0.620	0.610	0.650	0.625	0.626
4%	1.6mm	0.614	0.634	0.675	0.630	0.638
6%	24mm	0.647	0.651	0.692	0.688	0.670
8%	3..2mm	0.698	0.705	0.694	0.698	0.699
10%	4mm	0.721	0.738	0.728	0.740	0.732
12%	4.8mm	0.778	0.792	0.810	0.823	0.801
14%	5.6mm	0.864	0.852	0.903	0.874	0.873
16%	6.4mm	1.115	1.178	1.269	1.160	1.181
18%	7.2mm	1.122	1.176	1.316	1.255	1.217
20%	8mm	0	0	0	0	0

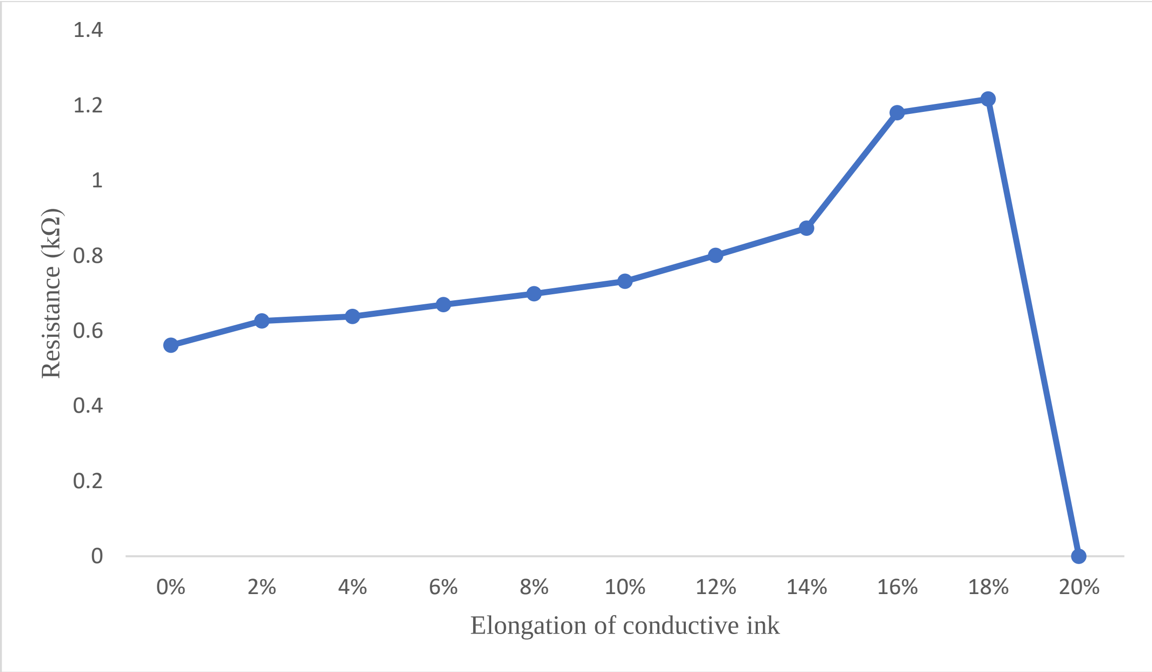

Figure 4.3: Graph of Resistivity against elongation of conductivity. (40mm length)

Table 4.3: Resistivity of conductive ink with 40mm length measured by 4-point probe.

L=40mm, w=5mm, t=0.2mm						
Elongation		R1(R/sq)	R2(R/sq)	R3(R/sq)	R4(R/sq)	Average (R/sq)
0%	0mm	453.24	453.24	906.48	1359.72	793.17
2%	0.8mm	1359.72	1359.72	1812.96	1359.72	1473.03
4%	1.6mm	1359.72	1359.72	1359.72	2266.20	1586.34
6%	24mm	2266.20	2266.20	1812.96	1359.72	1926.27
8%	3..2mm	2266.20	2266.20	2266.20	2266.20	2266.2
10%	4mm	2719.44	2719.44	2719.44	1812.96	2492.82
12%	4.8mm	2266.20	3172.68	2719.44	2719.44	2719.44
14%	5.6mm	1812.96	2266.20	2266.20	2719.44	2266.20
16%	6.4mm	2719.44	2266.20	2719.44	2266.20	2492.82
18%	7.2mm	3172.68	3172.68	3172.68	2719.44	3059.37
20%	8mm	2719.44	2266.20	2266.20	1812.96	2266.20

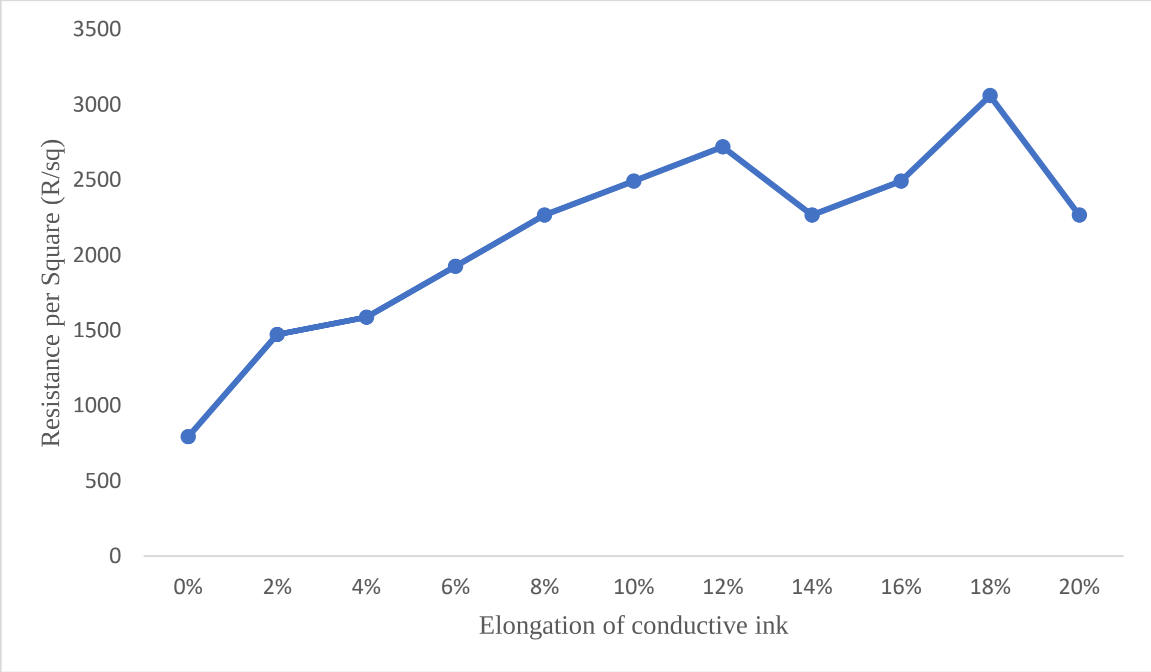

Figure 4.4: Graph of Resistance per square against elongation of conductivity. (40mm length)

4.4.1.2 Discussion on Relationship between Resistance of Conductive Ink and its Elongation (40mm length)

The data above shown that resistance of conductive ink that measure with multi-meter and 4-point probe at different elongation. According data from table 4.2, the resistance of the conductive ink is increase with the elongation. That mean when the conductive ink has lower conductivity when it is stretching. The cross-sectional area of the conductive ink is decrease hence the resistance of the conductive ink is increased. From Figure 4.3, we can see that the resistance of the conductive ink is increase significantly with elongation of 14% of its total length which is 0.56mm. This is because the conductive ink is started to crack when stretch with 0.56mm and cause the resistance increase significantly. The resistance is drop to 0 when stretch with 20% of elongation because the conductive ink is broken and can be observe with our eyes.

From figure 4.4, the reading from 4-point probe shown that the resistance per square of the conductive ink is drop when the conductive ink is stretch with 14% and 20% of its elongation. This is because the conductive ink started to crack at 14% of elongation and broken at 20% of elongation. When the conductive ink is crack, the crack part will become thicker due to the relaxing of the conductive ink. In other hand, the conductive ink in others part which does not have any crack are remain stretching. This cause the cracking part of the conductive ink per unit square have less resistance and the average resistance per square of the conductive ink decrease.

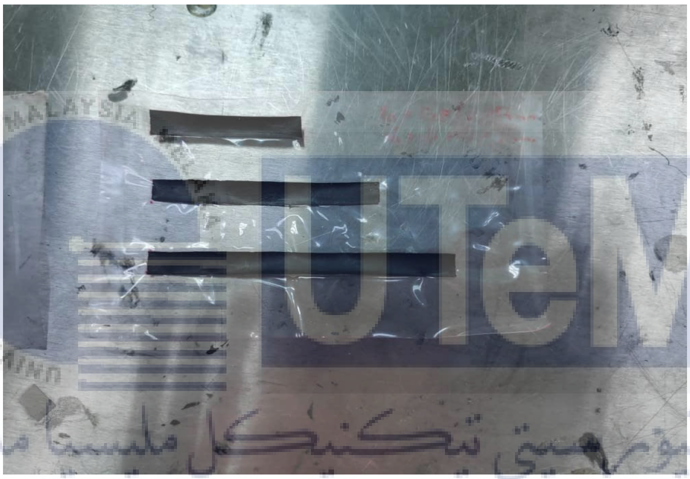

Figure 4.5: conductive ink with length of 40mm (top), 60mm (middle) and 80mm (bottom) before stretching.

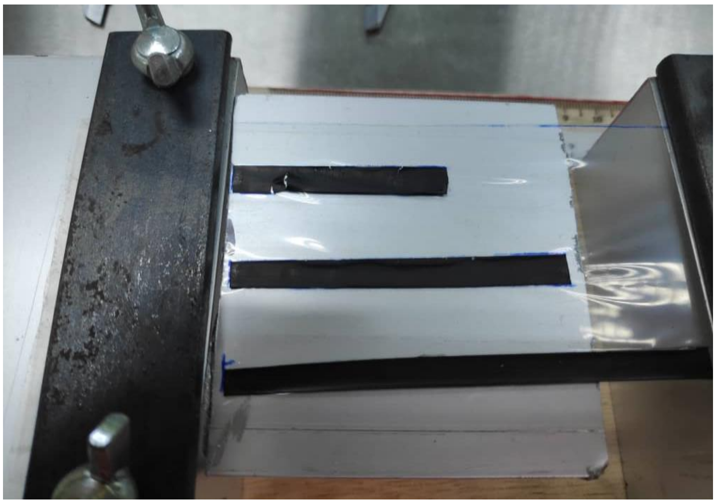

Figure 4.6: Conductive ink with 40mm length (top) is started to crack when stretch with 14% (5.6mm) of elongation.

Figure 4.7: Conductive ink with 40mm length (top) is broken when stretch with 20% (8mm) of elongation.

4.4.1.3 The microstructure of the conductive ink under microscope.

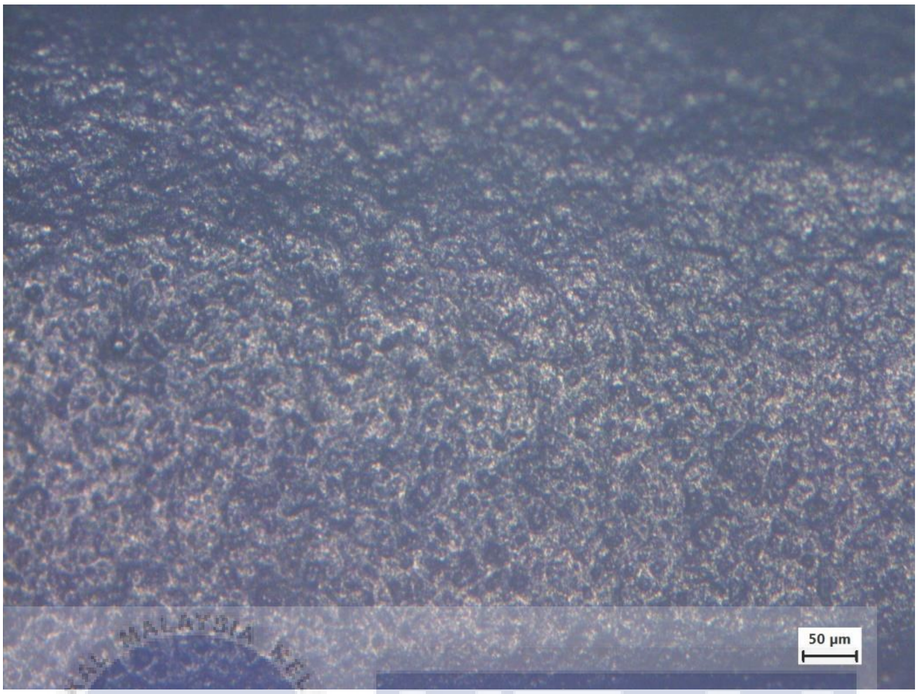

Figure 4.8: The microstructure of conductive ink (40mm length) before stretching.

Figure 4.9: The microstructure of conductive ink (40mm length) after stretching.

Figure 4.8 and 4.9 show the microstructure of the conductive ink before and after stretching. The microstructure of the conductive ink is smooth and does not have any imperfection at initial state. After stretching, there are lot of porosity on the surface of the conductive ink because of the deformation of conductive ink when stretching. Moreover, there are a crack on the middle of the conductive ink which represent the broken part of the conductive ink. All of the imperfections are affecting the conductivity of conductive ink.

4.4.2 Conductive ink with 60mm length, 5mm width and 0.2mm thickness

4.4.2.1 Resistance of the Conductive Ink that measured with Multi-meter and Four-Point Probe

Table 4.4: Resistivity of conductive ink with 60mm length measure by multi-meter.

L=60mm, w=5mm, t=0.2mm						
Elongation		R1 (kΩ)	R2 (kΩ)	R3 (kΩ)	R4 (kΩ)	Average (kΩ)
0%	0mm	0.939	0.990	0.996	0.991	0.979
2%	1.2mm	1.081	1.052	1.079	1.077	1.072
4%	2.4mm	1.100	1.094	1.117	1.093	1.101
6%	3.6mm	1.178	1.169	1.186	1.217	1.188
8%	4.8mm	1.290	1.261	1.321	1.323	1.299
10%	6mm	1.295	1.357	1.374	1.365	1.348
12%	7.2mm	1.326	1.305	1.424	1.396	1.363
14%	8.4mm	1.293	1.410	1.417	1.416	1.384
16%	9.6mm	1.444	1.363	1.475	1.434	1.429
18%	10.8mm	1.429	1.462	1.459	1.404	1.439
20%	12mm	1.562	1.428	1.481	1.494	1.491
22%	13.2mm	1.458	1.461	1.545	1.538	1.501
24%	14.4mm	1.468	1.522	1.553	1.497	1.510
26%	18.6mm	1.560	1.576	1.580	1.504	1.555
28%	16.8mm	1.807	1.838	1.870	1.829	1.836

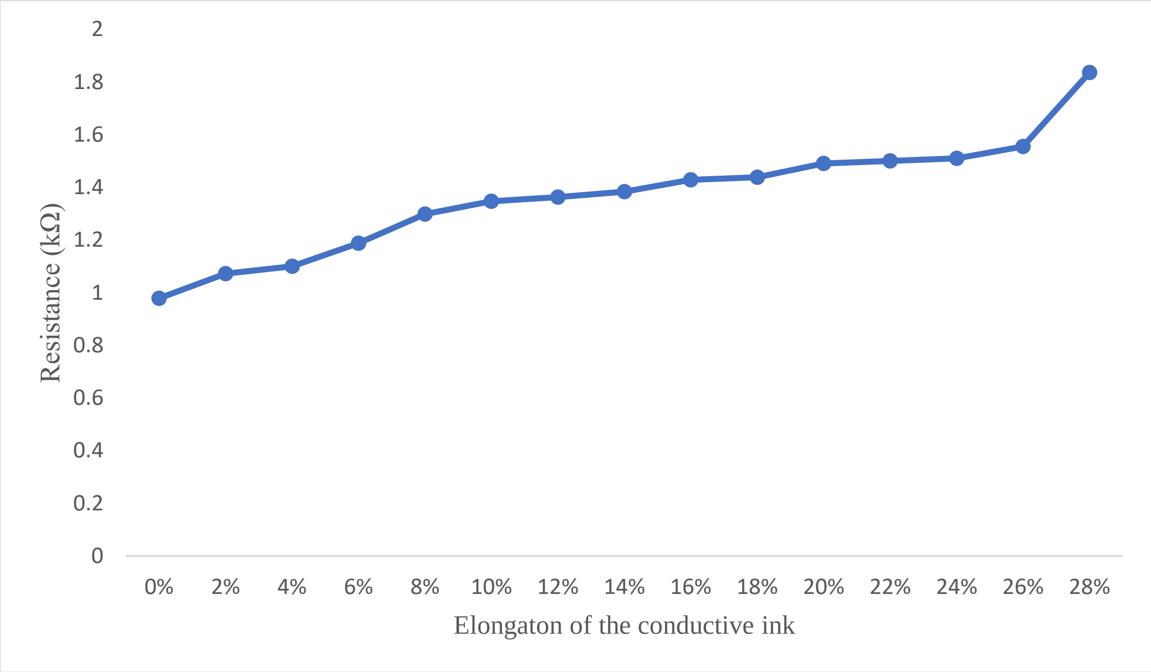

Figure 4.10: Graph of Resistivity against elongation of conductivity. (60mm length)

Table 4.5: Resistivity of conductive ink with 60mm length measured by 4-point probe.

L=60mm, w=5mm, t=0.2mm						
Elongation		R1(R/sq)	R2(R/sq)	R3(R/sq)	R4(R/sq)	Average (kΩ)
0%	0mm	906.48	906.48	906.48	453.24	793.17
2%	1.2mm	906.48	906.48	1359.72	1359.72	1133.1
4%	2.4mm	1812.96	1812.96	1812.96	1812.96	1812.96
6%	3.6mm	1812.96	2266.20	1812.96	2266.20	2039.58
8%	4.8mm	2266.20	2266.20	1812.96	1812.96	2039.58
10%	6mm	1812.96	2266.20	2266.20	2266.20	2152.89
12%	7.2mm	1812.96	2266.20	2266.20	2719.44	2266.20
14%	8.4mm	2266.20	2266.20	2719.44	2719.44	2492.82
16%	9.6mm	2266.20	2719.44	2266.20	2719.44	2492.82
18%	10.8mm	2719.44	2719.44	2719.44	2266.20	2606.13
20%	12mm	2719.44	2266.20	3172.68	2719.44	2719.44
22%	13.2mm	3172.68	3172.68	2719.44	3172.68	3059.37
24%	14.4mm	2266.20	3172.68	3172.68	4079.16	3172.68
26%	18.6mm	3172.68	3172.68	3172.68	4079.16	3399.30
28%	16.8mm	4079.16	3172.68	4079.16	3172.68	3625.92

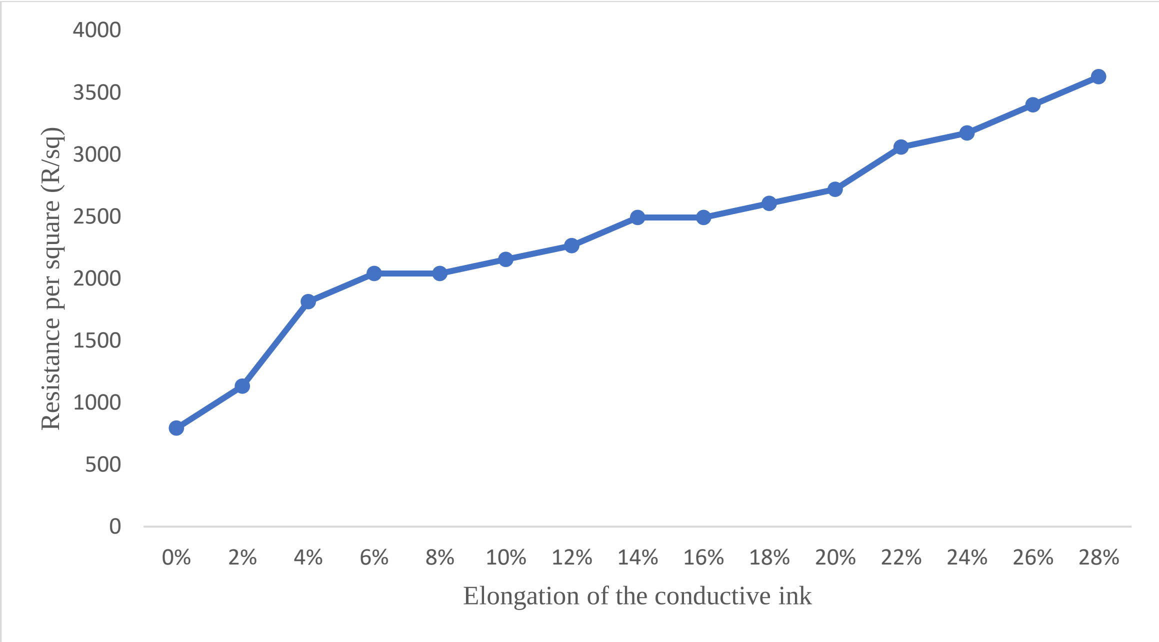

Figure 4.11: Graph of Resistance per square against elongation of conductivity. (60mm length)

4.4.2.2 Discussion on Relationship between Resistance of Conductive Ink and its Elongation (60mm length)

The data above show the relationship of resistivity of the conductive ink with length of 60mm and its elongation. From figure 4.10 and 4.11, we can see that the resistance of the conductive ink is increased steadily with its elongation. During the experiment, the conductive ink started to crack when it stretch with 16% of its total length which is 9.6mm. Although it started to crack but the imperfection does not like conductive ink with 40mm length that will affect the resistivity hence the resistivity does not increased significantly. 60mm length conductive ink stretch until 28% of its total length and still not broke. It only have some cracking at the side of conductive ink.

Figure 4.12: Conductive ink with length of 40mm (top), 60mm (middle) and 80mm (bottom) before stretching.

Figure 4.13: Conductive ink with 60mm length (middle) start to crack when stretch with 16% of its total length (9.6mm)

Figure 4.14: Crack of conductive ink with 60mm length (middle) when stretch with 28% of its total length.

4.4.2.3 The microstructure of the conductive ink under microscope.

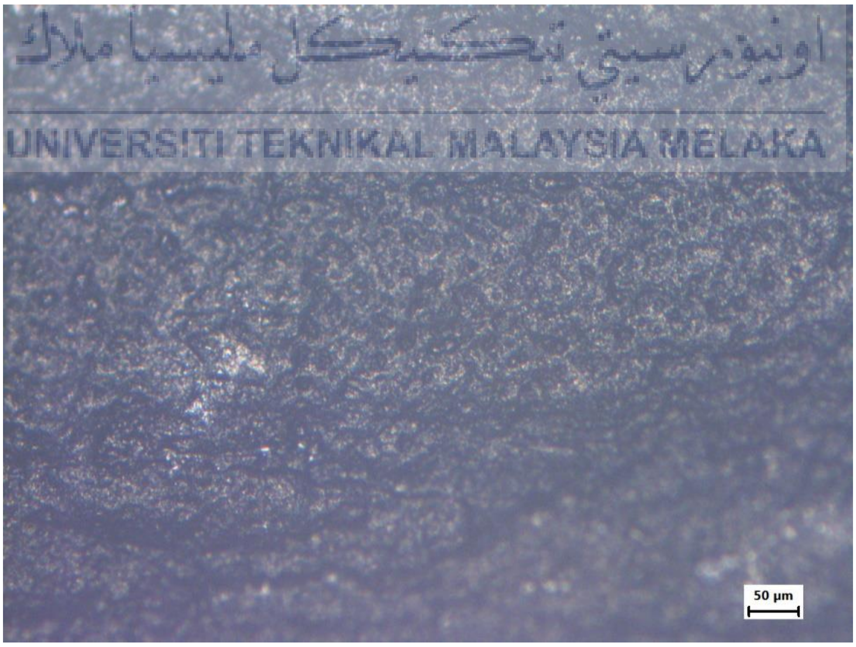

Figure 4.15: The microstructure of conductive ink (60mm length) before stretching.

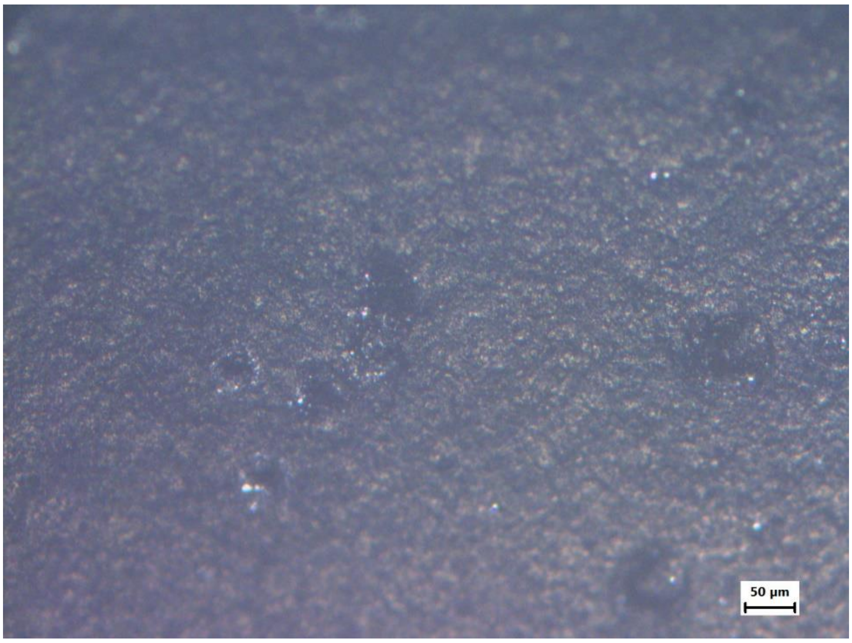

Figure 4.16: The microstructure of conductive ink (60mm length) after stretching.

The 60mm length of conductive ink is observed its microstructure before and after stretching. As we can see in figure 4.15, the surface of the conductive ink is smooth and does not have any imperfection before stretching. After stretching with 28% of its elongation, there have some porosity on the surface of the conductive ink. This cause the resistance of the conductive increased.

4.4.3 Conductive ink with 80mm length, 5mm width and 0.2mm thickness

4.4.3.1 Resistance of the Conductive Ink that measured with Multi-meter and Four-Point Probe

Table 4.6: Resistivity of conductive ink with 80mm length measure by multi-meter.

L=80mm, w=5mm, t=0.2mm						
Elongation		R1(kΩ)	R2(kΩ)	R3(kΩ)	R4(kΩ)	Average (kΩ)
0%	0mm	1.031	1.080	1.079	1.040	1.058
2%	1.6mm	1.168	1.144	1.135	1.119	1.142
4%	3.2mm	1.184	1.194	1.192	1.166	1.184
6%	4.8mm	1.287	1.323	1.306	1.315	1.308
8%	6.4mm	1.317	1.326	1.329	1.330	1.326
10%	8mm	1.315	1.416	1.390	1.339	1.365
12%	9.6mm	1.385	1.399	1.405	1.410	1.400
14%	11.2mm	1.408	1.413	1.395	1.410	1.407
16%	12.8mm	1.432	1.421	1.426	1.411	1.423
18%	14.4mm	1.482	1.478	1.468	1.462	1.473
20%	16.0mm	1.507	1.468	1.491	1.488	1.489
22%	17.6mm	1.510	1.532	1.487	1.501	1.508
24%	19.2mm	1.562	1.584	1.499	1.525	1.543
26%	20.8mm	1.599	1.569	1.578	1.600	1.587
28%	22.4mm	1.601	1.631	1.640	1.589	1.615

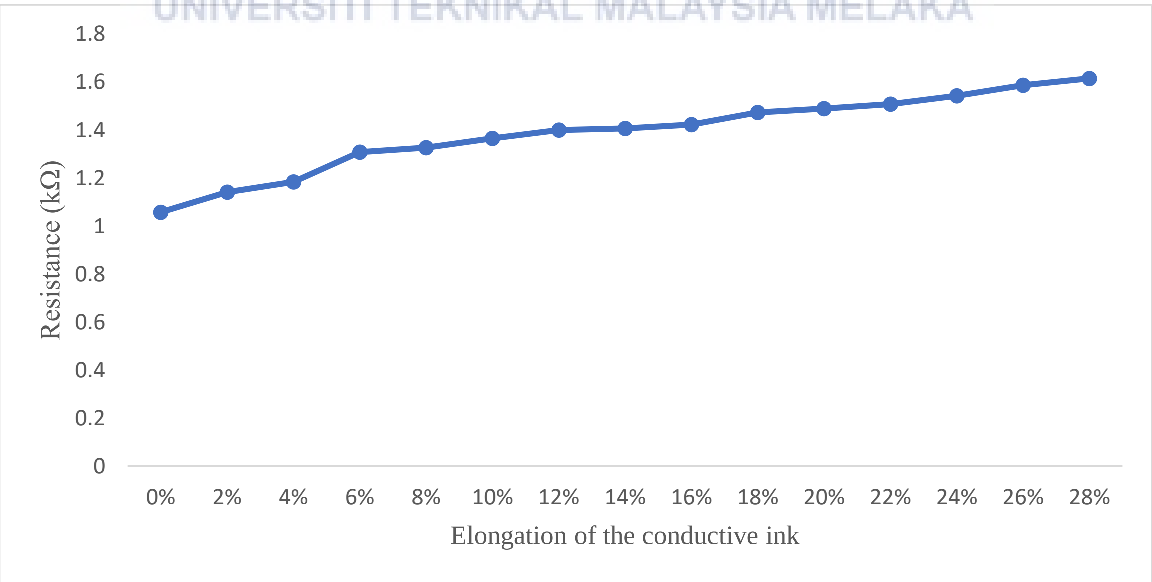

Figure 4.17: Graph of Resistivity against elongation of conductivity. (80mm length)

Table 4.7: Resistivity of conductive ink with 80mm length measured by 4-point probe.

L=80mm, w=5mm, t=0.2mm						
Elongation		R1(R/sq)	R2(R/sq)	R3(R/sq)	R4(R/sq)	Average (kΩ)
0%	0mm	906.48	906.48	906.48	906.48	906.48
2%	1.6mm	906.48	1359.72	906.48	1359.72	1133.1
4%	3.2mm	1359.72	1359.72	1359.72	1359.72	1359.72
6%	4.8mm	1359.72	1359.72	1359.72	1812.96	1473.03
8%	6.4mm	1812.96	1812.96	1812.96	1359.72	1699.65
10%	8mm	2266.20	1812.96	1812.96	1812.96	1926.27
12%	9.6mm	1812.96	2266.20	2266.20	1812.96	2039.58
14%	11.2mm	2719.44	2266.20	1812.96	2266.20	2266.20
16%	12.8mm	2266.20	1812.96	2719.44	2719.44	2379.51
18%	14.4mm	2719.44	2719.44	2719.44	2719.44	2719.44
20%	16.0mm	2719.44	2719.44	3172.68	2719.44	2832.75
22%	17.6mm	3172.68	2719.44	2719.44	2719.44	2832.75
24%	19.2mm	3172.68	2719.44	2719.44	3172.68	2946.12
26%	20.8mm	3172.68	2719.44	3172.68	3172.68	3059.37
28%	22.4mm	3172.68	4079.16	3172.68	3172.68	3399.3

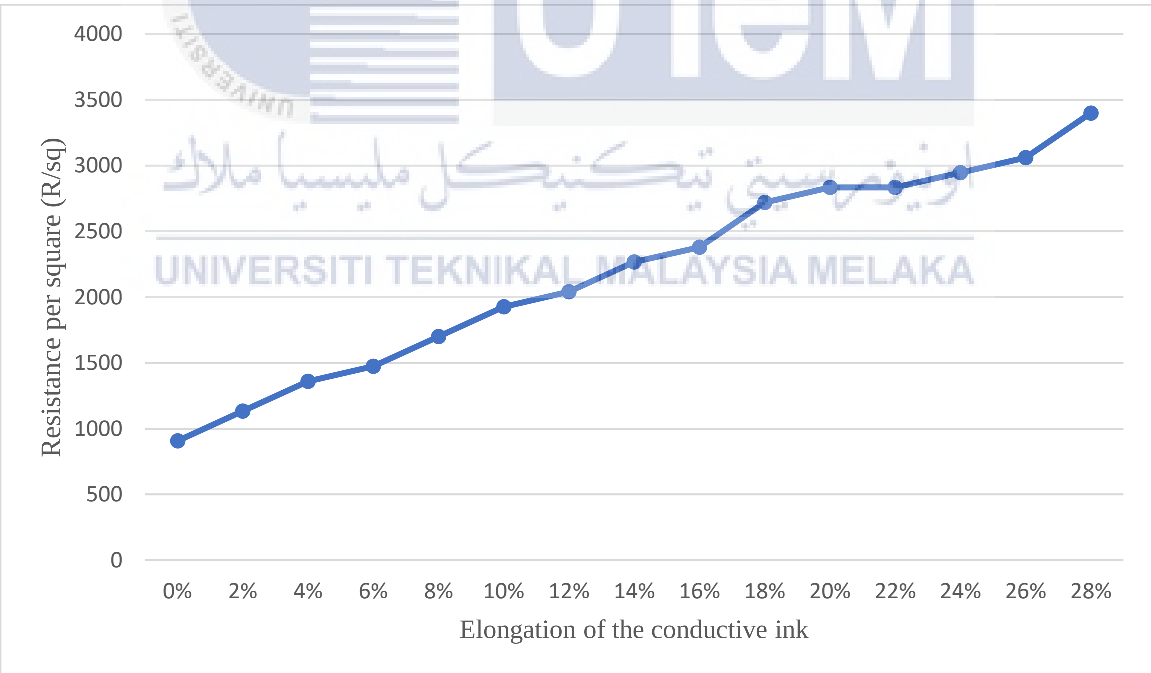

Figure 4.18: Graph of Resistance per square against elongation of conductivity. (80mm length)

4.4.3.2 Discussion on Relationship between Resistance of Conductive Ink and its Elongation (80mm length)

From the data above, the resistivity of the conductive ink with 80mm length are increased steadily with its elongation. During the experiment, there are no cracking occur on this conductive ink. The elongation is stop at 28% because the substrate is start to deform under plastic deformation. Hence, the conductive ink is stop stretching at 28% of its original length.

Figure 4.19: There are no cracking occur at the end of experiment.

4.4.3.3 The microstructure of the conductive ink under microscope.

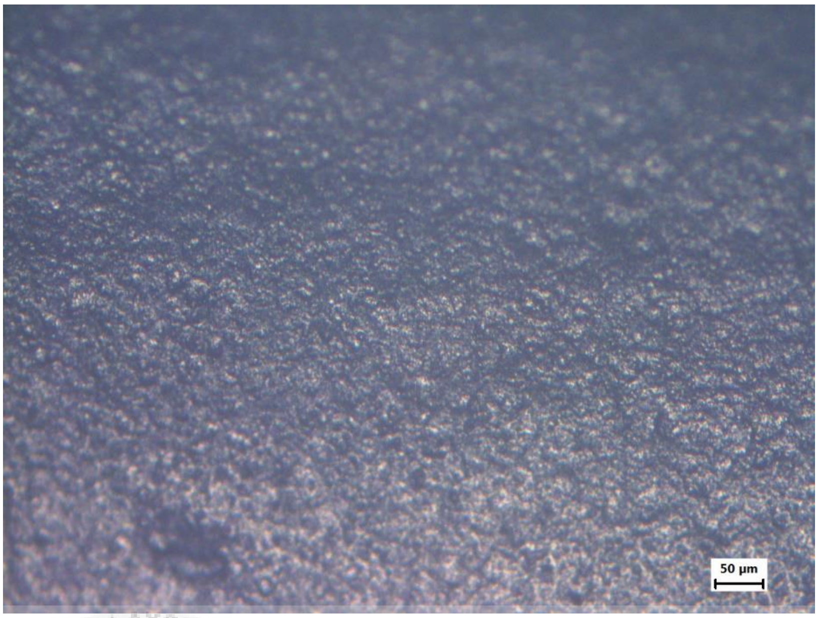

Figure 4.20: The microstructure of conductive ink (80mm length) before stretching.

Figure 4.21: The microstructure of conductive ink (80mm length) after stretching.

The microstructure of conductive ink with 80mm length before and after stretching are almost the same. Both have smooth surface and no imperfection on the surface of the conductive ink. The elongation does not affect so much to 80mm length of conductive ink.

4.5 Summarise of conductive ink with different length

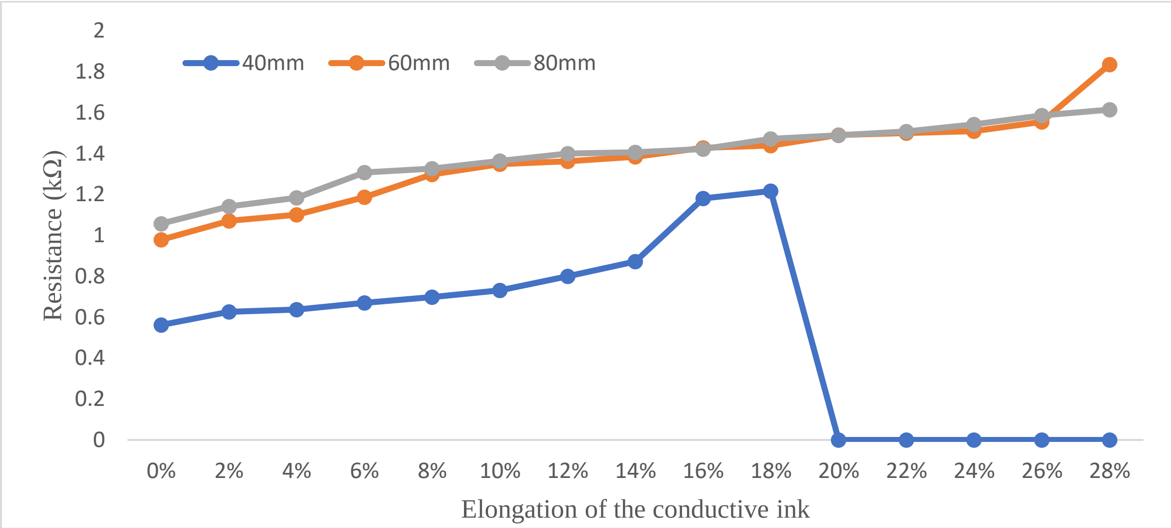

Figure 4.22: Resistance of 40mm, 60mm and 80mm length that measure by multi-meter.

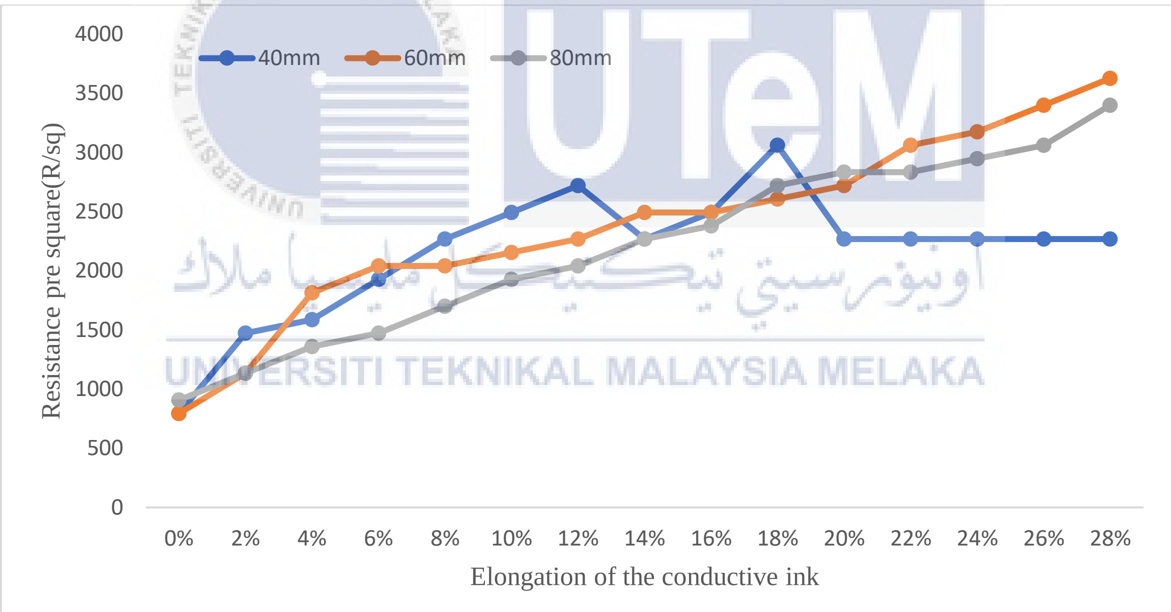

Figure 4.23: Resistance of 40mm, 60mm and 80mm length that measure by four-point probe.

The result above shown the longer length of conductive ink is better than shorter conductive ink. When the length of the conductive ink increased, the rate of cracking and broken is decreased. During experiment, 40mm length of conductive ink cracked at 14% of elongation and broke at 20% of elongation while 60mm length of conductive cracked on 16% and its does not break when stretch until 28% of initial length. Besides, 80mm length of the conductive ink does not have any deflection when stretch until 28% of its initial length. This show that the longer length of conductive ink had better stretchability.

Moreover, the sheet resistance of the conductive ink will not increase significantly when stretching at longer length of conductive ink. This is because there are no defection occur at the surface of the conductive ink during longer length of conductive ink. When surface of conductive ink is smooth and flat, the electric can travel smoothly and it will have better conductivity and smaller resistance. Hence, the longer the length of conductive ink, the better the conductivity of the conductive ink.

Table 4.8: Compare the strain between different length of the conductive ink.

Elongation (mm)	Strain		
	40mm	60mm	80mm
1	0.025	0.0167	0.0125
2	0.05	0.0333	0.025
3	0.075	0.05	0.0375
4	0.1	0.0667	0.05
5	0.125	0.0833	0.0625
6	0.15	0.1	0.075
7	0.175	0.117	0.0875
8	0.2	0.133	0.1
9	0.225	0.15	0.1125
10	0.25	0.167	0.125

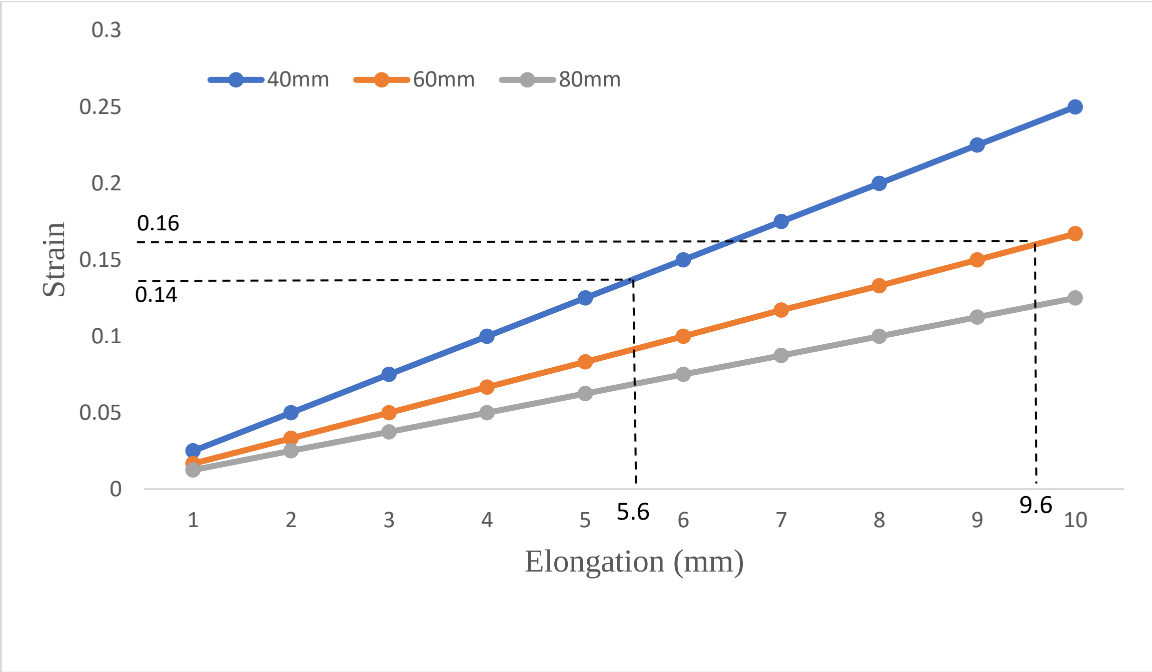

Figure 4.24: Graph of strain against elongation between different length of conductive ink.

From figure 2.4, there are comparison of strain level between 40mm, 60mm and 80mm length of conductive ink. The cracking point of 40 mm length conductive ink is at 5.6 mm of elongation and the strain level at cracking point is 0.14. Other than this, cracking point of 60mm length of conductive ink is 9.6mm of elongation with 016 of the strain level. The result show that the strain level of the cracking point between different length are very closed and we can predict that the 80 mm length conductive ink will crack when its strain level reach 015 to 0.2. This result shows that the conductive ink will crack when reach certain level of strain.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This chapter discussed about the conclusion and recommendation for the study based on the result and analysis from the previous chapter. The main purpose for this study is to determine the relationship between the conductivity of stretchable conductive ink and the elongation of the conductive ink. Refer to chapter 2, the conductivity of the conductive ink will decrease when the elongation is increase. this is because the distance of polymer chain inside the conductive ink are become farther and the electricity are hard to travel through the conductive ink. The method used to determine the conductivity of conductive ink is measure with four-point probe and multi-meter that had been mentioned in the previous chapter. Conductive ink is measured while being stretched to get the result under tensile stress. A stretching equipment were fabricated to clamp and stretch the conductive ink during experiment. Besides, the surface structure of conductive ink is important in this study. Conductive ink were observe under microscope when stretching and the surface structure were recorded down by using computer. The defection on the surface will affect the conductivity of the conductive ink. The defection will increase the resistivity of conductive ink and hence reduced the conductivity of the conductive ink.

The resistivity of the conductive ink were increased when the percentage of elongation were increased. This is because the cross-sectional area of the conductive ink is become smaller and the polymer chain of the conductive ink is become farther. The electricity are hard to travel along the conductive ink and hence the conductivity was decreased when stretching.

5.2 Recommendation

5.2.1 Different curing time

Continue the experiment by using different curing time of the conductive ink. Different curing time will produce different resistance of the conductive ink and it may affect the mechanical properties of the conductive ink. The conductive ink may have different maximum elongation when cure in different curing time.

5.2.2 Different humidity

Carry out the experiment with different humidity may affect the maximum elongation and the conductivity of the conductive ink. The conductive ink can be stretch in the completely seal up box that can control the humidity around the conductive ink. Then the following test such as four-point probe testing can be carry out to test the conductivity of the conductivity of the conductive ink.

5.2.3 Different thermal condition

Different thermal condition mean that carry out the experiment with different surrounding temperature. Different surrounding temperature may affect the mechanical properties of the conductive ink such as crack easily. Moreover, conductivity of the conductive ink may change with the temperature. So, test the conductive ink in different thermal condition might get the different result compare with room temperature.

5.2.4 Different type of conductive ink

Different type of conductive ink will have different type of mechanical properties and resistivity. Carry out the experiment with different type of conductive ink will have different result. Compare the result with carbon complex ink will have more accurate result and hence choose the best type of conductive ink to continue with further experiment such as different thermal condition or different humidity.

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APPENDICES

Bare Conductive®

Electric Paint®

Safety Data Sheet

ACCORDING TO EC-REGULATIONS
1907/2006 (REACH) & 1272/2008 (CLP)

1. IDENTIFICATION OF THE SUBSTANCE / MIXTURE AND OF THE COMPANY / UNDERTAKING

1.1	**Product identifier**	
	GHS Product Identifier	**Bare Conductive Paint**
	Chemical Name	*Water-based dispersion of carbon pigment in Natural resin*
	Other names	
	CAS No.	Mixture — Not applicable
	EINECS No.	Mixture — Not applicable

1.2	**Relevant identified uses of the substance or mixture and uses advised against**	
	Identified use(s)	Electrically conductive paint
	Uses advised against	None

1.3 Details of the supplier of the safety data sheet

Company Identification	Bare Conductive Limited First Floor 98 Commercial Street London E1 6LZ
Telephone	+44 (0)20 3432 5385
E-Mail (competent person)	**info@bareconductive.com**

1.4	**Emergency telephone number**	
	Emergency Phone No.	**+44 (0)20 3432 5385 / Technical manager**

2. HAZARDS IDENTIFICATION

2.1	**Classification of the substance or mixture**	
2.1.1	**Regulation (EC) No. 1272/2008 (CLP)**	
2.1.2	**Directives 1999/45/EC**	Preparation is not classified as hazardous according to Directives 1999/45/EC.
2.2	**Label elements**	
2.2.1	**Label elements**	According to Regulation (EC) No. 1272/2008 (CLP)
2.2.2	**Label elements**	According to Directive 1999/45/EC
	Hazard Symbol	Not applicable
	Risk Phrases	Not applicable
	Safety Phrases	Not applicable
2.3	**Other hazards**	
2.4	**Additional Information**	

3. COMPOSITION / INFORMATION ON INGREDIENTS

3.1 Substances

EC Classification No. 1272/2008

Ingredients	**%W/W**	**CAS No.**	**EC No.**	**Hazard statement(s)**
Water		7732-18-5	231-791-2	Not classified.
Natural Resin		Trade secret	Trade secret	Not classified.
Conductive carbon		Trade secret	Trade secret	Not classified.
Humectant		Trade secret	Trade secret	Not classified.
Processing aids and preservatives		Trade secret	Trade secret	Individual levels below 1% do not give rise to classification

EC Classification No. 67/548/EEC

Hazard statement(s)	**%W/W**	**CAS No.**	**EC No.**	**Classification and Risk Phrases**
None				

3.2 Substances

For full text of R/H/P phrases see section 16.